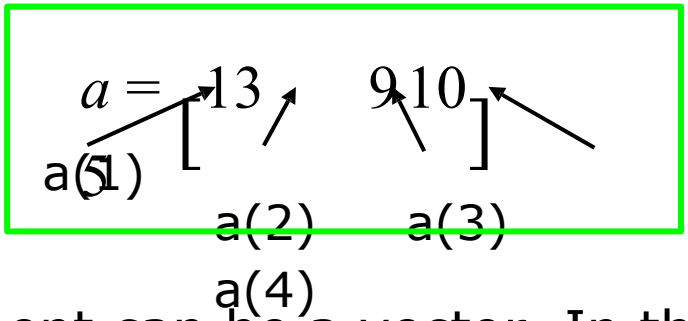
Индексирование, программирование, векторизация, графические возможности MatLab

Лекция 3-4

Vector Indexing

- MATLAB indexing starts with **1**, not **0**
  - We will not respond to any emails where this is the problem.
- a(n) returns the n^{th} element



- The index argument can be a vector. In this case, each element is looked up individually, and returned as a vector of the same size as the index vector.

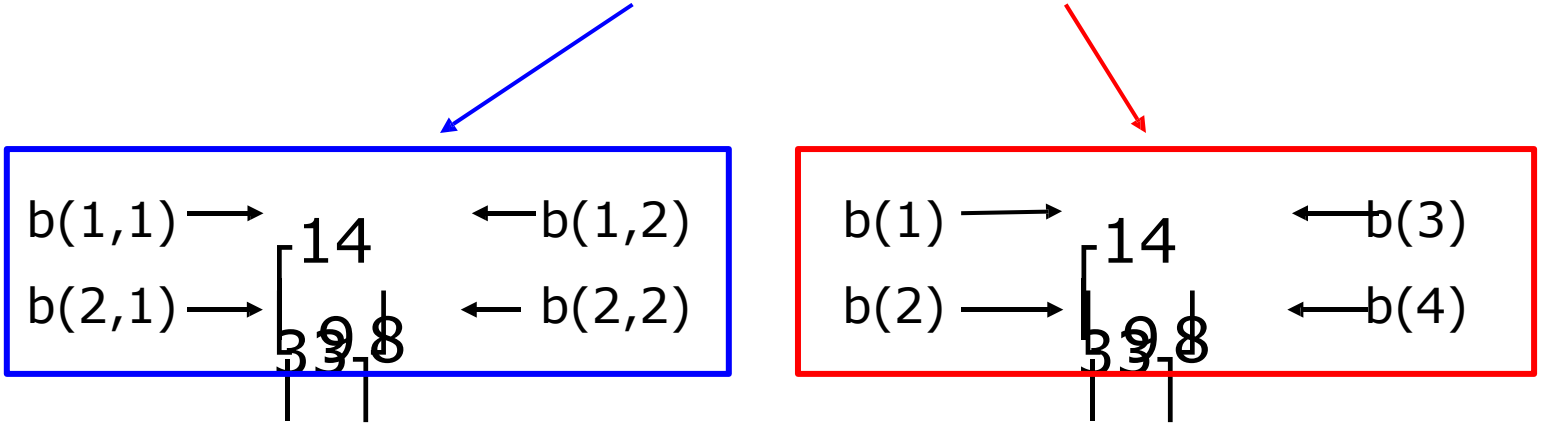
```
» x=[12 13 5 8];
» a=x(2:3);
» b=x(1:end-1);
```

→ `a=[13 5];`

→ `b=[12 13 5];`

Matrix Indexing

- Matrices can be indexed in two ways
  - using **subscripts** (row and column)
  - using linear **indices** (as if matrix is a vector)
- Matrix indexing: subscripts or linear indices



- Picking submatrices

```
» A = rand(5) % shorthand for 5x5 matrix
» A(1:3,1:2) % specify contiguous submatrix
» A([1 5 3], [1 4]) % specify rows and
columns
```

Advanced Indexing 1

- To select rows or columns of a matrix, use the **:**

$$c = \begin{bmatrix} 12 & 5 \\ -2 & 13 \end{bmatrix}$$

```
»
d=c(1,:);
»
e=c(:,2);
»
c(2,:)=[3
```

```
d=[12 5];
e=[5;13];
second row of c
```

```
6];
%replaces
```

Advanced Indexing 2

- MATLAB contains functions to help you find desired values within a vector or matrix

```
» vec = [5 3 1 9 7]
```

- To get the minimum value and its index:

```
» [minVal,minInd] = min(vec);
```

  - **max** works the same way

- To find any the indices of specific values or ranges

```
» ind = find(vec == 9);
» ind = find(vec > 2 & vec < 6);
```

  - **find** expressions can be very complex, more on this later

- To convert between subscripts and indices, use **ind2sub**, and **sub2ind**. Look up **help** to see how to use them.

Example of mapping linear indexes to subscripts

Example 1. The mapping from linear indexes to subscript equivalents for a 3-by-3 matrix is

1	4	7
2	5	8
3	6	9

1,1	1,2	1,3
2,1	2,2	2,3
3,1	3,2	3,3

This code determines the row and column subscripts in a 3-by-3 matrix, of elements with linear indices 3, 4, 5, 6.

```
IND = [3 4 5 6]
s = [3,3];
[I,J] = ind2sub(s,IND)

I =
     3     1     2     3

J =
     1     2     2     2
```

Использование векторориентированных функций (max, min, sort, sum, mean, prod и других) с матричным аргументом

В случае с матрицами, функция max определяет максимальные значения, стоящие в столбцах :

```
A = [4 3 5; 6 7 2; 3 1 8];
[V, I] = max(A);              % V=[6 7 8], I = [2 2 3]
V = max(A);                   % V=[6 7 8]
```

Для поиска максимального значения во всей матрице необходимо вызвать функцию дважды:

```
M = max(max(A));
```

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 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`

Vectorization makes coding fun!

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
```

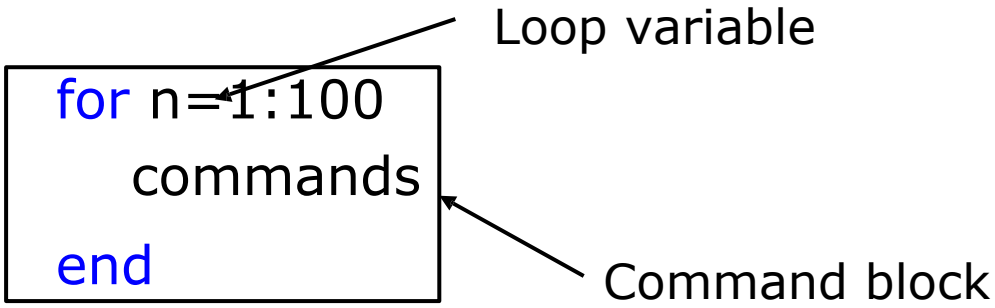
ELSEIF

```
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!

Outline

(1) **Functions**

(2) Flow Control

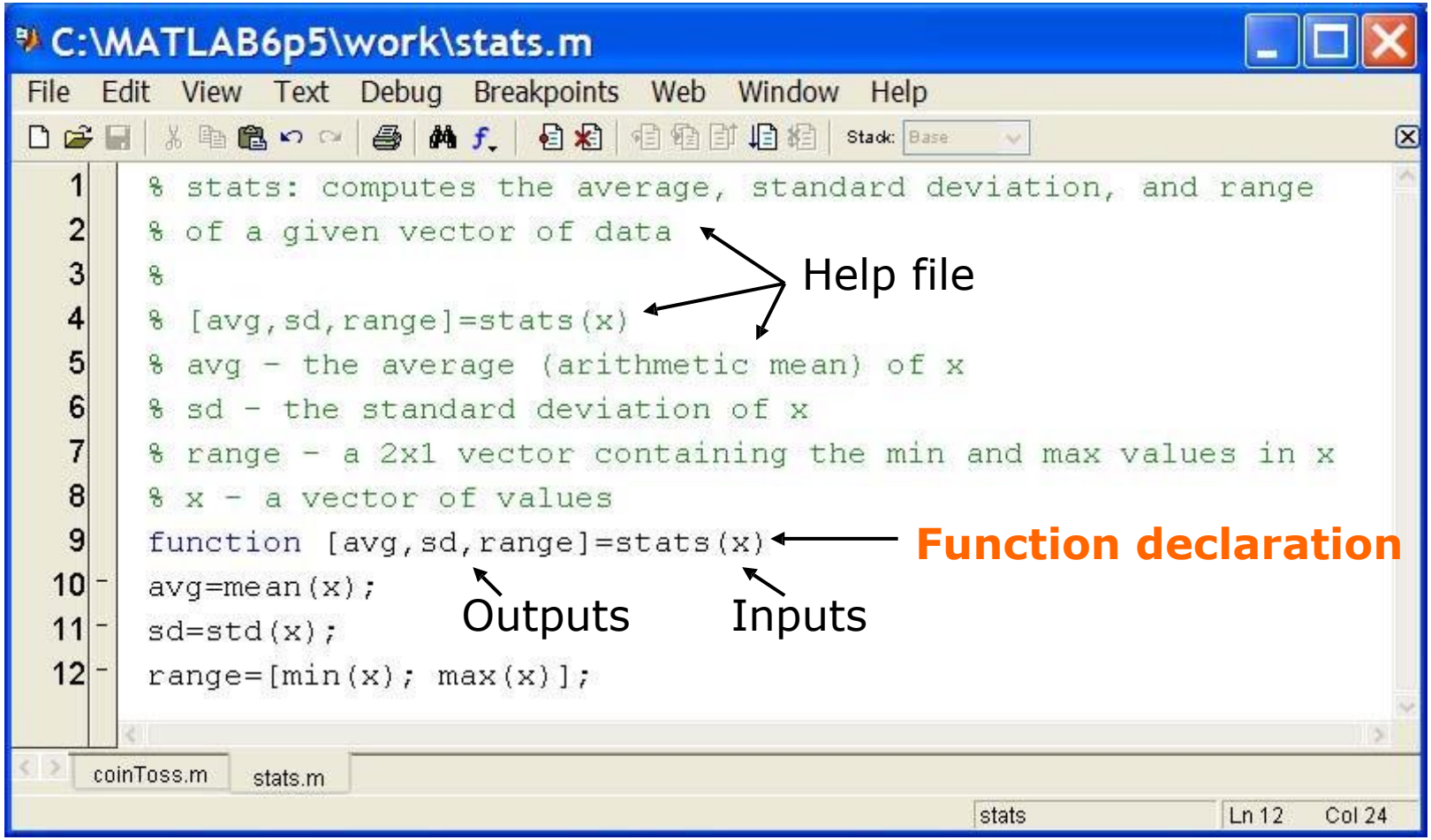
(3) Line Plots

(4) Image/Surface Plots

(5) Vectorization

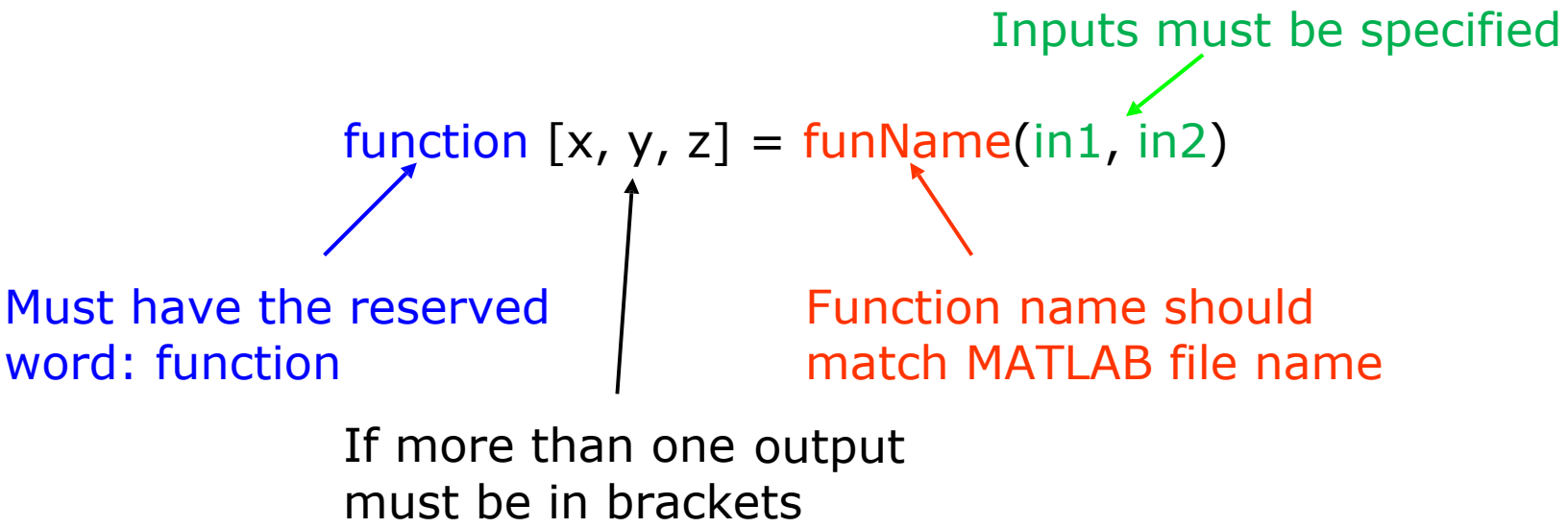
User-defined Functions

- 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

- 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 are OK matrices
» 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**)

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
```

Plotting

- Example
  - `x=linspace(0,4*pi,10);`
  - `y=sin(x);`

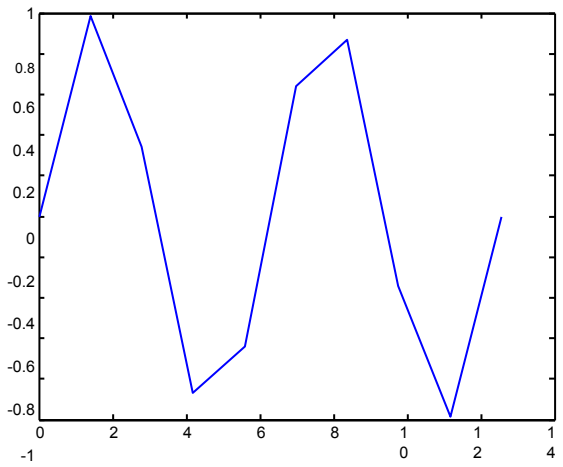
- Plot values against their index
  - `plot(y);`
- Usually we want to plot y versus x
  - `plot(x,y);`

MATLAB makes visualizing data fun and easy!

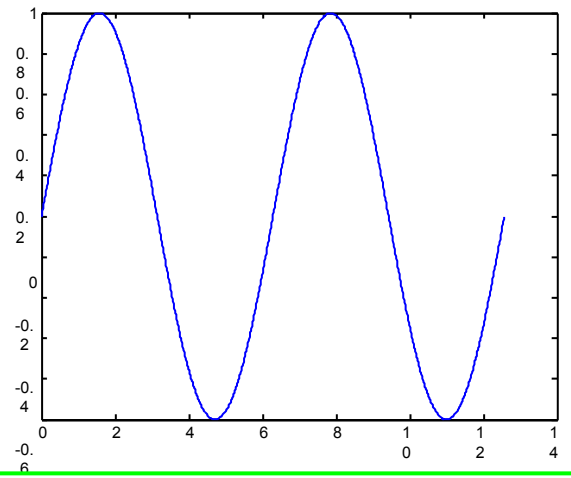
What does plot do?

- **plot** generates dots at each (x,y) pair and then connects the dots with a line
- To make plot of a function look smoother, evaluate at more points
  - » `x=linspace(0,4*pi,1000);`
  - » `plot(x,sin(x));`
- x and y vectors must be same size or else you'll get an error
  - » `plot([1 2], [1 2 3])`
    - error!!

10 x values:



1000 x values:



Outline

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

Plot Options

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

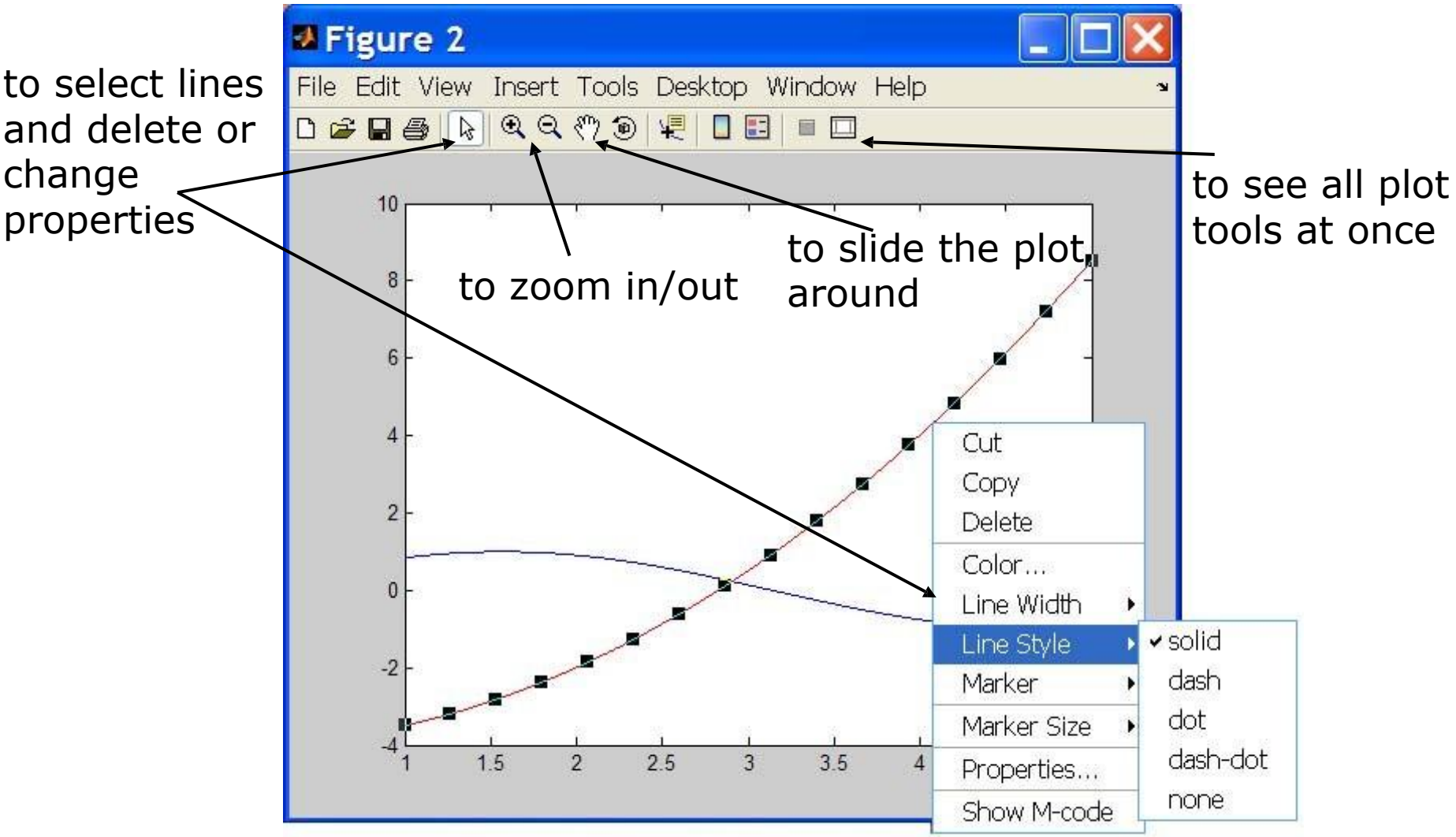
```
» plot(x,y,'k.-');
```

- 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

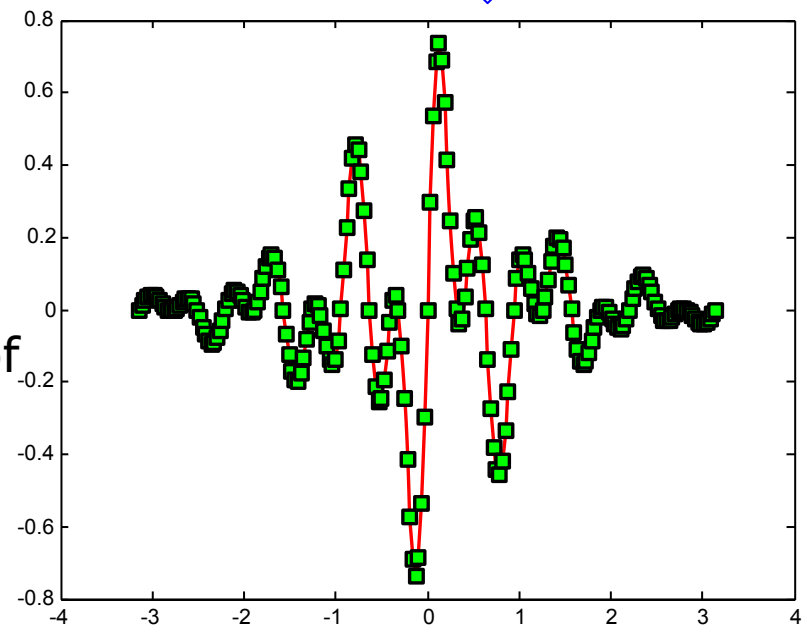


Line and Marker Options

- 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

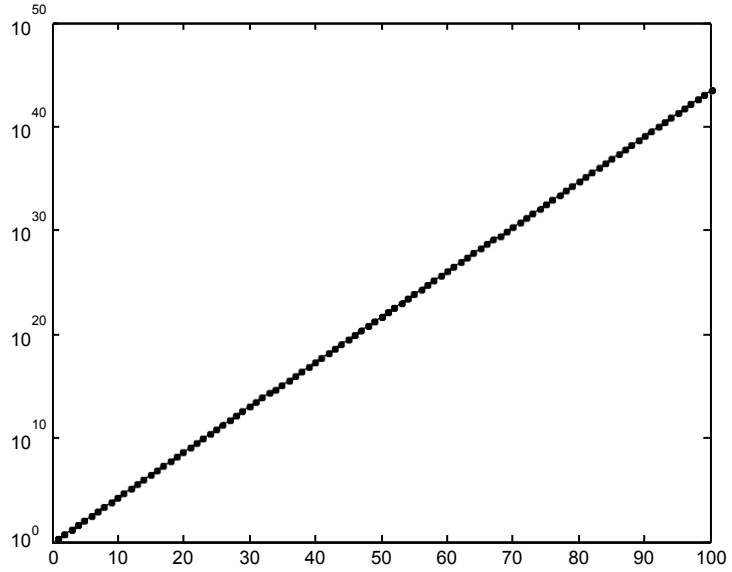
```
» x=-pi:pi/100:pi;
» y=cos(4*x).*sin(10*x).*exp(-abs(x));
» plot(x,y,'k-');
```

- 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.-');
```



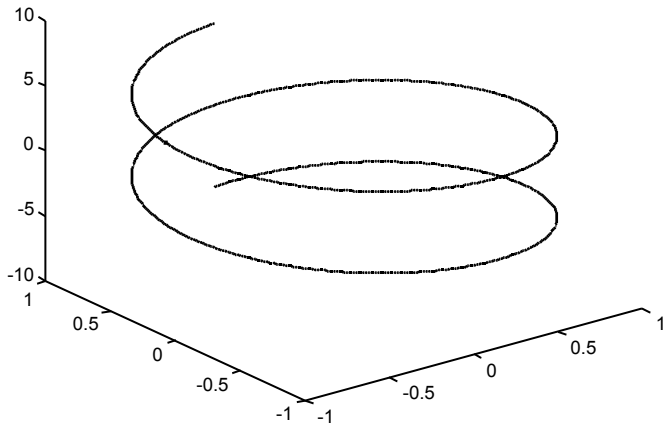
3D Line Plots

- 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)

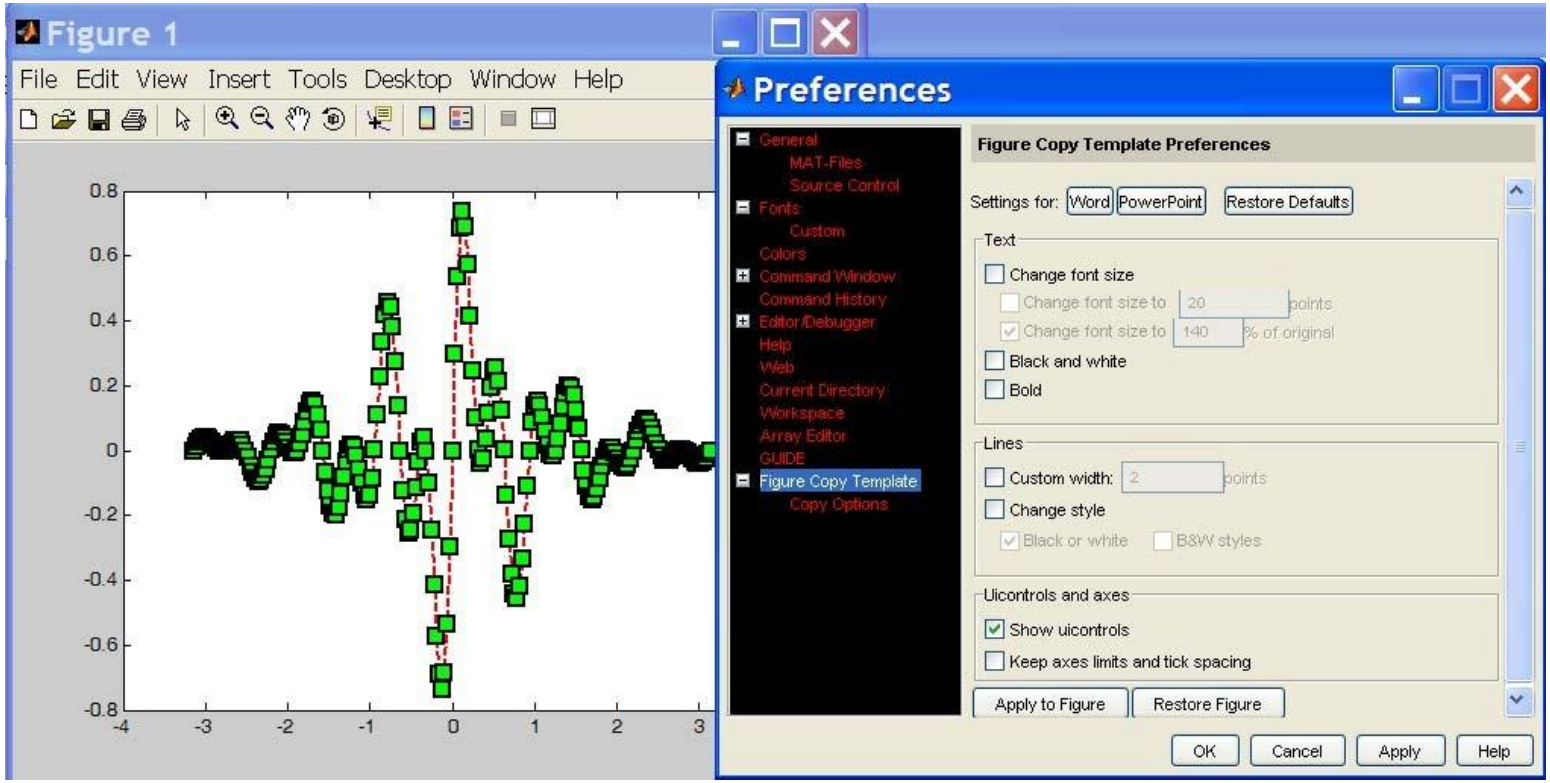
Multiple Plots in one Figure

- 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

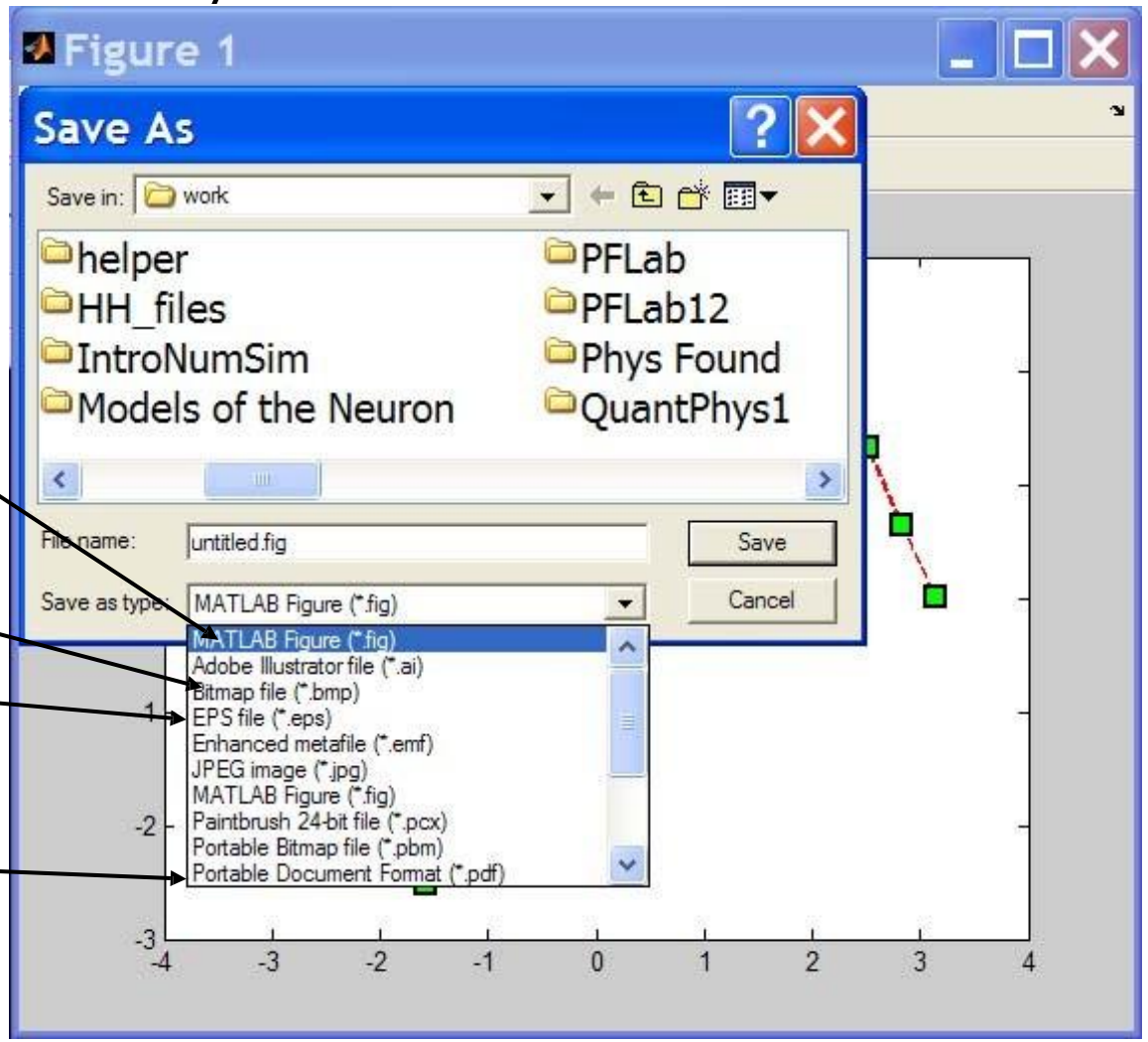
- Figures can be saved in many formats. The common ones are:

.fig preserves all information

.bmp uncompressed image

.eps high-quality scaleable format

.pdf compressed image

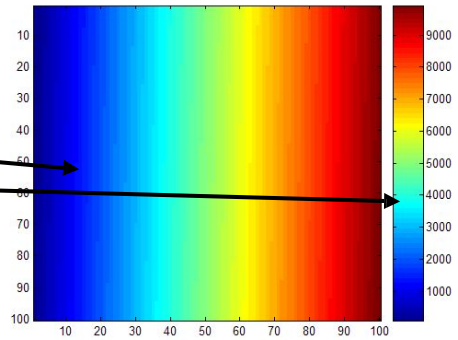


Outline

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

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])`

Функция reshape

Examples

Reshape a 3-by-4 matrix into a 2-by-6 matrix.

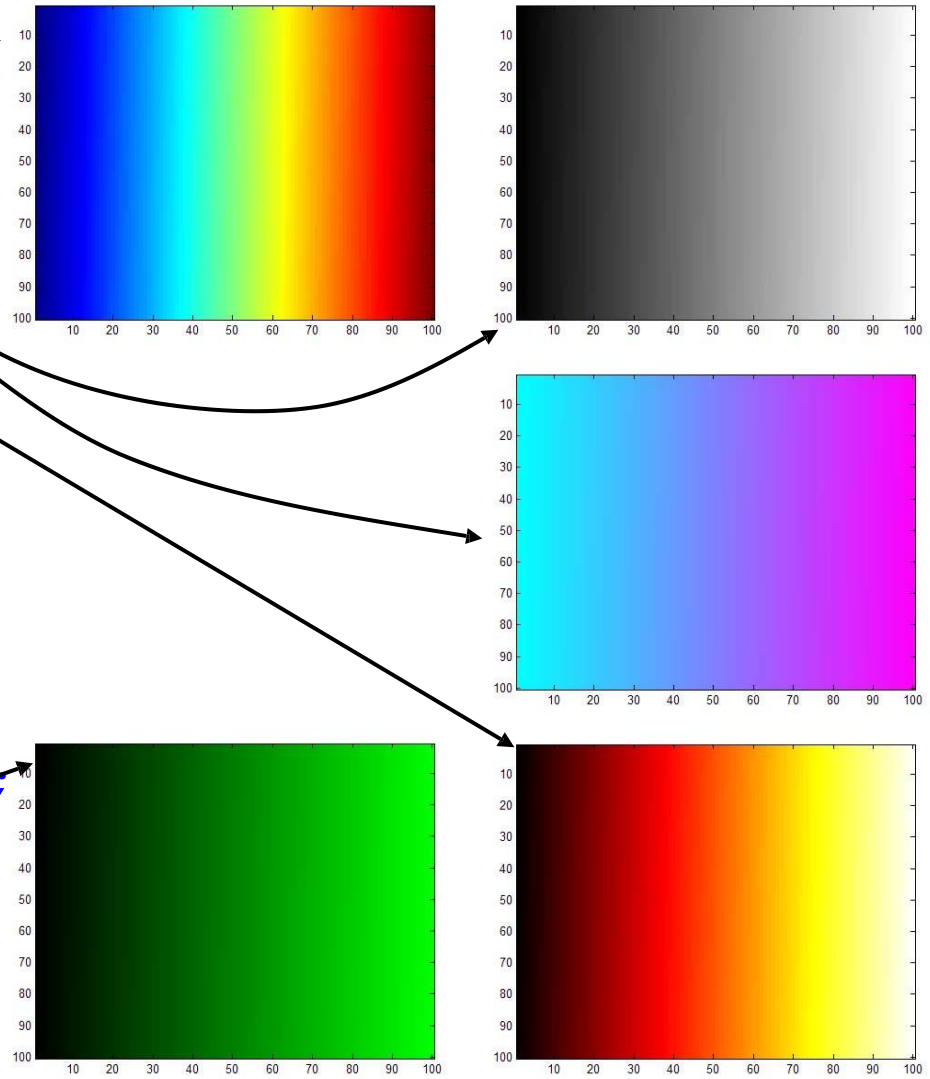
```
A =
     1     4     7    10
     2     5     8    11
     3     6     9    12

B = reshape(A,2,6)

B =
     1     3     5     7     9    11
     2     4     6     8    10    12
B = reshape(A,2,[])

B =
     1     3     5     7     9    11
     2     4     6     8    10    12
```

See Also

shiftdim, squeeze

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);`



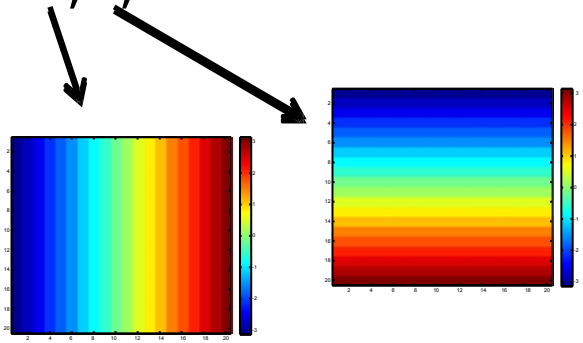
Surface Plots

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

$$f(x,y) = \sin(x)\cos(y)$$

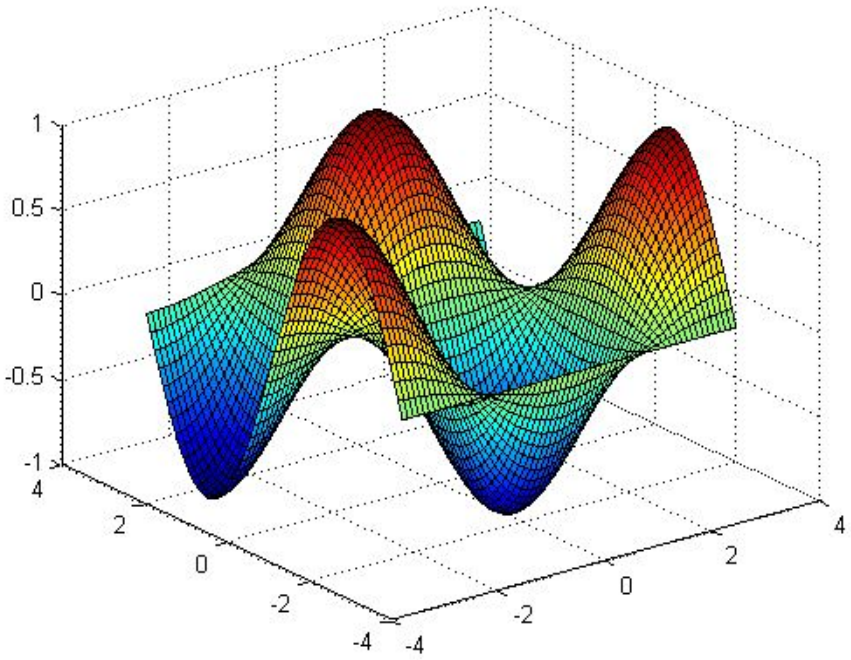
$$x \in [-\pi, \pi], y \in [-\pi, \pi]$$

- **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);`



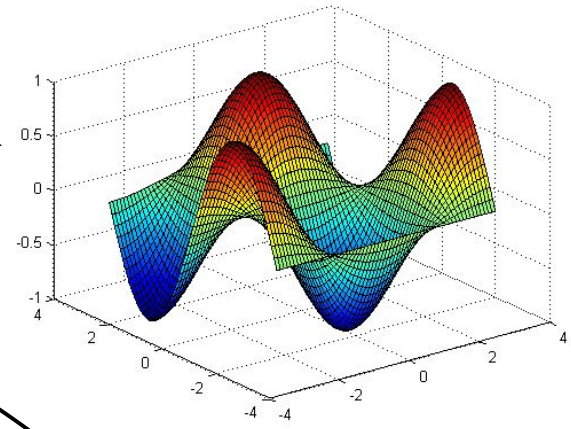
surf Options

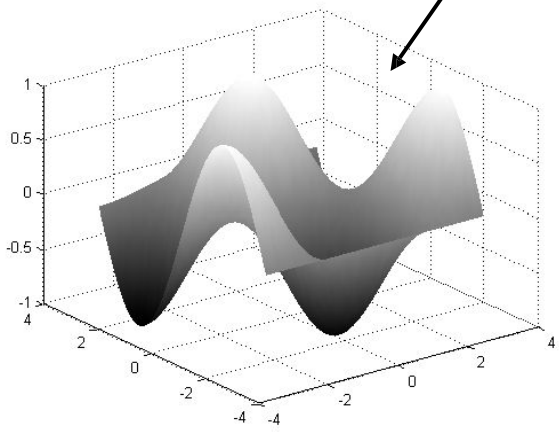
- See **help surf** for more options
- There are three types of surface shading

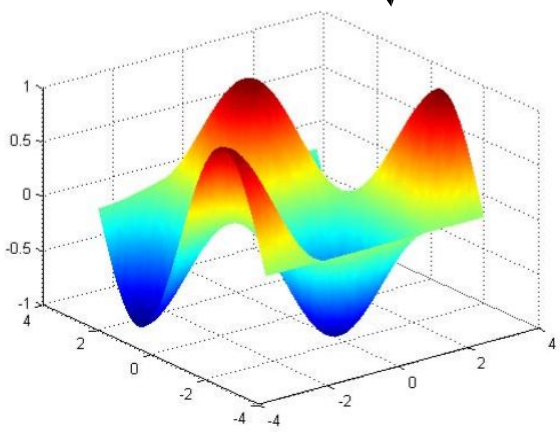
```
» shading faceted
» shading flat
» shading interp
```

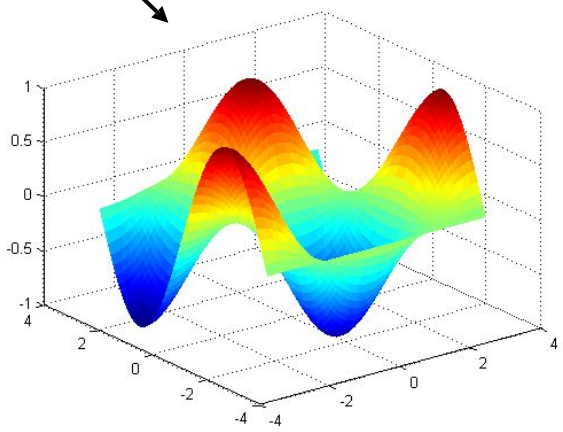
- You can change colormaps

```
» colormap(gray)
» shading interp
```



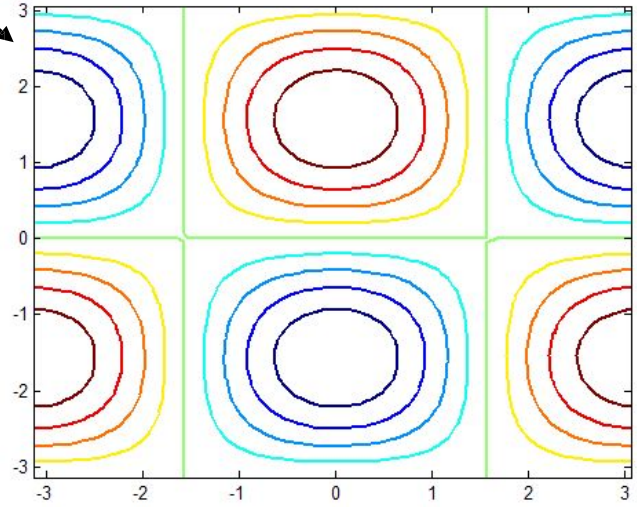


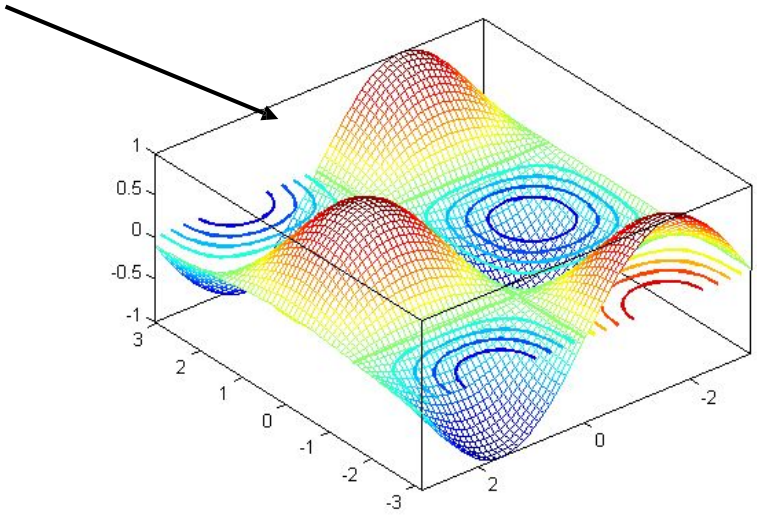




contour

- 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:

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

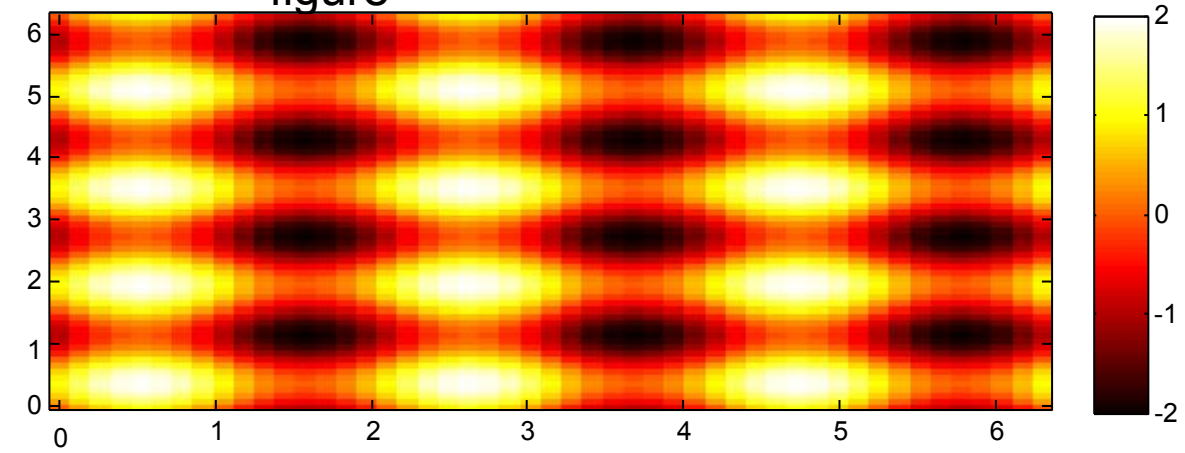
- y should be just like x, but using f2. (use **`meshgrid`** to get the X and Y matrices)
- In the top axis of your subplot, display an image of the Z matrix. Display the colorbar and use a **`hot`** colormap. Set the axis to xy (**`imagesc`**, **`colormap`**, **`colorbar`**, **`axis`**)
- In the bottom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

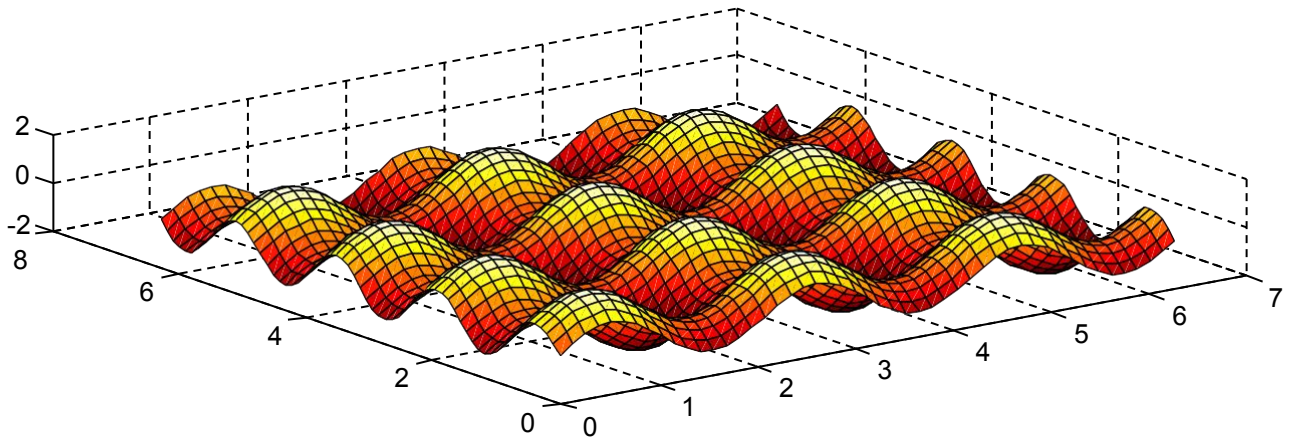
Exercise: 3-D Plots

```
»  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