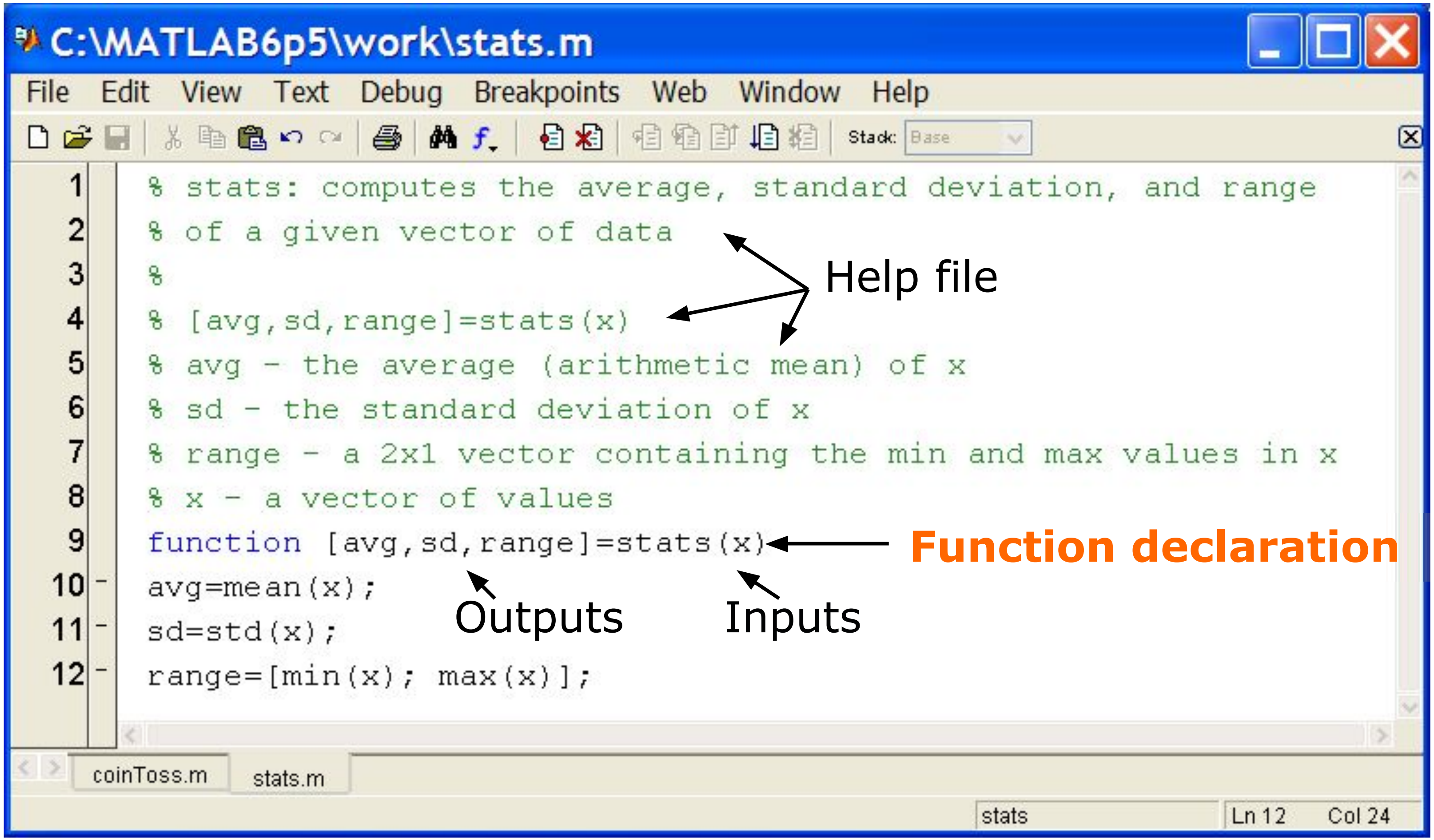
Lecture 2: Visualization and Programming

Outline for Lec 2

(1) **Functions**
(2) Flow Control
(3) Line Plots
(4) Image/Surface Plots
(5) Efficient Codes
(6) Debugging

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

Inputs

```
function [x, y, z] = funName(in1, in2)
```

Must have the reserved word: function

Function name should match m-file name

If more than one output, must be in brackets

- No need for return: MATLAB 'returns' the variables whose names match those in the function declaration (though, you can use **`return`** to break and go back to invoking function)
- Variable scope: Any variable created within the function but not returned disappears after the function stops running (They're called "local variables")

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 number of input and output arguments (see `varargin`, `nargin`, `varargout`, `nargout`)

Outline

(1) Functions
(2) **Flow Control**
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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	ELSE	ELSEIF

if cond
    commands
end
	if cond
	    commands1
	else
	    commands2
	end
		if cond1
		    commands1
		elseif cond2
		    commands2
		else
		    commands3
		end

Conditional statement: evaluates to true or false

- No need for parentheses: command blocks are between reserved words
- Lots of `elseif`'s? consider using `switch`

for

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

```
for n=1:100
    commands
end
```

Loop variable

Command block

- 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:
  - ➢ No 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! CTRL+C?!
- You can use `break` to exit a loop

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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.-’);`

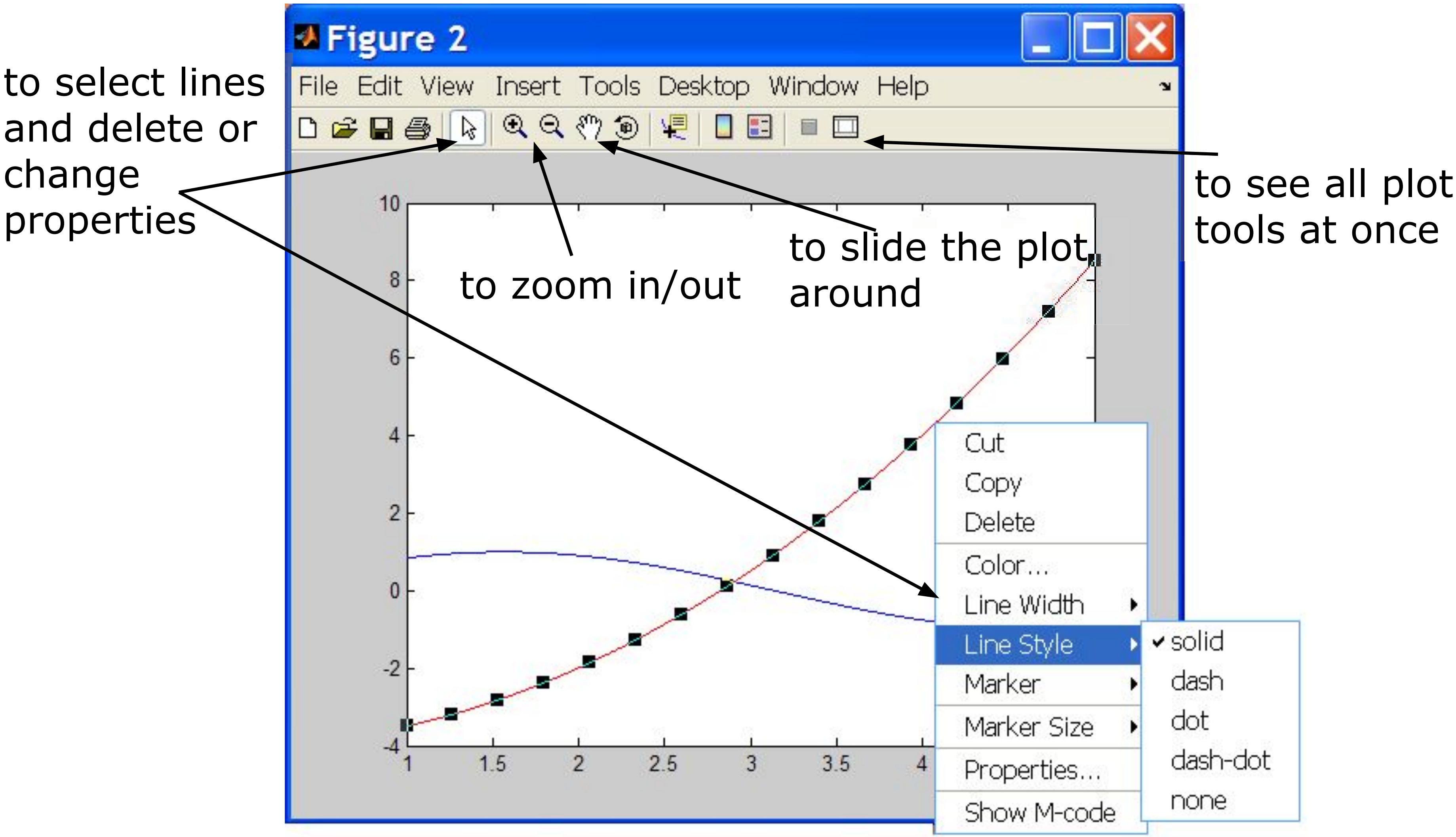
  color marker line-style

- 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 line styles

Playing with the Plot

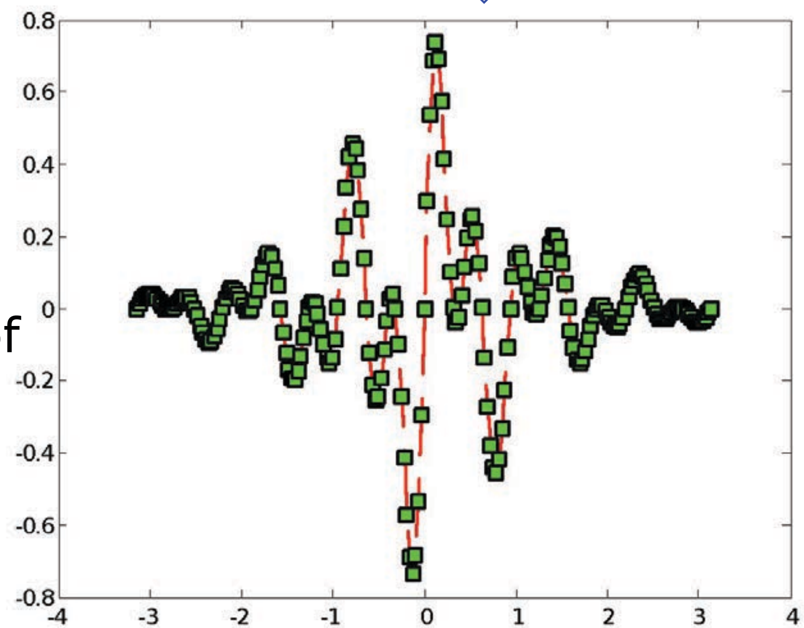


Line and Marker Options

- 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

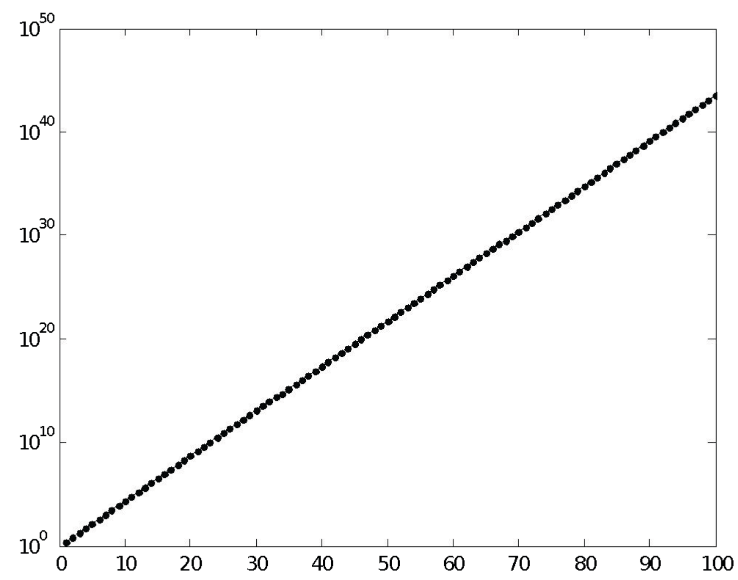
```
» x=-pi:pi/100:pi;
» y=cos(4*x).*sin(10*x).*exp(-abs(x));
» plot(x,y,'k-');
```

- 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

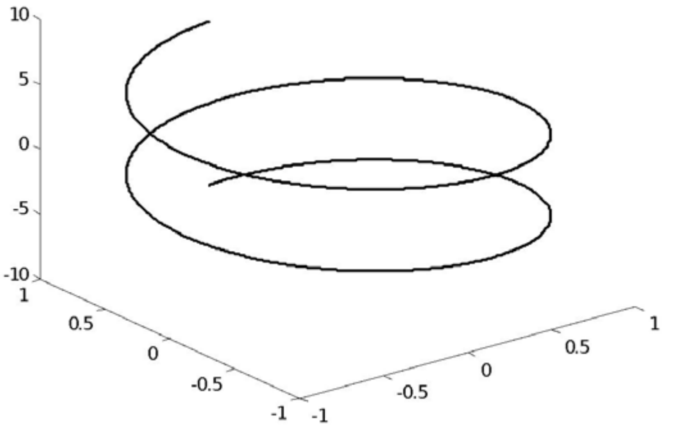
- We can plot in 3 dimensions just as easily as in 2D

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

3D Line Plots

- We can plot in 3 dimensions just as easily as in 2D
  - » `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 (see `doc axis` for more modes)

  » `axis square`
    - ➢ makes the current axis look like a square box

  » `axis tight`
    - ➢ fits axes to data

  » `axis equal`
    - ➢ makes x and y scales the same

  » `axis xy`
    - ➢ puts the origin in the lower left corner (default for plots)

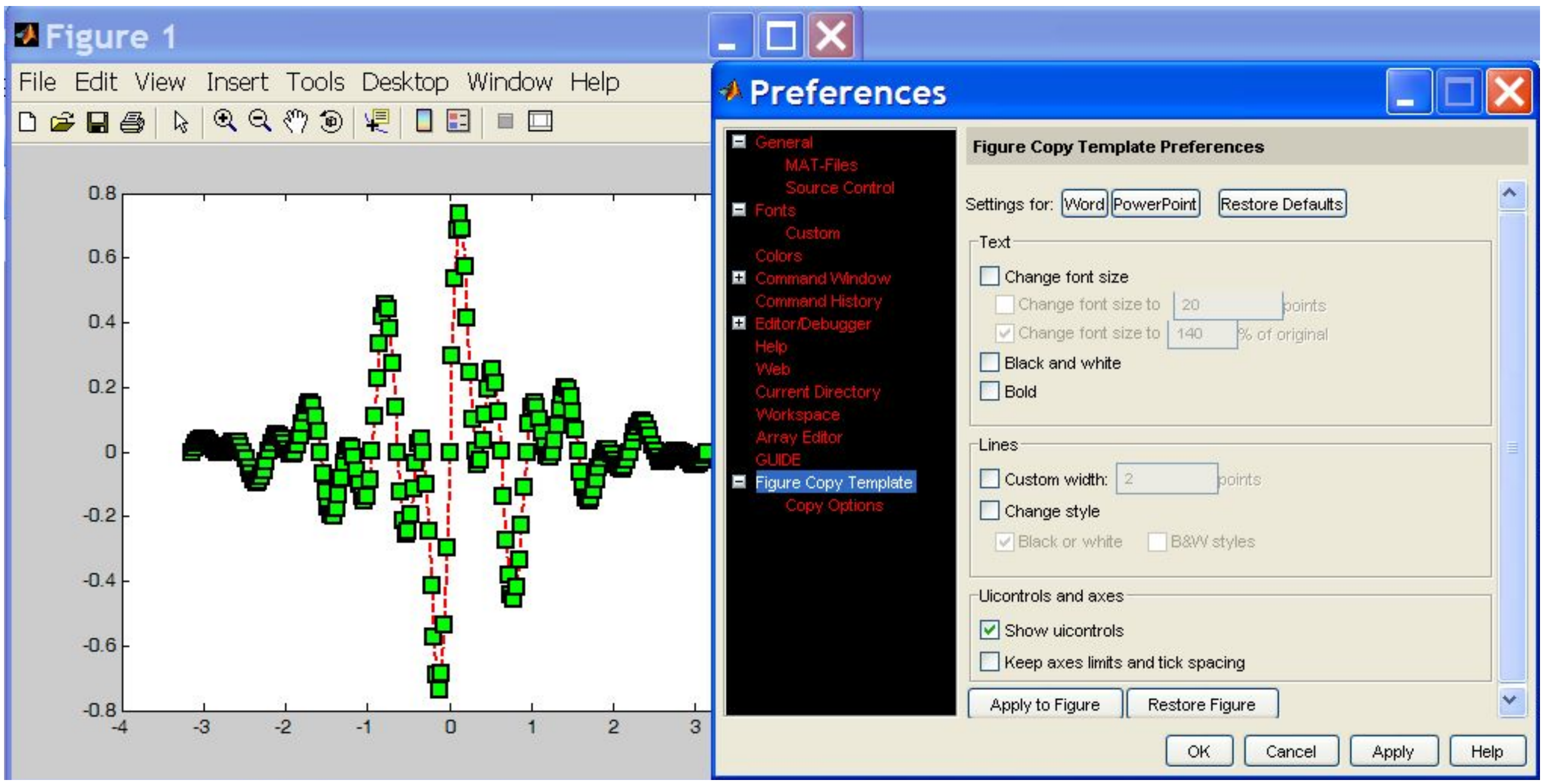
  » `axis ij`
    - ➢ puts the origin in the upper left corner (default for matrices/images)

Multiple Plots in one Figure

- To have multiple axes in one figure
  - » `subplot(2,3,1)`
    - ➢ makes a figure with 2 rows and 3 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)`
    - ➢ activates a range of axes and fuses them into one
- To close existing figures
  - » `close([1 3])`
    - ➢ closes figures 1 and 3
  - » `close all`
    - ➢ closes all figures (useful in scripts)

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

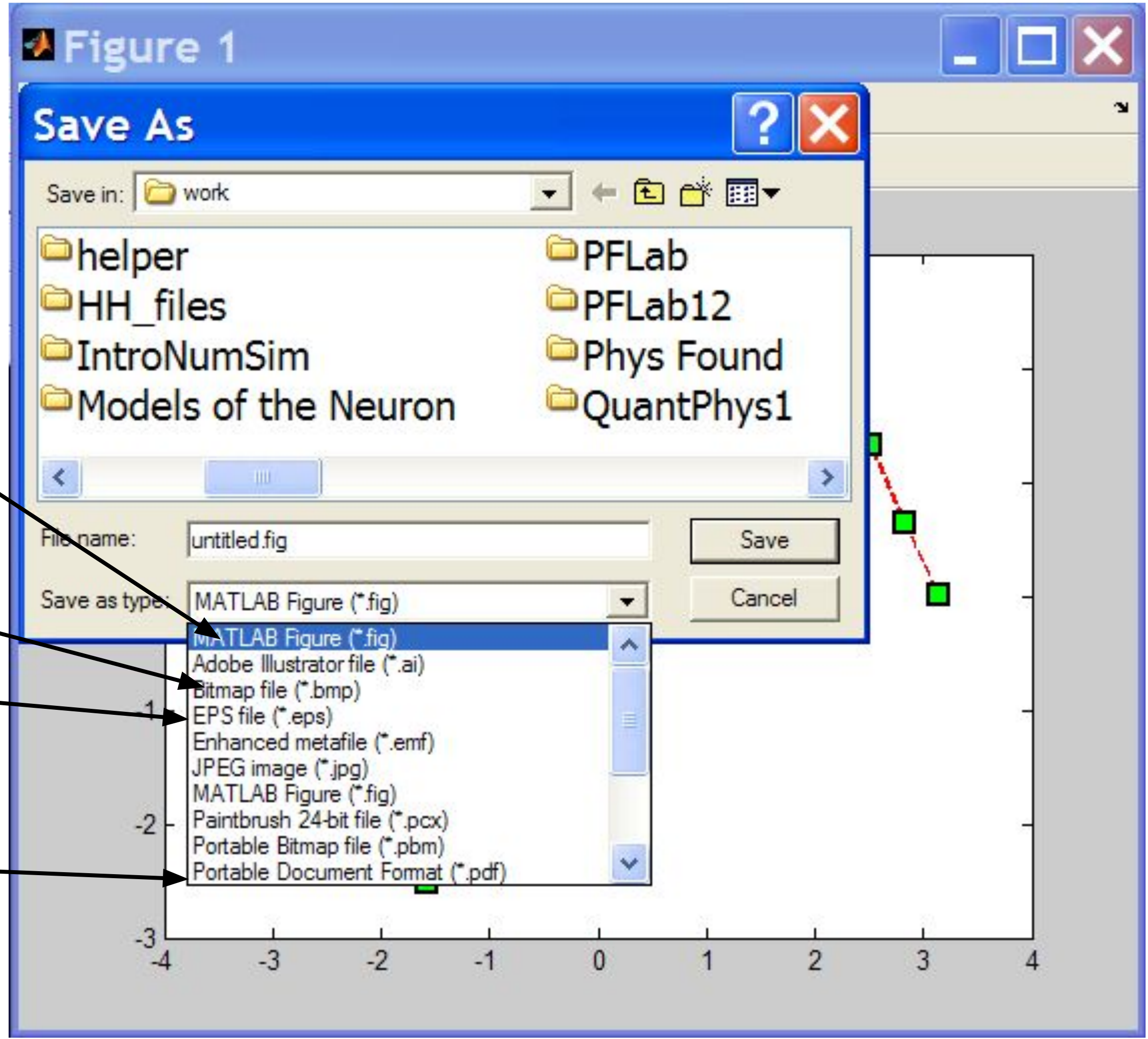
- Figures can be saved in many formats. The common ones are:

.fig preserves all information

.bmp uncompressed image

.eps high-quality scaleable format

.pdf compressed image



Outline

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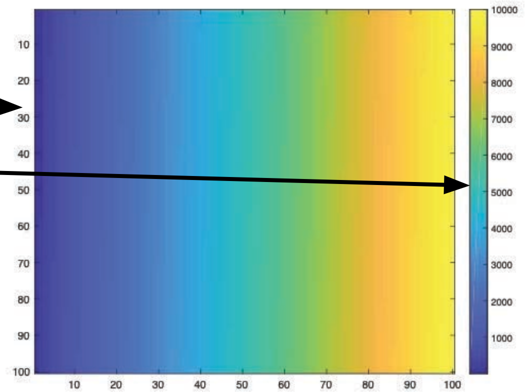
Visualizing matrices

- 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

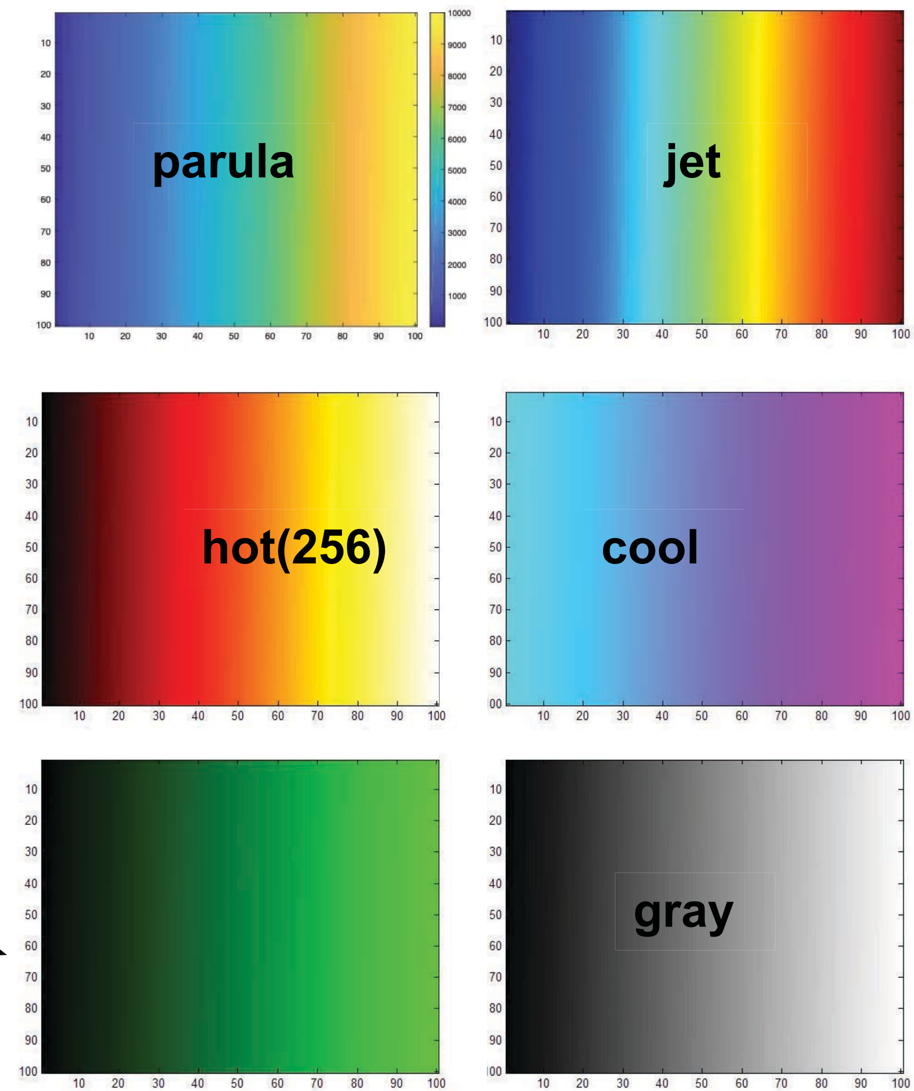
- Can set limits for the color axis (analogous to **`xlim`**, **`ylim`**)
  - » `caxis([3000 7000])`

Colormaps

- You can change the colormap:
  - » `imagesc(mat)`
    - ➢ default map is parula
  - » `colormap(gray)`
  - » `colormap(cool)`
  - » `colormap(hot(256))`

- See `help hot` for a list

- Can define custom color-map
  - » `map=zeros(256,3);`
  - » `map(:,2)=(0:255)/255;`
  - » `colormap(map);`



Surface Plots

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

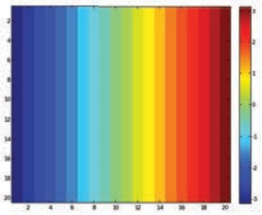
- Example:

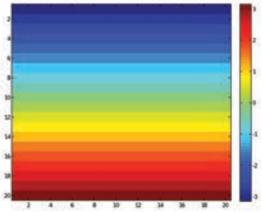
$$\boxed{\begin{array}{l} f(x,y) = sin(x)cos(y) \\ x \in [-\pi,\pi]; y \in [-\pi,\pi] \end{array}}$$

- **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
  - ➢ built-in function: **meshgrid**





surf

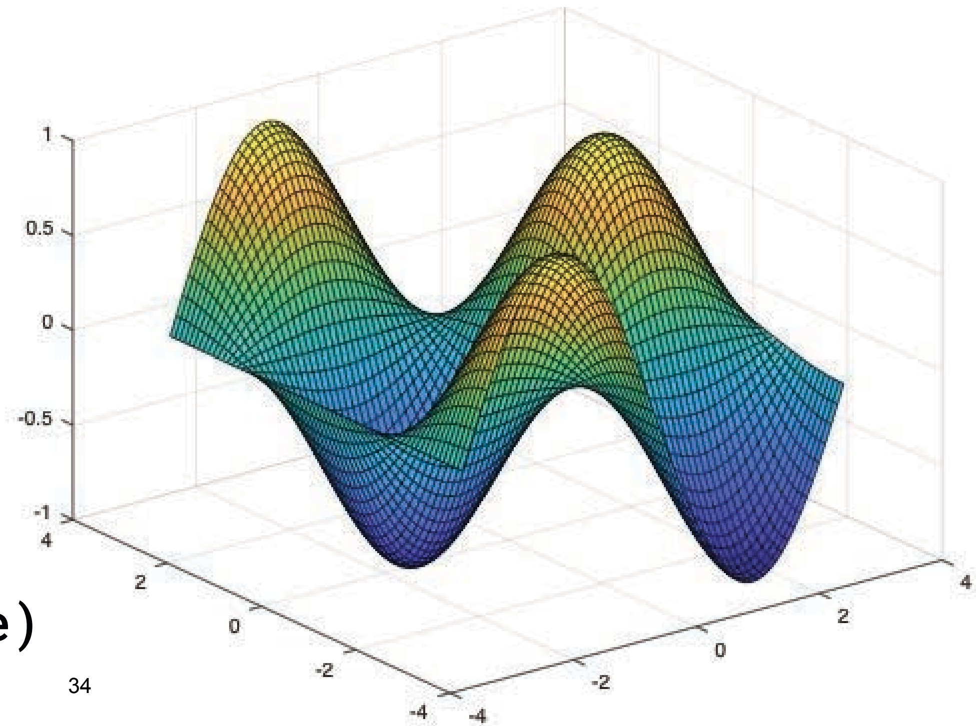
- Make the x and y vectors
  » `x=-pi:0.1:pi;`
  » `y=-pi:0.1:pi;`

- Use meshgrid to make matrices
  » `[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);`

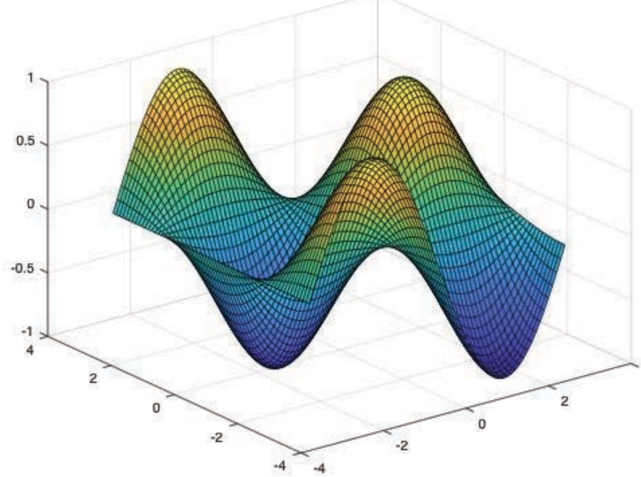
*Try typing `surf(membrane)`

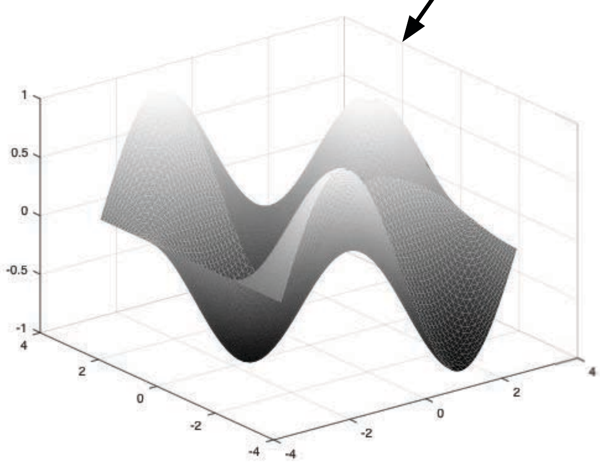


surf Options

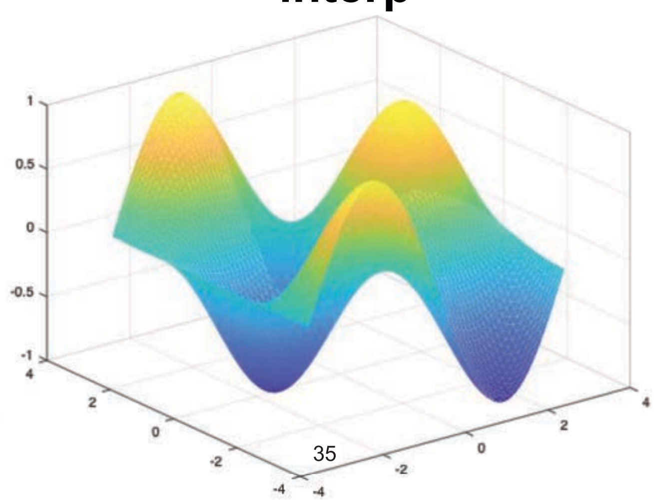
- See **help surf** for more options
- There are three types of surface shading
  - » **`shading faceted`**
  - » **`shading flat`**
  - » **`shading interp`**
- You can also change the colormap
  - » **`colormap(gray)`**

faceted

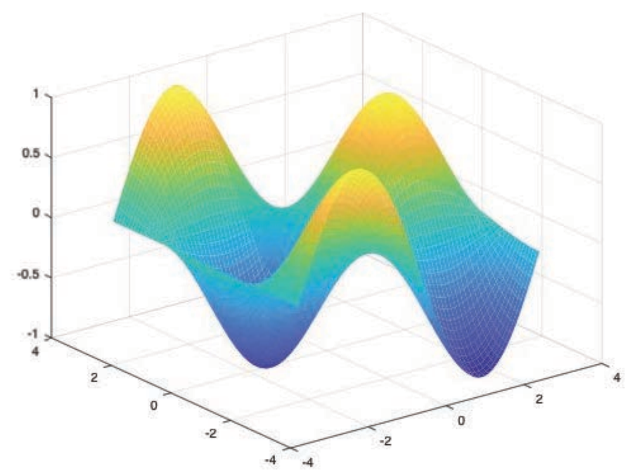




interp

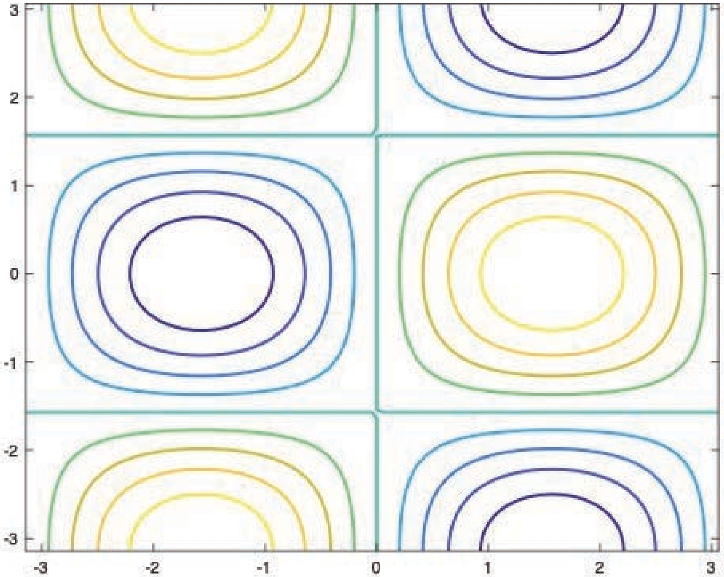


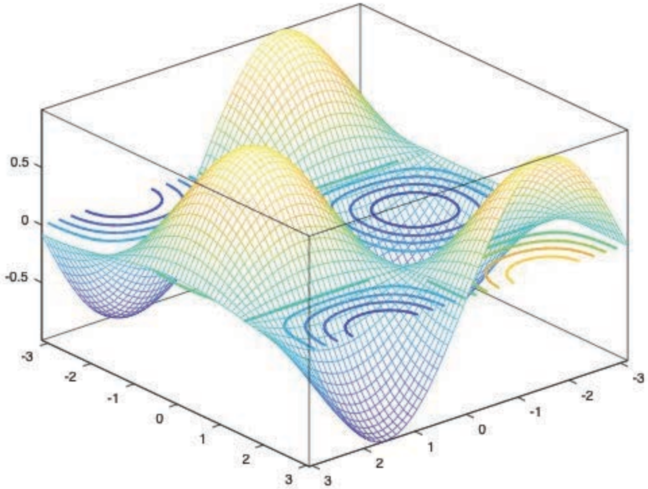
flat



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

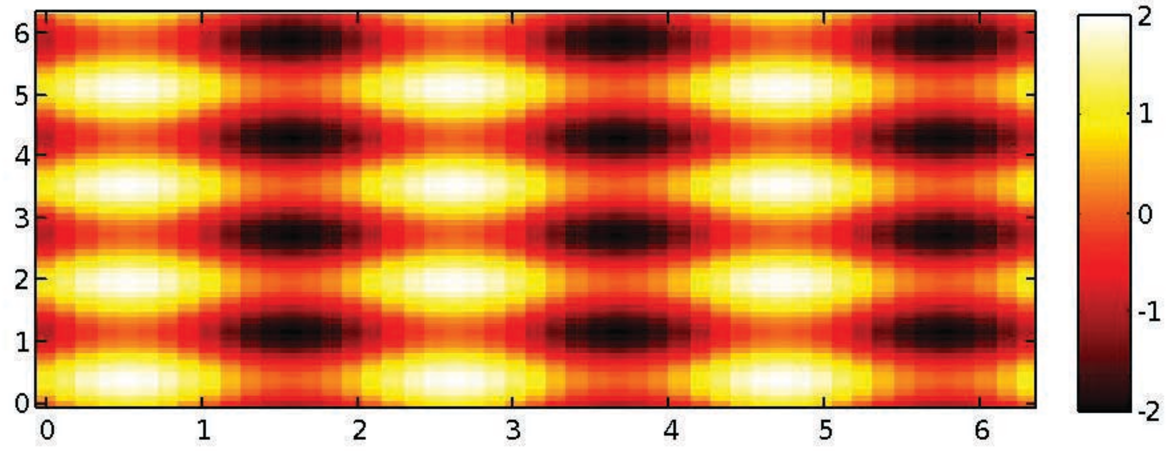
- Modify `plotSin` to do the following:
- If two inputs are given, evaluate the following function:

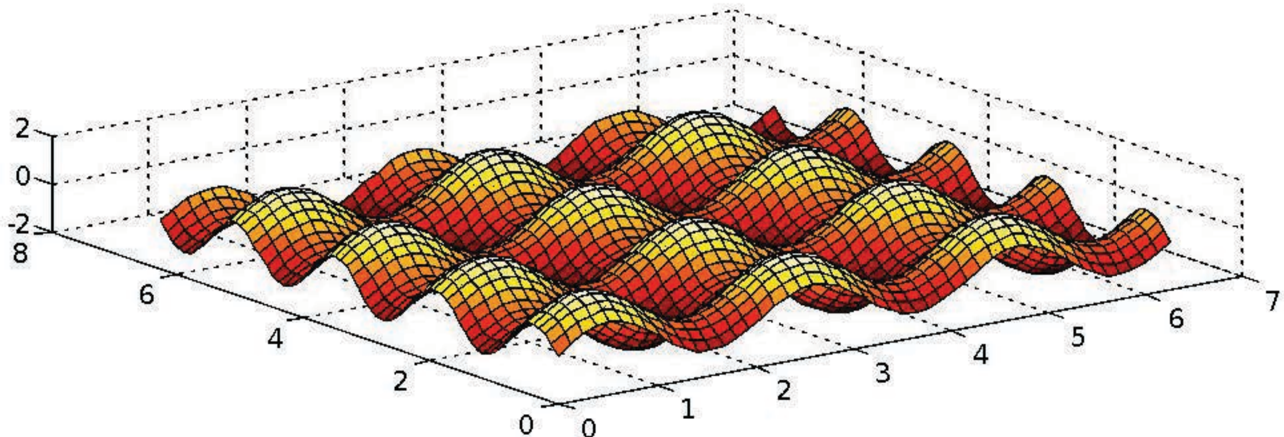
$$Z = \sin(f_1 x) + \sin(f_2 y)$$

- 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

`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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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` contains 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

& combines the two vectors using logical **and** operator

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));
```

Is there a better way?!

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

Vectorization

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

Vectorization

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- For instance, to add 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

Vectorization

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- Vectorized code is more efficient for MATLAB
- Use indexing and matrix operations to avoid loops
- For instance, to add every two consecutive terms:

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» for n=1:100
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»     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`

Preallocation

- Avoid variables growing inside a loop
- Re-allocation of memory is time consuming
- Preallocate the required memory by initializing the array to a default value
- For example:

```
» for n=1:100
»     res = % Very complex calculation %
»     a(n) = res;
» end
```

  - ➢ Variable `a` needs to be resized at every loop iteration

Preallocation

- Avoid variables growing inside a loop
- Re-allocation of memory is time consuming
- Preallocate the required memory by initializing the array to a default value
- For example:

```
» a = zeros(1, 100);
» for n=1:100
»     res = % Very complex calculation %
»     a(n) = res;
» end
```

  - ➢ Variable `a` is only assigned new values. No new memory is allocated

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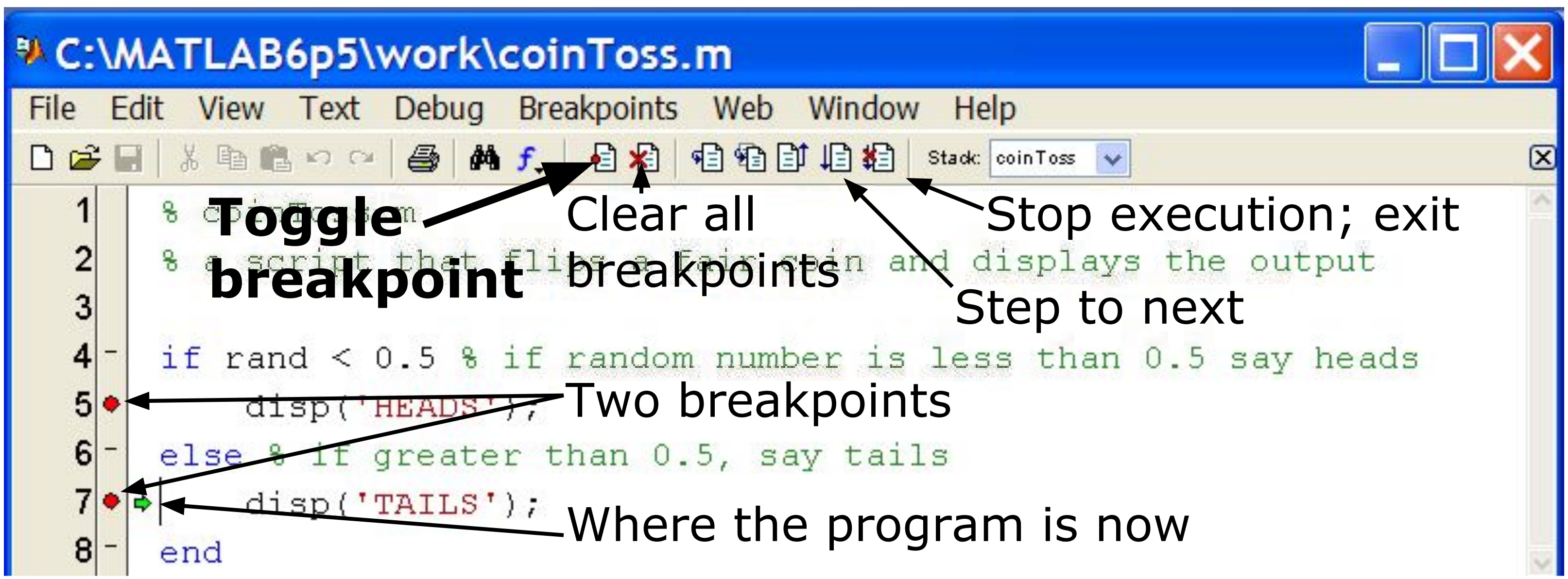
Display

- When debugging functions, use **disp** to print messages
  - » `disp('starting loop')`
  - » `disp('loop is over')`
    - ➢ `disp` prints the given string to the command window

- It's also helpful to show variable values
  - » `disp(['loop iteration ' num2str(n)]);`
    - ➢ Sometimes it's easier to just remove some semicolons

Debugging

- To use the debugger, set breakpoints
  - Click on – next to line numbers in m-files
  - Each red dot that appears is a breakpoint
  - Run the program
  - The program pauses when it reaches a breakpoint
  - Use the command window to probe variables
  - Use the debugging buttons to control debugger



Performance Measures

- It can be useful to know how long your code takes to run
  - ➢ To predict how long a loop will take
  - ➢ To pinpoint inefficient code

- You can time operations using **tic**/**toc**:

```
» tic
» Mystery1;
» a=toc;
» Mystery2;
» b=toc;
```

  - ➢ tic resets the timer
  - ➢ Each toc returns the current value in seconds
  - ➢ Can have multiple tocs per tic

Performance Measures

- Example: Sparse matrices

```
» A=zeros(10000); A(1,3)=10; A(21,5)=pi;
» B=sparse(A);
» inv(A);   % what happens?
» inv(B);   % what about now?
```

- If system is sparse, can lead to large memory/time savings

```
» A=zeros(1000); A(1,3)=10; A(21,5)=pi;
» B=sparse(A);
» C=rand(1000,1);
» tic; A\C; toc;   % slow!
» tic; B\C; toc;   % much faster!
```

Performance Measures

- For more complicated programs, use the profiler
  - » **`profile on`**
    - ➢ Turns on the profiler. Follow this with function calls
  - » **`profile viewer`**
    - ➢ Displays gui with stats on how long each subfunction took

Profile Summary

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Number of files called: 19

Filename	File Type	Calls	Total Time	Time Plot
newplot	M-function	1	0.802 s	
gcf	M-function	1	0.460 s	
newplot/ObserveAxesNextPlot	M-subfunction	1	0.291 s	
...matlab/graphics/private/clo	M-function	1	0.251 s	
allchild	M-function	1	0.100 s	
setdiff	M-function	1	0.050 s	

End of Lecture 2

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Vectorization makes coding fun!