FF505/FY505

Computational Science

Lecture 3
Programming: Control Flow
Graphics

Marco Chiarandini

Department of Mathematics & Computer Science
University of Southern Denmark

Outline

Resume

- Overview of MATLAB environment
- Overview of MATLAB programming and arrays
- Solving linear systems in MATLAB

- Matrix and element-by-element operations
- Mathematical functions
- Large sparse matrices and performance comparison

- You have been working at the posted exercises in small groups

Matrix Functions

Eigenvalues and eigenvectors:

```
A = ones(6)
trace(A)
A = A - tril(A)-triu(A,2)
eig(A)

diag(ones(3,1),-1)
[V,D]=eig(diag(1:4))

rank(A) % rank of A
orth(A) % orthonormal basis
```

Visualizing Eigenvalues

```
A=[5/4,0;0,3/4];
eigshow(A) %effect of operator A on unit
      verctor
```

Today

- Graphics: basic and advanced plotting
- Programming: Control structures
- Writing your own functions (and small programs)

Outline

Algorithms and Control Structures

Algorithm: an ordered sequence of instructions that perform some task in a finite amount of time.

Individual statements, instructions or function calls can be numbered and executed in sequence, but an algorithm has the ability to alter the order of its instructions. The order is referred to as control flow.

Three categories of control flow:

- Sequential operations
- Conditional operations: logical conditions that determine actions.
- Iterative operations (loops)

For an imperative or a declarative program a control flow statement is a statement whose execution results in a choice being made as to which of two or more paths should be followed.

For non-strict functional languages (like Matlab), functions and language constructs exist to achieve the same result, but they are not necessarily called control flow statements (eg, vectorization).

Relational Operators

<	Less than.
<=	Less than or equal to.
>	Greater than.
>=	Greater than or equal to.
==	Equal to.
~=	Not equal to.

```
islogical(5~=8)
ans =
     1
islogical(logical(5+8))
ans =

     1
>> logical(5+8)
ans =
     1
>> double(6>8)
ans =
     0
>> isnumeric(double(6>8))
ans =
     1
```

Logical Operators

`~`	NOT	`~A` returns an array the same dimension as A; the new array has ones where A is zero and zeros where A is nonzero.
`&`	AND	`A & B` returns an array the same dimension as A and B; the new array has ones where both A and B have nonzero elements and zeros where either A or B is zero.
`|`	OR	`A | B` returns an array the same dimension as A and B; the new array has ones where at least one element in A or B is nonzero and zeros where A and B are both zero.
`&&`	Short-Circuit AND	Operator for scalar logical expressions. `A && B` returns true if both A and B evaluate to true, and false if they do not.
`||`	Short-Circuit OR	Operator for scalar logical expressions. `A || B` returns true if either A or B or both evaluate to true, and false if they do not.

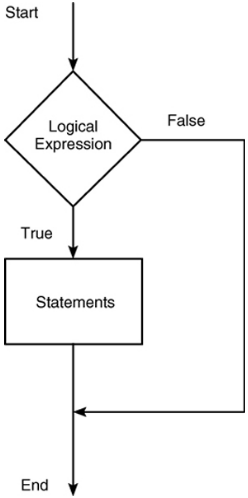
Precedence

1. Parentheses; evaluated starting with the innermost pair.
2. Arithmetic operators and logical NOT (~); evaluated from left to right.
3. Relational operators; evaluated from left to right.
4. Logical AND.
5. Logical OR.

The if Statement

The if statement's basic form is

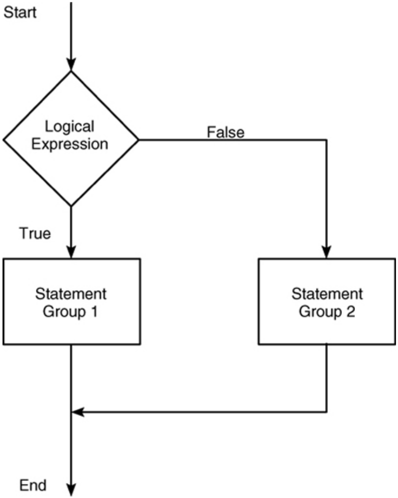
```
if logical expression
     statements
end
```



The `else` Statement

The basic structure for the use of the else statement is

```
if logical expression
    statement group 1
else
    statement group 2
end
```



```
if logical expression 1
   if logical expression 2
       statements
   end
end
```

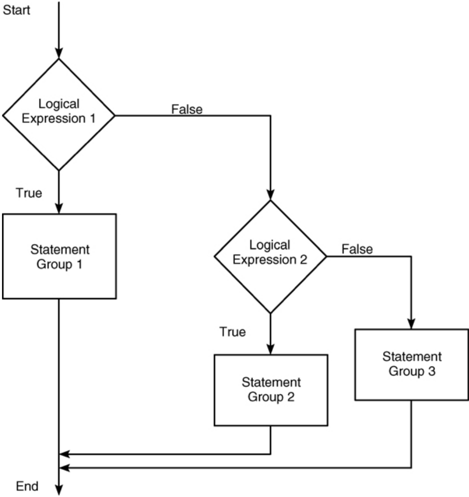
can be replaced with the more concise program

```
if logical expression 1 & logical
     expression 2
     statements
end
```

The `elseif` Statement

The general form of the if statement is

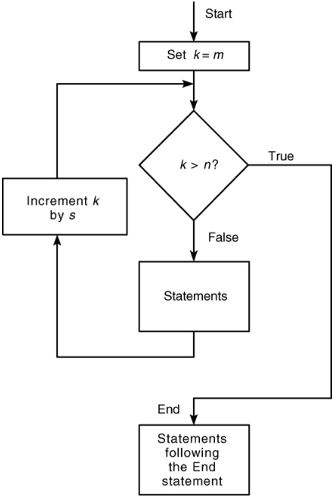
```
if logical expression 1
    statement group 1
elseif logical expression 2
    statement group 2
else
    statement group 3
end
```



`for` Loops

A simple example of a for loop is

```
for k = 5:10:35
    x = k^2
end
```

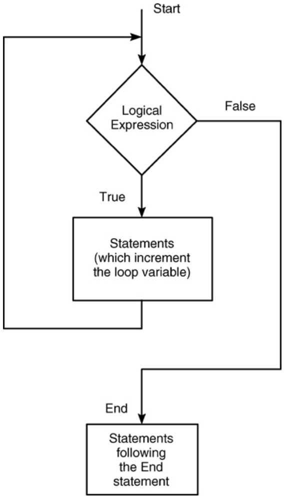


while Loops

```
while logical expression
   statements
end
```

The while loop is used when the looping process terminates because a specified condition is satisfied, and thus the number of passes is not known in advance.

```
x = 5;
while x < 25
   disp(x)
   x = 2*x - 1;
end
```



switch

```
switch input expression % (can be a
      scalar or string).
   case value1
      statement group 1
   case value2
      statement group 2
    .
    .
    .
   otherwise
      statement group n
end
```

```
switch angle
    case 45
      disp('Northeast')
    case 135
      disp('Southeast')
    case 225
      disp('Southwest')
    case 315
      disp('Northwest')
    otherwise
      disp('Direction Unknown')
end
```

Control Flow

if

```
if w(1)==0
    % <statement>
elseif w(1)==1
    % <statement>
else
    % <statement>
end
```

switch

```
method = 'Bilinear';
switch lower(method)
   case {'linear','bilinear'}
      disp('Method is linear')
   case 'cubic'
      disp('Method is cubic')
   case 'nearest'
      disp('Method is nearest')
   otherwise
      disp('Unknown method.')
end
```

for

```
w = [];
z = 0;
is = 1:10
for i=is
    w = [w, 2*i] % Same as \/
% w(i) = 2*i
% w(end+1) = 2*i
    z = z + i;
    % break;
    % continue;
end
% avoid! same as w = 2*[1:10], z = sum([1:10]);
```

while

```
w = [];
while length(w) < 3
    w = [w, 4];
    % break
end
```

Continue and Break

The continue statement passes control to the next iteration of the for loop or while loop in which it appears, skipping any remaining statements in the body of the loop.
The break statement is used to exit early from a for loop or while loop. In nested loops, break exits from the innermost loop only.

This will never end

```
while count <= 20
    if true
        continue
    end
    count = count + 1;
end
```

This will iterate once and stop

```
while count <= 20
    if true
        break
    end
    count = count + 1;
end
```

Vectorization

MATLAB is optimized for operations involving matrices and vectors.
Vectorization: The process of revising loop-based, scalar-oriented code to use MATLAB matrix and vector operations

A simple example to create a table of logarithms:

loop-based, scalar-oriented code:

```
x = .01;
for k = 1:1001
   y(k) = log10(x);
   x = x + .01;
end
```

A vectorized version of the same code is

```
x = .01:.01:10;
y = log10(x);
```

Some functions are vectorized, hence with vectors must use element-by-element operators to combine them.
Eg: $z = e^y \sin x$, x and y vectors:

```
z=exp(y).*sin(x)
```

Vectorization

Vectorizing your code is worthwhile for:

- Appearance: Vectorized mathematical code appears more like the mathematical expressions found in textbooks, making the code easier to understand.
- Less Error Prone: Without loops, vectorized code is often shorter. Fewer lines of code mean fewer opportunities to introduce programming errors.
- Performance: Vectorized code often runs much faster than the corresponding code containing loops.

Preallocation

Another speedup techinque is preallocation. Memory allocation is slow.

```
r = zeros(32,1);
for n = 1:32
   r(n) = rank(magic(n));
end
```

Without the preallocation MATLAB would enlarge the r vector by one element each time through the loop.

Outline

Introduction

Plot measured data (points) or functions (lines)

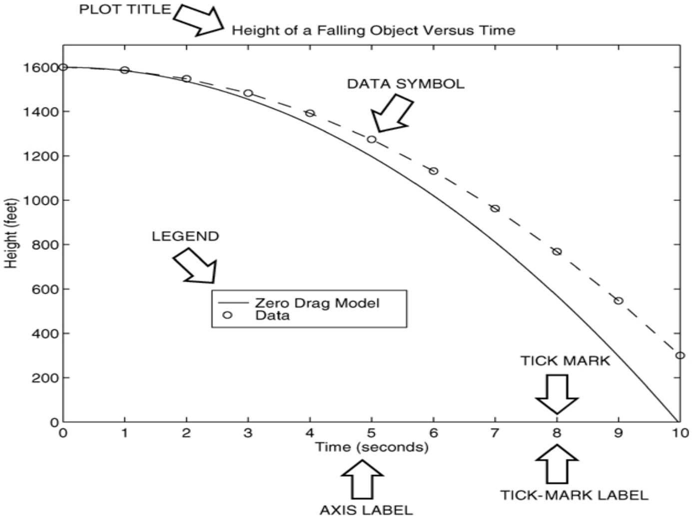
Two-dimensional plots or xy plots

```
help graph2d
```

Three-dimensional plots or xyz plots or surface plots

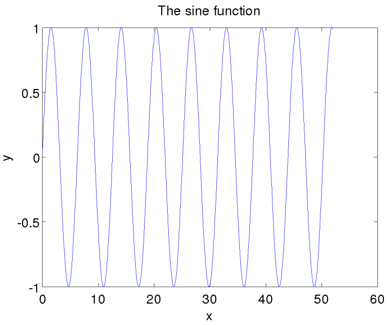
```
help graph3d
```

Nomenclature xy plot



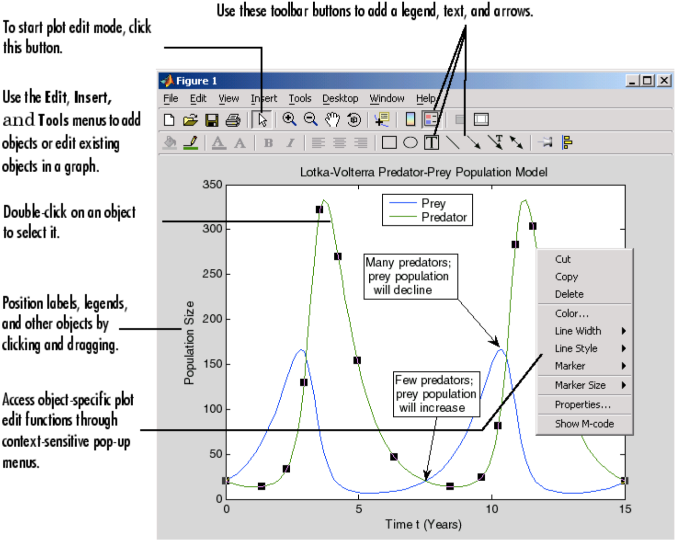
An Example: $y = \sin(x)$

```
x = 0:0.1:52;
y = sin(x)
plot(x,y)
xlabel('x')
ylabel('y')
title('The sine function')
```



The autoscaling feature in MATLAB selects tick-mark spacing.

Plotedit



But better to do this with lines of code, just in case you have to redo the plot.

Saving Figures

The plot appears in the Figure window. You can include it in your documents:

1. type
   `print -dpng foo`
   at the command line. This command sends the current plot directly to `foo.png`

   ⇝ `help print`

2. from the File menu, select Save As, write the name and select file format from Files of Types (eg, png, jpg, etc)
   .fig format is MATLAB format, which allows to edit

3. from the File menu, select Export Setup to control size and other parameters

4. on Windows, copy on clipboard and paste. From Edit menu, Copy Figure and Copy Options

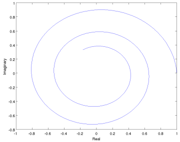
The grid and axis Commands

- `grid` command to display gridlines at the tick marks corresponding to the tick labels.
  `grid on` to add gridlines;
  `grid off` to stop plotting gridlines;
  `grid` to toggle

- `axis` command to override the MATLAB selections for the axis limits.
  `axis([xmin xmax ymin ymax])` sets the scaling for the x- and y-axes to the minimum and maximum values indicated. Note: no separating commas
  `axis square`, `axis equal`, `axis auto`

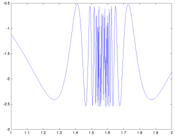
plot complex numbers

```
y=0.1+0.9i, plot(y)
z=0.1+0.9i, n=0:0.01:10,
plot(z.^n), xlabels('Real'), ylabel('Imaginary')
```



function plot command

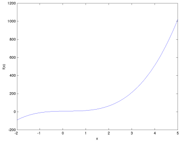
```
f=@(x) (cos(tan(x))-tan(sin(x)));
fplot(f,[1 2])
[x,y]=fplot(function,limits)
```



plotting polynomials

Eg, $f(x) = 9x^3 - 5x^2 + 3x + 7$ for $-2 \leq x \leq 5$:

```
a = [9,-5,3,7];
x = -2:0.01:5;
plot(x,polyval(a,x)),xlabel('x'),ylabel('f(x)')
```

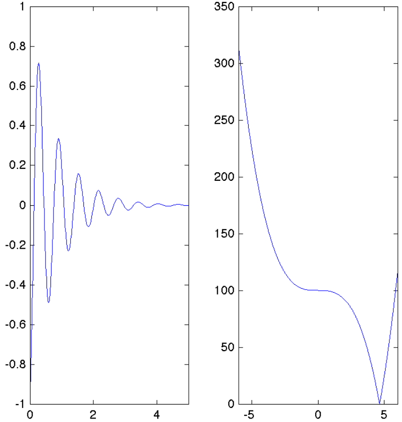


Subplots

`subplot` command to obtain several smaller subplots in the same figure.

`subplot(m,n,p)` divides the Figure window into an array of rectangular panes with m rows and n columns and sets the pointer after the pth pane.

```
x = 0:0.01:5;
y = exp(-1.2*x).*sin(10*x+5);
subplot(1,2,1)
plot(x,y),axis([0 5 -1 1])
x = -6:0.01:6;
y = abs(x.^3-100);
subplot(1,2,2)
plot(x,y),axis([-6 6 0 350])
```



Data Markers and Line Types

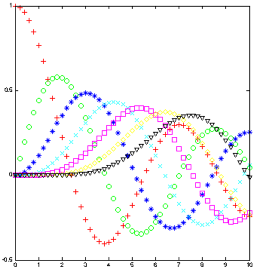
Three components can be specified in the string specifiers along with the plotting command. They are:

- Line style
- Marker symbol
- Color

```
plot(x,y,u,v,'--') % where the symbols '--' represent a dashed line
plot(x,y,'*',x,y,':') % plot y versus x with asterisks connected with a dotted line
plot(x,y,'g*',x,y,'r--') % green asterisks connected with a red dashed line
```

```
% Generate some data using the besselj
x = 0:0.2:10;
y0 = besselj(0,x);
y1 = besselj(1,x);
y2 = besselj(2,x);
y3 = besselj(3,x);
y4 = besselj(4,x);
y5 = besselj(5,x);
y6 = besselj(6,x);

plot(x, y0, 'r+', x, y1, 'go', x, y2, 'b*',
      x, y3, 'cx', ...
   x, y4, 'ms', x, y5, 'yd', x, y6, 'kv');
```



```
doc LineSpec
```

Specifier	LineStyle
'-'	Solid line (default)
'--'	Dashed line
':'	Dotted line
'-.'	Dash-dot line

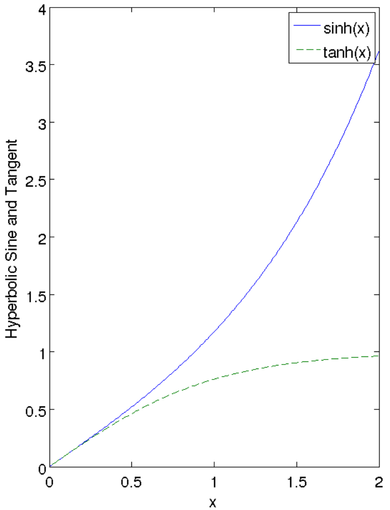
Specifier	Marker Type
'+'	Plus sign
'o'	Circle
'*'	Asterisk
'.'	Point
'x'	Cross
'square' or 's'	Square
'diamond' or 'd'	Diamond
'^'	Upward-pointing triangle
'v'	Downward-pointing triangle
'>'	Right-pointing triangle
'<'	Left-pointing triangle
'pentagram' or 'p'	Five-pointed star (pentagram)
'hexagram' or 'h''	Six-pointed star (hexagram)

Specifier	Color
r	Red
g	Green
b	Blue
c	Cyan
m	Magenta
y	Yellow
k	Black
w	White

Labeling Curves and Data

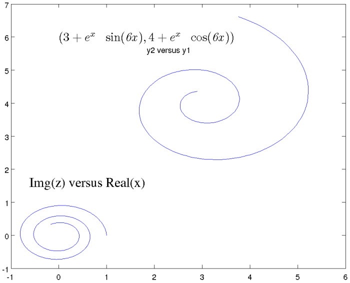
The legend command automatically obtains the line type used for each data set

```
x = 0:0.01:2;
y = sinh(x);
z = tanh(x);
plot(x,y,x,z,'--'),xlabel('x')
ylabel('Hyperbolic Sine and Tangent')
legend('sinh(x)','tanh(x)')
```



The hold Command and Text Annotations

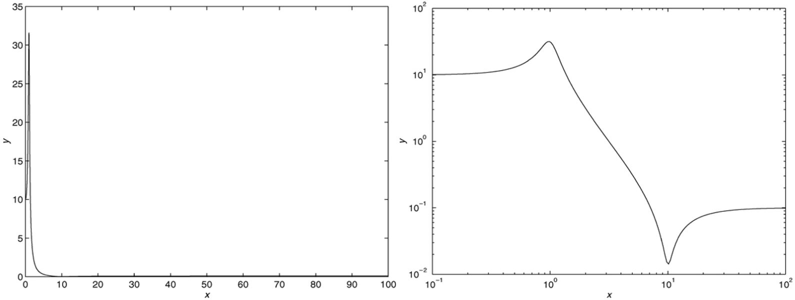
```
x=-1:0.01:1
y1=3+exp(-x).*sin(6*x);
y2=4+exp(-x).*cos(6*x);
plot((0.1+0.9i).^(0:0.01:10)), hold, plot(y1,y2)
gtext('y2 versus y1') % places in a point specified by the mouse
gtext('Img(z) versus Real(x)','FontName','Times','Fontsize',18)
```




```
text('Interpreter','latex',...
 'String',...
 '$(3+e^{-x}\sin({\it 6x}),4+e^{-x}\cos({\
     it 6x}))$',...
 'Position',[0,6],...
 'FontSize',16)
```

Search Text Properties in Help
Search Mathematical symbols, Greek Letter and TeX Characters

Axes Transformations



Instead of `plot`, plot with

```
loglog(x,y) % both scales logarithmic.
semilogx(x,y) % x scale logarithmic and the y scale rectilinear.
semilogy(x,y) % y scale logarithmic and the x scale rectilinear.
```

Logarithmic Plots

Remember:

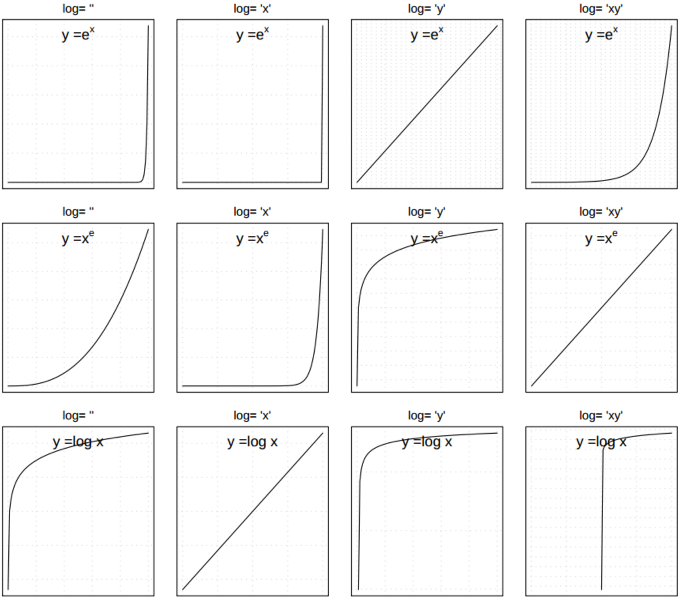
1. You cannot plot negative numbers on a log scale: the logarithm of a negative number is not defined as a real number.

2. You cannot plot the number 0 on a log scale: $\log_{10} 0 = -\infty$.

3. The tick-mark labels on a log scale are the actual values being plotted; they are not the logarithms of the numbers. Eg, the range of x values in the plot before is from $10^{-1} = 0.1$ to $10^{2} = 100$.

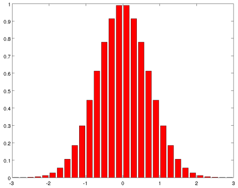
4. Gridlines and tick marks within a decade are unevenly spaced. If 8 gridlines or tick marks occur within the decade, they correspond to values equal to $2, 3, 4, \ldots, 8, 9$ times the value represented by the first gridline or tick mark of the decade.

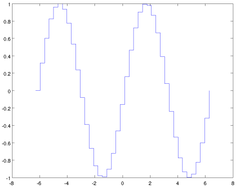
5. Equal distances on a log scale correspond to multiplication by the same constant (as opposed to addition of the same constant on a rectilinear scale).

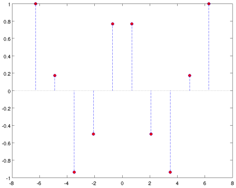

log= ''
y =e^x
log= 'x'
y =e^x
log= 'y'
y =e^x
log= 'xy'
y =e^x
log= ''
y =x^e
log= 'x'
y =x^e
log= 'y'
y =x^e
log= 'xy'
y =x^e
log= ''
y =log x
log= 'x'
y =log x
log= 'y'
y =log x
log= 'xy'
y =log x

Specialized plot commands

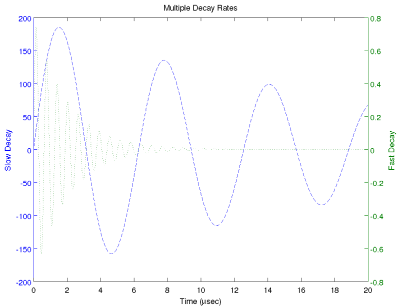
Command	Description
`bar(x,y)`	Creates a bar chart of y versus x
`stairs(x,y)`	Produces a stairs plot of y versus x.
`stem(x,y)`	Produces a stem plot of y versus x.

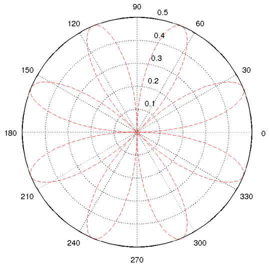






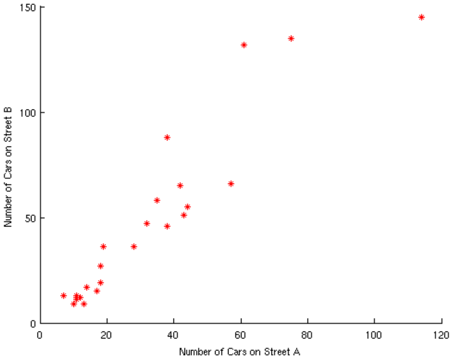
Command	Description
`plotyy(x1,y1,x2,y2)`	Produces a plot with two y-axes, y1 on the left and y2 on the right
`polar(theta,r,'type')`	Produces a polar plot from the polar co-ordinates theta and r, using the line type, data marker, and colors specified in the string type.





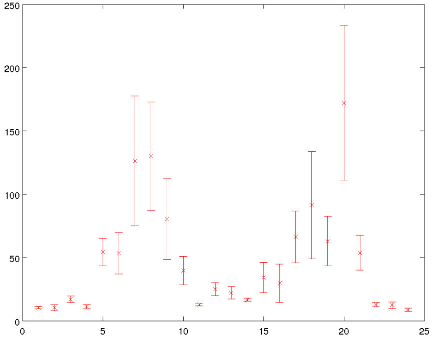
Scatter Plots

```
load count.dat
scatter(count(:,1),count(:,2),
     'r*')
xlabel('Number of Cars on
     Street A');
ylabel('Number of Cars on
     Street B');
```



Error Bar Plots

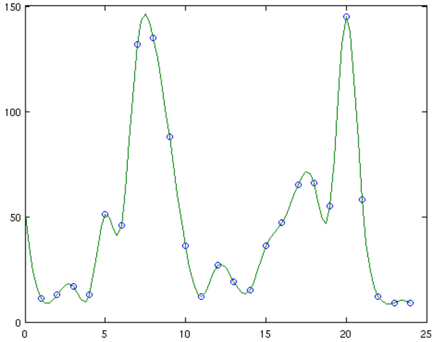
```
load count.dat;
y = mean(count,2);
e = std(count,1,2);
figure
errorbar(y,e,'xr')
```



Splines

Add interpolation

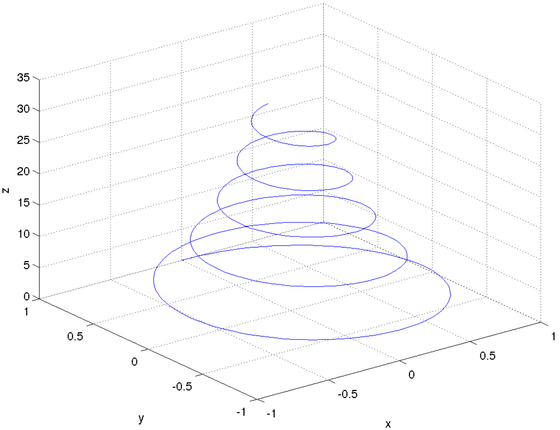
```
x=1:24
y=count(:,2)
xx=0:.25:24
yy=spline(x,y,xx)
plot(x,y,'o',xx,yy)
```



Three-Dimensional Line Plots

Plot in 3D the curve: $x = e^{-0.05t}\sin(t), y = e^{-0.05t}\cos(t), z = t$

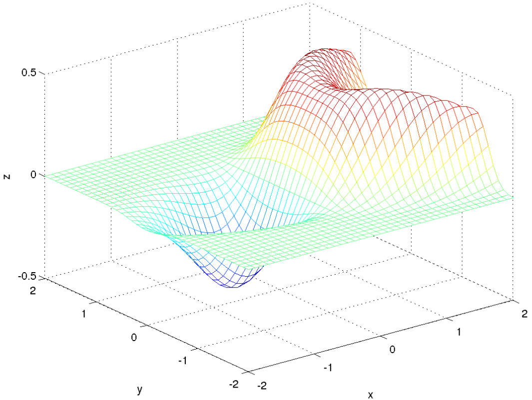
```
t = 0:pi/50:10*pi;
plot3(exp(-0.05*t).*sin(t), exp(-0.05*t).*cos(t), t)
xlabel('x'), ylabel('y'), zlabel('z'), grid
```



Surface Plots

Surface plot of the function $z = xe^{-[(x-y^2)^2+y^2]}$, for $-2 \leq x \leq 2$ and $-2 \leq y \leq 2$ with a spacing of 0.1

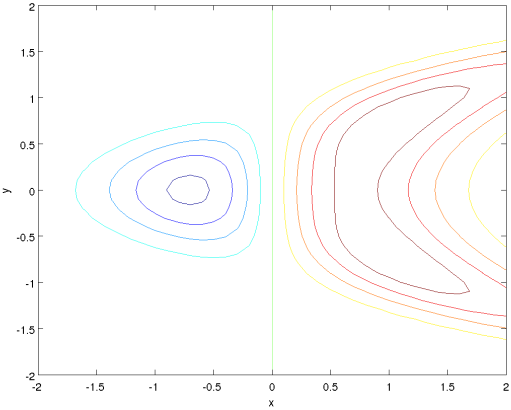
```
[X,Y] = meshgrid(-2:0.1:2);
Z = X.*exp(-((X-Y.^2).^2+Y.^2));
mesh(X,Y,Z), xlabel('x'), ylabel('y'), zlabel('z')
```



Contour Plots

Contour plot of the function $z = xe^{-[(x-y^2)^2+y^2]}$, for $-2 \leq x \leq 2$ and $-2 \leq y \leq 2$ with a spacing of 0.1

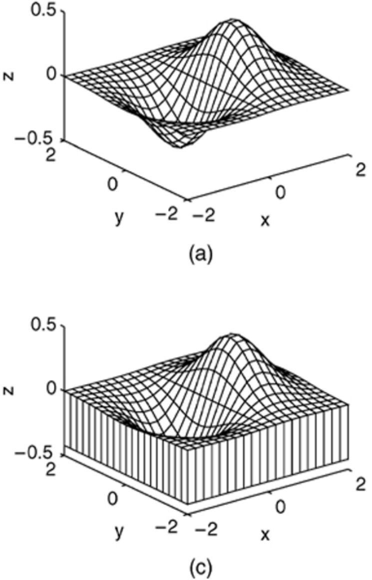
```
[X,Y] = meshgrid(-2:0.1:2);
Z = X.*exp(-((X-Y.^2).^2+Y.^2));
contour(X,Y,Z), xlabel('x'), ylabel('y')
```



Three-Dimensional Plotting Functions

Function	Description
`contour(x,y,z)`	Creates a contour plot.
`mesh(x,y,z)`	Creates a 3D mesh surface plot.
`meshc(x,y,z)`	Same as mesh but draws contours under the surface.
`meshz(x,y,z)`	Same as mesh but draws vertical reference lines under the surface.
`surf(x,y,z)`	Creates a shaded 3D mesh surface plot.
`surfc(x,y,z)`	Same as surf but draws contours under the surface.
`[X,Y] = meshgrid(x,y)`	Creates the matrices X and Y from the vectors x and y to define a rectangular grid.
`[X,Y] = meshgrid(x)`	Same as `[X,Y]= meshgrid(x,x)`.
`waterfall(x,y,z)`	Same as mesh but draws mesh lines in one direction only.

a) mesh, b) meshc, c) meshz, d) waterfall



Guidelines for Making Plots

- Should the experimental setup from the exploratory phase be redesigned to increase conciseness or accuracy?
- What parameters should be varied? What variables should be measured?
- How are parameters chosen that cannot be varied?
- Can tables be converted into curves, bar charts, scatter plots or any other useful graphics?
- Should tables be added in an appendix?
- Should a 3D-plot be replaced by collections of 2D-curves?
- Can we reduce the number of curves to be displayed?
- How many figures are needed?
- Should the x-axis be transformed to magnify interesting subranges?

- Should the x-axis have a logarithmic scale? If so, do the x-values used for measuring have the same basis as the tick marks?
- Make sure the each axis is labeled with the name of the quantity being plotted and its units.
- Make tick marks regularly paced and easy to interpret and interpolate, eg, 0.2, 0.4, rather than 0.23, 0.46
- Use the same scale limits and tick spacing on each plot if you need to compare information on more than one plot.
- Is the range of x-values adequate?
- Do we have measurements for the right x-values, i.e., nowhere too dense or too sparse?
- Should the y-axis be transformed to make the interesting part of the data more visible?
- Should the y-axis have a logarithmic scale?
- Is it misleading to start the y-range at the smallest measured value? (if not too much space wasted start from 0)
- Clip the range of y-values to exclude useless parts of curves?

- Can we use banking to 45^o?
- Are all curves sufficiently well separated?
- Can noise be reduced using more accurate measurements?
- Are error bars needed? If so, what should they indicate? Remember that measurement errors are usually not random variables.
- Connect points belonging to the same curve.
- Only use splines for connecting points if interpolation is sensible.
- Do not connect points belonging to unrelated owners.
- Use different point and line styles for different curves.
- Use the same styles for corresponding curves in different graphs.
- Place labels defining point and line styles in the right order and without concealing the curves.

- Captions should make figures self contained.
- Give enough information to make experiments reproducible.
- Golden ratio rule: make the graph wider than higher [Tufte 1983].
- Rule of 7: show at most 7 curves (omit those clearly irrelevant).
- Avoid: explaining axes, connecting unrelated points by lines, cryptic abbreviations, microscopic lettering, pie charts

Exercises

- Plot a segment between two points
- Measure how the time required to solve a linear system varies with the order of a matrix for the methods in ex. 5 of week 1 and plot in the same graph the curves representing the two methods. Vary the size of the matrix at intervals from 200 to 1000. You can add repetitions at each size and errorbars in the plot.

Demos

Try!

```
demo 'matlab'
```

Outline

Script and Function Files (M-files)

- Modularize
- Make interaction clear
  make functions interact via arguments (in case structures) rather than via global variables
- Partitioning
- Use existing functions
  (http://www.mathworks.com/matlabcentral/fileexchange)
- Any block of code appearing in more than one m-file should be considered for packaging as a function
- Subfunctions
  packaged in the same file as their functions
- Test scripts

Programming Style

- Document your scripts:
  - author and date of creation
  - what the script is doing
  - which input data is required
  - the function that the user has to call
  - definitions of variables used in the calculations and units of measurement for all input and all output variables!
- Organize your script as follows:
  1. input section (input data and/or input functions)
     Eg: `x=input("give me a number")`, `input("enter a key",'s')`
  2. calculation section
  3. output section (functions for displaying the output on the screen or files)
     Eg: `display(A)`, `display("text")`

Example

```
% Program M3eP32.m
% Program Falling_Speed.m: plots speed of a falling object.
% Created on March 1, 2009 by W. Palm III
%
% Input Variable:
% tfinal = final time (in seconds)
%
% Output Variables:
% t = array of times at which speed is computed (seconds)
% v = array of speeds (meters/second)
%
% Parameter Value:
g = 9.81; % Acceleration in SI units
%
% Input section:
tfinal = input('Enter the final time in seconds:');
%
% Calculation section:
dt = tfinal/500;
t = 0:dt:tfinal; % Creates an array of 501 time values.
v = g*t;
%
% Output section:
plot(t,v),xlabel('Time (seconds)'),ylabel('Speed (meters/second)')
```

Documentation

Effective documentation can be accomplished with the use of

- Proper selection of variable names to reflect the quantities they represent.
- Use of comments within the program.
- Use of structure charts.
- Use of flowcharts.
- A verbal description of the program, often in pseudocode.

More Guidelines on Style

More https://sites.google.com/site/matlabstyleguidelines