FF505/FY505

Computational Science

Lecture 3
Graphics
Writing Functions

Marco Chiarandini

Department of Mathematics & Computer Science
University of Southern Denmark

Outline

Resume

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

- Large sparse matrices and performance comparison
- Arrays
- Mathematical functions

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

Today

- Graphics: basic and advanced plotting
- Random numbers generation
- Writing your own functions (and small programs)

Outline

1. Graphics
   - 2D Plots
   - 3D Plots
2. Random Number Generators
3. Functions

Introduction

Plot measured data (points) or functions (lines)

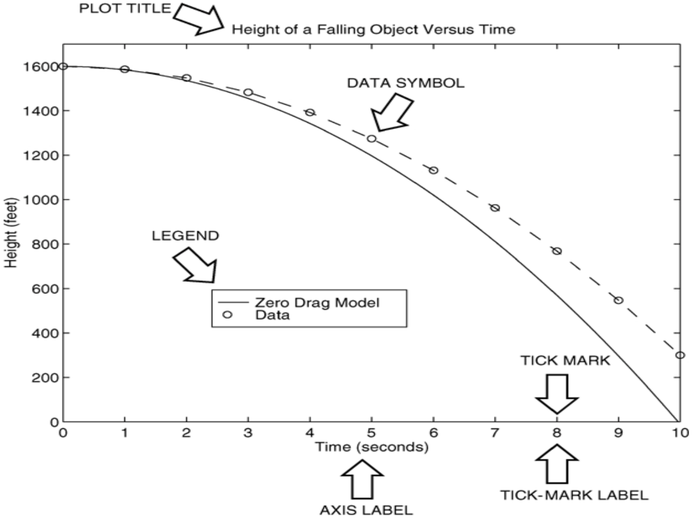
Two-dimensional plots or xy plots

```
help graph2d
```

Three-dimensional plots or xyz plots or surface plots

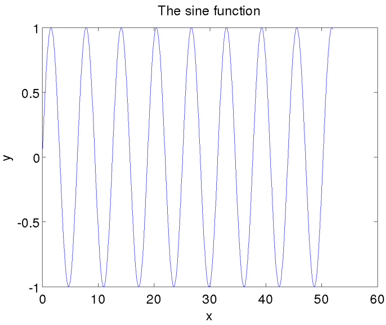
```
help graph3d
```

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.

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

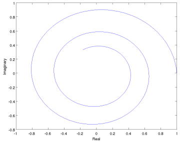
The grid and axis Commands

- `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`

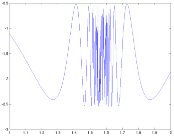
plot complex numbers

```
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

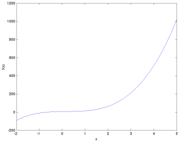
```
f=@(x) (cos(tan(x))-tan(sin(x)));
fplot(f,[1 2])
[x,y]=fplot(function,limits)
```



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)')
```

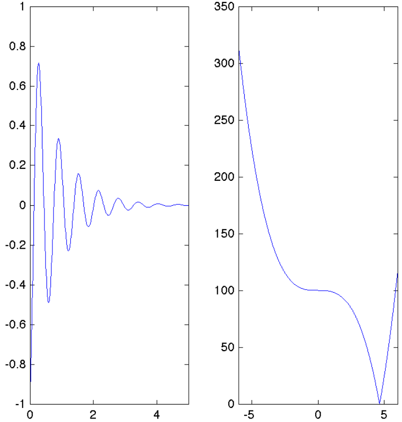


Subplots

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

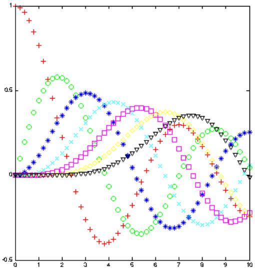
Three components can be specified in the string specifiers along with the plotting command. They are:

- 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

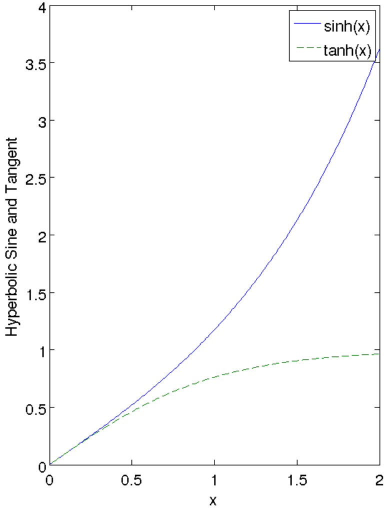
Specifier	Marker Type
'+'	Plus sign
'o'	Circle
'*'	Asterisk
'.'	Point
'x'	Cross
'square' or 's'	Square
'diamond' or 'd'	Diamond
'^'	Upward-pointing triangle
'v'	Downward-pointing triangle
'>'	Right-pointing triangle
'<'	Left-pointing triangle
'pentagram' or 'p'	Five-pointed star (pentagram)
'hexagram'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

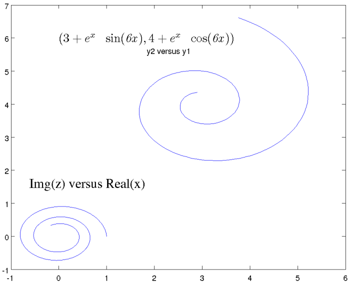
The legend command automatically obtains the line type used for each data set

```
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

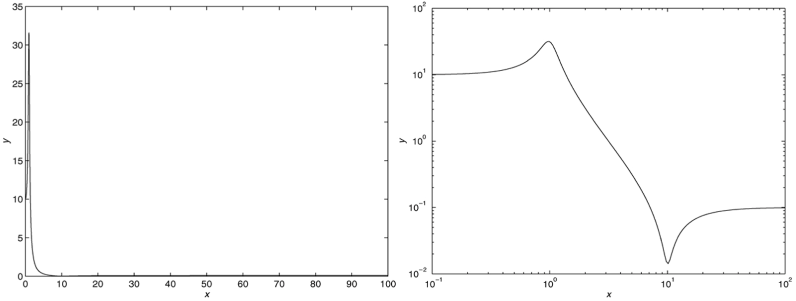
```
x=-1:0.01:1
y1=3+exp(-x).*sin(6*x);
y2=4+exp(-x).*cos(6*x);
plot((0.1+0.9i).^(0:0.01:10)), hold, plot(y1,y2)
gtext('y2 versus y1') % places in a point specified by the mouse
gtext('Img(z) versus Real(x)','FontName','Times','Fontsize',18)
```




```
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



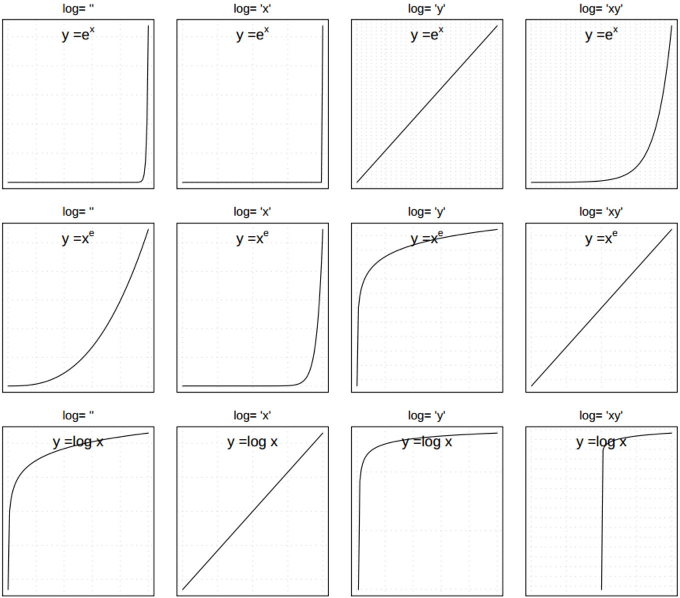
Instead of `plot`, plot with

```
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

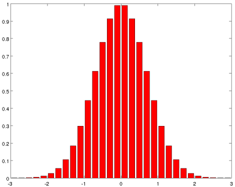
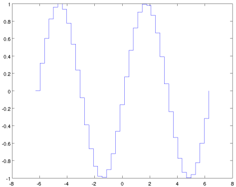
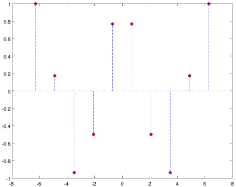
Remember:

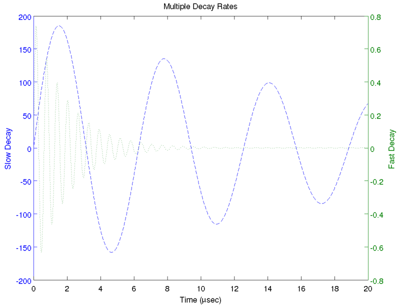
1. You cannot plot negative numbers on a log scale: the logarithm of a negative number is not defined as a real number.
2. You cannot plot the number 0 on a log scale: $\log_{10} 0 = -\infty$.
3. The tick-mark labels on a log scale are the actual values being plotted; they are not the logarithms of the 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).

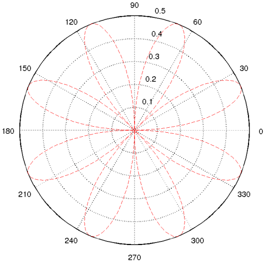

log= ''
y =e^x
log= 'x'
y =e^x
log= 'y'
y =e^x
log= 'xy'
y =e^x
log= ''
y =x^e
log= 'x'
y =x^e
log= 'y'
y =x^e
log= 'xy'
y =x^e
log= ''
y =log x
log= 'x'
y =log x
log= 'y'
y =log x
log= 'xy'
y =log x

Specialized plot commands

Command	Description
`bar(x,y)`	Creates a bar chart of y versus x
`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 coordinates theta and r, using the line type, data marker, and colors specified in the string type.
`stairs(x,y)`	Produces a stairs plot of y versus x.
`stem(x,y)`	Produces a stem plot of y versus x.

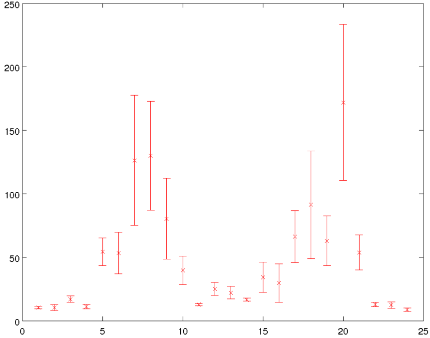





Multiple Decay Rates
Slow Decay
Fast Decay
Time (µsec)
200
150
100
50
0
-50
-100
-150
-200
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
2
4
6
8
10
12
14
16
18
20


90
60
30
0
330
300
270
240
210
180
150
120
0.1
0.2
0.3
0.4
0.5

Error Bar Plots

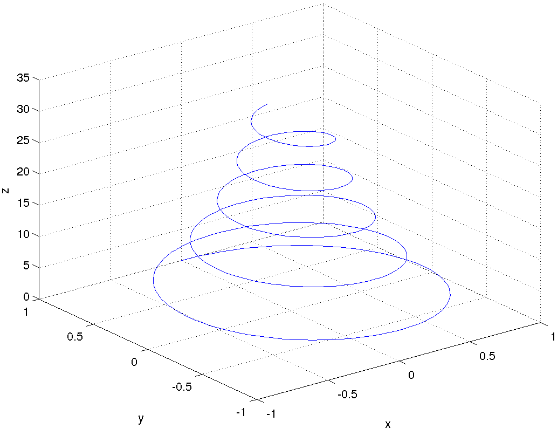
```
load count.dat;
y = mean(count,2);
e = std(count,1,2);
figure
errorbar(y,e,'xr')
```



Three-Dimensional Line Plots

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

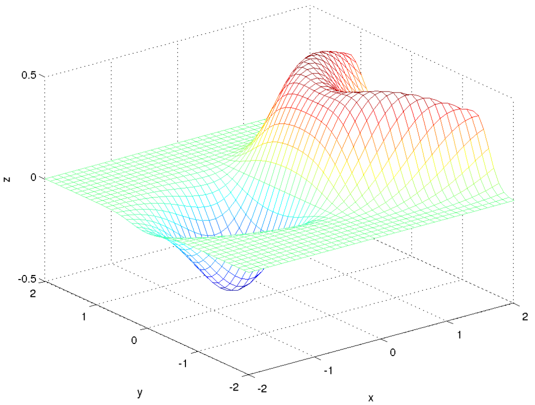
```
t = 0:pi/50:10*pi;
plot3(exp(-0.05*t).*sin(t), exp(-0.05*t).*cos(t), t)
xlabel('x'), ylabel('y'), zlabel('z'), grid
```



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

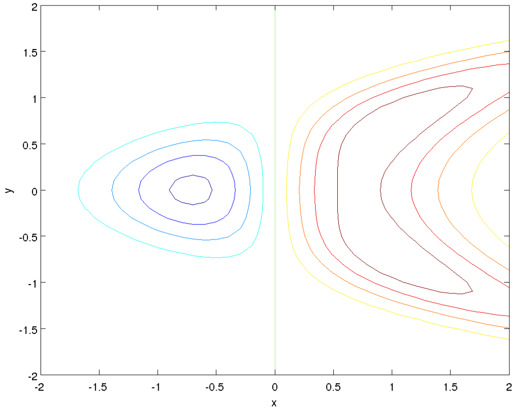
```
[X,Y] = meshgrid(-2:0.1:2);
Z = X.*exp(-((X-Y.^2).^2+Y.^2));
mesh(X,Y,Z), xlabel('x'), ylabel('y'), zlabel('z')
```



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

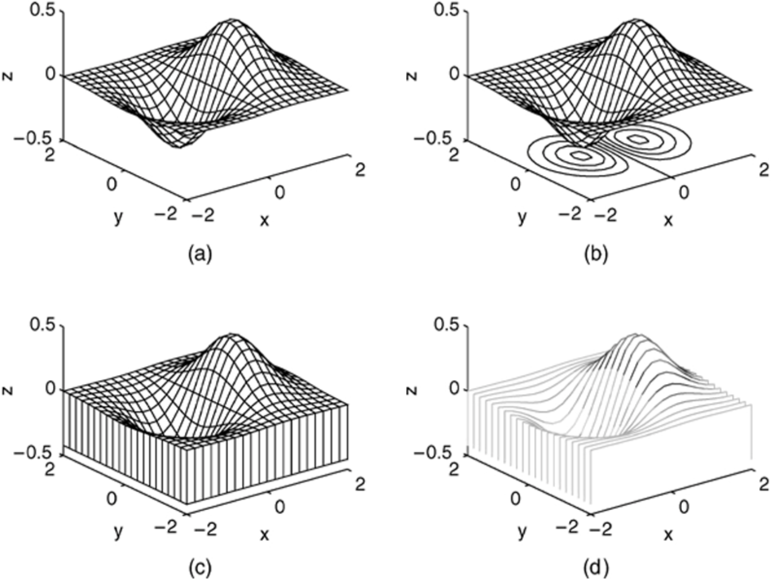
```
[X,Y] = meshgrid(-2:0.1:2);
Z = X.*exp(-((X-Y.^2).^2+Y.^2));
contour(X,Y,Z), xlabel('x'), ylabel('y')
```



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

Outline

Random Generators

In computers random numbers are generated by pseudo-random generators:

- sequence of numbers that approximates the properties of random numbers
- sequence not truly random, but completely determined by a relatively small set of initial values, called the PRNG's state, which includes a truly random seed

Characteristics of good generators:

- long period
- uniform unbiased distribution
- uncorrelated (time series analysis)
- efficient

Mersenne Twister is the default algorithm

search “seed” in the Help. Changing random number generator syntax

Outline

1. Graphics
   - 2D Plots
   - 3D Plots

2. Random Number Generators

3. Functions

User-Defined Functions

function M-file (as opposed to script M-file) defined by syntax:

```
function [output variables] = name(input variables)
```

Example

In `fun.m`

```
function z = fun(x,y)
u = 3*x;
z = u + 6*y.^2;
```

```
q = fun(3,7)
q =
   303
```

⇝ variables have local scope

Local Variables

Local Variables do not exist outside the function

```
>>x = 3;y = 7;
>>q = fun(x,y);
>>x
x =
3
>>y
y =
7
>>u
??? Undefined function or variable 'u'.
```