Matlab Tutorial

CS370 - Introduction to Numerical Computation

CS371 - Introduction to Computational Mathematics

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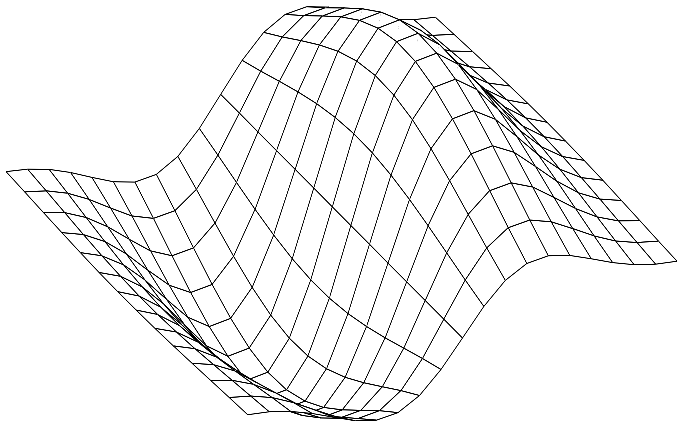
Outline

- Matlab Overview
- Useful Commands
- Matrix Construction and Flow Control
- Script/Function Files
- Basic Graphics



What is Matlab?

According to *The Mathworks*:

> MATLAB is an integrated technical computing environment that combines numeric computation, advanced graphics and visualization, and a high-level programming language.
>
> MATLAB includes hundreds of functions for:
>
> - Data analysis and visualization
> - Numeric and symbolic computation
> - Engineering and scientific graphics
> - Modeling, simulation, and prototyping
> - Programming, application development, and GUI design

Getting Started

- Web resources
  - ◊ Course Web page
  - ◊ www.mathworks.com
- Books
  - ◊ *Mastering Matlab 5/6*, D. Hanselman, B. Littlefield
  - ◊ *Introduction to Scientific Computing*, Van Loan

Running Matlab

- At the UNIX prompt:
  - ◊ *Don't type:* matlab
    - graphical desktop, slow
  - ◊ *Instead, type:* matlab -nodesktop -nosplash
    -text interface, faster
  - ◊ (other options: matlab -h)
- If you see the message

  ```
  Xlib: connection to "x.uwaterloo.ca:0.0" refused by server
  Xlib: Client is not authorized to connect to Server
  ```

  you need to set display permissions
- Use Matlab 5.3 or later for all assignments

```
@rees[102]% matlab -nodesktop -nosplash

                              < M A T L A B >
                  Copyright 1984-2002 The MathWorks, Inc.
                      Version 6.5.0.180913a Release 13
                                Jun 18 2002


  To get started, type one of these: helpwin, helpdesk, or demo.
  For product information, visit www.mathworks.com.

>>
```

How does Matlab work?

- Interactive environment
- Type commands at the prompt ('>>' typically)
- Case sensitive
- External programs/functions are in M-files (text files with a .m extension)
- Execute M-files by typing the filename (without the .m)
- Note: Almost everything in Matlab is an external function (use the `which` command to locate the source)

Basic Operations

- 'Matrix' is the only data type
- Vectors are $1 \times N$ or $N \times 1$ matrices
- Scalars are 1×1 matrices
- Addition and subtraction operate entry-wise, while

  `*`, `^`, `\` and `/`

  are matrix operations (unless preceded by a dot).
- Matrices and vectors are *1-offset*

Basic Example 1

```
>> A = [1 2 3 ; 4 5 6]
A =
     1     2     3
     4     5     6

>> test = A*A
??? Error using ==> *
Inner matrix dimensions must agree.

>> test = A*A'
test =
    14    32
    32    77
```

Basic Example 2

```
>> A = [1 2 ; 3 4]
A =
     1     2
     3     4

>> A^2
ans =
     7    10
    15    22

>> A.^2
ans =
     1     4
     9    16
```

Transposes

- Strictly, A' is *complex conjugate transpose* of A
- Usual (non-conjugate) transpose is A.'
-
```
>> A = [1+i, 2+2i, 3+3i]
A =
   1.0000 + 1.0000i   2.0000 + 2.0000i   3.0000 + 3.0000i
>> A'
ans =
   1.0000 - 1.0000i
   2.0000 - 2.0000i
   3.0000 - 3.0000i
>> A.'
ans =
   1.0000 + 1.0000i
   2.0000 + 2.0000i
   3.0000 + 3.0000i
```

Basic Example 3 - Solving Ax=b

```
>> A = [1,15,4; 2,15,20; 3,30,9];
>> b = [1;22;9];
>> x=A\b

x =
    6.0667
   -0.5867
    0.9333

>> x=inv(A)*b

x =
    6.0667
   -0.5867
    0.9333
```

Useful commands

- help - Obtain help for a specific function
- lookfor - Keyword search of help text
- more {on/off} - Paging
- clear - Remove variables
- close - Close figure windows
- whos - List currently defined variables
- format - Set output format (e.g., number of digits)
- % - comment line in an M-file

help

- help function will give detailed information about 'function'
- Displays the comments at the top of the M-file
- Some of the help screens read like UNIX man pages
- Related items are listed at the end
- Despite the help text, all command are lower case
- Second command to use when you are stuck

lookfor

- First command to use when you are stuck
- lookfor XYZ searches the first comment line for the string XYZ
- Useful if you do not know the function name, but expect that the function exists
- Can be slow

more

- more {on/off}
- Turn screen paging on or off
- Works like the Unix more command

clear

- clear X - Remove the variable X
- clear X* - Remove all variables starting with string X
- clear - Remove all variables
- clear all - Removes everything (variables, functions, globals and MEX links)
- Often useful at the beginning of script files
- (To clear command window: clc)

close

- close - Close the current figure
- close all - Close all figure windows
- Useful at the start of script files

whos

- who - list all variables
- whos - list all variables, with size information

```
>> whos
  Name       Size            Bytes  Class


  ans        1x17               34  char array
  x         14x21             2352  double array
  y         14x22             2464  double array
  z         14x21             2352  double array
Grand total is 913 elements using 7202 bytes
```

- Useful if you keep getting array size mismatches (remember that Matlab is 1-offset)

format

- `>> 1/3`
  ```
  ans =
     0.3333
  ```
- ```
  >> format long
  >> 1/3
  ans =
     0.333333333333333
  ```
- ```
  >> format short e
  >> 1/3
  ans =
     3.3333e-01
  ```
- help format

Command line tricks

- Up/Down arrow keys to cycle through commands
- Partially typing a command and hitting up arrow will search the command stack
- Can type multi-line commands, but each line is saved separately (ie. not very useful for re-entering loop commands)
- A command can span two lines by using ... at the end of the first line

Constructing Matrices

- Type in all the numbers directly (semi-colons or new lines create new rows)
- Use ones or zeros
- Use the colon notation
  - ◊ start:step:final (e.g. 3:2:7 = [3 5 7])
  - ◊ steps can be negative (e.g. 7:-2:3 = [7 5 3])
  - ◊ start:final assumes a step of 1
  - ◊ colon by itself means 'all' (eg. A(1,:) is all columns in row 1)
- A variety of other methods exist (load, algebra, other functions)
- Note that vectors and arrays are dynamic

Example

```
>> m1 = zeros(1,3)
m1 =
     0     0     0

>> m2 = ones(3)
m2 =
     1     1     1
     1     1     1
     1     1     1

>> m3(2:3,:) = [m2(3,:); [1:1:3]]
m3 =
     0     0     0
     1     1     1
     1     2     3
```

Dimensions of Matrices and Vectors

- size(A) for matrices, length(x) for vectors
-
```
>> A = [1 2 3; 4 5 6]
A =
     1     2     3
     4     5     6
>> [m n] = size(A)
m =
     2
n =
     3
>> x = [1 2 3 4]
x =
     1     2     3     4
>> length(x)
ans =
     4
```

Control Structures

- For statements:

```
FOR I = 1:N,
    FOR J = 1:N,
        A(I,J) = 1/(I+J-1);
    END
END
```

- While loops

```
WHILE X > 1,
    X = X - 1;
END
```

Control Structures (cont.)

- IF statements

```
IF expression
    statements
ELSEIF expression
    statements
.
.
.
ELSE
    statements
END
```

Relational and Logical Operators

- Relational operators

  `<   <=   >   >=   ==   ~= (in C: !=)`

- Logical operators

	Matlab	C
AND	&	&&
OR	|	||
NOT	~	!

- ```
  >> A = 1:9
  A =
       1     2     3     4     5     6     7     8     9
  >> tf = (A>2)&(A<6)
  tf =
       0     0     1     1     1     0     0     0     0
  ```
  ```

Vectorizing Loops

```
>> cs370marks = [24 36 11 42 33 55 30];
>> for i=1:length(cs370marks)
       cs370marks(i) = 10*cs370marks(i)^(1/2);
   end
>> cs370marks
cs370marks =
   48.9898   60.0000   33.1662   64.8074   57.4456
   74.1620   54.7723

>> cs370marks = [24 36 11 42 33 55 30];
>> cs370marks = 10*cs370marks.^(1/2)
cs370marks =
   48.9898   60.0000   33.1662   64.8074   57.4456
   74.1620   54.7723
```

Script files

- Matlab commands can be placed in text files with .m extensions
- The commands are interpreted/executed when the filename is typed at the Matlab prompt (no .m extension)
- The effect is identical to typing the commands (i.e. all new variables remain, all old variables are accessible)
- Convenient if the same set of commands need to be executed wth minor changes
- Commonly used for ‘driver’ programs on assignments

Function Files

- Defined in text files with .m extensions
- Called by typing the filename (no .m)
- Functions do not have access to existing variables (separate scope)
- Functions can accept/return zero or more values
- Control is lost when the end of the file is reached, or the command return is encountered

Function Example

```
function [newmarks] = bell(oldmarks, method)
% Whatever appears here is displayed when the user
% types ‘help bell’

% This line will not appear in the help text
if method == 1
    newmarks = 10*oldmarks.^(1/2);
elseif method == 2
    newmarks = oldmarks + 10*ones(1, length(oldmarks));
else
    newmarks = oldmarks;
end
return
```

Function Example

```
>> help bell

  Whatever appears here is displayed when the user
  types 'help bell'

>> m = [23 67 43 49 75 55];
>> bell(m,1)
ans =
   47.9583   81.8535   65.5744   70.0000   86.6025   74.1620
>> m_new = bell(m,2)
m_new =
    33    77    53    59    85    65
```

Debugging

- See help debug
- Set a breakpoint with dbstop
- Trace through the execution with dbstep
- Show the execution stack with dbstack
- Continue execution with dbcont
- Quit debugging with dbquit

Text Strings

- Use single quotes to define text: 'string'
- Use disp to display text without the associated variable name (also works for variables)
- Can have an array of strings if each string has the same length
- Can convert from numbers to strings using the num2str command

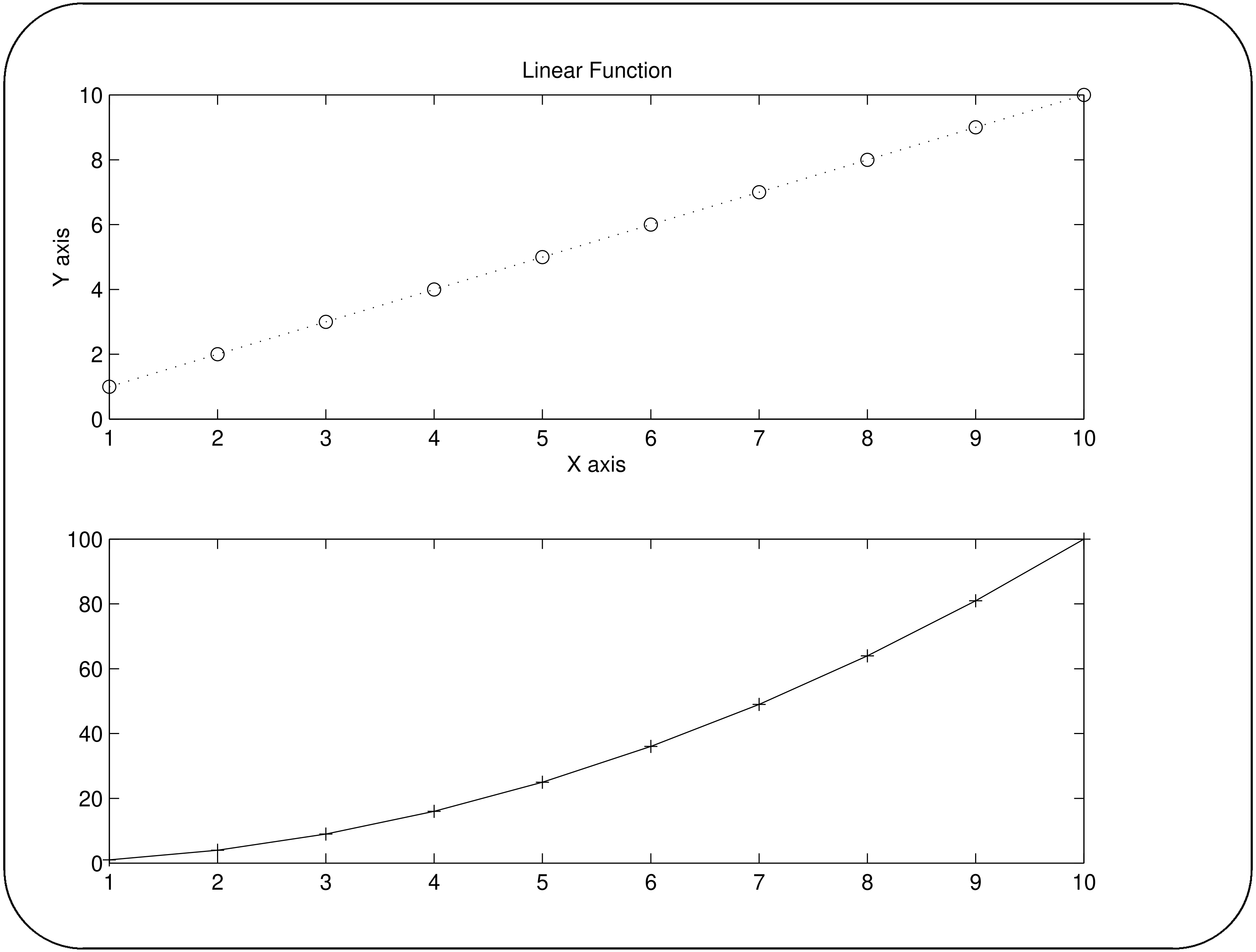
```
>> a = 1;
>> b = 5;
>> t = ['Plot ' num2str(a) ' of ' num2str(b)];
>> disp(t)
Plot 1 of 5
```

Graphics

- Matlab has excellent graphics support for experimenting with data
- Since the data is ‘live’, you can quickly and easily change plots and figures
- Figure windows can easily be saved and printed (as postscript)
- A nice monitor/machine can make a BIG difference

2D plots

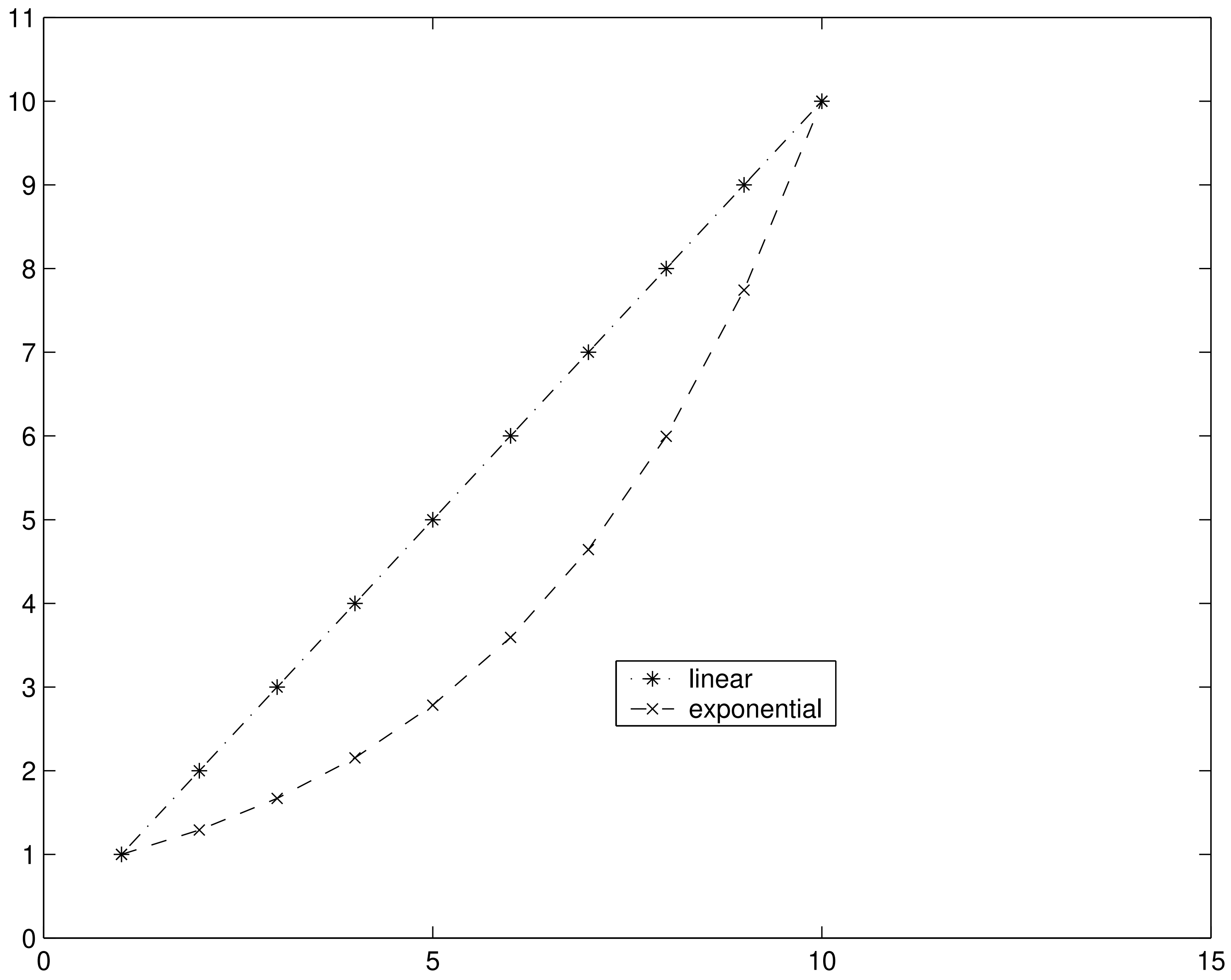
```
>> x = [1:1:10];
>> y_lin = x;
>> y_quad = x.^2;
>> subplot(2,1,1), plot(x,y_lin,'bo:')
>> title('Linear Function')
>> xlabel('X axis')
>> ylabel('Y axis')
>> subplot(2,1,2), plot(x,y_quad,'r+-')
>> print -deps fig1.eps
>> close
```


Linear Function
Y axis
X axis
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
100
80
60
40
20
0

2D plots (cont.)

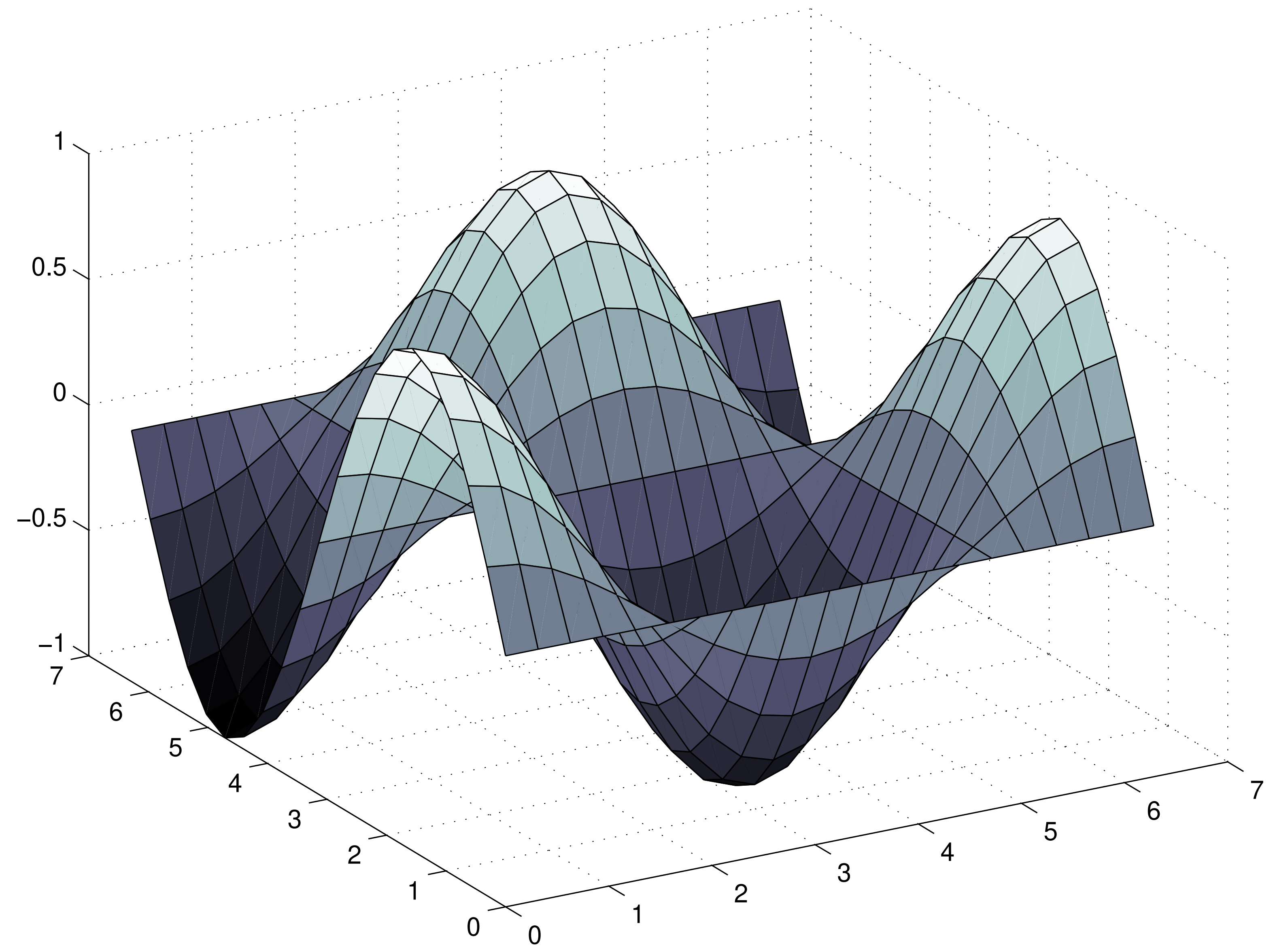
```
>> x=linspace(1,10,10);
>> y_lin = x
y_lin =
     1     2     3     4     5     6     7     8     9    10
>> y_log = logspace(0,1,10)
y_log =
  Columns 1 through 6
    1.0000    1.2915    1.6681    2.1544    2.7826    3.5938
  Columns 7 through 10
    4.6416    5.9948    7.7426   10.0000

>> plot(x,y_lin,'*-.')
>> hold on
>> plot(x,y_log,'x--')
>> axis([0 15 0 11])
>> legend('linear', 'exponential')
```


linear
exponential
0
1
2
3
4
5
6
7
8
9
10
11
0
5
10
15

3D plots

```
>> figure
>> x=[0:2*pi/20:2*pi];
>> y=x;
>> z=sin(x)'*cos(y);
>> surf(x,y,z)
>> colormap('bone')
>> view(-30,30)
>> print -deps mesh3d.eps
```



1
0.5
0
−0.5
−1
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7

Efficiency Issues

- Vectorize loops whenever possible
- Pre-allocate arrays whenever possible
- Experiment with TIC, TOC, CPUTIME
- We will be checking for efficient code on assignments

Summary

- Use help and lookfor on a regular basis
- Use more on and semi-colons to maintain an intelligible display
- When interpreting error messages, remember that all variables are matrices
- Use script files and functions to automate repetitive tasks (anything over 5 lines should probably be in an M-file)
- Try to use operations on vectors/matrices, instead of loop constructs