Programming with MATLAB

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Reference:

1. *Applied Numerical Methods with MATLAB for Engineers*, Chapter 3 & Teaching material

Chapter Objectives (1/2)

- Learning how to create well-documented M-files in the edit window and invoke them from the command window
- Understanding how script and function files differ.
- Understanding how to incorporate help comments in functions
- Knowing how to set up M-files so that they interactively prompt users for information and display results in the command window
- Understanding the role of subfunctions and how the are accessed
- Knowing how to create and retrieve data files

Chapter Objectives (2/2)

- Learning how to write clear and well-documented M-files by employing structured programming constructs to implement logic and repetition
- Recognizing the difference between **`if...elseif`** and **`switch`** constructs
- Recognizing the difference between **`for...end`** and **`while`** structures
- Understanding what is meant by vectorization and why it is beneficial
- Knowing how to animate MATLAB plots
- Understanding how anonymous functions can be employed to pass function functions to function M-files

M-files

- While commands can be entered directly to the command window, MATLAB also allows you to put commands in text files called *M-files*. *M-files* are so named because the files are stored with a `.m` extension.

- There are two main kinds of M-file
  - Script files
  - Function files

Script Files

- A *script file* is merely a set of MATLAB commands that are saved on a file
  - When MATLAB runs a script file, it is as if you typed the characters stored in the file on the command window

- Scripts can be executed either by typing their name (without the .m) in the command window, by selecting the `Debug, Run` (or `Save and Run`) command in the editing window, or by hitting the `F5` key while in the editing window
  - Note that the latter two options will save any edits you have made, while the former will run the file as it exists on the drive

Function Files

- *Function files* serve an entirely different purpose from script files
  - Function files can accept input arguments from and return outputs to the command window
  - But variables created and manipulated within the function do not impact the command window (i.e., “local” variables)

Function File Syntax

- The general syntax for a function is:

```
function outvar = funcname(arglist)
% helpcomments
statements
outvar = value;
```

where

– *outvar*: output variable name

– *funcname:* function's name

– *arglist:* input argument list; comma-delimited list of what the function calls values passed to it

– *helpcomments:* text to show with `help funcname`

– *statements:* MATLAB commands for the function

Subfunctions

- A function file can contain a single function, but it can also contain a *primary function* and one or more *subfunctions*
- The primary function is whatever function is listed first in the M-file - its function name should be the same as the file name
- Subfunctions are listed below the primary function. Note that they are *only* accessible by the main function and subfunctions within the same M-file and *not* by the command window or any other functions or scripts

Input

- The easiest way to get a value from the user is the input command:
  - `n = input('promptstring')`
    MATLAB will display the characters in *promptstring*, and whatever value is typed is stored in *n*. For example, if you type *pi*, *n* will store 3.1416…
  - `n = input('promptstring', 's')`
    MATLAB will display the characters in *promptstring*, and whatever characters are typed will be stored as a string in *n*. For example, if you type *pi*, *n* will store the letters *p* and *i* in a 2x1 char array

Output

- The easiest way to display the value of a matrix is to type its name, but that will not work in function or script files. Instead, use the `disp` command

```
disp(value)
```

will show the *`value`* on the screen

- If *`value`* is a string, enclose it in single quotes

Formatted Output

- For formatted output, or for output generated by combining variable values with literal text, use the *`fprintf`* command:

```
fprintf('format', x, y,...)
```

  where *`format`* is a string specifying how you want the value of the variables *`x`*, *`y`*, and more to be displayed - including literal text to be printed along with the values

- The values in the variables are formatted based on format codes

Format and Control Codes

- Within the `format` string, the following format codes define how a numerical value is displayed:
  %d - integer format
  %e - scientific format with lowercase e
  %E - scientific format with uppercase E
  %f - decidmal format
  %g - the more compact of %e or %f
- The following control codes produce special results within the `format` string:
  \n - start a new line
  \t - tab
  \\ - print the \ character
- To print a ' put a pair of ' in the `format` string

Creating and Accessing Files

- MATLAB has a built-in file format that may be used to save and load the values in variables

  - `save` *`filename var1 var2 ... varn`*

    saves the listed variables into a file named *`filename`*`.mat`. If no variable is listed, all variables are saved

  - `load` *`filename var1 var2 ...varn`*

    loads the listed variables from a file named *`filename`*`.mat`. If no variable is listed, all variables in the file are loaded

- Note - these are not text files!

ASCII Files

- To create user-readable files, append the flag `-ascii` to the end of a `save` command. This will save the data to a text file in the same way that `disp` sends the data to a screen
- Note that in this case, MATLAB does *not* append anything to the file name so you may want to add an extension such as *.txt* or *.dat*
- To load a rectangular array from a text file, simply use the *load* command and the file name. The data will be stored in a matrix with the same name as the file (but without any extension)

Structured Programming

- Structured programming allows MATLAB to make decisions or selections based on conditions of the program
- Decisions in MATLAB are based on the result of logical and relational operations and are implemented with `if`, `if…else`, and `if…elseif` structures
- Selections in MATLAB are based on comparisons with a test expression and are implemented with `switch` structures

Relational Operators

- From Table 3.2: Summary of relational operators in MATLAB:

Example	Operator	Relationship
`x == 0`	`==`	Equal
`unit ~= 'm'`	`~=`	Not equal
`a < 0`	`<`	Less than
`s > t`	`>`	Greater than
`3.9 <= a/3`	`<=`	Less than or equal to
`r >= 0`	`>=`	Greater than or equal to

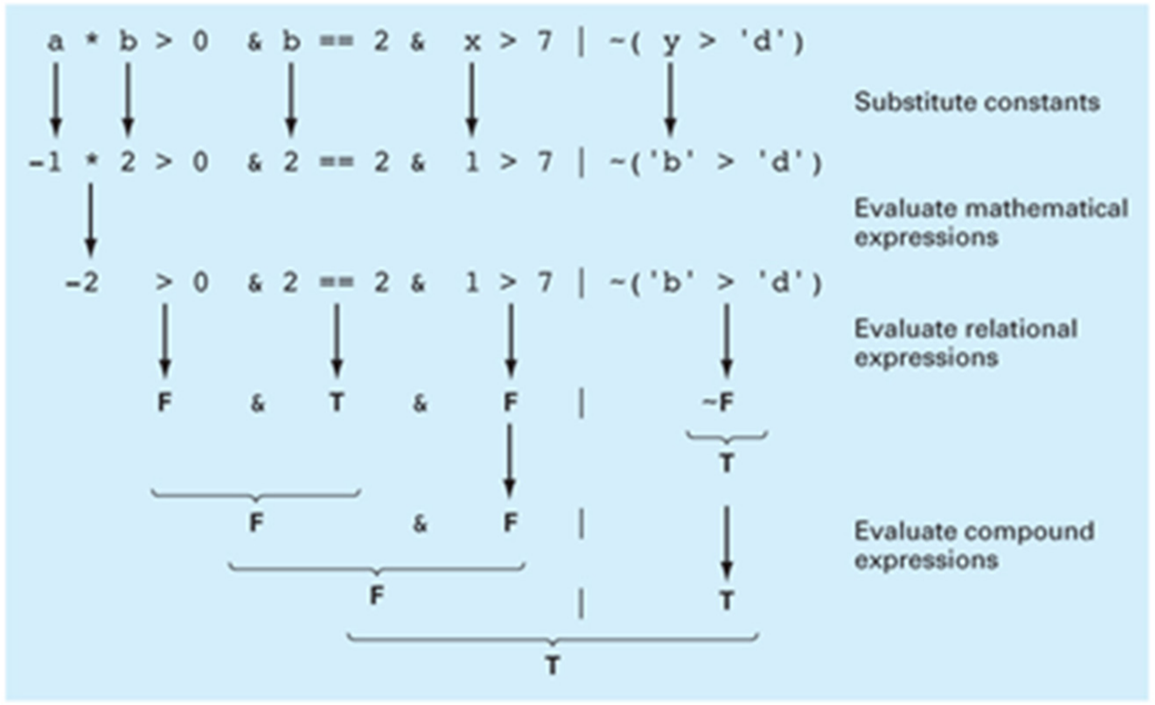
Logical Operators

- ~x (Not): true if x is false (or zero); false otherwise
- x & y (And): true if both x and y are true (or non-zero)
- x | y (Or): true if either x or y are true (or non-zero)

Order of Operations (1/2)

- Priority can be set using parentheses
  - After that, 1) **mathematical expressions** are highest priority, followed by 2) **relational operators**, followed by 3) **logical operators**. All things being equal, expressions are performed from left to right
- ***Not*** (~) is the highest priority logical operator, followed by ***And*** (&) and finally ***Or*** (|)
- Generally, do not combine two relational operators!
  If `x`=5, 3<`x`<4 should be **false** (mathematically), but it is calculated as an expression in MATLAB as:
  `3<5<4`, which leads to `true<4` at which point `true` is converted to `1`, and `1<4` is **true**!
  - Use `(3<x)&(x<4)` to properly evaluate

Order of Operations (2/2)



a * b > 0 & b == 2 & x > 7 | ~(y > 'd')
Substitute constants
-1 * 2 > 0 & 2 == 2 & 1 > 7 | ~('b' > 'd')
Evaluate mathematical expressions
-2 > 0 & 2 == 2 & 1 > 7 | ~('b' > 'd')
Evaluate relational expressions
F & T & F | ~F
T
F & F | T
Evaluate compound expressions
F | T
T

FIGURE 3.1
A step-by-step evaluation of a complex decision.

Decisions

- Decisions are made in MATLAB using **if** structures, which may also include several **elseif** branches and possibly a catch-all **else** branch
- Deciding which branch runs is based on the result of conditions which are either **true** or **false**
  - If an if tree hits a true condition, that branch (and that branch only) runs, then the tree terminates
  - If an if tree gets to an else statement without running any prior branch, that branch will run
- **Note** - if the condition is a matrix, it is considered true if and only if all entries are true (or non-zero)

Selections (1/2)

- Selections are made in MATLAB using **switch** structures, which may also include a catch-all **otherwise** choice
- Deciding which branch runs is based on comparing the value in some test expression with values attached to different cases
  - If the test expression matches the value attached to a case, that case's branch will run
  - If no cases match and there is an otherwise statement, that branch will run

Selections (2/2)

```
 switch testepression
 case value_1
    statement_s1
 case value_2
    statement_s2
  .
  .
  .
 otherwise
    statement_otherwise
end
```

Loops

- Another programming structure involves loops, where the same lines of code are run several times. There are two types of loop:
  - A **for** loop ends after a specified number of repetitions established by the number of columns given to an index variable
  - A **while** loop ends on the basis of a logical condition

`for` Loops

- One common way to use a **`for…end`** structure is:

```
for index = start:step:finish
  statements
end
```

where the *`index`* variable takes on successive values in the vector created using the : operator

Vectorization

- Sometimes, it is more efficient to have MATLAB perform calculations on an entire array rather than processing an array element by element. This can be done through *vectorization*

`for` loop	Vectorization

`i = 0;`
`for t = 0:0.02:50`
`  i = i + 1;`
`  y(i) = cos(t);`
`end`
	`t = 0:0.02:50;`
	`y = cos(t);`

`while` Loops (1/2)

- A while loop is fundamentally different from a for loop since while loops can run an indeterminate number of times. The general syntax is

  ```
   while condition
       statements
  end
  ```

  where the ***`condition`*** is a logical expression. If the ***`condition`*** is true, the *`statements`* will run and when that is finished, the loop will again check on the ***`condition`***

- Note - though the ***`condition`*** may become false as the *`statements`* are running, the only time it matters is after all the statements have run

`while` Loops (2/2)

```
X=8
while X>0
   x=x-3;
   disp(x)
end

>>
X=
   8
   5
   2
  -1
```

Early Termination

- Sometimes it will be useful to break out of a for or while loop early - this can be done using a **break** statement, generally in conjunction with an if structure

- Example:

```
x = 24
while (1)
   x = x - 5
   if x < 0, break, end
end
```

will produce x values of 24, 19, 14, 9, 4, and -1, then stop

`pause` Commands

- The command `pause` cause a procedure to stop and wait until any key is hit

```
for n=3:10
  mesh(magic(n))
  pause
end
```

- `pause(n)` causes the procedure to halt for *n* seconds

Animation

- Two ways to animate plots in MATLAB:
  - Using looping with simple plotting functions
    - This approach merely replots the graph over and over again
    - Judiciously use the `axis` command so that the plots scales are fixed

```
for j=1:n
  plot commands
end
```

  - Using special function: `getframe` and `movie`
    - This allows you to capture a sequence of plots (`getframe`) and then play them back (`movie`)

```
for j=1:n
  plot commands
  M(j)=getframe;
end
movie(M)
```

Each time the loop executes, the `plot commands` create an updated version of a plot, which is stored in the vector `M`. The `n` images are then played back by `movie`.

Example: Launched Projectile

- The (x, y) coordinates of a projectile can be generated as a function of time, t, with the following parametric equations

$x = v_0 \cos(\theta_0\, t)$ [displacement]

$y = v_0 \sin(\theta_0\, t) - 0.5\, gt^2$ [height]

where v_0 = initial velocity (m/s)

θ_0 = initial angle (radians)

g = gravitational constant (= 9.81 m/s^2)

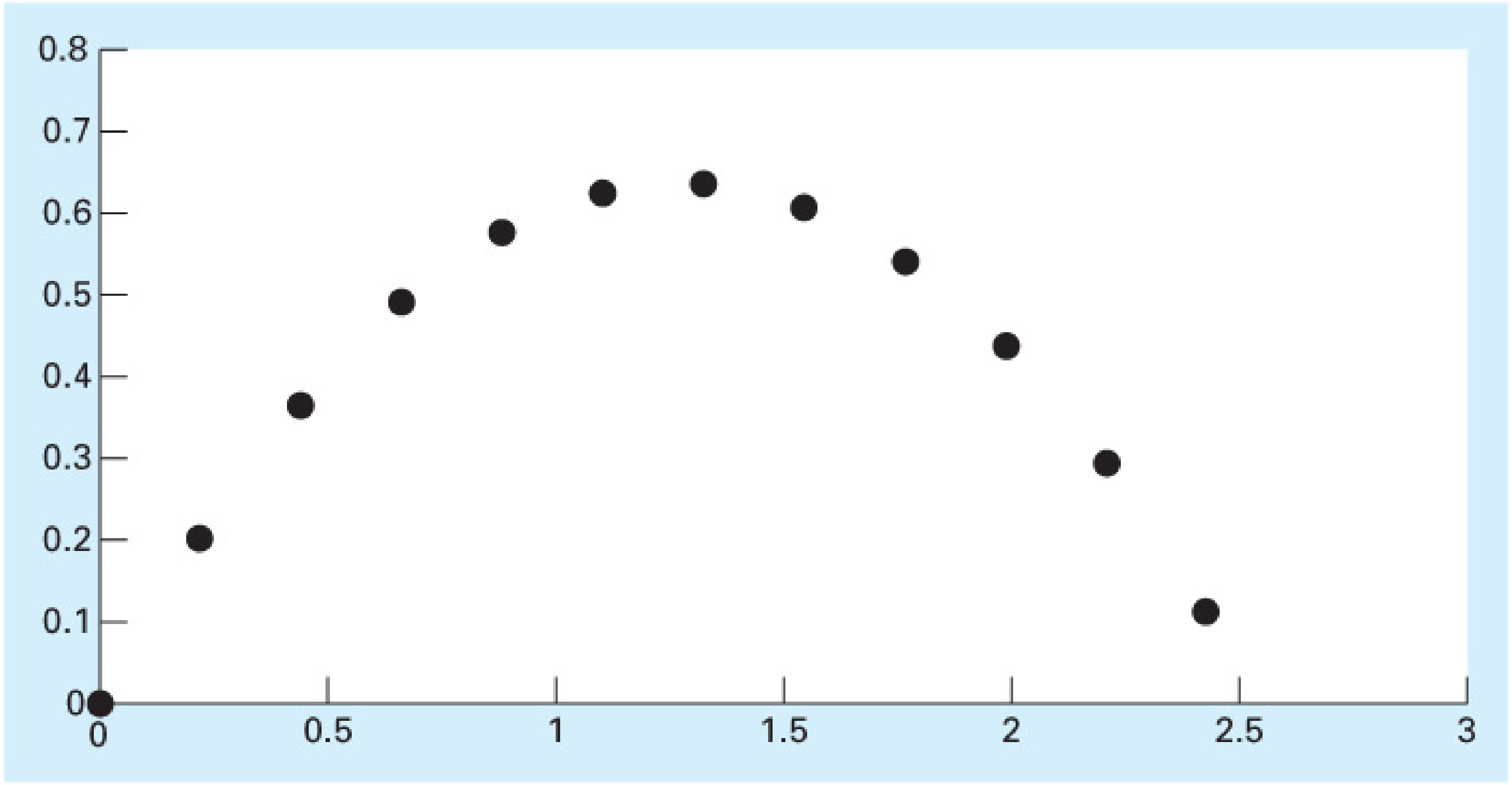
Script

- The following code illustrates both approaches

```
clc,clf,clear
g=9.81; theta0=45*pi/180; v0=5;
t(1)=0;x=0;y=0;
plot(x,y,'o','MarkerFaceColor','b','MarkerSize',8)
axis([0 3 0 0.8])
M(1)=getframe;
dt=1/128;
for j = 2:1000
  t(j)=t(j-1)+dt;
  x=v0*cos(theta0)*t(j);
  y=v0*sin(theta0)*t(j)-0.5*g*t(j)^2;
  plot(x,y,'o','MarkerFaceColor','b','MarkerSize',8)
  axis([0 3 0 0.8])    % fix the ranges for the x and y axes
  M(j)=getframe;
  if y<=0, break, end
end
pause
movie(M,1)
```

Result

FIGURE 3.2
Plot of a projectile's trajectory.



Nesting and Indentation

- Structures can be placed within other structures. For example, the `statements` portion of a `for` loop can be comprised of an `if...elseif...else` structure

- For clarity of reading, the `statements` of a structure are generally **indented** to show which lines of controlled are under the control of which structure

Anonymous & Inline Functions

- ***Anonymous functions*** are simple one-line functions created without the need for an M-file
  `fhandle = @(arg1, arg2, ...) expression`

```
>> f1=@(x, y)  x^2+y^2;
>>f1(3,4)
ans =
       25
```

```
>>a=4; b=2;
>>f2=@(x)  a*x^b;
>>f2(3)
ans =
       36
```

- ***Inline functions*** are essentially the same as anonymous functions, but with a different syntax:
  `fhandle = inline('expression', 'arg1', 'arg2',...)`

```
>> f1=inline('x^2+y^2','x','y');
```

- **Anonymous functions** can access the values of variables in the workspace upon creation, while **inline functions** cannot

Function Functions (1/2)

- ***Function functions*** are functions that operate on other functions which are passed to it as input arguments

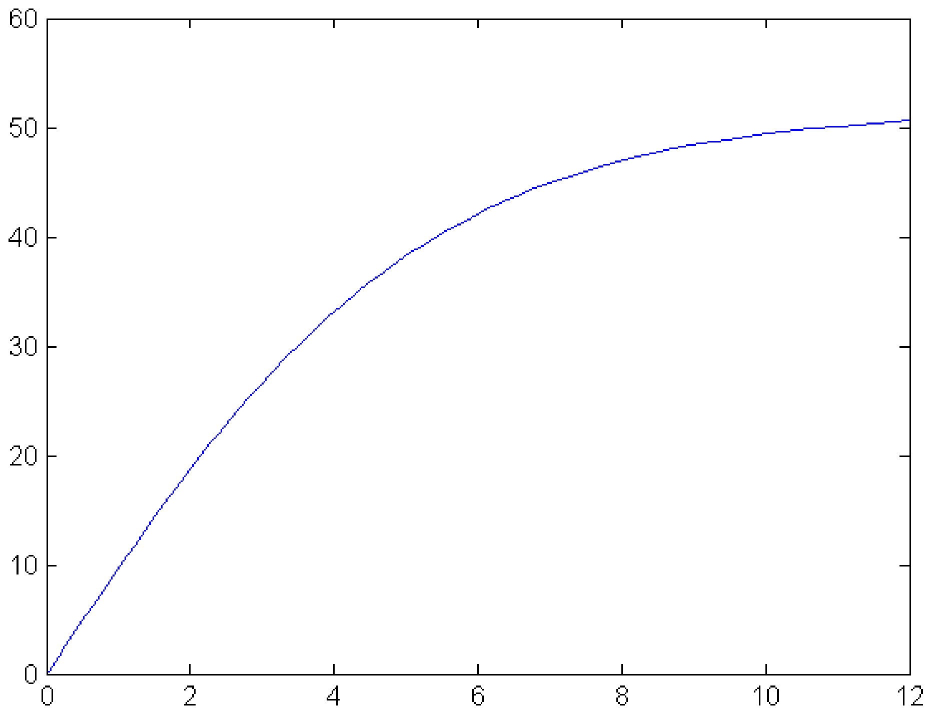
```
>> vel=@(t) ...
sqrt(9.81*68.1/0.25)*tanh(sqrt(9.81*0.25/68.1)*t);
>>fplot(vel,[0 12])
```

  - The input argument may be the handle of an anonymous or inline function, the name of a built-in function, or the name of a M-file function

- Using function functions will allow for more dynamic programming

Function Functions (2/2)

- A plot of velocity versus time generated with the `fplot` function



60
50
40
30
20
10
0
0
2
4
6
8
10
12