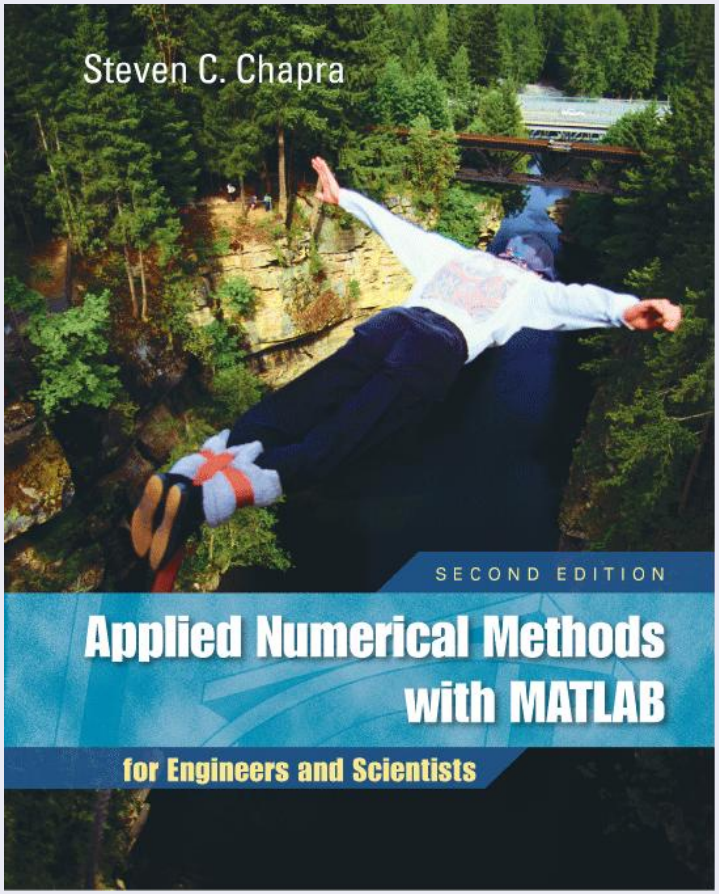

Part 1
Chapter 2

MATLAB Fundamentals

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Chapter Objectives

- Learning how real and complex numbers are assigned to variables.
- Learning how vectors and matrices are assigned values using simple assignment, the color operator, and the `linspace` and `logspace` functions.
- Understanding the priority rules for constructing mathematical expressions.
- Gaining a general understanding of built-in functions and how you can learn more about them with MATLAB's Help facilities.
- Learning how to use vectors to create a simple line plot based on an equation.

The MATLAB Environment

- MATLAB uses three primary windows-
  - Command window - used to enter commands and data
  - Graphics window(s) - used to display plots and graphics
  - Edit window - used to create and edit M-files (programs)
- Depending on your computer platform and the version of MATLAB used, these windows may have different looks and feels.

Calculator Mode

- The MATLAB command widow can be used as a calculator where you can type in commands line by line. Whenever a calculation is performed, MATLAB will assign the result to the built-in variable `ans`
- Example:

```
>> 55 - 16
ans =
     39
```

MATLAB Variables

- While using the `ans` variable may be useful for performing quick calculations, its transient nature makes it less useful for programming.
- MATLAB allows you to assign values to variable names. This results in the storage of values to memory locations corresponding to the variable name.
- MATLAB can store individual values as well as arrays; it can store numerical data and text (which is actually stored numerically as well).
- MATLAB does not require that you pre-initialize a variable; if it does not exist, MATLAB will create it for you.

Scalars

- To assign a single value to a variable, simply type the variable name, the = sign, and the value:

```
>> a = 4
a =
   4
```

- Note that variable names must start with a letter, though they can contain letters, numbers, and the underscore (_) symbol

Scalars (cont)

- You can tell MATLAB not to report the result of a calculation by appending the semi-solon (`;`) to the end of a line. The calculation is still performed.
- You can ask MATLAB to report the value stored in a variable by typing its name:

```
>> a
a =
   4
```

Scalars (cont)

- You can use the complex variable `i` (or `j`) to represent the unit imaginary number.
- You can tell MATLAB to report the values back using several different formats using the format command. Note that the values are still *stored* the same way, they are just displayed on the screen differently. Some examples are:
  - `short` - scaled fixed-point format with 5 digits
  - `long` - scaled fixed-point format with 15 digits for double and 7 digits for single
  - `short eng` - engineering format with at least 5 digits and a power that is a multiple of 3 (useful for SI prefixes)

Format Examples

- ```
  >> format short; pi
  ans =
      3.1416
  >> format long; pi
  ans =
     3.14159265358979
  >> format short eng; pi
  ans =
       3.1416e+000
  >> pi*10000
  ans =
      31.4159e+003
  ```
- Note - the format remains the same unless another `format` command is issued.
  ```

Arrays, Vectors, and Matrices

- MATLAB can automatically handle rectangular arrays of data - one-dimensional arrays are called *vectors* and two-dimensional arrays are called *matrices*.
- Arrays are set off using square brackets [and] in MATLAB
- Entries within a row are separated by spaces or commas
- Rows are separated by semicolons

Array Examples

```
>> a = [1 2 3 4 5 ]
a =
     1     2     3     4     5
>> b = [2;4;6;8;10]
b =
     2
     4
     6
     8
    10
```

- Note 1 - MATLAB does not *display* the brackets
- Note 2 - if you are using a monospaced font, such as Courier, the displayed values should line up properly

Matrices

- A 2-D array, or matrix, of data is entered row by row, with spaces (or commas) separating entries within the row and semicolons separating the rows:
-
```
>> A = [1 2 3; 4 5 6; 7 8 9]
A =
     1     2     3
     4     5     6
     7     8     9
```

Useful Array Commands

- The transpose operator (apostrophe) can be used to flip an array over its own diagonal. For example, if `b` is a row vector, `b'` is a column vector containing the complex conjugate of `b`.
- The command window will allow you to separate rows by hitting the Enter key - script files and functions will allow you to put rows on new lines as well.
- The `who` command will report back used variable names; `whos` will also give you the size, memory, and data types for the arrays.

Clearing Commands

- When running a program many times, the command window may become cluttered. Clear the command window with “clc.” (clear command).
- Good programming practice: At the beginning of the program, clear all variables: “clear” – removes all variables from workspace
  and/or “clear all”—clears all objects in workspace, plus resets all assumptions

Accessing Array Entries

- Individual entries within a array can be both read and set using either the *index* of the location in the array or the row and column.
- The index value starts with 1 for the entry in the top left corner of an array and increases down a column - the following shows the indices for a 4 row, 3 column matrix:

```
 1   5   9
 2   6  10
 3   7  11
 4   8  12
```

Accessing Array Entries (cont)

- Assuming some matrix C:

```
C =
   2      4      9
   3      3     16
   3      0      8
  10     13     17
```

- `C(2)` would report 3
- `C(4)` would report 10
- `C(13)` would report an error!
- Entries can also be access using the row and column:
- `C(2,1)` would report 3
- `C(3,2)` would report 0
- `C(5,1)` would report an error!

Array Creation - Built In

- There are several built-in functions to create arrays:
  - `zeros(r,c)` will create an `r` row by `c` column matrix of zeros
  - `zeros(n)` will create an `n` by `n` matrix of zeros
  - `ones(r,c)` will create an `r` row by `c` column matrix of ones
  - `ones(n)` will create an `n` by `n` matrix one ones
- `help elmat` has, among other things, a list of the elementary matrices

Diagonal Matrices

- Read the diagonal of a matrix:
  - diag(A)

```
ans =
      1
      5
      9
```

- Create a matrix with a diagonal and zeros:

```
v=[1 2 3];
X=diag(v,0)%zero indicates we wish the
%column v to be on the main diagonal. To
%place v on the upper/lower diagonal, use
%“1” or “-1”, respectively.
```

Creating diagonal matrices

```
X =
     1     0     0
     0     2     0
     0     0     3

X=diag(v,1)
X =
     0     1     0     0
     0     0     2     0
     0     0     0     3
     0     0     0     0
```

Array Creation - Colon Operator

- The colon operator : is useful in several contexts. It can be used to create a linearly spaced array of points using the notation
  `start:diffval:limit`
  where `start` is the first value in the array, `diffval` is the difference between successive values in the array, and `limit` is the *boundary* for the last value (though not necessarily the last value).

```
>>1:0.6:3
ans =
    1.0000   1.6000   2.2000   2.8000
```

Colon Operator - Notes

- If `diffval` is omitted, the default value is 1:

```
>>3:6
ans =
     3     4     5     6
```

- To create a decreasing series, `diffval` must be negative:

```
>> 5:-1.2:2
ans =
    5.0000    3.8000    2.6000
```

- If `start+diffval>limit` for an increasing series or `start+diffval<limit` for a decreasing series, an empty matrix is returned:

```
>>5:2
ans =
   Empty matrix: 1-by-0
```

- To create a column, transpose the output of the colon operator, not the limit value; that is, `(3:6)'` not `3:6'`

Array Creation - `linspace`

- To create a row vector with a specific number of linearly spaced points between two numbers, use the `linspace` command.
- `linspace(x1, x2, n)` will create a linearly spaced array of `n` points between `x1` and `x2`

```
>>linspace(0, 1, 6)
ans =
  0  0.2000  0.4000  0.6000  0.8000  1.0000
```

- If `n` is omitted, 100 points are created.
- To generate a column, transpose the output of the `linspace` command.

Array Creation - `logspace`

- To create a row vector with a specific number of logarithmically spaced points between two numbers, use the `logspace` command.
- `logspace(x1, x2, n)` will create a logarithmically spaced array of `n` points between 10^{x1} and 10^{x2}

```
>>logspace(-1, 2, 4)
ans =
   0.1000    1.0000   10.0000  100.0000
```

- If `n` is omitted, 100 points are created.
- To generate a column, transpose the output of the `logspace` command.

Mathematical Operations

- Mathematical operations in MATLAB can be performed on both scalars and arrays.
- The common operators, in order of priority, are:

^	Exponentiation	4^2 = 8
-	Negation (unary operation)	-8 = -8
* /	Multiplication and Division	2*pi = 6.2832 pi/4 = 0.7854
\	Left Division	6\2 = 0.3333
+ -	Addition and Subtraction	3+5 = 8 3-5 = -2

Order of Operations

- The order of operations is set first by parentheses, then by the default order given above:
  - `y = -4 ^ 2` gives `y = -16`

    since the exponentiation happens first due to its higher default priority, but
  - `y = (-4) ^ 2` gives `y = 16`

    since the negation operation on the 4 takes place first

Complex Numbers

- All the operations above can be used with complex quantities (i.e. values containing an imaginary part entered using `i` or `j` and displayed using `i`)

```
x = 2+i*4; (or 2+4i, or 2+j*4, or 2+4j)
y = 16;
3 * x
ans =
   6.0000 +12.0000i
x+y
ans =
  18.0000 + 4.0000i
x'
ans =
    2.0000 - 4.0000i
```

Vector-Matrix Calculations

- MATLAB can also perform operations on vectors and matrices.
- The * operator for matrices is defined as the *outer product* or what is commonly called “matrix multiplication.”
  - The number of columns of the first matrix must match the number of rows in the second matrix.
  - The size of the result will have as many rows as the first matrix and as many columns as the second matrix.
  - The exception to this is multiplication by a 1x1 matrix, which is actually an array operation.
- The ^ operator for matrices results in the matrix being matrix-multiplied by itself a specified number of times.
  - Note - in this case, the matrix must be square!

Element-by-Element Calculations

- At times, you will want to carry out calculations item by item in a matrix or vector. The MATLAB manual calls these *array operations*. They are also often referred to as *element-by-element* operations.
- MATLAB defines .* and ./ (note the dots) as the array multiplication and array division operators.
  - For array operations, both matrices must be the same size *or* one of the matrices must be 1x1
- Array exponentiation (raising each element to a corresponding power in another matrix) is performed with .^
  - Again, for array operations, both matrices must be the same size *or* one of the matrices must be 1x1

Built-In Functions

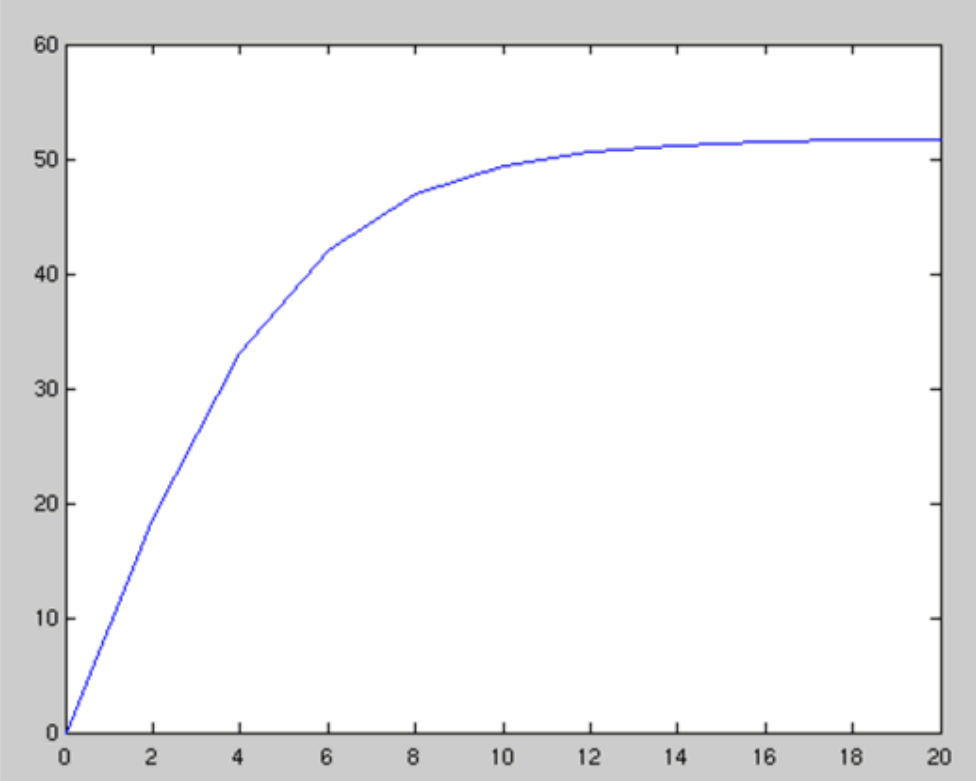
- There are several built-in functions you can use to create and manipulate data.
- The built-in help function can give you information about both what exists and how those functions are used:
  - `help elmat` will list the elementary matrix creation and manipulation functions, including functions to get information about matrices.
  - `help elfun` will list the elementary math functions, including trig, exponential, complex, rounding, and remainder functions.
- The built-in `lookfor` command will search help files for occurrences of text and can be useful if you know a function's purpose but not its name

Graphics

- MATLAB has a powerful suite of built-in graphics functions.
- Two of the primary functions are `plot` (for plotting 2-D data) and `plot3` (for plotting 3-D data).
- In addition to the plotting commands, MATLAB allows you to label and annotate your graphs using the `title`, `xlabel`, `ylabel`, and `legend` commands.

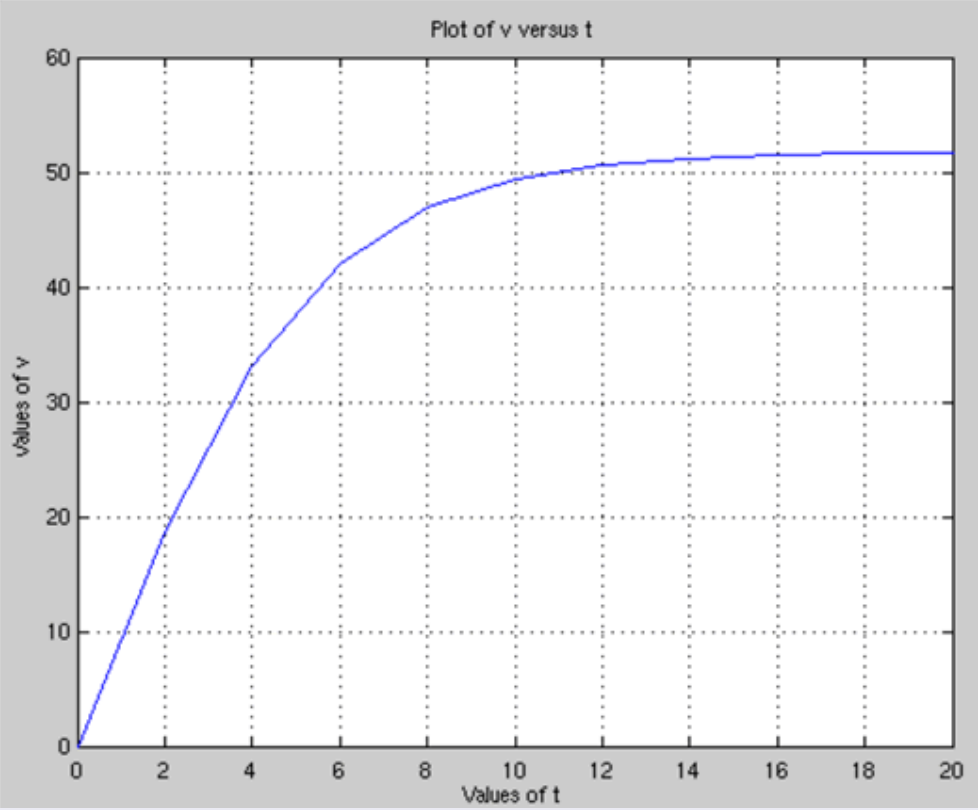
Plotting Example

- ```
  t = [0:2:20]';
  g = 9.81; m = 68.1; cd = 0.25;
  v = sqrt(g*m/cd)*tanh(sqrt(g*cd/m)*t);
  plot(t, v)
  ```


  ```

Plotting Annotation Example

- ```
  title('Plot of v versus t')
  xlabel('Values of t')
  ylabel('Values of v')
  grid
  ```


  ```

Plotting Options

- When plotting data, MATLAB can use several different colors, point styles, and line styles. These are specified at the end of the `plot` command using *plot specifiers* as found in Table 2.2.
- The default case for a single data set is to create a blue line with no points. If a line style is specified with no point style, no point will be drawn at the individual points; similarly, if a point style is specified with no point style, no line will be drawn.
- Examples of plot specifiers:
  - ‘ro:’ - red dotted line with circles at the points
  - ‘gd’ - greed diamonds at the points with no line
  - ‘m--’ - magenta dashed line with no point symbols

Other Plotting Commands

- `hold on` and `hold off`
  - `hold on` tells MATLAB to keep the current data plotted and add the results of any further plot commands to the graph. This continues until the `hold off` command, which tells MATLAB to clear the graph and start over if another plotting command is given. `hold on` should be used *after* the first plot in a series is made.
- `subplot(m, n, p)`
  - `subplot` splits the figure window into an `m`x`n` array of small axes and makes the pth one active. Note - the first subplot is at the top left, then the numbering continues across the row. This is different from how elements are numbered within a matrix!