

# MATLAB Fundamentals

## 1. Introduction

## 2. Using the MATLAB Desktop

### Summary: Working with Live Scripts

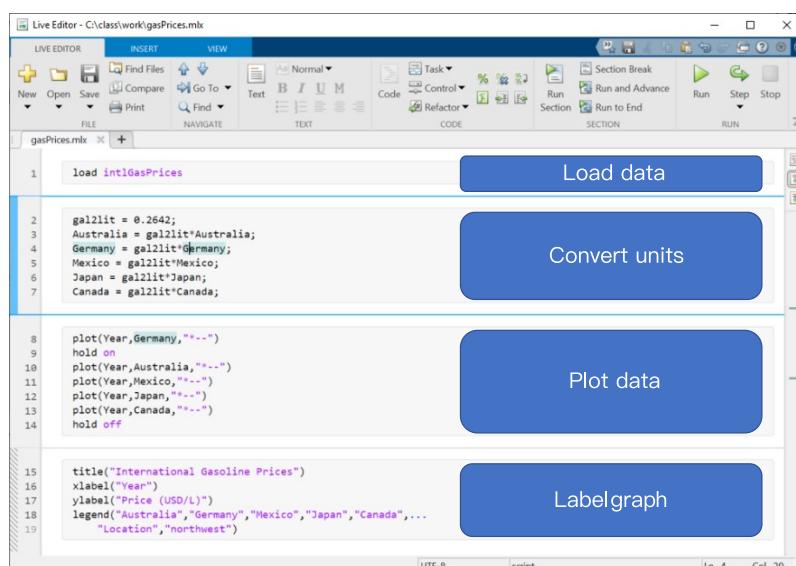
#### Create and Run a Script

Use the controls in the MATLAB toolbar to create and run scripts.

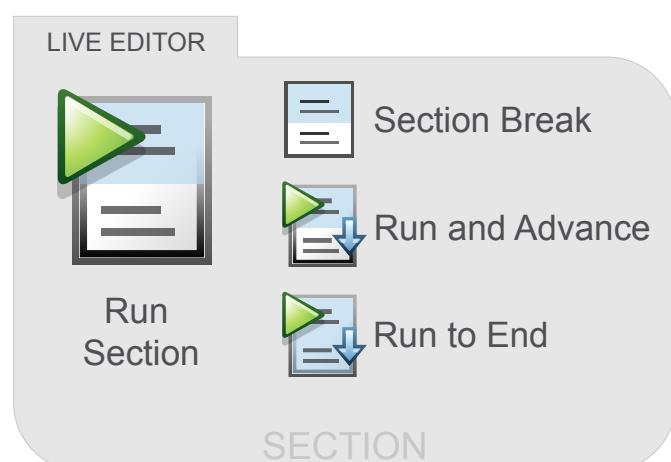


#### Code Sections

Code sections allow you to organize your code and run sections of code independently. On the **Live Editor** tab, in the **Section** section, click **Section Break** to create a new code section, or press **Ctrl+Alt+Enter**.



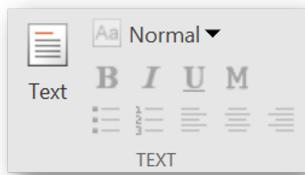
You can run and add code sections in the **Section** section of the **Live Editor** tab in the toolbar.



## Comments and Text

To insert a line of text, click the  **Text** button in the **Text** section of the **Live Editor** tab in the MATLAB Toolstrip.

Format the text using the formatting options provided in the **Text** section.



## Comments

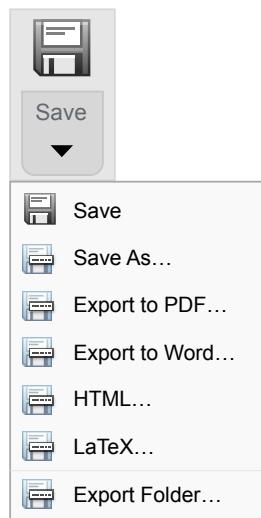
To create a comment, add `% comment` where you want to add more information.

```
load gCosts
% Converts from US$/gal to US$/L
gal2lit = 0.2642; % conversion factor
Germany = gal2lit*Germany;
Australia = gal2lit*Australia;
Mexico = gal2lit*Mexico;
```

## Exporting Live Script Files

You can export your live script and results using the **Save** button in the **Live Editor** tab.

Available formats include PDF, Word, HTML, and LaTeX.



## 3. Creating and Manipulating Arrays

### Summary: Creating and Manipulating Arrays

#### Manually Entering Arrays

##### Create a Row Vector

Use square brackets and separate the values using a comma or a space.

`a = [10 15 20 25]`

`a =`  
10 15 20 25

### Create a Column Vector

Use square brackets and separate the values using a semi-colon.

`b = [2;3;5;7]`

`b =`  
2  
3  
5  
7

### Transpose a Vector

Use the transpose operator `'`.

`c = b'`

`c =`  
2 3 5 7

### Create a Matrix

Use square brackets and enter values row-by-row. Separate values in a row using a comma or a space, and use a semicolon to start a new row.

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

`A =`  
1 3 5  
2 4 6

### Creating Evenly-Spaced Vectors

#### Given the Start Value, End Value, and Interval

Use the colon operator to separate the starting value, interval, and the ending value.

`a = 3:2:7`

`a =`  
3 5 7

#### When Interval is 1

Use the colon operator to separate the starting and the ending value.

`b = 3:7`

`b =`  
3 4 5 6 7

#### Given the Start Value, End Value, and Number of Elements

Use the function `linspace` when the number of elements in the vector are known.

`c = linspace(3.2,8.1,5)`

`c =`  
3.2 4.42 5.65 6.87 8.1

$$X = \text{ones}(3,4) \Rightarrow \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

$$X = 5 * \text{ones}(3,4) \Rightarrow \begin{bmatrix} 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \end{bmatrix}$$

$$X = \text{rand}(100,1) \Rightarrow \begin{bmatrix} 0.81 \\ 0.90 \\ \vdots \\ 0.23 \end{bmatrix}$$

$$X = a + (b-a) * \text{rand}(m,n)$$

$\downarrow$

$$\mathcal{U}(a,b)$$

$$X = \text{randn}(100,1) \Rightarrow \begin{bmatrix} -0.79 \\ 0.84 \\ \vdots \\ 0.71 \end{bmatrix}$$

$N(0,1)$

$$X = \text{mean} + \text{sd} * \text{randn}(m,n)$$

$\downarrow$

$$N(\text{mean}, \text{sd})$$

$$X = \text{randi}([1,20], m, 1) \Rightarrow \begin{bmatrix} 12 \\ 18 \\ \vdots \\ 15 \end{bmatrix}$$

$\downarrow$

$\text{integer}$

## Concatenating Arrays

### Horizontal Concatenation

$$\left[ \begin{array}{c|c} \text{blue grid} & \text{yellow grid} \end{array} \right] = \begin{array}{c|ccccc} \text{blue} & \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \end{array}$$

Separate elements using a  
comma (,) or space ( )

### Vertical Concatenation

$$\left[ \begin{array}{c|c} \text{blue grid} & \text{orange grid} \\ \hline \end{array} \right] = \begin{array}{c|ccccc} \text{blue} & \text{blue} & \text{blue} & \text{orange} & \text{orange} \end{array}$$

Separate elements  
using a **semicolon** ( ; )

### Combined Concatenation

$$\left[ \begin{array}{c|c} \text{blue grid} & \text{yellow grid} \\ \hline \cdots & \cdots \end{array} \right] = \begin{array}{c|ccccc} \text{blue} & \text{yellow} & \text{yellow} & \text{yellow} & \text{yellow} \\ \text{grey} & \text{green} & \text{green} & \text{green} & \text{green} \end{array}$$

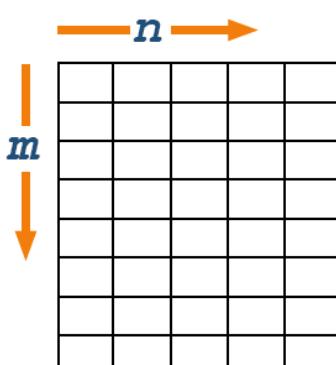
Create each row separating elements with a  
comma (,) or space ( ), then separate the rows  
with a **semicolon** ( ; )

## Array Creation Functions

Several functions exist that allow you to create arrays.

**A = fun(m, n);**

  
compan                    pascal  
eye                      rand  
gallery                  randn  
hadamard                rosser  
hankel                  toeplitz  
hilb                     vander  
invhilb                wilkinson  
magic                   zeros  
ones

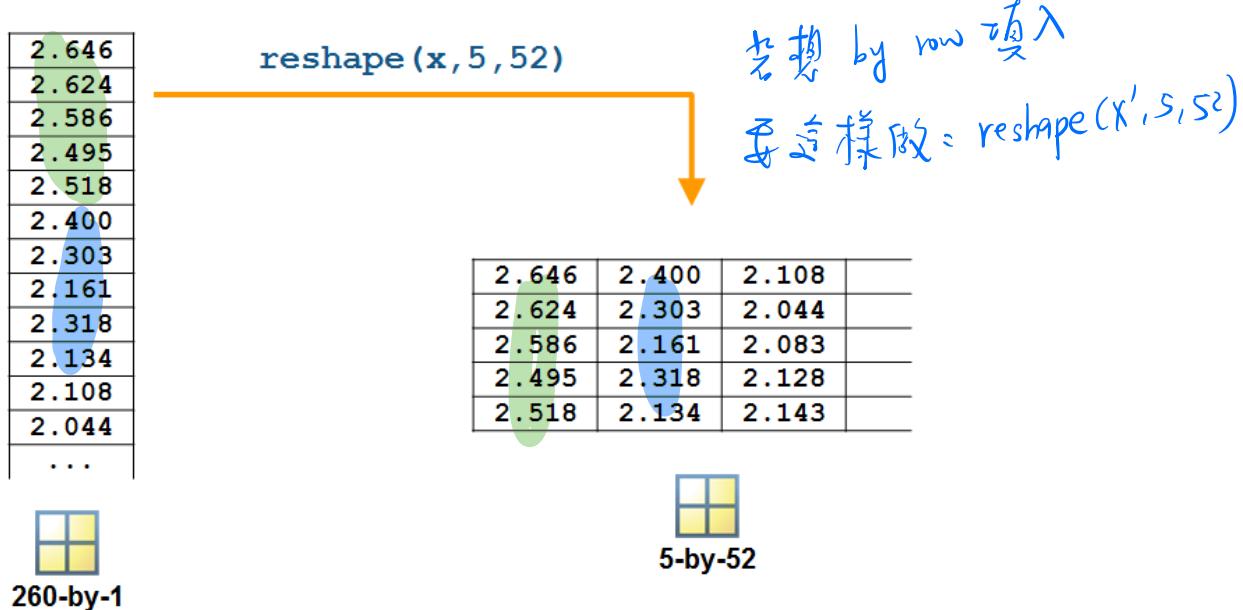


Most of these functions support the calling syntaxes shown below.

Calling syntax	Output
<code>fun(m, n)</code>	m-by-n
<code>fun(n)</code>	n-by-n

## Reshaping Arrays

The following column of information is reshaped into a matrix.



Specify the dimensions for the new array.

For convenience, you can also leave one of the dimensions blank when calling `reshape` and that dimension will be calculated automatically.

```
x = rand(260,1);
```

```
y = reshape(x,5,52);
```

```
y = reshape(x,5,[]);
```

↑

空的指綫

他会自动计算

$$A = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$$

$$\Rightarrow A(:) \Rightarrow \begin{bmatrix} 1 \\ 3 \\ 2 \\ 4 \end{bmatrix} \text{ or } \text{reshape}(A, [4], 1)$$

## 4. Accessing Data in Arrays

Summary: Accessing Data in Arrays

Indexing

$$\Rightarrow B = A' \quad \text{or} \quad \text{reshape}(A', [4], 1)$$

$$B(:) \Rightarrow \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

<b>1</b>	2.3
<b>2</b>	1.5
<b>3</b>	1.3
<b>4</b>	0.9
<b>5</b>	1.3

**v**

	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
<b>1</b>	1.5	1.1	2.6	0.9
<b>2</b>	1.5	2.4	1.7	1.4
<b>3</b>	2.5	1.6	1.9	0.7
<b>4</b>	2.4	1.1	1.8	2.5
<b>5</b>	1.9	2.8	0.6	0.6

**M**

Extract one element from a vector

`v(2)`

1.5

Extract the last element from a vector

`v(end)`

1.3

Extract multiple elements from a vector

`v([1 end-2:end])`

2.3

1.3

0.9

1.3

When you are extracting elements of a matrix you need to provide two indices, the row and column numbers.

Extract one element from a matrix

`M(2,3)`

1.7

Extract an entire column. Here, it is the last one.

`M(:, end)`

0.9

1.4

0.7

2.5

0.6

Extract multiple elements from a matrix.

`M([1 end], 2)`

1.1

2.8

## Changing Elements in Arrays

Change one element from a vector

`v(2) = 0`

2.3  
0  
1.3  
0.9  
1.3

Change multiple element of a vector to the same value

`v(1:3) = 0`

0  
0  
0  
0.9  
1.3

Change multiple element of a vector to different values

`v(1:3) = [3 5 7]`

3  
5  
7  
0.9  
1.3

Assign a non-existent value

`v(9) = 42`

3  
5  
7  
0.9  
1.3  
0  
0  
0  
42

Remove elements from a vector

`v(1:3) = []`

0.9  
1.3  
0  
0  
0  
42

Changing elements in matrices works the same way as with vectors, but you must specify both rows and columns.

## 5. Mathematical and Statistical Operations with Arrays

### Summary: Mathematical and Statistical Operations with Arrays

#### Performing Operations on Arrays

There are many operators that behave in element-wise manner, i.e., the operation is performed on each element of the array

individually.

## Mathematical Functions

$$\sin \left( \begin{array}{|c|c|} \hline & \\ \hline & \\ \hline & \\ \hline & \\ \hline \end{array} \right) = \begin{array}{|c|c|} \hline \sin(\square) & \sin(\square) \\ \hline \sin(\square) & \sin(\square) \\ \hline \sin(\square) & \sin(\square) \\ \hline \end{array}$$

Other Similar Functions	
sin	Sine
cos	Cosine
log	Logarithm
round	Rounding Operation
sqrt	Square Root
mod	Modulus
Many more	

## Matrix Operations (Including Scalar Expansion)

$$\begin{array}{|c|c|} \hline & \\ \hline & \\ \hline & \\ \hline & \\ \hline \end{array} + \begin{array}{|c|} \hline \square \\ \hline \end{array} = \begin{array}{|c|c|} \hline + & + \\ \hline + & + \\ \hline + & + \\ \hline \end{array}$$

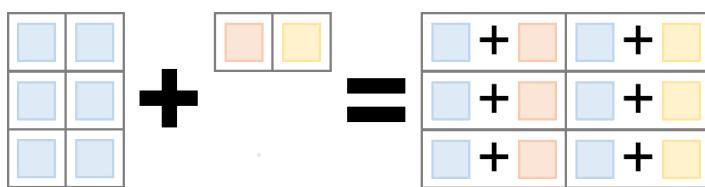
Operators	
+	Addition
-	Subtraction
*	Multiplication
/	Division
^	Exponentiation (Matrix exponentiation)

## Element-wise Operations

$$\begin{array}{|c|c|} \hline & \\ \hline & \\ \hline & \\ \hline & \\ \hline \end{array} + \begin{array}{|c|c|} \hline & \\ \hline & \\ \hline & \\ \hline & \\ \hline \end{array} = \begin{array}{|c|c|} \hline + & + \\ \hline + & + \\ \hline + & + \\ \hline \end{array}$$

Operators	
+	Addition
-	Subtraction
.*	Element-wise Multiplication
./	Element-wise Division
.^	Element-wise Exponentiation

## Implicit Expansion



Operators	
+	Addition
-	Subtraction
.*	Element-wise Multiplication
./	Element-wise Division
.^	Element-wise Exponentiation

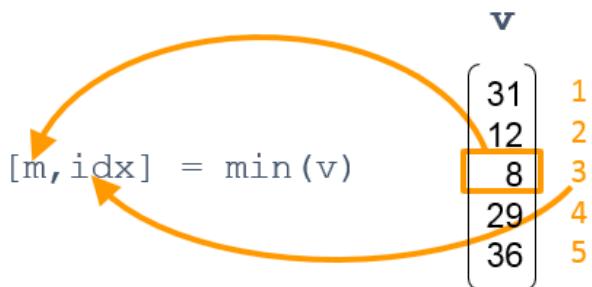
Array operations can be performed on operands of different compatible sizes. Two arrays have compatible sizes if the size of each dimension is either the same or one.

## Calculating Statistics of Vectors

### Common Statistical Functions

Function	Description
min	Returns the minimum element
max	Returns the maximum element
mean	Returns the average of the elements
median	Returns the median value of the elements

### Using min and max



### Ignoring NaNs

When using statistical functions, you can ignore NaN values

```
avg = mean(v, "omitnan")
```

## Statistical Operations on Matrices

Some common mathematical functions which calculate a value for each column in a matrix include:

Function	Behavior
max	Largest elements
min	Smallest elements
mean	Average or mean value
median	Median value
mode	Most frequent values
std	Standard deviation
var	Variance
sum	Sum of elements
prod	Product of elements

```
A = [8 2 4 ; 3 2 6 ; 7 5 3 ; 7 10 8]
```

```
A =
```

8	2	4
3	2	6
7	5	3
7	10	8

```
Amax = max(A)
```

```
Amax =
```

8	10	8
---	----	---

```
Astd = std(A)
```

```
Astd =
```

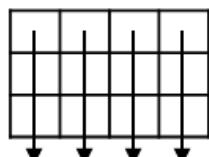
2.2174	3.7749	2.2174
--------	--------	--------

```
Asum = sum(A)
```

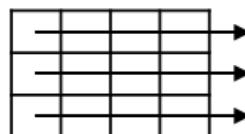
```
Asum =
```

25	19	21
----	----	----

Many statistical functions accept an optional dimensional argument that specifies whether the operation should be applied to columns independently (the default) or to rows.



**Dimension = 1**



**Dimension = 2**

```
>> M = mean(A,dim)
```

#### Outputs

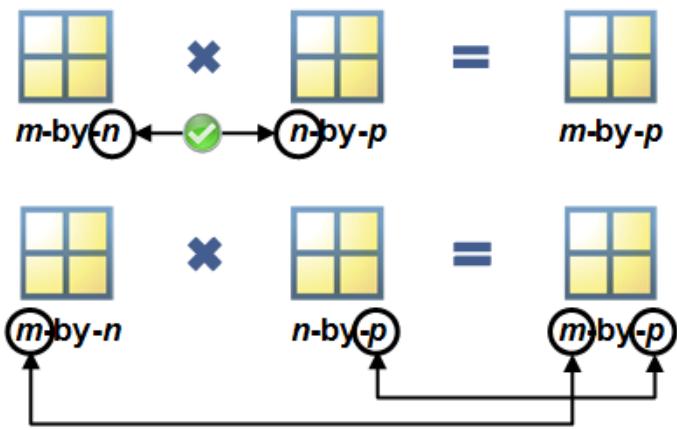
M	Vector of average values along dimension dim.
---	---

#### Inputs

A	Matrix
dim	Dimension across which the mean is taken. 1 : the mean of each column 2 : the mean of each row

## Matrix Multiplication

Matrix multiplication requires that the inner dimensions agree. The resultant matrix has the outer dimensions.



### Solving Systems of Linear Equations

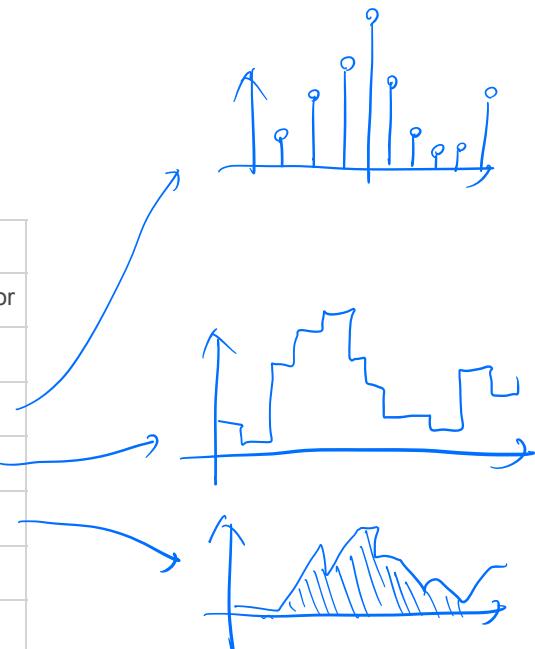
Expression	Interpretation
$x = B/A$	Solves $x \cdot A = B$ (for $x$ )
$x = A \setminus B$	Solves $A \cdot x = B$ (for $x$ )

## 6. Visualizing Data in 2D and 3D

Summary: Visualizing Data in 2D and 3D

### Identifying Available Plot Types

Function	Description
scatter	Scatter plot, with variable marker size and color
bar	Bar graph (vertical and horizontal)
stem	Discrete sequence (signal) plot
stairs	Stairstep graph
area	Filled area plot
pie	Pie chart
histogram	Histogram



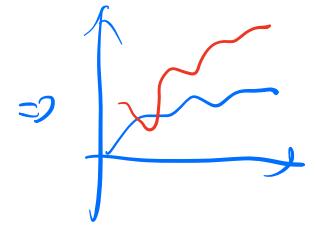
```
>> scatter(x,y,n,c,filled)
```

Y  
50  
red  
size�

\* 如果要疊圖，要使用 hold on , hold off

Inputs	
x	x-data
y	y-data
n	marker size
c	color
filled	If provided, markers will be filled in disks. Otherwise, they are circles.

plot(x, y<sub>1</sub>, "-b")  
hold on  
plot(x, y<sub>2</sub>, "-r")  
hold off



See the complete list of all available plots [here](#).

## Customizing Annotations

Arrays of strings are useful for annotating visualizations. Use square brackets, [ ], with spaces and semicolons, ; to create a string array the same way you create a numeric matrix.

```
x = ["hello" "sweet"; "peaceful" "world"]
x =
2x2 string array
"hello"      "sweet"
"peaceful"   "world"
```

ylabel("\pi r^2")

You can use markup in your labels.

<u>xticks</u> Sets tick locations along the x-axis.
<u>xticklabels</u> Labels the x-axis ticks.
<u>xtickangle</u> Rotates the x-axis tick labels.

~~yticks("label here")~~ ~~title("my title")~~  
~~ylabel("label")~~

## Customizing Plot Properties

### Specifying Property Values

plot(x, y, linespec, Property1, Value1, Property2, Value2, Property3, Value3, ...)

"o-" "MarkerSize", 10, "MarkerFaceColor", "g" → green

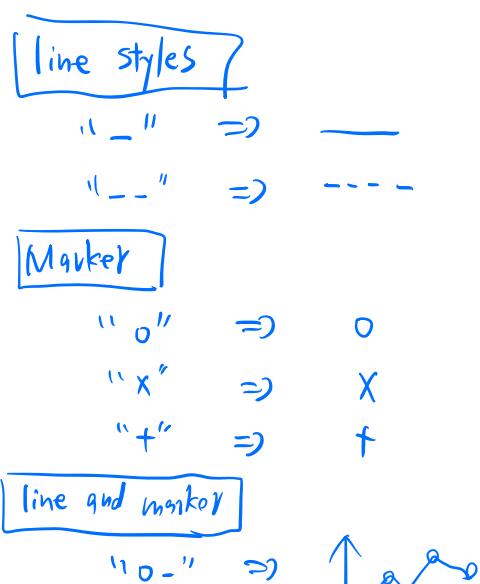
See the complete list of line specifications here: <https://www.mathworks.com/help/matlab/ref/linespec.html>.

Common line properties to modify:

- "LineWidth" (width of the line and marker edges)
- "MarkerSize" (size of the marker symbols)
- "MarkerEdgeColor" (color of the edge of the marker symbols)
- "MarkerFaceColor" (color of the interior of the marker symbols)
- "Color" (color of the line, particularly when given as RGB values)

[MATLAB Line Properties reference](#)

### Specifying Colors



red ("r")	green ("g")	blue ("b")	black ("k")
magenta ("m")	yellow ("y")	cyan ("c")	white ("w")

↓

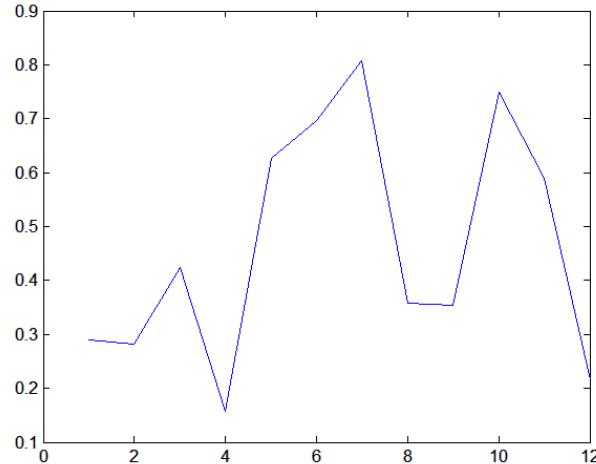
Or as a vector [R G B] where each value is from 0 to 1.

→ `plot(x, y, "color", "k")`  
 → `plot(x, y, "color", [0.8, 0.6, 0])`

## Axis Control

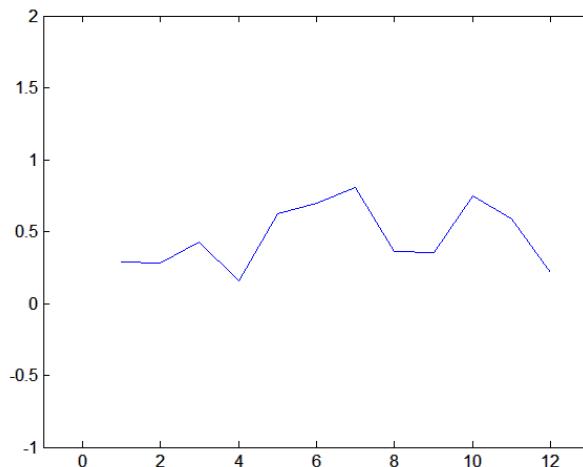
### Get Axes Limits

`v = axis` → 会把目前的图  
的 x, y lim 带出来  
  
`v =`  
`0 12 0.1 0.9`  
`xlim for min`  
`max`  
`ylim for min max`



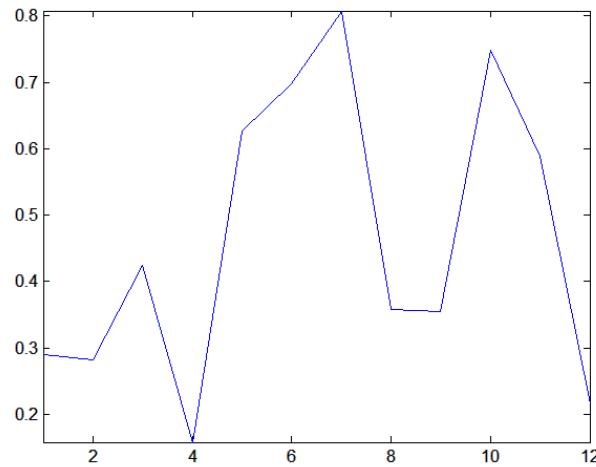
### Custom Axis Limits

`xlim([-1 13])`  
`ylim([-1 2])`



### Axis Limits = Data Range

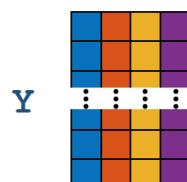
`axis tight`



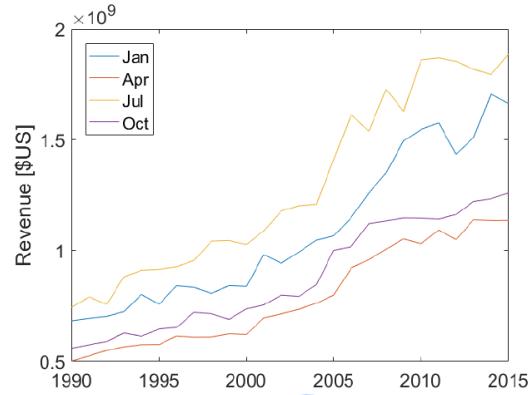
## Plotting Multiple Columns

You can use the `plot` function on a matrix to plot each column as a separate line in your plot.

`plot(x, Y)`

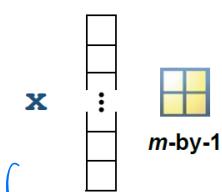


$n$  plots

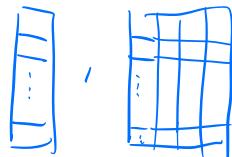


`plot(Y)` 將會有  $n$  個 column 的線圖  
但  $X$  軸的數值是  $[1, 2, \dots]$

## Visualizing Matrices



`plot(x, Y)`



`xlabel("Year")`

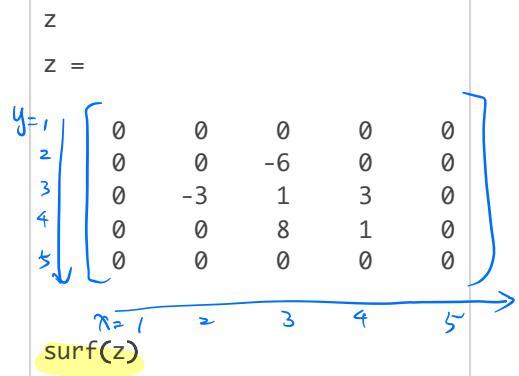
You can use visualization functions to plot your three-dimensional data.

`z` is a 5-by-5 matrix

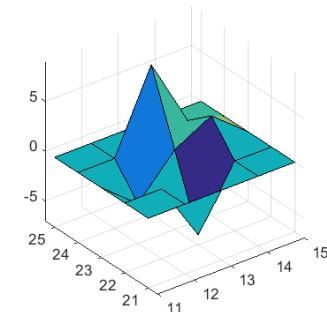
The surf function plots  $z(j,k)$  over the point  $x=k$  and  $y=j$

To specify  $x$  and  $y$  coordinates, you can pass them in as vectors.  
Here,

- The number of elements of  $x$  must match the number of columns of  $z$
- The number of elements of  $y$  must match the number of rows of  $z$



`x = 11:15;`  
`y = 21:25;`  
`surf(x,y,z)`

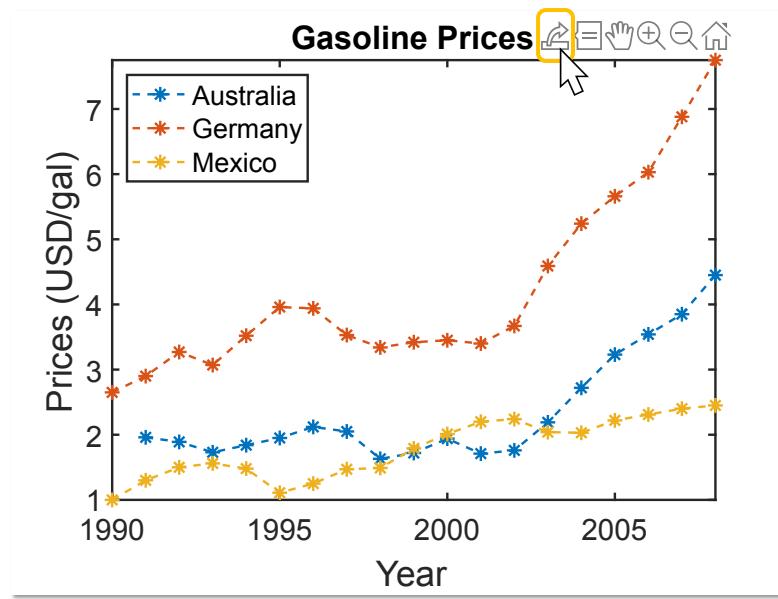
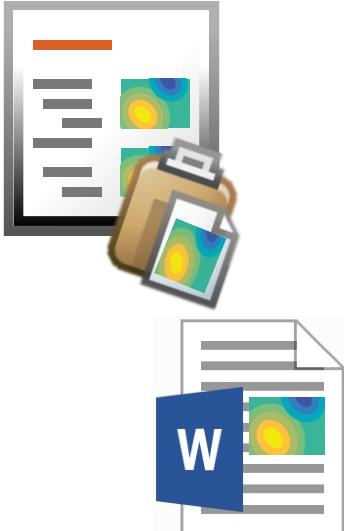


⇒ 可用 `mesh(x, y, z)` ⇒ 沒有邊線的 surface

`contour(x, y, z)` ⇒ 有邊線 contour

## Exporting a Figure

You can either copy and paste output or export a figure as an image file.



## 7. Conditional Data Selection

Summary: Conditional Data Selection

### Logical Operations and Variables

#### Relational Operators

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

```
v = [6 7 8 9];
w = [2 4 8 16];
NE = v ~= w
NE =
1 1 0 1
```

#### Logical Operators

&	AND
	OR
~	NOT

```
v = [6 7 8 9];
w = [2 4 8 16];
x = 5;
A = (v > x) & (w > x)
A =
0 0 1 1
```

### Counting Elements

Purpose	Function	Output
Are any of the elements true?	<u>any</u>	true/false
Are all the elements true?	<u>all</u>	true/false
How many elements are true?	<u>nnz</u>	double
What are the indices of the elements that are true?	<u>find</u>	double

number of non-zero

= R for which  $\Rightarrow V = [ \text{false} \text{ true} \text{ true} \text{ false} ]$   
 $\text{find}(V) \Rightarrow [2 \ 3]$

↓  
find(v, 3, "last")  
↓  
~J 找出 v 中  $\geq$  true 的，最後 3 个  
可表示 "first"

## Logical Indexing

**Purpose:** Select the elements of an array based on certain criteria.

5
3
1
7

x

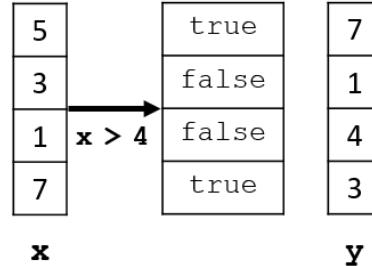
7
1
4
3

y

**Step 1:** Create a logical vector by evaluating the given condition.

**Example:**

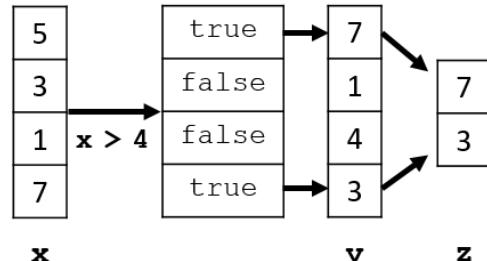
idx = x > 4



**Step 2:** Use the logical vector as an index into another array to extract the elements corresponding to the true values.

**Example:**

idx = x > 4      or      z = y(idx)  
z = y(x > 4)



## 8. Review Project I

## 9. Tables of Data

**Summary:** Tables of Data

### Storing Data in a Table

The `readtable` function creates a table in MATLAB from a data file.

```
EPL = readtable("EPLresults.xlsx", "TextType", "string");
```

The `table` function can create a table from workspace variables.

The `array2table` function can convert a numeric array to a table. The `VariableNames` property can be specified as a string array of names to include as variable names in the table.

```
teamWinsTable = table(team,wins)
teamWins =
    Team      Wins
    -----  -----
    "Arsenal"   20
    "Chelsea"   12
    "Leicester City" 23
    "Manchester United" 19
```

```
stats = array2table(wdl, ...
    "VariableNames",["Wins" "Draws" "Losses"])
stats =
    Wins   Draws   Losses
    ----  -----  -----
    20     11      7
    12     14     12
    23     12      3
    19     9      10
```

## Sorting Table Data

The `sortrows` function sorts the data in ascending order, by default.

Use the optional "descend" parameter to sort the list in descending order.

You can also sort on multiple variables, in order, by specifying a string array of variable names.

You can also show `summary` statistics for variables in a table.

```
EPL = sortrows(EPL,"HomeWins");
EPL = sortrows(EPL,"HomeWins","descend");
EPL = sortrows(EPL,["HomeWins" "AwayWins"],"descend");
summary(EPL)
```

## Extracting Portions of a Table

Display the original table.

Team	HW	HD	HL	AW	AD	AL
"Leicester City"	12	6	1	11	6	2
"Arsenal"	12	4	3	8	7	4
"Manchester City"	12	2	5	7	7	5
"Manchester United"	12	5	2	7	4	8
"Chelsea"	5	9	5	7	5	7
"Bournemouth"	5	5	9	6	4	9
"Aston Villa"	2	5	12	1	3	15

EPL(2:4,[1 2 5])

ans =

Team	HW	AW
"Arsenal"	12	8
"Manchester City"	12	7
"Manchester United"	12	7

↑ HW 移到 TEAM 前面

\* EPL = movevars(EPL, "HW", "Before", "TEAM")

\* EPL = movevars(EPL, "HW", "After", "TEAM")

EPL(2:4,["Team" "HW" "AW"])

ans =

Team	HW	AW
"Arsenal"	12	8
"Manchester City"	12	7
"Manchester United"	12	7

You may also use the name of the variable for indexing.

If you want to reference more than one variable, use a string array containing the variable names.

Remove column : df(:, ["A", "B"]) = []  $\Rightarrow$  移除 A, B 2列

Extracting Data from a Table df = removevars(df, ["A", "B"])  $\Rightarrow$  same ♪

Display the original table.

You can use dot notation to extract data for use in calculations or plotting.

EPL

EPL =

Team	HW	HD	HL	AW	AD	AL
"Leicester City"	12	6	1	11	6	2
"Arsenal"	12	4	3	8	7	4
"Manchester City"	12	2	5	7	7	5
"Manchester United"	12	5	2	7	4	8

tw = EPL.HW + EPL.AW

tw =

23

20

19

19

You can also use dot notation to create new variables in a table.

If you want to extract multiple variables, you can do this using curly braces.

Specify row indices to extract specific rows.

```
EPL.TW = EPL.HW + EPL.AW  
EPL =  
    Team      HW   HD   HL   AW   AD   AL   TW  
    -----  
    "Leicester City"  12   6   1   11   6   2   23  
    "Arsenal"        12   4   3   8    7   4   20  
    "Manchester City" 12   2   5   7    7   5   19  
    "Manchester United" 12   5   2   7    4   8   19
```

```
draws = EPL[:, ["HD" "AD"]]  
draws =  
    6    6  
    4    7  
    2    7  
    5    4
```

结果会变 array, 不是 table

```
draws13 = EPL{[1 3], ["HD" "AD"]}  
draws =  
    6    6  
    2    7
```

## Exporting Tables

You can use the `writetable` function to create a file from a table.

```
writetable(tableName, "myFile.txt", "Delimiter", "\t")
```

The file format is based on the file extension, such as `.txt`, `.csv`, or `.xlsx`, but you can also specify a delimiter.

`writetable` Write a table to a file.

`writetable(EPL, "EPL2015-16.csv")`

## 10. Organizing Tabular Data

### Summary: Organizing Tabular Data

#### Combining Tables

If the tables are already aligned so that the rows correspond to the same observation, you can concatenate them with square brackets.

`[teamInfo games]`

**teamInfo**

	Team	Payroll_M	Manager
1	"Leicester ...	48.2000	"Claudio Ran...
2	"Arsenal"	192	"Arsène Wen...
3	"Tottenham ...	110.5000	"Mauricio Po...
4	"Mancheste...	193.8000	"Manuel Pell...
5	"Mancheste...	203	"Louis van G...

**games**

	Wins	Draws	Losses
1	23	12	3
2	20	11	7
3	19	13	6
4	19	9	10
5	19	9	10

Leicester  
Arsenal  
Tottenham  
Manchester City  
Manchester United

If the tables are *not* already aligned so that the rows correspond to the same observation, you can still combine the data by merging them with a join.

**uswntTop3**

	Player	Goals
1	"Alex Morgan"	6
2	"Megan Rapinoe"	6
3	"Rose Lavelle"	3

**posTop3**

	Player	Position
1	"Rose Lavelle"	"midfielder"
2	"Alex Morgan"	"forward"
3	"Megan Rapinoe"	"forward"

The join function can combine tables with a common variable.

```
top3 = join(uswntTop3, posTop3)
top3 =
```

Player	Goals	Position
"Alex Morgan"	6	"forward"
"Megan Rapinoe"	6	"forward"
"Rose Lavelle"	3	"midfielder"

## Table Properties

Display the table properties.

### EPL.Properties

```
ans =
Table Properties with properties:
```

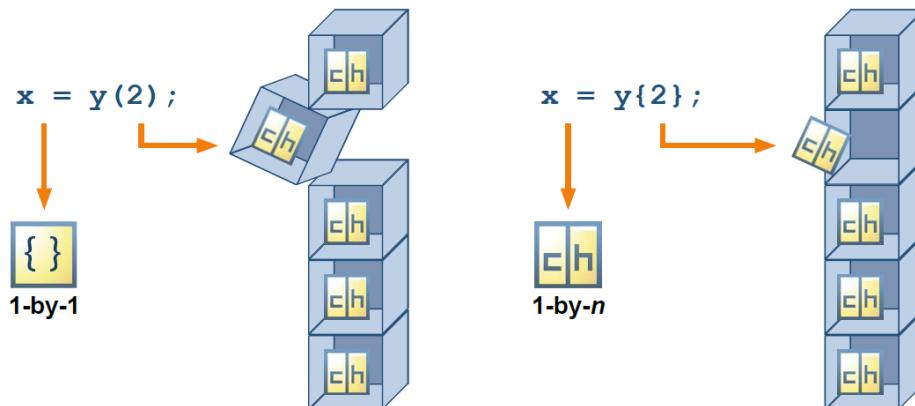
- Description: ''
- UserData: □
- DimensionNames: {'Row' 'Variable'}
- VariableNames: {1x11 cell}
- VariableDescriptions: {1x11 cell}
- VariableUnits: {}
- VariableContinuity: □
- RowNames: {}
- CustomProperties: No custom properties are set.

You can access an individual property of Properties using dot notation.

### EPL.Properties.VariableNames

```
ans =
1x11 cell array
Columns 1 through 4
{'Team'}    {'HomeWins'}    {'HomeDraws'}    {'HomeLosses'}
Columns 5 through 8
{'HomeGF'}   {'HomeGA'}     {'AwayWins'}    {'AwayDraws'}
Columns 9 through 11
{'AwayLosses'} {'AwayGF'}    {'AwayGA'}
```

## Indexing into Cell Arrays



The variable varNames is a cell array that contains character arrays of different lengths in each cell.

Using parentheses to index produces a cell array, not the character array inside the cell.

In order to extract the contents inside the cell, you should index using curly braces, {}.

Using curly braces allows you to rename the variable.

```
varNames = teamInfo.Properties.VariableNames
```

'Team'	'Payroll_M__'	'Manager'	'ManagerHireDate'
--------	---------------	-----------	-------------------

varName(2)

'Payroll_M__'
---------------

varName{2}

'Payroll\_M\_\_'

**varName{2} = 'Payroll'**

'Team'	'Payroll'	'Manager'	'ManagerHireDate'
--------	-----------	-----------	-------------------

## 11. Specialized Data Types

### Summary: Specialized Data Types

## Working with Dates and Times

Dates are often automatically detected and brought in as datetime arrays.

Many functions operate on datetime arrays directly, such as `sortrows`.

You can create a `datetime` array using numeric inputs. The first input is year, then month, then day.

To create a vector, you can specify an array as input to the `datetime` function.

teamInfo

ans =

Manager	ManagerHireDate
"Rafael Benítez"	3/11/2016
"Claudio Ranieri"	7/13/2015
"Ronald Koeman"	6/16/2014
"David Unsworth"	5/12/2016
"Slaven Bilić"	6/9/2015

`sortrows(teamInfo, "ManagerHireDate")`

ans =

Manager	ManagerHireDate
"Ronald Koeman"	6/16/2014
"Slaven Bilić"	6/9/2015
"Claudio Ranieri"	7/13/2015
"Rafael Benítez"	3/11/2016
"David Unsworth"	5/12/2016

`t = datetime(1977,12,13)`

t =  
13-Dec-1977

`ts = datetime([1903;1969],[12;7],[17;20])`

ts =  
17-Dec-1903      `t = datetime(2022, 9, 1=4)`  
20-Jul-1969       $\Rightarrow 1\text{-Sep-2022}$   $2\text{-Sep-2022}$   $3\text{-Sep-2022}$   
 $\leftarrow \text{Sep-2022}$

おさらいの：

`datetime("2022-03-08 22:00:35", "InputFormat", "yyyy-MMdd HH:mm:ss")`  
`datetime("2022-03-08", "InputFormat", "yyyy-MM-dd")`

## Operating on Dates and Times

Create datetime variables to work with.

Use subtraction to produce a duration variable.

Functions such as `years` and `days` can help make better sense of the output.

They can also create durations from a numeric value.

`seasonStart = datetime(2015,8,8)`

seasonStart =  
08-Aug-2015

`seasonEnd = datetime(2016,5,17)`

seasonEnd =  
17-May-2016

`seasonLength = seasonEnd - seasonStart`

seasonLength =  
6792:00:00

→ hour  
→ days  
→ months  
→ years (seasonLength)

`seasonLength = days(seasonLength)`

seasonLength =  
283

`seconds(5)`

ans =  
5 seconds

days()

hours()

minutes()

seconds()

→ 年月日時分秒

→ 分秒

→ 秒

→ 毫秒

⇒ 可用 `datetime` + `duration` 方式  
`a = datetime(2022, 9, 1, 10, 10, 5)`

把 5 改成 integer, 改成 duration 格式, 單位秒

$a + \text{minutes}(10) \Rightarrow "2022-9-1 10:20:05"$

Use the `between` function to produce a context-dependent `calendarDuration` variable.

Create a calendar duration from a numeric input with functions such as `calmonths` and `calyears`.

`seasonLength = between(seasonStart, seasonEnd)`

`seasonLength =`  
`9mo 9d`

`calmonths(2)`

`ans =`  
`2mo`

You can learn more about datetime and duration functions in the documentation.

[Create Date and Time Arrays](#)

## Representing Discrete Categories

`x` is a string array.

You can convert `x` into a categorical array, `y`, using the `categorical` function.

You can use `==` to create a logical array, and count elements using `nnz`.

You can view category statistics using the `summary` function.

You can view combine categories using the `mergecats` function.

```
x = ["C" "B" "C" "A" "B" "A" "C"];
x =
    "C"      "B"      "C"      "A"      "B"      "A"      "C"
```

`y = categorical(x);`

```
y =
    C      B      C      A      B      A      C
```

`nnz(x == "C")`

```
ans =
    3
```

`categories(y)`

$\Rightarrow 'A' 'B' 'C'$

`summary(y)`

A	B	C
2	2	3

`y = mergecats(y, ["B" "C"], "D")`

```
y =
    D      D      D      A      D      A      D
```

$X = [2, 4, 1, 2, 2, 1, 2, 4]$

$xlevels = ["tiny", "small", "big", "huge"]$

$y = categorical(X, [1, 2, 3, 4], xlevels) \Rightarrow y = [small, huge, tiny, \dots]$

$y = categorical(X, [1, 2, 3, 4], xlevels, "Ordinal", true)$

$\Rightarrow y > "big" \Rightarrow [0, 1, 0, 0, 0, \dots]$

## 12. Preprocessing Data

Summary: Preprocessing Data

### Normalizing Data

`normalize` Normalize data using a specified normalization method.

Normalize the columns of a matrix using z-scores.

`xNorm = normalize(x)`

Center the mean of the columns in a matrix on zero.

Scale the columns of a matrix by the first element of each column.

Stretch or compress the data in each column of a matrix into a specified interval.

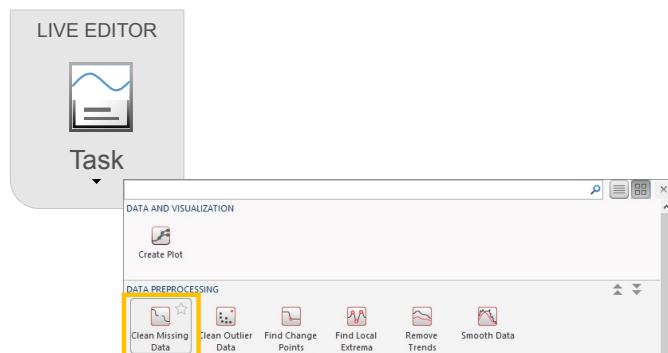
```
xNorm = normalize(x,"center","mean")
```

```
xNorm = normalize(x,"scale","first")
```

```
xNorm = normalize(x,"range",[a b])
```

## Working with Missing Data

The **Clean Missing Data** task can be used to remove or interpolate missing data. You can add one to a script by selecting it from the **Live Editor** tab in the toolbar.



Data contains missing values, in the form of both -999 and NaN.

The [ismissing](#) function identifies only the NaN elements by default.

Specifying the set of missing values ensures that [ismissing](#) identifies all the missing elements.

Use the [standardizeMissing](#) function to convert all missing values to NaN.

Use the [rmmissing](#) function to remove missing values.

```
x = [2 NaN 5 3 -999 4 NaN];
```

```
ismissing(x)
```

```
ans =
1x7 logical array
0 1 0 0 0 0 1
```

```
ismissing(x,[-999,NaN])
```

```
ans =
1x7 logical array
0 1 0 0 1 0 1
```

```
xNaN = standardizeMissing(x,-999)
```

```
xNaN =
2 NaN 5 3 NaN 4 NaN
```

```
cleanX = rmmissing(xNaN)
```

```
cleanX =
2 5 3 4
```

Ignores NaNs by default  
(default flag is "omitnan")

Includes NaNs by default  
(default flag is "includenan")

max	cov
min	mean
	median
	std
	var

Data Type	Meaning of "Missing"
<b>double</b>	NaN
<b>single</b>	
string array	Empty string (<missing>)
datetime	NaT
duration	NaN
calendarDuration	
categorical	<undefined>

## Interpolating Missing Data

`fillmissing` Fills missing values of an array or table.

Interpolation assuming equal spacing of observations.

Interpolation with given observation locations.

`z = fillmissing(y,"method")`

`z = fillmissing(y,"method","SamplePoints",x)`

Method	Meaning
"next"	The missing value is the same as the next nonmissing value in the data.
"previous"	The missing value is the same as the previous nonmissing value in the data.
"nearest"	The missing value is the same as the nearest (next or previous) nonmissing value in the data.
"linear"	The missing value is the linear interpolation (average) of the previous and next nonmissing values.
"spline"	Cubic spline interpolation matches the derivatives of the individual interpolants at the data points. This results in an interpolant that is smooth across the whole data set. However, this can also introduce spurious oscillations in the interpolant between data points.
"pchip"	The cubic Hermite interpolating polynomial method forces the interpolant to maintain the same monotonicity as the data. This prevents oscillation between data points.

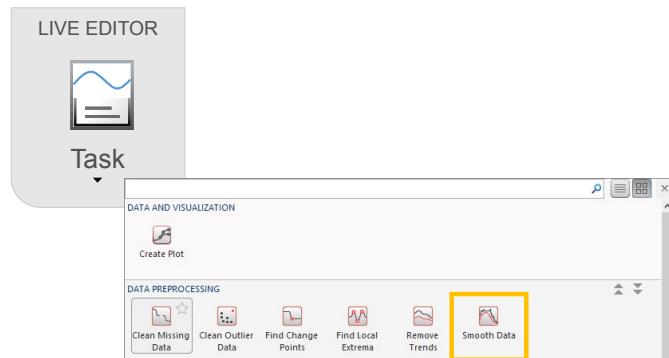
---

## 13. Common Data Analysis Techniques

### Summary: Common Data Analysis Techniques

## Moving Window Operations

The **Smooth Data** task can be used to smooth variation or noise in data. You can add one to a script by selecting it from the **Live Editor** tab in the toolbar.



The **Smooth Data** task uses the `smoothdata` function.

Mean calculated with a centered moving  $k$ -point window.

Mean calculated with a moving window with  $kb$  points backward and  $kf$  points forward from the current point.

Median calculated with a centered moving  $k$ -point window.

Median calculated with a centered moving  $k$ -point window using sample points defined in  $x$ .

```
z = smoothdata(y, "movmean", k)
```

```
z = smoothdata(y, "movmean", [kb kf])
```

```
z = smoothdata(y, "movmedian", k)
```

```
z = smoothdata(y, "movmedian", k, "SamplePoints", x)
```

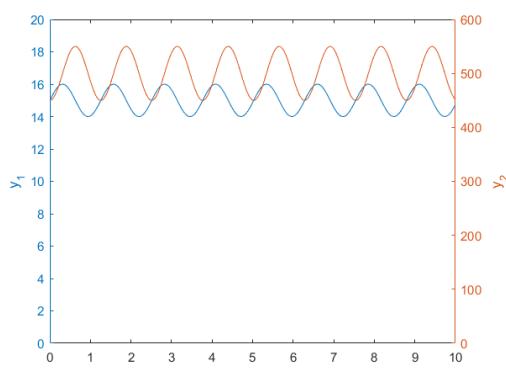
## Linear Correlation

You can investigate relationships between variables visually and computationally:

- Plot multiple series together. Use `yyaxis` to add another vertical axis to allow for different scales.
- Plot variables against each other. Use `plotmatrix` to create an array of scatter plots.
- Calculate linear correlation coefficients. Use `corrcoef` to calculate pairwise correlations.

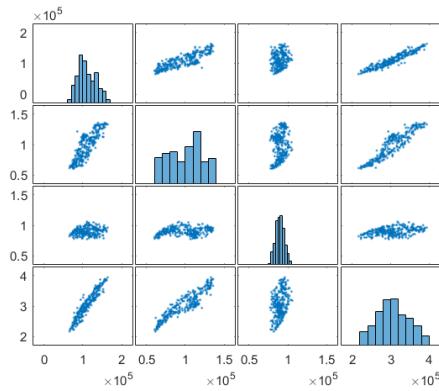
Plot multiple series together.

```
yyaxis left  
plot(...)  
yyaxis right  
plot(...)
```



Plot variables against each other.

```
plotmatrix(data)
```



Calculate linear correlation coefficients.

```
corrcoef(data)
```

```
ans =
```

1.0000	0.8243	0.1300	0.9519
0.8243	1.0000	0.1590	0.9268
0.1300	0.1590	1.0000	0.2938
0.9519	0.9268	0.2938	1.0000

## Polynomial Fitting

polyfit *Fits a polynomial to data.*

polyval *Evaluates a polynomial at specified locations.*

### Simple fitting

Fit polynomial to data.

```
c = polyfit(x,y,n);
```

Evaluate fitted polynomial.

```
yfit = polyval(c,xfit);
```

### Fitting with centering and scaling

Fit polynomial to data.

```
[c,~,scl] = polyfit(x,y,n);
```

Evaluate fitted polynomial.

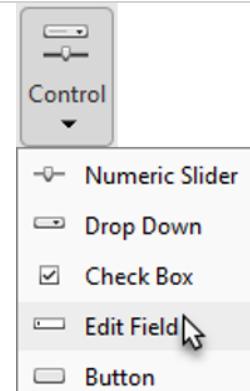
```
yfit = polyval(c,xfit,□,scl);
```

## 14. Programming Constructs

### Summary: Programming Constructs

## User Interaction

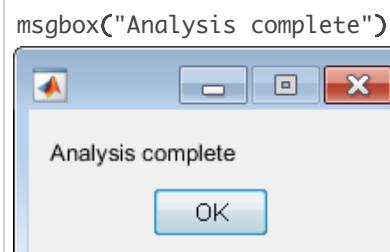
You can add a live control to get input from the user.



You can use `disp` to show output on the command window.

```
disp("Message")
Message
warning("Missing data")
Warning: Missing data
error("Missing data")
Missing data
```

You can use `warning` and `error` as well.



The `msgbox`, `errordlg`, and `warndlg` functions can display messages to the user.

## Decision Branching

The `condition_1` is evaluated as true or false.

If `condition_1` is true, then the `code_1` code block is executed.

Otherwise, the next case is tested. There can be any number of cases.

If none of the cases are a match, then the code, `code_e`, in `else` is executed.

Always end the expression with the keyword `end`

```
if condition_1
    code_1
elseif condition_2
    code_2
elseif condition_3
    code_3
else
    code_e
end
```

Evaluate expression to return a value.

If expression equals *value\_1*, then *code\_1* is executed. Otherwise, the next case is tested. There can be any number of cases.

If none of the cases are a match, then the code, *code\_3*, in **otherwise** is executed. The **otherwise** block is optional.

Always end the expression with the keyword **end**

**switch expression**

```
case value 1  
    code_1  
case value 2  
    code_2  
otherwise  
    code_3  
end
```

## Determining Size



*m-by-n*



*n-by-1*



*1-by-n*

<code>size(x)</code>	<code>[m n]</code>	<code>[n 1]</code>	<code>[1 n]</code>
<code>size(x,1)</code>	<i>m</i>	<i>n</i>	1
<code>size(x,2)</code>	<i>n</i>	1	<i>n</i>
<code>length(x)</code>	<code>max(m,n)</code>	<i>n</i>	<i>n</i>
<code>numel(x)</code>	<i>m*n</i>	<i>n</i>	<i>n</i>

Use size to find the dimensions of a matrix.

```
s = size(prices)  
s =  
    19      10  
  
[m,n] = size(prices)  
m =  
    19  
n =  
    10  
  
m = size(prices,1)  
m =  
    19  
  
n = size(prices,2)  
n =  
    10
```

Use `length` when working with vectors where one of the dimensions returned by `size` is 1.

Use `numel` to find the total number of elements in an array of any dimension.

```
m = length(Year)
```

```
m =  
19
```

```
N = numel(prices)
```

```
N =  
190
```

## For Loops

The index is defined as a vector. Note the use of the colon syntax to define the values that the index will take.

```
for index = first:increment:last  
    code  
end
```

## While Loops

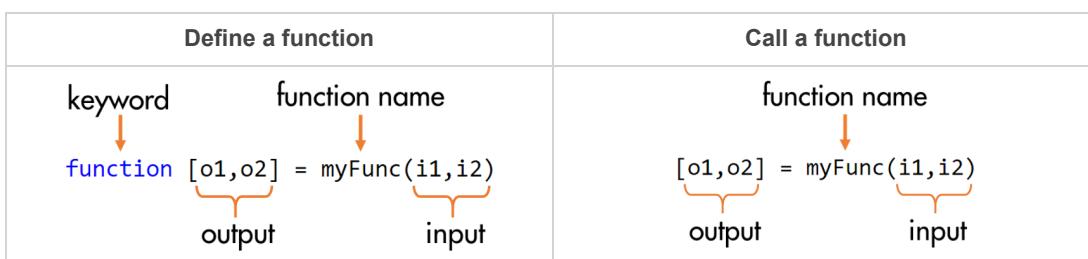
The condition is a variable or expression that evaluates to `true` or `false`. While `condition` is `true`, code executes. Once `condition` becomes `false`, the loop ceases execution.

```
while condition  
    code  
end
```

# 15. Increasing Automation with Functions

## Summary: Increasing Automation with Functions

### Creating and Calling Functions

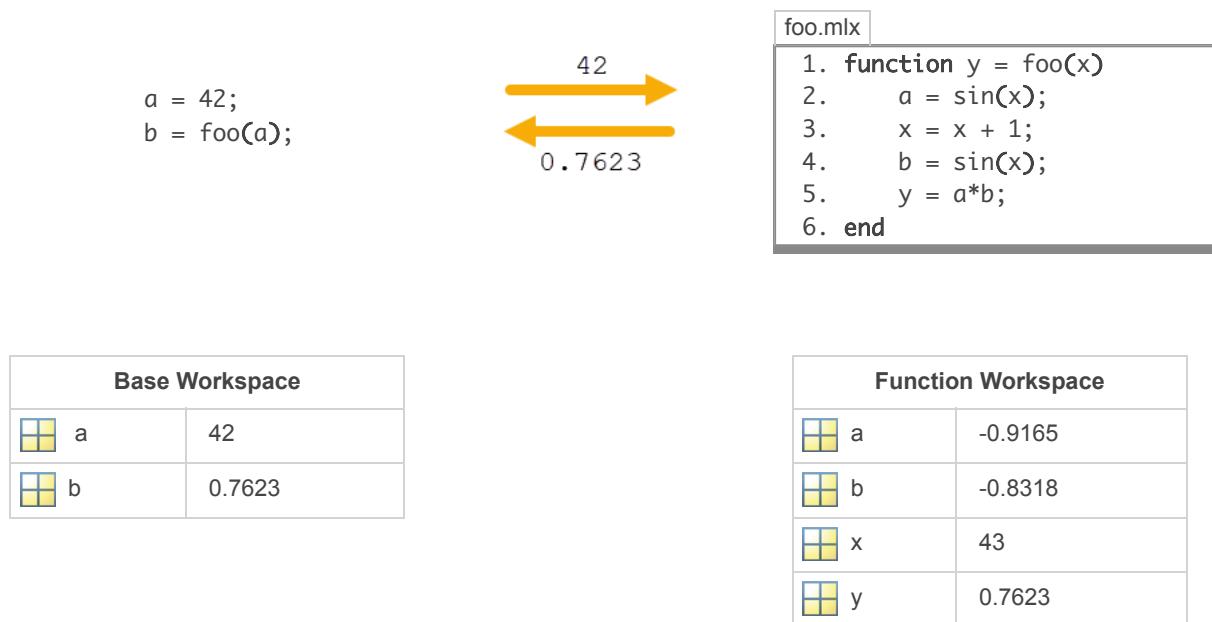


### Function Files

Function Type	Function Visibility
<b>Local functions:</b> Functions that are defined within a script.	Visible only within the file where they are defined.
<b>Functions:</b> Functions that are defined in separate files.	Visible to other script and function files.

### Workspaces

A function maintains its own workspace to store variables created in the function body.



## MATLAB Path and Calling Precedence

In MATLAB, there are rules for interpreting any named item. These rules are referred to as the function precedence order. Most of the common reference conflicts can be resolved using the following order:

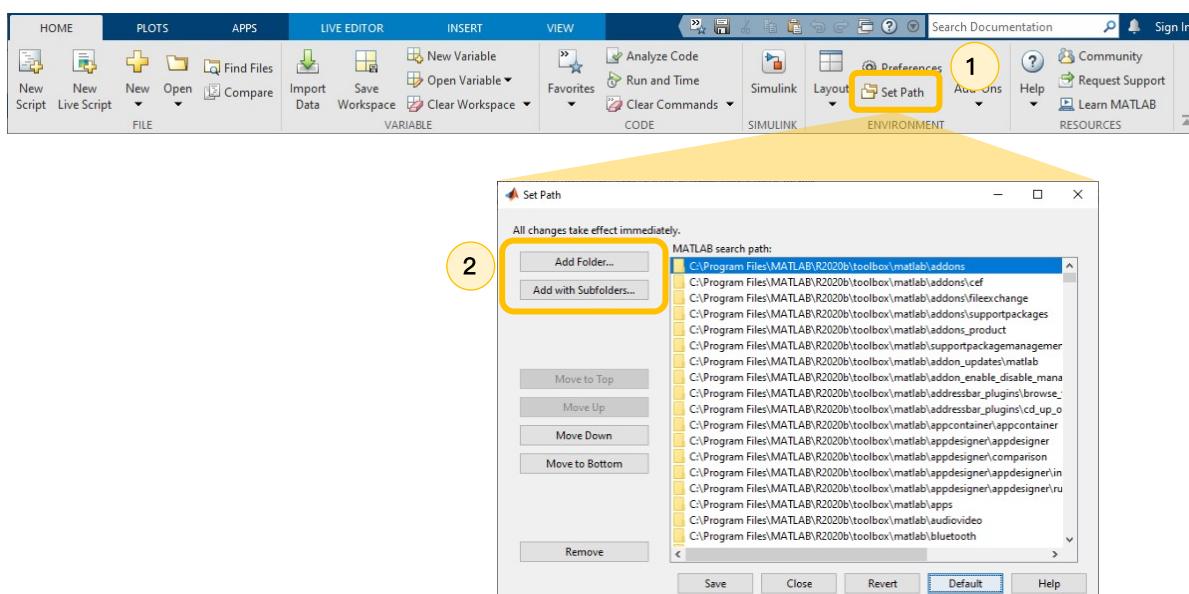
1. Variables
2. Functions defined in the current script
3. Files in the current folder
4. Files on MATLAB search path

A more comprehensive list can be found [here](#).

The search path, or *path* is a subset of all the folders in the file system. MATLAB can access all files in the folders on the search path.

To add folders to the search path:

1. On the **Home** tab, in the **Environment** section, click **Set Path**.
2. Add a single folder or a set of folders using the buttons highlighted below.

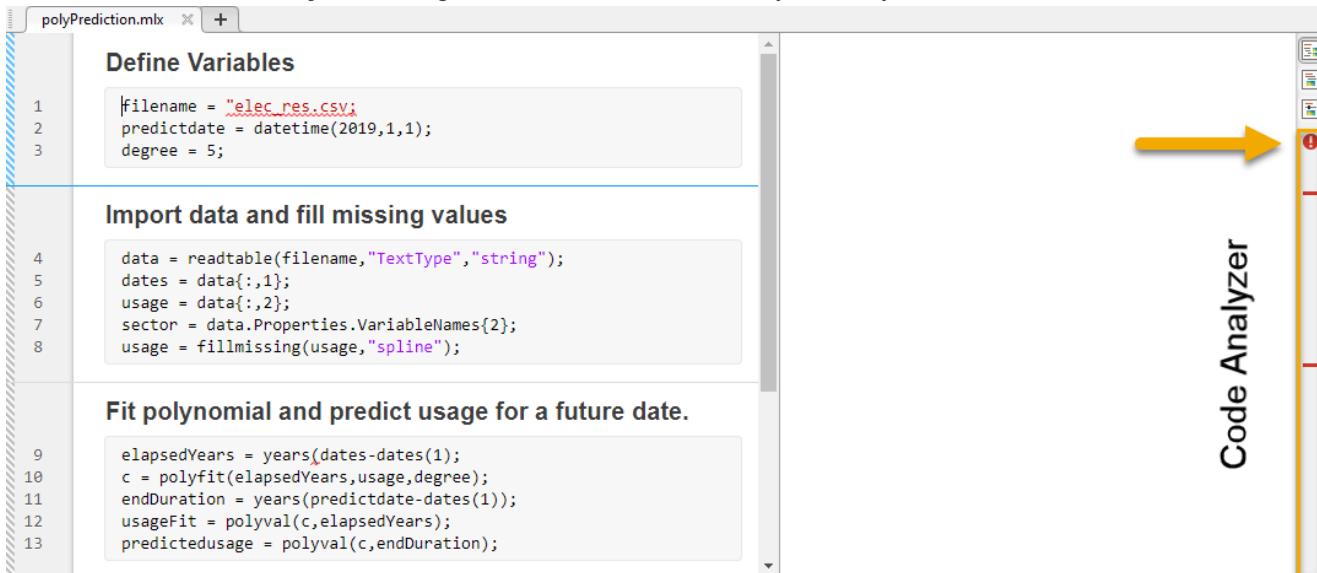


## 16. Troubleshooting Code

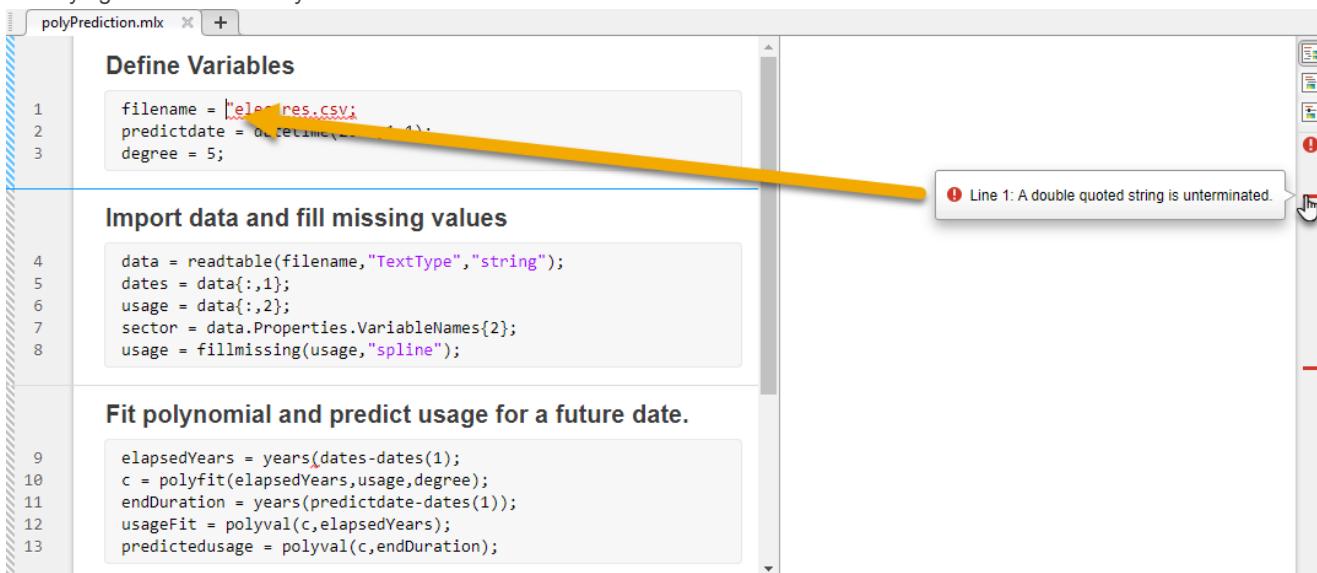
### Summary: Troubleshooting Code

#### Code Analyzer

Use the MATLAB **Code Analyzer**. messages shown in the Editor to identify and fix syntax errors.



The small red icon at the top of the **Code Analyzer**. indicates there are errors in the script. Click on it to show red lines identifying the locations of syntax errors.



Red indicator lines in the **Code Analyzer**. identify specific syntax errors. You can mouse over one to see a description of that issue. The first indicator line describes the mistake you saw in the error message: the closing quotation mark is missing.

Clicking an indicator line puts your cursor where the error was found so you can fix it. Notice that the broken portion of the code is red and underlined.

```

1 filename = "elec_res.csv"; ✓
2 predictdate = datetime(2019,1,1);
3 degree = 5;

4 data = readtable(filename,"TextType","string");
5 dates = data{:,1};
6 usage = data{:,2};
7 sector = data.Properties.VariableNames{2};
8 usage = fillmissing(usage,"spline");

9 elapsedYears = years(dates-dates(1));
10 c = polyfit(elapsedYears,usage,degree);
11 endDuration = years(predictdate-dates(1));
12 usageFit = polyval(c,elapsedYears);
13 predictedUsage = polyval(c,endDuration);

```

After you fix the error, the code in line 1 is no longer red and underlined. The corresponding indicator line goes away. There is still one syntax error left, though. You should fix all syntax errors flagged by the **Code Analyzer** before running your script or function.

Icon	Meaning
⚠	There is a potential for unexpected results or poor code performance.
❗	There are syntax errors that must be addressed.

The **Code Analyzer** identifies both syntax errors and warnings.

## Inspecting Variables

Runtime errors are bugs that aren't syntax errors.



Run time errors can produce an execution-stopping error or just be something you didn't mean to do. An effective way to troubleshoot them is to inspect variables.



Remove semicolons to inspect the output.

1 load elecPrices  
2 avgYrPrices = priceYr.\*dollar2019;  
3 avgElecPrice = mean(avgYrPrices)

avgYrPrices = 30x30

15.3220	14.7033	14.2736	13.8587	13.5127	...
15.7262	15.0911	14.6501	14.2243	13.8692	
16.0778	15.4285	14.9777	14.5423	14.1793	
...	...	...	...	...	

avgElecPrice = 1x30  
19.7075 18.9116 ...

Mouse over a variable to see its size and a preview.

1 load elecPrices  
2 avgYrPrices = priceYr.\*dollar2019;  
3 avgElecPrice = mean(avgYrPrices)

avgElecPrice = 1x30  
19.7075 18.9116 ...

Line 2: avgYrPrices = priceYr.\*dollar2019;

Click on a variable to view each place where the variable is used, created, or modified. Click the gray indicator lines in the **Code Analyzer** to go directly to the line where a variable is used.

**Workspace**

Name	Class	Size
avgElecPrice	double	1x30
avgYrPrices	double	30x30
dollar2019	double	1x30
priceYr	double	30x1

**Variables - priceYr**

	1	2	3	4
1	7.8331			
2	8.0397			
3	8.2195			
4	8.3236			
5	8.3868			
6	8.3056			

Look at the variables in the **Workspace** for a preview. Double click them to inspect elements in the **Variable Editor**.

## Stepping Through Code

When variables change throughout a script, you can step through your code to inspect intermediate values. You can run section by section or set breakpoints.

### Run and Advance

You can run scripts section by section. In the **Section** section of the **Live Editor** tab in the Toolbar, you can break up your code into sections to run one at a time.

LIVE EDITOR - C:\class\work\gasPrices.m

```

1 galilit = 0.0842;
2 Australia = galilit*Australia;
3 Germany = galilit*Germany;
4 Mexico = galilit*Mexico;
5 Canada = galilit*Canada;
6 hold off

7 plotYear,Australia,"+-."
8 hold on
9 plotYear,Germany,"+-."
10 plotYear,Mexico,"+-."
11 plotYear,Canada,"+-."
12 hold off

13 title("International Gasoline Prices")
14 xlabel("Year")
15 ylabel("Price (USD/l)")
16 legend("Australia","Germany","Mexico","Canada",...
    "Location","northwest")
17

```

This is the current section.



**Section Break:** Add a section break to create a code section.

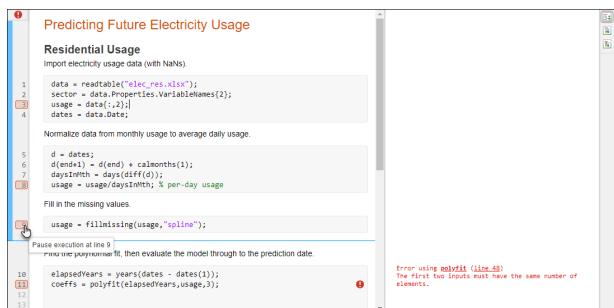


**Run and Advance:** Run code in the current section, then move to the next section.

## Setting Breakpoints

You can also set breakpoints in scripts and functions to stop code execution before specific lines. This works particularly well with functions, where you otherwise don't have access to the workspace. Breakpoints give you access to the same tools you have in scripts for inspecting variables.

Add breakpoints by clicking line numbers.



**Continue:** Run code until the next breakpoint (or the end of the script).



**Step:** Run only the next line of code.

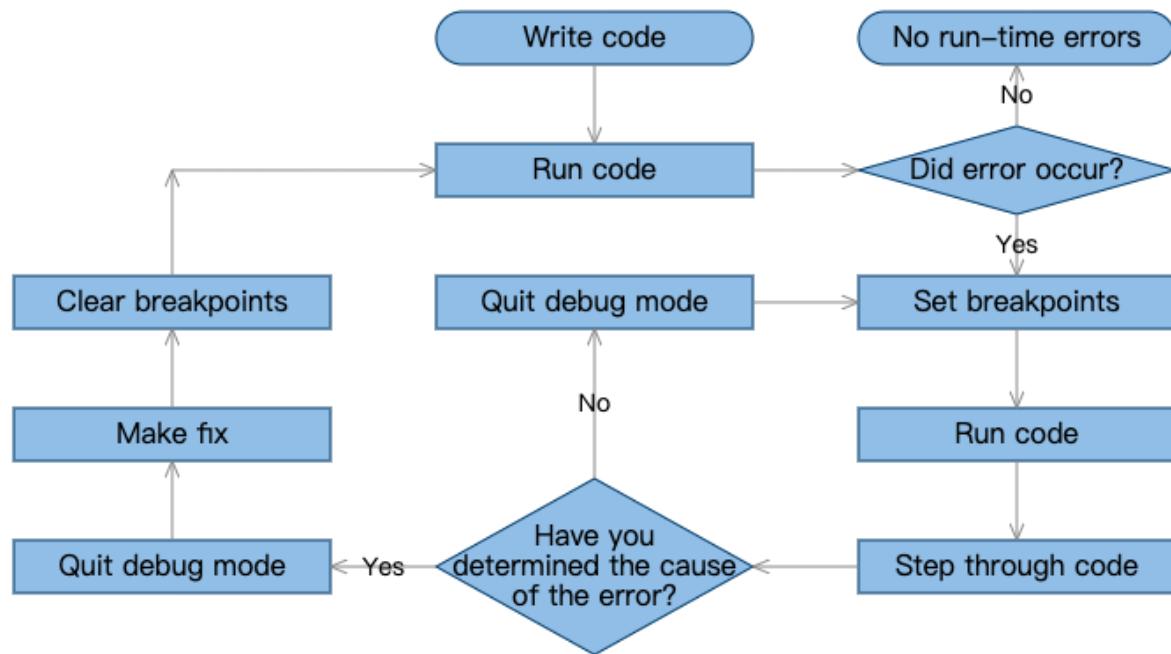


**Stop:** Stop code execution and exit debug mode.

Don't forget to clear your breakpoints and save your work!

## A Debugging Workflow

When debugging MATLAB code, a common workflow is as follows.



Note that after you've identified and fixed any bugs, you should stop your debugging session, save your changes, and clear all breakpoints before running your code again.

## 17. Review Project II

## 18. Conclusion