

# MATLAB Companion Script for *Machine Learning* ex1 (Optional)

## Introduction

Coursera's *Machine Learning* was designed to provide you with a greater understanding of machine learning algorithms- what they are, how they work, and where to apply them. You are also shown techniques to improve their performance and to address common issues. As is mentioned in the course, there are many tools available that allow you to use machine learning algorithms *without* having to implement them yourself. This Live Script was created by MathWorks to help *Machine Learning* students explore the data analysis and machine learning tools available in MATLAB.

## FAQ

### Who is this intended for?

- This script is intended for students using MATLAB Online who have completed ex1 and want to learn more about the corresponding machine learning tools in MATLAB.

### How do I use this script?

- In the sections that follow, read the information provided about the data analysis and machine learning tools in MATLAB, then run the code in each section and examine the results. You may also be presented with instructions for using a MATLAB machine learning app. This script should be located in the ex1 folder which should be set as your Current Folder in MATLAB Online.

### Can I use the tools in this companion script to complete the programming exercises?

- No. Most algorithm steps implemented in the programming exercises are handled automatically by MATLAB machine learning functions. Additionally, the results will be similar, but not identical, to those in the programming exercises due to differences in implementation, parameter settings, and randomization.

### Where can I obtain help with this script or report issues?

- As this script is not part of the original course materials, please direct any questions, comments, or issues to the *MATLAB Help* discussion forum.

## Linear Regression

In this script, linear regression models for both single and multiple variables are implemented using the `fitlm` function from the [Statistics and Machine Learning Toolbox](#). A quick tutorial is also included on using the *Regression Learner App*, which provides a graphical interface for creating regression models.

## Files needed for this script

- ex1data1.txt - Dataset for linear regression with one variable
- ex1data2.txt - Dataset for linear regression with multiple variables

## Table of Contents

MATLAB Companion Script for Machine Learning ex1 (Optional).....	1
Introduction.....	1
FAQ.....	1
Linear Regression.....	1
Files needed for this script.....	1
Linear Regression with One Variable.....	2
Load the data into a table.....	2
Fit a linear model using the fitlm function.....	7
Making predictions using the LinearModel variable.....	7
Linear Regression with Multiple Variables.....	8
Load and preview the data.....	8
Fit a linear model using fitlm and estimate housing prices.....	10
Using the Regression Learner App.....	10
Open the app and select the variables.....	11
Select and train the model.....	11
Evaluate the model.....	11
Export the model.....	11

## Linear Regression with One Variable

This section covers the MATLAB implementation of single variable linear regression corresponding to the first part of ex1. Recall that the file ex1data1.txt contains two columns of data: the first column corresponds to the populations of cities and the second column contains the profit of food trucks in those cities.

### Load the data into a table

The `table` datatype is now the preferred datatype for most data analysis and machine learning tasks in MATLAB. In this script we will use tables instead of vectors and matrices. A `table` consists of rows and columns where each column corresponds to a variable, and each row corresponds to an observation.

Run the code below to:

- Read the profit data into a `table` using the `readtable` function
- Add descriptive names to the `table` variables
- Compute summary statistics on each variable
- Display the methods available for working with `table` variables.

```
clear;
data = readtable('ex1data1.txt'); % read tabular data into a table
data.Properties.VariableNames = {'Population', 'Profit'} % name the variables
```

```
data = 97x2 table
```

	Population	Profit
1	6.1101	17.5920
2	5.5277	9.1302
3	8.5186	13.6620

	Population	Profit
4	7.0032	11.8540
5	5.8598	6.8233
6	8.3829	11.8860
7	7.4764	4.3483
8	8.5781	12.0000
9	6.4862	6.5987
10	5.0546	3.8166
11	5.7107	3.2522
12	14.1640	15.5050
13	5.7340	3.1551
14	8.4084	7.2258
15	5.6407	0.7162
16	5.3794	3.5129
17	6.3654	5.3048
18	5.1301	0.5608
19	6.4296	3.6518
20	7.0708	5.3893
21	6.1891	3.1386
22	20.2700	21.7670
23	5.4901	4.2630
24	6.3261	5.1875
25	5.5649	3.0825
26	18.9450	22.6380
27	12.8280	13.5010
28	10.9570	7.0467
29	13.1760	14.6920
30	22.2030	24.1470
31	5.2524	-1.2200
32	6.5894	5.9966
33	9.2482	12.1340
34	5.8918	1.8495
35	8.2111	6.5426
36	7.9334	4.5623
37	8.0959	4.1164

	Population	Profit
38	5.6063	3.3928
39	12.8360	10.1170
40	6.3534	5.4974
41	5.4069	0.5566
42	6.8825	3.9115
43	11.7080	5.3854
44	5.7737	2.4406
45	7.8247	6.7318
46	7.0931	1.0463
47	5.0702	5.1337
48	5.8014	1.8440
49	11.7000	8.0043
50	5.5416	1.0179
51	7.5402	6.7504
52	5.3077	1.8396
53	7.4239	4.2885
54	7.6031	4.9981
55	6.3328	1.4233
56	6.3589	-1.4211
57	6.2742	2.4756
58	5.6397	4.6042
59	9.3102	3.9624
60	9.4536	5.4141
61	8.8254	5.1694
62	5.1793	-0.7428
63	21.2790	17.9290
64	14.9080	12.0540
65	18.9590	17.0540
66	7.2182	4.8852
67	8.2951	5.7442
68	10.2360	7.7754
69	5.4994	1.0173
70	20.3410	20.9920
71	10.1360	6.6799

	Population	Profit
72	7.3345	4.0259
73	6.0062	1.2784
74	7.2259	3.3411
75	5.0269	-2.6807
76	6.5479	0.2968
77	7.5386	3.8845
78	5.0365	5.7014
79	10.2740	6.7526
80	5.1077	2.0576
81	5.7292	0.4795
82	5.1884	0.2042
83	6.3557	0.6786
84	9.7687	7.5435
85	6.5159	5.3436
86	8.5172	4.2415
87	9.1802	6.7981
88	6.0020	0.9270
89	5.5204	0.1520
90	5.0594	2.8214
91	5.7077	1.8451
92	7.6366	4.2959
93	5.8707	7.2029
94	5.3054	1.9869
95	8.2934	0.1445
96	13.3940	9.0551
97	5.4369	0.6170

```
summary(data)
```

Variables:

**Population:** 97×1 double

Values:

Min	5.0269
Median	6.5894
Max	22.203

**Profit:** 97×1 double

Values:

Min	-2.6807
Median	4.5623
Max	24.147

`methods(data)`

Methods for class table:

<code>addprop</code>	<code>head</code>	<code>innerjoin</code>	<code>issortedrows</code>	<code>ndims</code>	<code>rmprop</code>	<code>setxor</code>	<code>stack</code>
<code>addvars</code>	<code>height</code>	<code>intersect</code>	<code>join</code>	<code>numel</code>	<code>rowfun</code>	<code>size</code>	<code>summary</code>
<code>cat</code>	<code>horzcat</code>	<code>isempty</code>	<code>mergevars</code>	<code>outerjoin</code>	<code>rows2vars</code>	<code>sortrows</code>	<code>table</code>
<code>convertvars</code>	<code>inner2outer</code>	<code>ismember</code>	<code>movevars</code>	<code>removevars</code>	<code>setdiff</code>	<code>splitvars</code>	<code>tail</code>

Use the help control below to view descriptions of the functions for working with `table` variables displayed above.

help [table.topkrows](#)

**topkrows** Top K sorted rows of table.

`B = topkrows(A,K)` returns the top K rows of A sorted in descending order by all of the variables in A. The rows in B are sorted first by the first variable, next by the second variable, and so on.

`B = topkrows(A,K,VARS)` returns the top K rows sorted by the variables specified by VARS. VARS can be a positive integer, a vector of positive integers, a variable name, a string array or cell array containing one or more variable names, or a logical vector. VARS can also include the name of the row dimension, i.e. `A.Properties.DimensionNames{1}`, to sort by row names as well as by data variables. By default, the row dimension name is 'Row'.

`B = topkrows(A,K,'RowNames')` returns the top K rows sorted by the row names.

`B = topkrows(A,K,VARS,DIRECTION)` also specifies the sort direction(s). DIRECTION can be:

- 'descend' - (default) Sorts in descending order.
- 'ascend' - Sorts in ascending order.

**topkrows** sorts A in ascending or descending order according to all variables specified by VARS. Use a different direction for each variable by specifying DIRECTION as a cell array. For example, `topkrows(A,5,[2 3],{'ascend' 'descend'})`. Specify VARS as `1:SIZE(A,2)` to sort using all variables.

`B = topkrows(A,K,VARS,DIRECTION,'ComparisonMethod',C)` specifies how to compare complex numbers. The comparison method C can be:

- 'auto' - (default) Compares real numbers according to 'real', and complex numbers according to 'abs'.
- 'real' - Compares according to `REAL(A)`. Elements with equal real parts are then sorted by `IMAG(A)`.
- 'abs' - Compares according to `ABS(A)`. Elements with equal magnitudes are then sorted by `ANGLE(A)`.

`[B,I] = topkrows(...)` also returns an index vector I that describes the order of the K selected rows such that `B = A(I,:)`.

See also `sortrows`.

## Fit a linear model using the `fitlm` function

There are many available functions in the Statistics and Machine Learning Toolbox for fitting a model to data. To fit a linear regression model to the data in our `table`, we'll use the `fitlm` function. As we will see, there is no need to add a column of ones to the data for a bias term, to create a separate cost function, or to implement gradient descent to converge on the model parameters as in ex1- these tasks are automatically taken care of by `fitlm`. The output of `fitlm` is a `LinearModel` variable which contains all of the information about the model.

Run the code in this section to fit the linear model. The model coefficients ( $\theta$ ) are extracted from the model variable and printed out for you below- compare to your results from ex1. After running, double-click on the variable `linMdl` in the MATLAB workspace to examine its properties further. Variable properties can also be extracted and displayed using the `.' operator, as in the code below used to extract the Coefficients property. The result is a table of the model coefficients and additional statistical information.`

```
linMdl = fitlm(data);
linMdl.Coefficients
```

```
ans = 2x4 table
```

	Estimate	SE	tStat	pValue
1 (Intercept)	-3.8958	0.7195	-5.4147	4.6079e-07
2 Population	1.1930	0.0797	14.9608	1.0232e-26

```
theta = linMdl.Coefficients.Estimate;
fprintf('Theta computed by fitlm: [%f; %f]',theta(1),theta(2))
```

```
Theta computed by fitlm: [-3.895781; 1.193034]
```

## Making predictions using the `LinearModel` variable

Below we use the `predict` function to predict profit for different populations using the model trained in the previous section. Note that the first input to `predict` is a trained model variable, while the second input is a feature value or list of values in the form of a vector, matrix or table. Run the code in this section and compare with your results from ex1.

```
% Predict values for population sizes of 35,000 and 70,000
predict1 = predict(linMdl,3.5);
fprintf('For population = 35,000, we predict a profit of %f', predict1*10000);
```

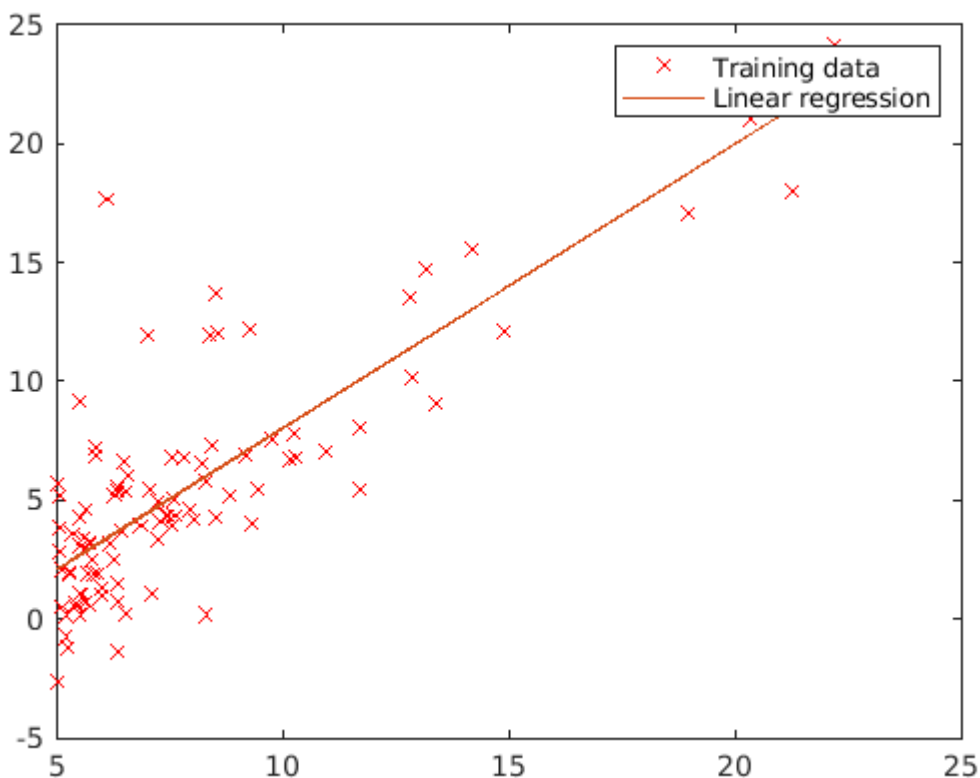
```
For population = 35,000, we predict a profit of 2798.368764
```

```
predict2 = predict(linMdl,7);
fprintf('For population = 70,000, we predict a profit of %f', predict2*10000);
```

```
For population = 70,000, we predict a profit of 44554.546310
```

```
% Plot the linear fit
plot(data.Population,data.Profit,'rx'); hold on
profit = predict(linMdl,data);
```

```
plot(data.Population, profit, '-')
legend('Training data', 'Linear regression'); hold off
```



## Linear Regression with Multiple Variables

### Load and preview the data

Recall that the file `ex1data2.txt` contains a training set of housing prices in Portland, Oregon. Each row corresponds to a house where the element in the first column is the size of the house (in square feet), the second column is the number of bedrooms, and the third column is the price of the house. Run this section to load the data into a `table`. After a `table` is displayed as output you can perform basic sort and filter operations on a given columns as follows:

1. Hover the mouse pointer over the desired variable name (column heading)
2. Click on the down arrow when it appears
3. Choose the desired sort option to sort all rows in the table based on the value in that variable OR
4. Enter a specific range in the boxes provided to select only rows whose value for the selected variable falls inside that range
5. The MATLAB code required to perform 3 and/or 4 is automatically displayed below the `table`. If desired, the code can be copied to the clipboard or added to the script using the 'Copy' and 'Update' code buttons.



After running this section, experiment with sorting and filtering the data `table` below. (Since we want to use all the observations in `data`, there is no need to copy the code or add it to the script.)

```
clear;
% Load Data
data = readtable('ex1data2.txt');
data.Properties.VariableNames = {'Size', 'Bedrooms', 'Price'}
```

`data = 39×3 table | Reduced from 47 rows`

	Size	Bedrooms	Price
1	4215	4	549000
2	3890	3	573900
3	3137	3	579900
4	3031	4	599000
5	3000	4	539900
6	2637	3	299900
7	2609	4	499998
8	2567	4	314000
9	2526	3	469000
10	2400	3	369000
11	2300	4	449900
12	2238	3	329900
13	2200	3	475000
14	2162	4	287000
15	2132	4	345000
16	2104	3	399900
17	2040	4	314900
18	2000	3	347000
19	1985	4	299900
20	1962	4	259900
21	1940	4	239999
22	1890	3	329999
23	1852	4	299900
24	1811	4	285900
25	1767	3	252900
26	1604	3	242900
27	1600	3	329900
28	1534	3	314900

	Size	Bedrooms	Price
29	1494	3	242500
30	1458	3	464500
31	1437	3	249900
32	1427	3	198999
33	1380	3	212000
34	1268	3	259900
35	1239	3	229900
36	1236	3	199900
37	1203	3	239500
38	1200	3	299000
39	1100	3	249900

## Fit a linear model using `fitlm` and estimate housing prices

The `fitlm` function can be used to fit a regression model with multiple variables as well. Note that the last column (variable) in the input table is considered the response variable by `fitlm` by default while all other variables are considered predictors. A different response variable can be specified, if desired- see the `fitlm` documentation for more information. Run this section to fit a linear model, display the model the coefficients, and predict the price of a 1650 sqft, 3-bedroom house. Compare with your results from ex1.

```
linMdl = fitlm(data);
theta = linMdl.Coefficients.Estimate;
fprintf('Theta computed by fitlm: [%f; %f]', theta(1), theta(2))
```

```
Theta computed by fitlm: [89597.909543; 139.210674]
```

```
price = predict(linMdl,[1650 3]); % Enter your price formula here
fprintf('Predicted price of a 1650 sq-ft, 3 br house: $%f', price);
```

```
Predicted price of a 1650 sq-ft, 3 br house: $293081.464335
```

## Using the Regression Learner App

In this section, we reproduce the results of the previous section while providing an introduction to the [Regression Learner App](#). This app offers a graphical interface for building, training, and evaluating linear regression models. Run the code below to clear the workspace and reload the housing data, then follow the steps in the next few sections.

```
clear;
% Load Data
data = readtable('ex1data2.txt');
data.Properties.VariableNames = {'Size', 'Bedrooms', 'Price'};
```

**Note:** If you have difficulty reading the instructions below while the app is open in MATLAB Online, export this script to a pdf file which you can then use to display the instructions in a separate browser tab or window. To export this script, click on the 'Save' button in the 'Live Editor' tab above, then select 'Export to PDF'.

## Open the app and select the variables

1. In the MATLAB Apps tab, select the **Regression Learner** app from the Machine Learning section (you may need to expand the menu of available apps).
2. Select '**New Session -> From Workspace**' to start a new interactive session.
3. Under '**Workspace Variable**', select '**data**' (if not already selected).
4. Under '**Response**' select '**Price**' (if not already selected).
5. Under '**Predictors**' select '**Size**' and '**Bedrooms**' (if not already selected).
6. Under '**Validation**' select '**No Validation**'
7. Click the '**Start Session**' button.

## Select and train the model

There are many available models to choose from (the default model is 'Fine Tree'). To train a regression model corresponding to the one in the previous section obtained using `fitlm`:

1. Expand the model list and select '**Linear**' from the '**Linear Regression Models**' list.
2. Select '**Train**' to fit the model.

## Evaluate the model

After training, there are several options available for evaluating model performance.

- The training results, including error values, prediction speed, and training time for the selected model is shown in the '**Current Model**' pane.
- The model predictions for the training data are visualized in the '**Response Plot**', which is shown by default. To plot the response by variable, select the desired feature variable from the choices in '**X-axis**'.
- The '**Predicted vs. Actual**' and '**Residuals**' plots offer additional visual means of visualizing and evaluating model performance.

## Export the model

To export a linear regression model variable from the app into the workspace:

1. Select '**Export Model -> Export Model**'.
2. Select the default output variable name ('trainedModel').
3. Extract the linear model to the variable `linMdl` by running the command below

```
linMdl = trainedModel.LinearModel
```

`linMdl` variable now contains the linear regression model. It can be used to predict housing prices using the `predict` function using the methods provided earlier for working with `LinearModel` variables returned from `fitlm`.