

# Machine Learning: Programming Exercise 5

## Regularized Linear Regression and Bias vs. Variance

In this exercise, you will implement regularized linear regression and use it to study models with different bias-variance properties.

### Files needed for this exercise

- `ex5.mlx` - MATLAB Live Script that steps you through the exercise
- `ex5data1.mat` - Dataset
- `submit.m` - Submission script that sends your solutions to our servers
- `featureNormalize.m` - Feature normalization function
- `fmincg.m` - Function minimization routine (similar to `fminunc`)
- `plotFit.m` - Plot a polynomial fit
- `trainLinearReg.m` - Trains linear regression using your cost function
- `*linearRegCostFunction.m` - Regularized linear regression cost function
- `*learningCurve.m` - Generates a learning curve
- `*polyFeatures.m` - Maps data into polynomial feature space
- `*validationCurve.m` - Generates a cross validation curve

*\*indicates files you will need to complete*

### Confirm that your Current Folder is set correctly

Click into this section, then click the 'Run section' button above. This will execute the `dir` command below to list the files in your Current Folder. The output should contain all of the files listed above and the 'lib' folder. If it does not, right-click the 'ex5' folder and select 'Open' before proceeding or see the instructions in `README.mlx` for more details.

```
dir

.                ex5_companion.mlx      fmincg.m          linearRegCostFunction.m  submit
..              ex5data1.mat        learningCurve.m    plotFit.m              token.
ex5.mlx         featureNormalize.m    lib                polyFeatures.m          trainI
```

### Before you begin

The workflow for completing and submitting the programming exercises in MATLAB Online differs from the original course instructions. Before beginning this exercise, make sure you have read through the instructions in `README.mlx` which is included with the programming exercise files. `README` also contains solutions to the many common issues you may encounter while completing and submitting the exercises in MATLAB Online. Make sure you are following instructions in `README` and have checked for an existing solution before seeking help on the discussion forums.

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## 1. Regularized Linear Regression

In the first half of the exercise, you will implement regularized linear regression to predict the amount of water flowing out of a dam using the change of water level in a reservoir. In the next half, you will go through some diagnostics of debugging learning algorithms and examine the effects of bias vs. variance.

### 1.1 Visualizing the dataset

We will begin by visualizing the dataset containing historical records on the change in the water level,  $x$ , and the amount of water flowing out of the dam,  $y$ . This dataset is divided into three parts:

- A **training** set that your model will learn on:  $x$ ,  $y$
- A **cross validation** set for determining the regularization parameter:  $x_{val}$ ,  $y_{val}$
- A **test** set for evaluating performance. These are 'unseen' examples which your model did not see during training:  $x_{test}$ ,  $y_{test}$

The code below will plot the training data (Figure 1). In the following parts, you will implement linear regression and use that to fit a straight line to the data and plot learning curves. Following that, you will implement polynomial regression to find a better fit to the data.

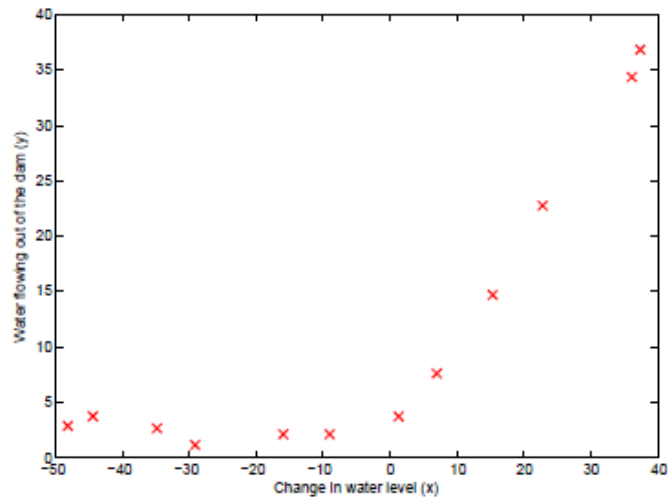
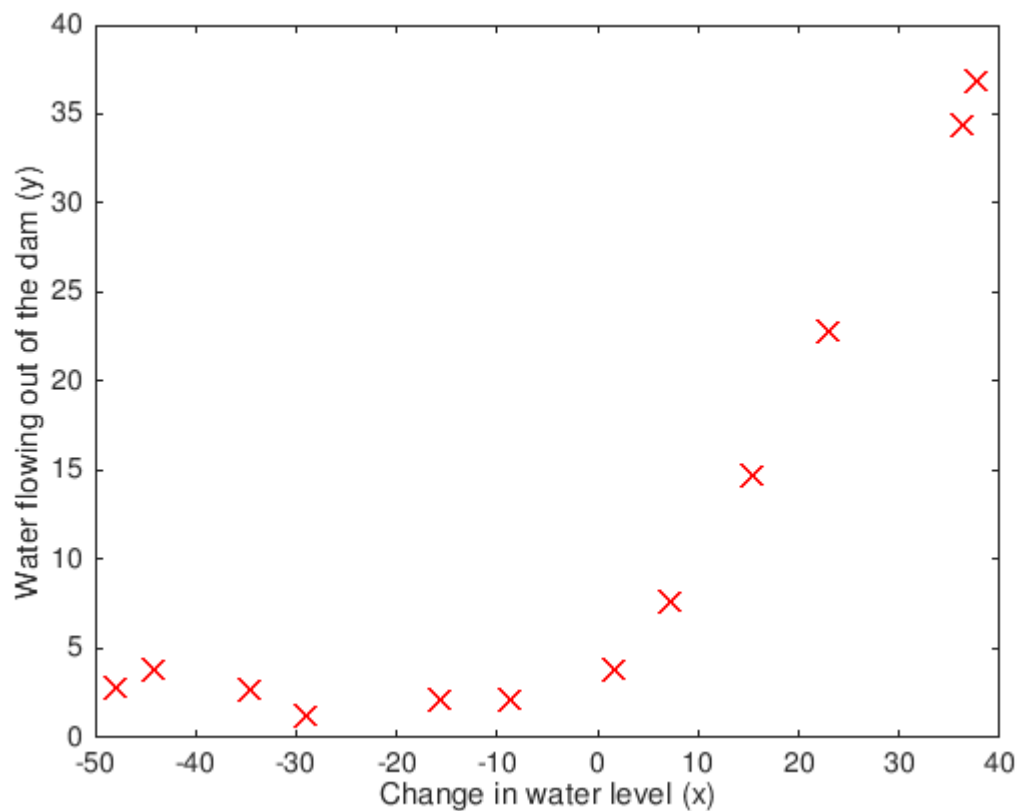


Figure 1: Data

```
% Load from ex5data1:  
% You will have X, y, Xval, yval, Xtest, ytest in your environment  
load ('ex5data1.mat');  
% m = Number of examples  
m = size(X, 1);  
  
% Plot training data  
figure;  
plot(X, y, 'rx', 'MarkerSize', 10, 'LineWidth', 1.5);  
xlabel('Change in water level (x)');  
ylabel('Water flowing out of the dam (y)');
```



## 1.2 Regularized linear regression cost function

Recall that regularized linear regression has the following cost function:

$$J(\theta) = \frac{1}{2m} \left( \sum_{i=1}^m (h_{\theta}(x^{(i)}) - y^{(i)})^2 \right) + \frac{\lambda}{2m} \left( \sum_{j=1}^n \theta_j^2 \right)$$

where  $\lambda$  is a regularization parameter which controls the degree of regularization (thus, helps preventing overfitting). The regularization term puts a penalty on the overall cost  $J$ . As the magnitudes of the model parameters  $\theta_j$  increase, the penalty increases as well. Note that you should not regularize the  $\theta_0$  term. (In MATLAB, the  $\theta_0$  term is represented as `theta(1)` since indexing in MATLAB starts from 1).

You should now complete the code in the file `linearRegCostFunction.m`. Your task is to write a function to calculate the regularized linear regression cost function. If possible, try to vectorize your code and avoid writing loops. When you are finished, the code below will run your cost function using `theta` initialized at `[1; 1]`. You should expect to see an output of 303.993.

```
theta = [1 ; 1];
J = linearRegCostFunction([ones(m, 1) X], y, theta, 1);
fprintf('Cost at theta = [1 ; 1]: %f', J);
```

```
Cost at theta = [1 ; 1]: 303.993192
```

You should now submit your solutions. Enter **submit** at the command prompt, then enter or confirm your login and token when prompted.

### 1.3 Regularized linear regression gradient

Correspondingly, the partial derivative of regularized linear regression's cost for  $\theta_j$  is defined as

$$\frac{\partial J(\theta)}{\partial \theta_0} = \frac{1}{m} \sum_{i=1}^m (h_{\theta}(x^{(i)}) - y^{(i)}) x_j^{(i)} \text{ for } j = 0$$
$$\frac{\partial J(\theta)}{\partial \theta_j} = \left( \frac{1}{m} \sum_{i=1}^m (h_{\theta}(x^{(i)}) - y^{(i)}) x_j^{(i)} \right) + \frac{\lambda}{m} \theta_j \text{ for } j = 1$$

In `linearRegCostFunction.m`, add code to calculate the gradient, returning it in the variable `grad`. When you are finished, the code below will run your gradient function using `theta` initialized at `[1; 1]`. You should expect to see a gradient of `[-15.30; 598.250]`.

```
[J, grad] = linearRegCostFunction([ones(m, 1) X], y, theta, 1);  
fprintf('Gradient at theta = [1 ; 1]: [%f; %f] \n', grad(1), grad(2));
```

```
Gradient at theta = [1 ; 1]: [-15.303016; 598.250744]
```

You should now submit your solutions. Enter **submit** at the command prompt, then enter or confirm your login and token when prompted.

### 1.4 Fitting linear regression

Once your cost function and gradient are working correctly, the code in this section will run the code in `trainLinearReg.m` to compute the optimal values of  $\theta$ . This training function uses `fmincg` to optimize the cost function. In this part, we set regularization parameter  $\lambda$  to zero. Because our current implementation of linear regression is trying to fit a 2-dimensional  $\theta$ , regularization will not be incredibly helpful for a  $\theta$  of such low dimension. In the later parts of the exercise, you will be using polynomial regression with regularization.

```
% Train linear regression with lambda = 0  
lambda = 0;  
[theta] = trainLinearReg([ones(m, 1) X], y, lambda);
```

```
Iteration    1 | Cost: 1.052435e+02  
Iteration    2 | Cost: 2.237391e+01  
Iteration    3 | Cost: 2.237391e+01  
Iteration    4 | Cost: 2.237391e+01  
Iteration    5 | Cost: 2.237391e+01  
Iteration    6 | Cost: 2.237391e+01  
Iteration    7 | Cost: 2.237391e+01  
Iteration    8 | Cost: 2.237391e+01  
Iteration    9 | Cost: 2.237391e+01  
Iteration   10 | Cost: 2.237391e+01  
Iteration   11 | Cost: 2.237391e+01  
Iteration   12 | Cost: 2.237391e+01  
Iteration   13 | Cost: 2.237391e+01  
Iteration   15 | Cost: 2.237391e+01  
Iteration   17 | Cost: 2.237391e+01  
Iteration   19 | Cost: 2.237391e+01
```

Iteration	21	Cost: 2.237391e+01
Iteration	23	Cost: 2.237391e+01
Iteration	25	Cost: 2.237391e+01
Iteration	27	Cost: 2.237391e+01
Iteration	29	Cost: 2.237391e+01
Iteration	31	Cost: 2.237391e+01
Iteration	33	Cost: 2.237391e+01
Iteration	35	Cost: 2.237391e+01
Iteration	37	Cost: 2.237391e+01
Iteration	39	Cost: 2.237391e+01
Iteration	41	Cost: 2.237391e+01
Iteration	43	Cost: 2.237391e+01
Iteration	45	Cost: 2.237391e+01
Iteration	47	Cost: 2.237391e+01
Iteration	49	Cost: 2.237391e+01
Iteration	51	Cost: 2.237391e+01
Iteration	53	Cost: 2.237391e+01
Iteration	55	Cost: 2.237391e+01
Iteration	57	Cost: 2.237391e+01
Iteration	59	Cost: 2.237391e+01
Iteration	61	Cost: 2.237391e+01
Iteration	63	Cost: 2.237391e+01
Iteration	65	Cost: 2.237391e+01
Iteration	67	Cost: 2.237391e+01
Iteration	69	Cost: 2.237391e+01
Iteration	71	Cost: 2.237391e+01
Iteration	73	Cost: 2.237391e+01
Iteration	75	Cost: 2.237391e+01
Iteration	77	Cost: 2.237391e+01
Iteration	79	Cost: 2.237391e+01
Iteration	81	Cost: 2.237391e+01
Iteration	83	Cost: 2.237391e+01
Iteration	85	Cost: 2.237391e+01
Iteration	87	Cost: 2.237391e+01
Iteration	89	Cost: 2.237391e+01
Iteration	91	Cost: 2.237391e+01
Iteration	93	Cost: 2.237391e+01
Iteration	95	Cost: 2.237391e+01
Iteration	97	Cost: 2.237391e+01
Iteration	99	Cost: 2.237391e+01
Iteration	101	Cost: 2.237391e+01
Iteration	103	Cost: 2.237391e+01
Iteration	105	Cost: 2.237391e+01
Iteration	107	Cost: 2.237391e+01
Iteration	109	Cost: 2.237391e+01
Iteration	111	Cost: 2.237391e+01
Iteration	113	Cost: 2.237391e+01
Iteration	115	Cost: 2.237391e+01
Iteration	117	Cost: 2.237391e+01
Iteration	119	Cost: 2.237391e+01
Iteration	121	Cost: 2.237391e+01
Iteration	123	Cost: 2.237391e+01
Iteration	125	Cost: 2.237391e+01
Iteration	127	Cost: 2.237391e+01
Iteration	129	Cost: 2.237391e+01
Iteration	131	Cost: 2.237391e+01
Iteration	133	Cost: 2.237391e+01
Iteration	135	Cost: 2.237391e+01
Iteration	137	Cost: 2.237391e+01
Iteration	139	Cost: 2.237391e+01
Iteration	141	Cost: 2.237391e+01
Iteration	143	Cost: 2.237391e+01
Iteration	145	Cost: 2.237391e+01
Iteration	147	Cost: 2.237391e+01
Iteration	149	Cost: 2.237391e+01

Iteration	151	Cost: 2.237391e+01
Iteration	153	Cost: 2.237391e+01
Iteration	155	Cost: 2.237391e+01
Iteration	157	Cost: 2.237391e+01
Iteration	159	Cost: 2.237391e+01
Iteration	161	Cost: 2.237391e+01
Iteration	163	Cost: 2.237391e+01
Iteration	165	Cost: 2.237391e+01
Iteration	167	Cost: 2.237391e+01
Iteration	169	Cost: 2.237391e+01
Iteration	171	Cost: 2.237391e+01
Iteration	173	Cost: 2.237391e+01
Iteration	175	Cost: 2.237391e+01
Iteration	177	Cost: 2.237391e+01
Iteration	179	Cost: 2.237391e+01
Iteration	181	Cost: 2.237391e+01
Iteration	183	Cost: 2.237391e+01
Iteration	185	Cost: 2.237391e+01
Iteration	187	Cost: 2.237391e+01
Iteration	189	Cost: 2.237391e+01
Iteration	191	Cost: 2.237391e+01
Iteration	193	Cost: 2.237391e+01
Iteration	195	Cost: 2.237391e+01
Iteration	197	Cost: 2.237391e+01
Iteration	199	Cost: 2.237391e+01

Finally, the code below should also plot the best fit line, resulting in an image similar to Figure 2. The best fit line tells us that the model is not a good fit to the data because the data has a nonlinear pattern.

```
% Plot fit over the data
figure;
plot(X, y, 'rx', 'MarkerSize', 10, 'LineWidth', 1.5);
xlabel('Change in water level (x)');
ylabel('Water flowing out of the dam (y)');
hold on;
plot(X, [ones(m, 1) X]*theta, '--', 'LineWidth', 2)
hold off;
```

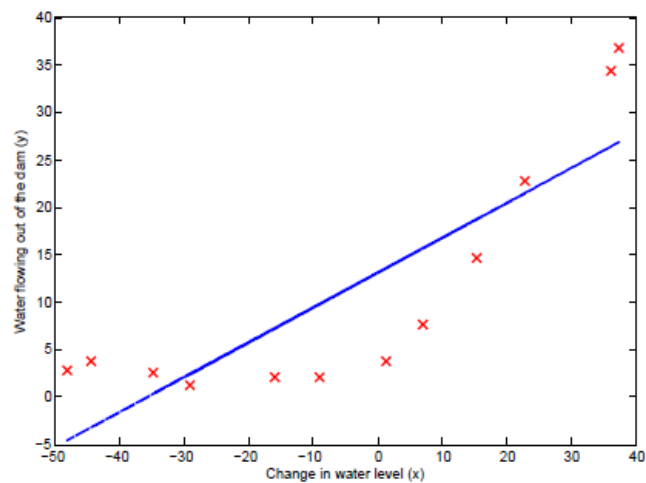
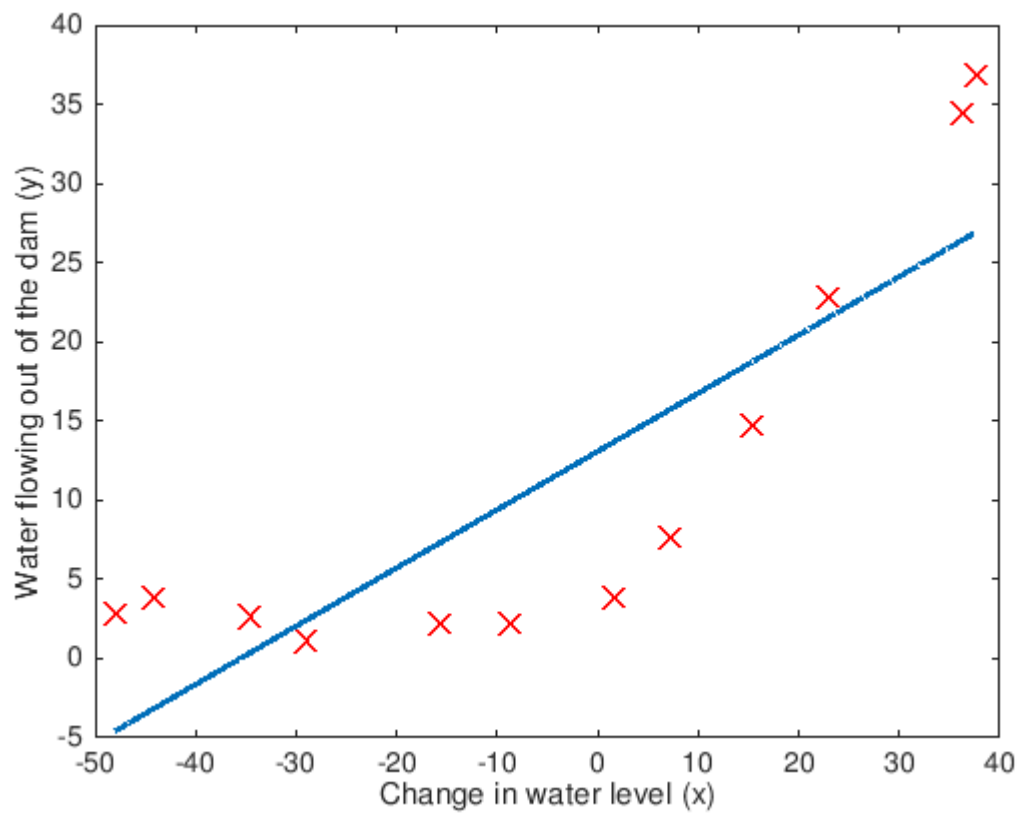


Figure 2: Linear Fit

While visualizing the best fit as shown is one possible way to debug your learning algorithm, it is not always easy to visualize the data and model. In the next section, you will implement a function to generate learning curves that can help you debug your learning algorithm even if it is not easy to visualize the data.

## 2. Bias-variance



An important concept in machine learning is the bias-variance tradeoff. Models with high bias are not complex enough for the data and tend to underfit, while models with high variance overfit the training data. In this part of the exercise, you will plot training and test errors on a learning curve to diagnose bias-variance problems.

## 2.1 Learning curves

You will now implement code to generate the learning curves that will be useful in debugging learning algorithms. Recall that a learning curve plots training and cross validation error as a function of training set size. Your job is to fill in `learningCurve.m` so that it returns a vector of errors for the training set and cross validation set.

To plot the learning curve, we need a training and cross validation set error for different training set sizes. To obtain different training set sizes, you should use different subsets of the original training set  $X$ . Specically, for a training set size of  $i$ , you should use the first  $i$  examples (i.e.,  $X(1:i, :)$  and  $Y(1:i)$ ). You can use the `trainLinearReg` function to find the  $\theta$  parameters. Note that `lambda` is passed as a parameter to the `learningCurve` function. After learning the  $\theta$  parameters, you should compute the error on the training and cross validation sets. Recall that the training error for a dataset is defined as

$$J_{\text{train}}(\theta) = \frac{1}{2m} \left[ \sum_{i=1}^m (h_{\theta}(x^{(i)}) - y^{(i)})^2 \right]$$

In particular, note that the training error does not include the regularization term. One way to compute the training error is to use your existing cost function and set  $\lambda$  to 0 only when using it to compute the training error and cross validation error. When you are computing the training set error, make sure you compute it on the training subset (i.e.,  $X(1:n, :)$  and  $Y(1:n)$ , instead of the entire training set). However, for the cross validation error, you should compute it over the entire cross validation set. You should store the computed errors in the vectors `error_train` and `error_val`.

In Figure 3, you can observe that both the train error and cross validation error are high when the number of training examples is increased. This reflects a high bias problem in the model - the linear regression model is too simple and is unable to fit our dataset well. In the next section, you will implement polynomial regression to fit a better model for this dataset.

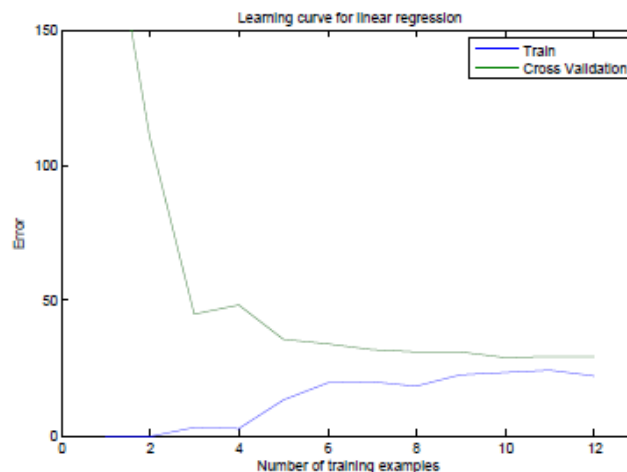


Figure 3: Linear regression learning curve

When you are finished, run the code below to compute the learning curves and produce a plot similar to Figure 3.

```
lambda = 0;
[error_train, error_val] = learningCurve([ones(m, 1) X], y, [ones(size(Xval, 1), 1) Xval], lambda, 10000, 1000000);
```

Iteration	1	Cost: 2.663868e-01
Iteration	2	Cost: 3.944305e-31
Iteration	3	Cost: 0.000000e+00
Iteration	1	Cost: 4.282328e-01
Iteration	2	Cost: 8.295365e-30
Iteration	3	Cost: 4.930381e-32
Iteration	1	Cost: 1.021540e+02
Iteration	2	Cost: 3.286595e+00
Iteration	1	Cost: 1.438726e+02
Iteration	2	Cost: 1.035224e+02
Iteration	3	Cost: 7.536716e+01
Iteration	4	Cost: 1.615422e+01
Iteration	5	Cost: 3.619255e+00
Iteration	6	Cost: 2.843661e+00
Iteration	7	Cost: 2.843655e+00
Iteration	8	Cost: 2.843037e+00
Iteration	9	Cost: 2.842919e+00
Iteration	10	Cost: 2.842916e+00
Iteration	11	Cost: 2.842678e+00
Iteration	13	Cost: 2.842678e+00
Iteration	15	Cost: 2.842678e+00
Iteration	1	Cost: 1.592641e+02
Iteration	2	Cost: 2.404966e+01
Iteration	3	Cost: 2.354137e+01
Iteration	4	Cost: 2.281160e+01
Iteration	5	Cost: 2.276969e+01
Iteration	6	Cost: 2.224060e+01
Iteration	7	Cost: 1.920606e+01
Iteration	8	Cost: 1.475292e+01
Iteration	9	Cost: 1.430565e+01
Iteration	10	Cost: 1.388881e+01
Iteration	11	Cost: 1.327330e+01
Iteration	12	Cost: 1.323519e+01
Iteration	13	Cost: 1.319411e+01
Iteration	14	Cost: 1.317355e+01
Iteration	15	Cost: 1.315411e+01
Iteration	16	Cost: 1.315405e+01
Iteration	17	Cost: 1.315405e+01
Iteration	18	Cost: 1.315405e+01
Iteration	19	Cost: 1.315405e+01
Iteration	20	Cost: 1.315405e+01
Iteration	21	Cost: 1.315405e+01
Iteration	22	Cost: 1.315405e+01
Iteration	1	Cost: 1.531141e+02
Iteration	2	Cost: 1.350947e+02
Iteration	3	Cost: 1.137334e+02
Iteration	4	Cost: 4.404199e+01
Iteration	5	Cost: 2.957435e+01
Iteration	6	Cost: 2.719561e+01
Iteration	7	Cost: 1.949283e+01
Iteration	8	Cost: 1.949128e+01
Iteration	9	Cost: 1.945708e+01
Iteration	10	Cost: 1.944472e+01
Iteration	11	Cost: 1.944472e+01
Iteration	12	Cost: 1.944471e+01
Iteration	13	Cost: 1.944453e+01
Iteration	14	Cost: 1.944425e+01

Iteration	15	Cost: 1.944411e+01
Iteration	16	Cost: 1.944396e+01
Iteration	17	Cost: 1.944396e+01
Iteration	18	Cost: 1.944396e+01
Iteration	19	Cost: 1.944396e+01
Iteration	20	Cost: 1.944396e+01
Iteration	21	Cost: 1.944396e+01
Iteration	22	Cost: 1.944396e+01
Iteration	23	Cost: 1.944396e+01
Iteration	24	Cost: 1.944396e+01
Iteration	25	Cost: 1.944396e+01
Iteration	26	Cost: 1.944396e+01
Iteration	27	Cost: 1.944396e+01
Iteration	28	Cost: 1.944396e+01
Iteration	29	Cost: 1.944396e+01
Iteration	30	Cost: 1.944396e+01
Iteration	31	Cost: 1.944396e+01
Iteration	32	Cost: 1.944396e+01
Iteration	33	Cost: 1.944396e+01
Iteration	34	Cost: 1.944396e+01
Iteration	35	Cost: 1.944396e+01
Iteration	36	Cost: 1.944396e+01
Iteration	37	Cost: 1.944396e+01
Iteration	1	Cost: 1.383936e+02
Iteration	2	Cost: 1.210275e+02
Iteration	3	Cost: 1.013004e+02
Iteration	4	Cost: 3.457729e+01
Iteration	5	Cost: 2.808710e+01
Iteration	6	Cost: 2.732288e+01
Iteration	7	Cost: 2.011513e+01
Iteration	8	Cost: 2.011508e+01
Iteration	9	Cost: 2.010693e+01
Iteration	10	Cost: 2.010640e+01
Iteration	11	Cost: 2.010629e+01
Iteration	12	Cost: 2.010382e+01
Iteration	13	Cost: 2.009852e+01
Iteration	1	Cost: 1.237772e+02
Iteration	2	Cost: 1.202532e+02
Iteration	3	Cost: 1.195134e+02
Iteration	4	Cost: 9.334231e+01
Iteration	5	Cost: 4.813526e+01
Iteration	6	Cost: 2.573641e+01
Iteration	7	Cost: 1.854364e+01
Iteration	8	Cost: 1.819798e+01
Iteration	9	Cost: 1.819165e+01
Iteration	10	Cost: 1.818808e+01
Iteration	11	Cost: 1.817419e+01
Iteration	12	Cost: 1.817414e+01
Iteration	13	Cost: 1.817380e+01
Iteration	14	Cost: 1.817286e+01
Iteration	15	Cost: 1.817286e+01
Iteration	17	Cost: 1.817286e+01
Iteration	1	Cost: 1.089984e+02
Iteration	2	Cost: 1.064701e+02
Iteration	3	Cost: 1.054742e+02
Iteration	4	Cost: 2.266786e+01
Iteration	5	Cost: 2.266786e+01
Iteration	6	Cost: 2.266758e+01
Iteration	7	Cost: 2.260941e+01
Iteration	8	Cost: 2.260941e+01
Iteration	1	Cost: 1.108611e+02
Iteration	2	Cost: 2.497543e+01
Iteration	3	Cost: 2.496421e+01
Iteration	4	Cost: 2.494838e+01
Iteration	5	Cost: 2.493176e+01

Iteration	6	Cost: 2.490651e+01
Iteration	7	Cost: 2.474387e+01
Iteration	8	Cost: 2.326170e+01
Iteration	9	Cost: 2.326170e+01
Iteration	10	Cost: 2.326166e+01
Iteration	11	Cost: 2.326146e+01
Iteration	12	Cost: 2.326146e+01
Iteration	13	Cost: 2.326146e+01
Iteration	14	Cost: 2.326146e+01
Iteration	15	Cost: 2.326146e+01
Iteration	16	Cost: 2.326146e+01
Iteration	17	Cost: 2.326146e+01
Iteration	18	Cost: 2.326146e+01
Iteration	19	Cost: 2.326146e+01
Iteration	20	Cost: 2.326146e+01
Iteration	1	Cost: 1.023394e+02
Iteration	2	Cost: 2.443039e+01
Iteration	3	Cost: 2.443033e+01
Iteration	4	Cost: 2.442972e+01
Iteration	5	Cost: 2.441042e+01
Iteration	6	Cost: 2.435852e+01
Iteration	7	Cost: 2.431735e+01
Iteration	8	Cost: 2.431733e+01
Iteration	9	Cost: 2.431727e+01
Iteration	10	Cost: 2.431725e+01
Iteration	12	Cost: 2.431725e+01
Iteration	13	Cost: 2.431725e+01
Iteration	14	Cost: 2.431725e+01
Iteration	16	Cost: 2.431725e+01
Iteration	18	Cost: 2.431725e+01
Iteration	20	Cost: 2.431725e+01
Iteration	21	Cost: 2.431725e+01
Iteration	23	Cost: 2.431725e+01
Iteration	25	Cost: 2.431725e+01
Iteration	1	Cost: 1.052435e+02
Iteration	2	Cost: 2.237391e+01
Iteration	3	Cost: 2.237391e+01
Iteration	4	Cost: 2.237391e+01
Iteration	5	Cost: 2.237391e+01
Iteration	6	Cost: 2.237391e+01
Iteration	7	Cost: 2.237391e+01
Iteration	8	Cost: 2.237391e+01
Iteration	9	Cost: 2.237391e+01
Iteration	10	Cost: 2.237391e+01
Iteration	11	Cost: 2.237391e+01
Iteration	12	Cost: 2.237391e+01
Iteration	13	Cost: 2.237391e+01
Iteration	15	Cost: 2.237391e+01
Iteration	17	Cost: 2.237391e+01
Iteration	19	Cost: 2.237391e+01
Iteration	21	Cost: 2.237391e+01
Iteration	23	Cost: 2.237391e+01
Iteration	25	Cost: 2.237391e+01
Iteration	27	Cost: 2.237391e+01
Iteration	29	Cost: 2.237391e+01
Iteration	31	Cost: 2.237391e+01
Iteration	33	Cost: 2.237391e+01
Iteration	35	Cost: 2.237391e+01
Iteration	37	Cost: 2.237391e+01
Iteration	39	Cost: 2.237391e+01
Iteration	41	Cost: 2.237391e+01
Iteration	43	Cost: 2.237391e+01
Iteration	45	Cost: 2.237391e+01
Iteration	47	Cost: 2.237391e+01
Iteration	49	Cost: 2.237391e+01

Iteration	51	Cost: 2.237391e+01
Iteration	53	Cost: 2.237391e+01
Iteration	55	Cost: 2.237391e+01
Iteration	57	Cost: 2.237391e+01
Iteration	59	Cost: 2.237391e+01
Iteration	61	Cost: 2.237391e+01
Iteration	63	Cost: 2.237391e+01
Iteration	65	Cost: 2.237391e+01
Iteration	67	Cost: 2.237391e+01
Iteration	69	Cost: 2.237391e+01
Iteration	71	Cost: 2.237391e+01
Iteration	73	Cost: 2.237391e+01
Iteration	75	Cost: 2.237391e+01
Iteration	77	Cost: 2.237391e+01
Iteration	79	Cost: 2.237391e+01
Iteration	81	Cost: 2.237391e+01
Iteration	83	Cost: 2.237391e+01
Iteration	85	Cost: 2.237391e+01
Iteration	87	Cost: 2.237391e+01
Iteration	89	Cost: 2.237391e+01
Iteration	91	Cost: 2.237391e+01
Iteration	93	Cost: 2.237391e+01
Iteration	95	Cost: 2.237391e+01
Iteration	97	Cost: 2.237391e+01
Iteration	99	Cost: 2.237391e+01
Iteration	101	Cost: 2.237391e+01
Iteration	103	Cost: 2.237391e+01
Iteration	105	Cost: 2.237391e+01
Iteration	107	Cost: 2.237391e+01
Iteration	109	Cost: 2.237391e+01
Iteration	111	Cost: 2.237391e+01
Iteration	113	Cost: 2.237391e+01
Iteration	115	Cost: 2.237391e+01
Iteration	117	Cost: 2.237391e+01
Iteration	119	Cost: 2.237391e+01
Iteration	121	Cost: 2.237391e+01
Iteration	123	Cost: 2.237391e+01
Iteration	125	Cost: 2.237391e+01
Iteration	127	Cost: 2.237391e+01
Iteration	129	Cost: 2.237391e+01
Iteration	131	Cost: 2.237391e+01
Iteration	133	Cost: 2.237391e+01
Iteration	135	Cost: 2.237391e+01
Iteration	137	Cost: 2.237391e+01
Iteration	139	Cost: 2.237391e+01
Iteration	141	Cost: 2.237391e+01
Iteration	143	Cost: 2.237391e+01
Iteration	145	Cost: 2.237391e+01
Iteration	147	Cost: 2.237391e+01
Iteration	149	Cost: 2.237391e+01
Iteration	151	Cost: 2.237391e+01
Iteration	153	Cost: 2.237391e+01
Iteration	155	Cost: 2.237391e+01
Iteration	157	Cost: 2.237391e+01
Iteration	159	Cost: 2.237391e+01
Iteration	161	Cost: 2.237391e+01
Iteration	163	Cost: 2.237391e+01
Iteration	165	Cost: 2.237391e+01
Iteration	167	Cost: 2.237391e+01
Iteration	169	Cost: 2.237391e+01
Iteration	171	Cost: 2.237391e+01
Iteration	173	Cost: 2.237391e+01
Iteration	175	Cost: 2.237391e+01
Iteration	177	Cost: 2.237391e+01
Iteration	179	Cost: 2.237391e+01

```

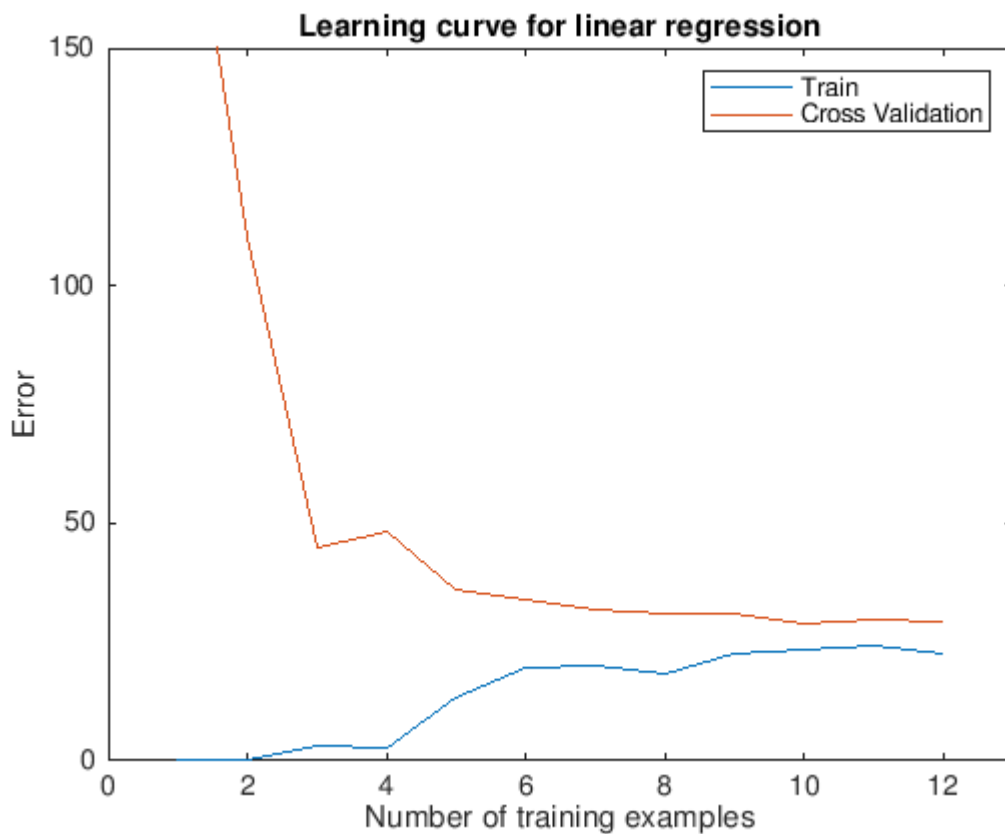
Iteration 181 | Cost: 2.237391e+01
Iteration 183 | Cost: 2.237391e+01
Iteration 185 | Cost: 2.237391e+01
Iteration 187 | Cost: 2.237391e+01
Iteration 189 | Cost: 2.237391e+01
Iteration 191 | Cost: 2.237391e+01
Iteration 193 | Cost: 2.237391e+01
Iteration 195 | Cost: 2.237391e+01
Iteration 197 | Cost: 2.237391e+01
Iteration 199 | Cost: 2.237391e+01

```

```

plot(1:m, error_train, 1:m, error_val);
title('Learning curve for linear regression')
legend('Train', 'Cross Validation')
xlabel('Number of training examples')
ylabel('Error')
axis([0 13 0 150])

```



```
fprintf('# Training Examples\tTrain Error\tCross Validation Error\n');
```

```
# Training Examples Train Error Cross Validation Error
```

```

for i = 1:m
    fprintf(' \t%d\t\t\t%f\t%f\n', i, error_train(i), error_val(i));
end

```

```

1  0.000000 205.121096
2  0.000000 110.300366

```

```

3  3.286595 45.010231
4  2.842678 48.368911
5  13.154049 35.865165
6  19.443963 33.829962
7  20.098522 31.970986
8  18.172859 30.862446
9  22.609405 31.135998
10 23.261462 28.936207
11 24.317250 29.551432
12 22.373906 29.433818

```

### 3. Polynomial regression

The problem with our linear model was that it was too simple for the data and resulted in underfitting (high bias). In this part of the exercise, you will address this problem by adding more features. For use polynomial regression, our hypothesis has the form:

$$\begin{aligned}
 h_{\theta}(x) &= \theta_0 + \theta_1 * (\text{waterLevel}) + \theta_2 * (\text{waterLevel})^2 + \dots + \theta_p * (\text{waterLevel})^p \\
 &= \theta_0 + \theta_1 x_1 + \theta_2 x_2 + \dots + \theta_p x_p
 \end{aligned}$$

Notice that by defining  $x_1 = (\text{waterLevel})$ ,  $x_2 = (\text{waterLevel})^2$ ,  $\dots$ ,  $x_p = (\text{waterLevel})^p$ , we obtain a linear regression model where the features are the various powers of the original value (*waterLevel*).

Now, you will add more features using the higher powers of the existing feature  $x$  in the dataset. Your task in this part is to complete the code in `polyFeatures.m` so that the function maps the original training set  $x$  of size  $m \times 1$  into its higher powers. Specifically, when a training set  $X$  of size  $m \times 1$  is passed into the function, the function should return a  $m \times p$  matrix `X_poly`, where column 1 holds the original values of  $x$ , column 2 holds the values of  $x.^2$ , column 3 holds the values of  $x.^3$ , and so on. Note that you don't have to account for the zero-th power in this function. Now that you have a function that will map features to a higher dimension, the code in the next section will apply it to the training set, the test set, and the cross validation set (which you haven't used yet).

*You should now submit your solutions. Enter **submit** at the command prompt, then enter or confirm your login and token when prompted.*

#### 3.1 Learning Polynomial Regression

After you have completed `polyFeatures.m`, run the code below to train polynomial regression using your linear regression cost function. Keep in mind that even though we have polynomial terms in our feature vector, we are still solving a linear regression optimization problem. The polynomial terms have simply turned into features that we can use for linear regression. We are using the same cost function and gradient that you wrote for the earlier part of this exercise.

For this part of the exercise, you will be using a polynomial of degree 8. It turns out that if we run the training directly on the projected data, it will not work well as the features would be badly scaled (e.g., an example with  $x = 40$  will now have a feature  $x_8 = 40^8 = 6.5 \times 10^{12}$ ). Therefore, you will need to use feature normalization. Before learning the parameters  $\theta$  for the polynomial regression, code in below will first call `featureNormalize` to normalize the features of the training set, storing the `mu`, `sigma` parameters

separately. We have already implemented this function for you and it is the same function from the first exercise.

```
p = 8;

% Map X onto Polynomial Features and Normalize
X_poly = polyFeatures(X, p);
[X_poly, mu, sigma] = featureNormalize(X_poly); % Normalize
X_poly = [ones(m, 1), X_poly]; % Add Ones

% Map X_poly_test and normalize (using mu and sigma)
X_poly_test = polyFeatures(Xtest, p);
X_poly_test = X_poly_test - mu; % uses implicit expansion instead of bsxfun
X_poly_test = X_poly_test ./ sigma; % uses implicit expansion instead of bsxfun
X_poly_test = [ones(size(X_poly_test, 1), 1), X_poly_test]; % Add Ones

% Map X_poly_val and normalize (using mu and sigma)
X_poly_val = polyFeatures(Xval, p);
X_poly_val = X_poly_val - mu; % uses implicit expansion instead of bsxfun
X_poly_val = X_poly_val ./ sigma; % uses implicit expansion instead of bsxfun
X_poly_val = [ones(size(X_poly_val, 1), 1), X_poly_val]; % Add Ones

fprintf('Normalized Training Example 1:\n');
```

Normalized Training Example 1:

```
fprintf(' %f \n', X_poly(1, :));
```

```
1.000000
-0.362141
-0.755087
0.182226
-0.706190
0.306618
-0.590878
0.344516
-0.508481
```

```
lambda = 0;
[theta] = trainLinearReg(X_poly, y, lambda);
```

Iteration	1	Cost: 8.273077e+01
Iteration	2	Cost: 2.687496e+01
Iteration	3	Cost: 1.327780e+01
Iteration	4	Cost: 3.455324e+00
Iteration	5	Cost: 2.870493e+00
Iteration	6	Cost: 2.404364e+00
Iteration	7	Cost: 2.372779e+00
Iteration	8	Cost: 1.771555e+00
Iteration	9	Cost: 1.210317e+00
Iteration	10	Cost: 9.411622e-01
Iteration	11	Cost: 7.981808e-01
Iteration	12	Cost: 7.556890e-01
Iteration	13	Cost: 6.697776e-01
Iteration	14	Cost: 4.869518e-01
Iteration	15	Cost: 4.470589e-01
Iteration	16	Cost: 4.428080e-01
Iteration	17	Cost: 4.336816e-01



Iteration	18	Cost: 4.279806e-01
Iteration	19	Cost: 4.226922e-01
Iteration	20	Cost: 3.993263e-01
Iteration	21	Cost: 3.870294e-01
Iteration	22	Cost: 3.767528e-01
Iteration	23	Cost: 3.574273e-01
Iteration	24	Cost: 3.364148e-01
Iteration	25	Cost: 3.358976e-01
Iteration	26	Cost: 3.339839e-01
Iteration	27	Cost: 3.330929e-01
Iteration	28	Cost: 3.329722e-01
Iteration	29	Cost: 3.311447e-01
Iteration	30	Cost: 3.294476e-01
Iteration	31	Cost: 3.286225e-01
Iteration	32	Cost: 3.032946e-01
Iteration	33	Cost: 2.808510e-01
Iteration	34	Cost: 2.677573e-01
Iteration	35	Cost: 2.654536e-01
Iteration	36	Cost: 2.643261e-01
Iteration	37	Cost: 2.550952e-01
Iteration	38	Cost: 2.545373e-01
Iteration	39	Cost: 2.520712e-01
Iteration	40	Cost: 2.519101e-01
Iteration	41	Cost: 2.514485e-01
Iteration	42	Cost: 2.512185e-01
Iteration	43	Cost: 2.505467e-01
Iteration	44	Cost: 2.503816e-01
Iteration	45	Cost: 2.501629e-01
Iteration	46	Cost: 2.483445e-01
Iteration	47	Cost: 2.462036e-01
Iteration	48	Cost: 2.419397e-01
Iteration	49	Cost: 2.394933e-01
Iteration	50	Cost: 2.366426e-01
Iteration	51	Cost: 2.331064e-01
Iteration	52	Cost: 2.315196e-01
Iteration	53	Cost: 2.279762e-01
Iteration	54	Cost: 2.278730e-01
Iteration	55	Cost: 2.278083e-01
Iteration	56	Cost: 2.277903e-01
Iteration	57	Cost: 2.277236e-01
Iteration	58	Cost: 2.275362e-01
Iteration	59	Cost: 2.273722e-01
Iteration	60	Cost: 2.271478e-01
Iteration	61	Cost: 2.269241e-01
Iteration	62	Cost: 2.268479e-01
Iteration	63	Cost: 2.267368e-01
Iteration	64	Cost: 2.266895e-01
Iteration	65	Cost: 2.264923e-01
Iteration	66	Cost: 2.264473e-01
Iteration	67	Cost: 2.261752e-01
Iteration	68	Cost: 2.260357e-01
Iteration	69	Cost: 2.246966e-01
Iteration	70	Cost: 2.243852e-01
Iteration	71	Cost: 2.220315e-01
Iteration	72	Cost: 2.214060e-01
Iteration	73	Cost: 2.192219e-01
Iteration	74	Cost: 2.190576e-01
Iteration	75	Cost: 2.187953e-01
Iteration	76	Cost: 2.185552e-01
Iteration	77	Cost: 2.184418e-01
Iteration	78	Cost: 2.183557e-01
Iteration	79	Cost: 2.176737e-01
Iteration	80	Cost: 2.176022e-01
Iteration	81	Cost: 2.171220e-01
Iteration	82	Cost: 2.170515e-01

Iteration	83	Cost: 2.167836e-01
Iteration	84	Cost: 2.167641e-01
Iteration	85	Cost: 2.166020e-01
Iteration	86	Cost: 2.164653e-01
Iteration	87	Cost: 2.146624e-01
Iteration	88	Cost: 2.124832e-01
Iteration	89	Cost: 2.124027e-01
Iteration	90	Cost: 2.122823e-01
Iteration	91	Cost: 2.122201e-01
Iteration	92	Cost: 2.120567e-01
Iteration	93	Cost: 2.119668e-01
Iteration	94	Cost: 2.118488e-01
Iteration	95	Cost: 2.118274e-01
Iteration	96	Cost: 2.115975e-01
Iteration	97	Cost: 2.115167e-01
Iteration	98	Cost: 2.114027e-01
Iteration	99	Cost: 2.113492e-01
Iteration	100	Cost: 2.108737e-01
Iteration	101	Cost: 2.108189e-01
Iteration	102	Cost: 2.106924e-01
Iteration	103	Cost: 2.103854e-01
Iteration	104	Cost: 2.096211e-01
Iteration	105	Cost: 2.086086e-01
Iteration	106	Cost: 2.078328e-01
Iteration	107	Cost: 2.053193e-01
Iteration	108	Cost: 2.022514e-01
Iteration	109	Cost: 2.016763e-01
Iteration	110	Cost: 2.014518e-01
Iteration	111	Cost: 2.011953e-01
Iteration	112	Cost: 2.008846e-01
Iteration	113	Cost: 2.008231e-01
Iteration	114	Cost: 2.007336e-01
Iteration	115	Cost: 2.006698e-01
Iteration	116	Cost: 2.004391e-01
Iteration	117	Cost: 2.003649e-01
Iteration	118	Cost: 2.000645e-01
Iteration	119	Cost: 1.999290e-01
Iteration	120	Cost: 1.995902e-01
Iteration	121	Cost: 1.994100e-01
Iteration	122	Cost: 1.991483e-01
Iteration	123	Cost: 1.987118e-01
Iteration	124	Cost: 1.981287e-01
Iteration	125	Cost: 1.976985e-01
Iteration	126	Cost: 1.971647e-01
Iteration	127	Cost: 1.971356e-01
Iteration	128	Cost: 1.971279e-01
Iteration	129	Cost: 1.970732e-01
Iteration	130	Cost: 1.964910e-01
Iteration	131	Cost: 1.961885e-01
Iteration	132	Cost: 1.961217e-01
Iteration	133	Cost: 1.955607e-01
Iteration	134	Cost: 1.955375e-01
Iteration	135	Cost: 1.952931e-01
Iteration	136	Cost: 1.951576e-01
Iteration	137	Cost: 1.942583e-01
Iteration	138	Cost: 1.938395e-01
Iteration	139	Cost: 1.934828e-01
Iteration	140	Cost: 1.934470e-01
Iteration	141	Cost: 1.930246e-01
Iteration	142	Cost: 1.928470e-01
Iteration	143	Cost: 1.921011e-01
Iteration	144	Cost: 1.918886e-01
Iteration	145	Cost: 1.915949e-01
Iteration	146	Cost: 1.915563e-01
Iteration	147	Cost: 1.912242e-01

Iteration	148	Cost: 1.911722e-01
Iteration	149	Cost: 1.909908e-01
Iteration	150	Cost: 1.908000e-01
Iteration	151	Cost: 1.904710e-01
Iteration	152	Cost: 1.903946e-01
Iteration	153	Cost: 1.902309e-01
Iteration	154	Cost: 1.901956e-01
Iteration	155	Cost: 1.897420e-01
Iteration	156	Cost: 1.897320e-01
Iteration	157	Cost: 1.894898e-01
Iteration	158	Cost: 1.891643e-01
Iteration	159	Cost: 1.891019e-01
Iteration	160	Cost: 1.889144e-01
Iteration	161	Cost: 1.887883e-01
Iteration	162	Cost: 1.885876e-01
Iteration	163	Cost: 1.883254e-01
Iteration	164	Cost: 1.882543e-01
Iteration	165	Cost: 1.882217e-01
Iteration	166	Cost: 1.881893e-01
Iteration	167	Cost: 1.881428e-01
Iteration	168	Cost: 1.880951e-01
Iteration	169	Cost: 1.880156e-01
Iteration	170	Cost: 1.879722e-01
Iteration	171	Cost: 1.879188e-01
Iteration	172	Cost: 1.878303e-01
Iteration	173	Cost: 1.878081e-01
Iteration	174	Cost: 1.875755e-01
Iteration	175	Cost: 1.875432e-01
Iteration	176	Cost: 1.871931e-01
Iteration	177	Cost: 1.867808e-01
Iteration	178	Cost: 1.866430e-01
Iteration	179	Cost: 1.866073e-01
Iteration	180	Cost: 1.864848e-01
Iteration	181	Cost: 1.864609e-01
Iteration	182	Cost: 1.864261e-01
Iteration	183	Cost: 1.864189e-01
Iteration	184	Cost: 1.863364e-01
Iteration	185	Cost: 1.863030e-01
Iteration	186	Cost: 1.862206e-01
Iteration	187	Cost: 1.861571e-01
Iteration	188	Cost: 1.860338e-01
Iteration	189	Cost: 1.859290e-01
Iteration	190	Cost: 1.854147e-01
Iteration	191	Cost: 1.852929e-01
Iteration	192	Cost: 1.850222e-01
Iteration	193	Cost: 1.849550e-01
Iteration	194	Cost: 1.846662e-01
Iteration	195	Cost: 1.845437e-01
Iteration	196	Cost: 1.844558e-01
Iteration	197	Cost: 1.843992e-01
Iteration	198	Cost: 1.842558e-01
Iteration	199	Cost: 1.841118e-01
Iteration	200	Cost: 1.839924e-01

After learning the parameters  $\theta$ , the code below will generate two plots (Figures 4,5) for polynomial regression with  $\lambda = 0$ .

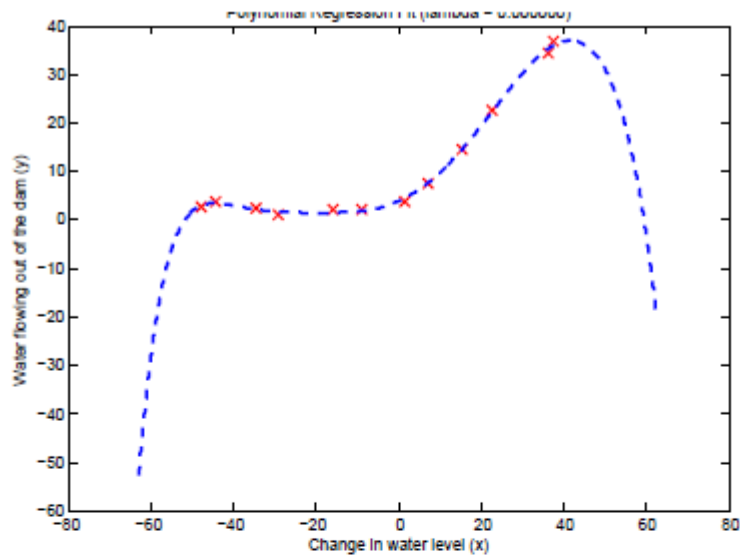


Figure 4: Polynomial fit,  $\lambda = 0$

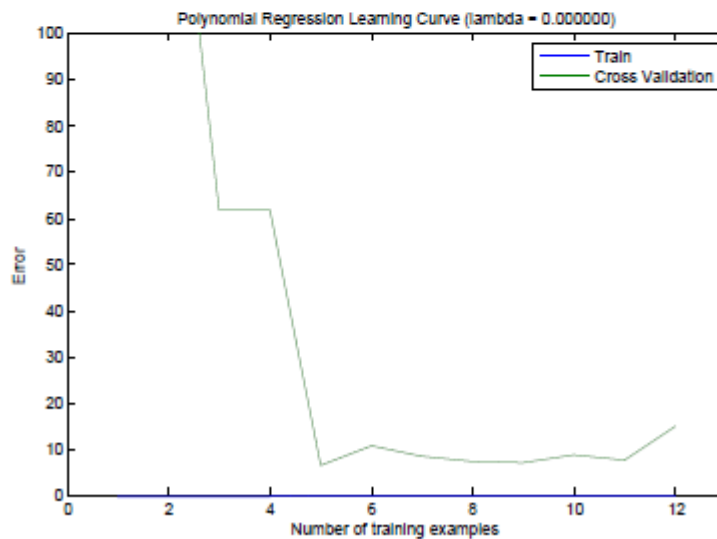
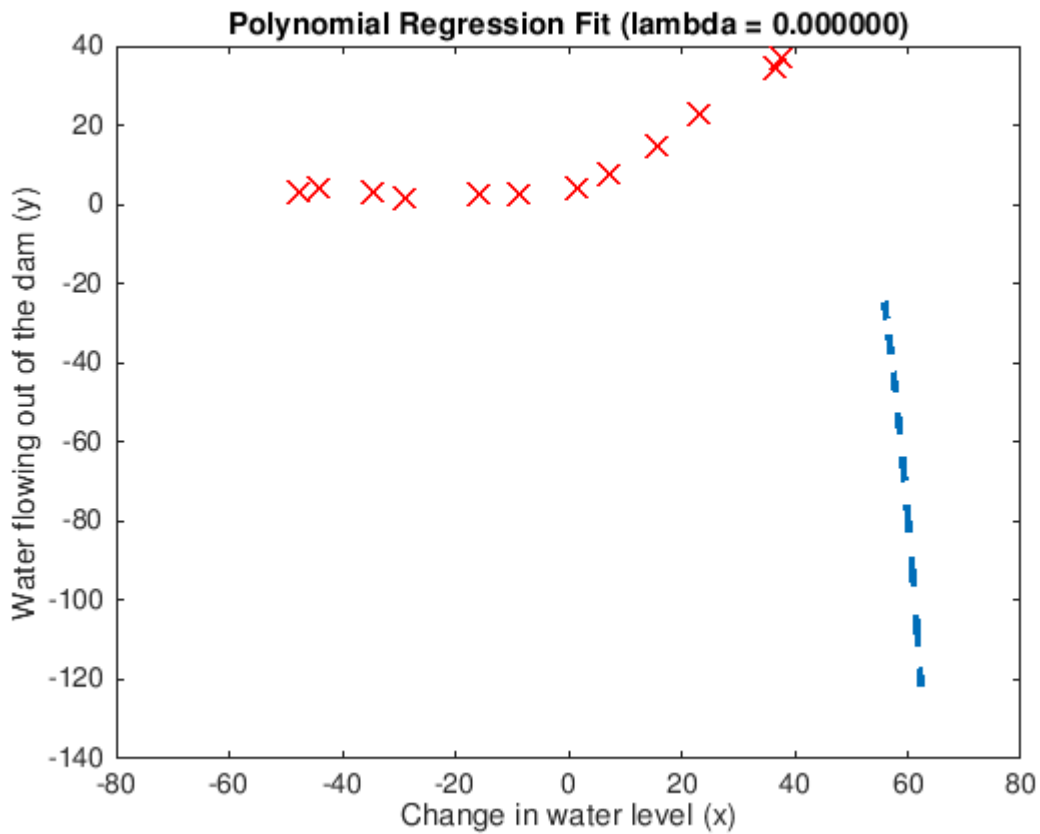


Figure 5: Polynomial learning curve,  $\lambda = 0$

From Figure 4, you should see that the polynomial fit is able to follow the datapoints very well - thus, obtaining a low training error. However, the polynomial fit is very complex and even drops off at the extremes. This is an indicator that the polynomial regression model is overfitting the training data and will not generalize well.

```
% Plot training data and fit
plot(X, y, 'rx', 'MarkerSize', 10, 'LineWidth', 1.5);
plotFit(min(X), max(X), mu, sigma, theta, p);
xlabel('Change in water level (x)');
ylabel('Water flowing out of the dam (y)');
title(sprintf('Polynomial Regression Fit (lambda = %f)', lambda));
```



```
[error_train, error_val] = learningCurve(X_poly, y, X_poly_val, yval, lambda);
```

Iteration	1	Cost: 3.386454e-01
Iteration	2	Cost: 9.860761e-32
Iteration	3	Cost: 0.000000e+00
Iteration	1	Cost: 5.373343e-02
Iteration	2	Cost: 2.656989e-04
Iteration	3	Cost: 1.480972e-05
Iteration	4	Cost: 5.990643e-09
Iteration	5	Cost: 5.988323e-09
Iteration	6	Cost: 3.486918e-09
Iteration	7	Cost: 1.434079e-09
Iteration	8	Cost: 3.000269e-10
Iteration	9	Cost: 2.770617e-10
Iteration	10	Cost: 2.238010e-11
Iteration	11	Cost: 7.142836e-12
Iteration	12	Cost: 2.852759e-12
Iteration	13	Cost: 1.304524e-13
Iteration	14	Cost: 3.801759e-26
Iteration	15	Cost: 6.162976e-32
Iteration	16	Cost: 4.930381e-32
Iteration	17	Cost: 1.232595e-32
Iteration	1	Cost: 3.023381e+01
Iteration	2	Cost: 9.745401e-01
Iteration	3	Cost: 4.827305e-01
Iteration	4	Cost: 1.170249e-02
Iteration	5	Cost: 9.696908e-04
Iteration	6	Cost: 5.299258e-04
Iteration	7	Cost: 1.985836e-04
Iteration	8	Cost: 6.032119e-05
Iteration	9	Cost: 6.225212e-07
Iteration	10	Cost: 3.894758e-07

Iteration	11	Cost: 7.703724e-08
Iteration	12	Cost: 5.688321e-08
Iteration	13	Cost: 5.385450e-09
Iteration	14	Cost: 1.603656e-10
Iteration	15	Cost: 1.516867e-11
Iteration	16	Cost: 9.627464e-12
Iteration	17	Cost: 2.794098e-12
Iteration	18	Cost: 7.766257e-13
Iteration	19	Cost: 1.571268e-13
Iteration	20	Cost: 2.248291e-16
Iteration	21	Cost: 5.079311e-17
Iteration	22	Cost: 1.499569e-17
Iteration	23	Cost: 3.850977e-18
Iteration	24	Cost: 1.581009e-29
Iteration	25	Cost: 2.383017e-31
Iteration	1	Cost: 7.960488e-01
Iteration	2	Cost: 2.114171e-01
Iteration	3	Cost: 2.702642e-02
Iteration	4	Cost: 7.283459e-19
Iteration	5	Cost: 3.937030e-25
Iteration	6	Cost: 1.204650e-25
Iteration	7	Cost: 4.310755e-27
Iteration	8	Cost: 1.608105e-28
Iteration	9	Cost: 1.602374e-28
Iteration	11	Cost: 1.593746e-28
Iteration	1	Cost: 9.143237e+01
Iteration	2	Cost: 3.022402e+01
Iteration	3	Cost: 1.003676e+01
Iteration	4	Cost: 1.760707e+00
Iteration	5	Cost: 7.349265e-01
Iteration	6	Cost: 3.526117e-01
Iteration	7	Cost: 1.400699e-01
Iteration	8	Cost: 1.030584e-01
Iteration	9	Cost: 6.535012e-02
Iteration	10	Cost: 6.365050e-02
Iteration	11	Cost: 6.118870e-02
Iteration	12	Cost: 6.026806e-02
Iteration	13	Cost: 5.870519e-02
Iteration	14	Cost: 5.501043e-02
Iteration	15	Cost: 5.001926e-02
Iteration	16	Cost: 4.950221e-02
Iteration	17	Cost: 4.272931e-02
Iteration	18	Cost: 3.806196e-02
Iteration	19	Cost: 3.194723e-02
Iteration	20	Cost: 2.952742e-02
Iteration	21	Cost: 2.940133e-02
Iteration	22	Cost: 2.818694e-02
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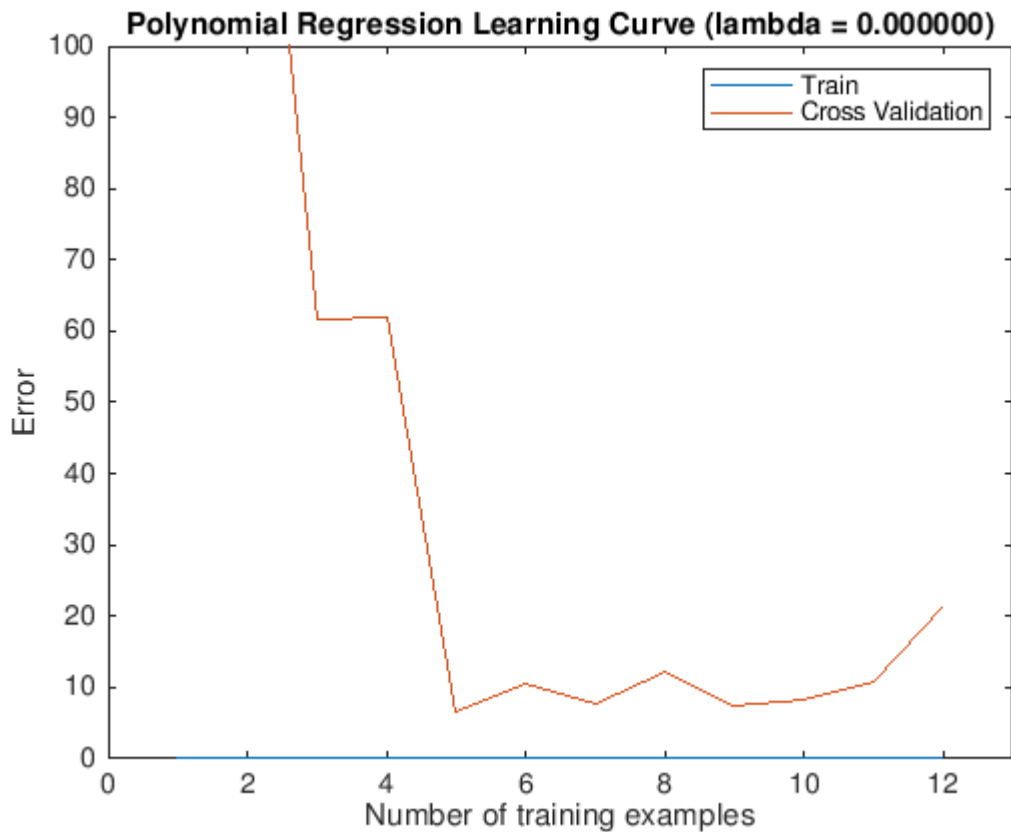
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Iteration	90	Cost: 2.122823e-01
Iteration	91	Cost: 2.122201e-01
Iteration	92	Cost: 2.120567e-01
Iteration	93	Cost: 2.119668e-01
Iteration	94	Cost: 2.118488e-01
Iteration	95	Cost: 2.118274e-01
Iteration	96	Cost: 2.115975e-01
Iteration	97	Cost: 2.115167e-01
Iteration	98	Cost: 2.114027e-01
Iteration	99	Cost: 2.113492e-01
Iteration	100	Cost: 2.108737e-01
Iteration	101	Cost: 2.108189e-01
Iteration	102	Cost: 2.106924e-01
Iteration	103	Cost: 2.103854e-01
Iteration	104	Cost: 2.096211e-01
Iteration	105	Cost: 2.086086e-01
Iteration	106	Cost: 2.078328e-01
Iteration	107	Cost: 2.053193e-01
Iteration	108	Cost: 2.022514e-01
Iteration	109	Cost: 2.016763e-01
Iteration	110	Cost: 2.014518e-01
Iteration	111	Cost: 2.011953e-01
Iteration	112	Cost: 2.008846e-01
Iteration	113	Cost: 2.008231e-01
Iteration	114	Cost: 2.007336e-01
Iteration	115	Cost: 2.006698e-01
Iteration	116	Cost: 2.004391e-01
Iteration	117	Cost: 2.003649e-01
Iteration	118	Cost: 2.000645e-01
Iteration	119	Cost: 1.999290e-01
Iteration	120	Cost: 1.995902e-01
Iteration	121	Cost: 1.994100e-01
Iteration	122	Cost: 1.991483e-01
Iteration	123	Cost: 1.987118e-01
Iteration	124	Cost: 1.981287e-01
Iteration	125	Cost: 1.976985e-01
Iteration	126	Cost: 1.971647e-01
Iteration	127	Cost: 1.971356e-01
Iteration	128	Cost: 1.971279e-01
Iteration	129	Cost: 1.970732e-01
Iteration	130	Cost: 1.964910e-01
Iteration	131	Cost: 1.961885e-01
Iteration	132	Cost: 1.961217e-01
Iteration	133	Cost: 1.955607e-01
Iteration	134	Cost: 1.955375e-01
Iteration	135	Cost: 1.952931e-01

Iteration	136		Cost: 1.951576e-01
Iteration	137		Cost: 1.942583e-01
Iteration	138		Cost: 1.938395e-01
Iteration	139		Cost: 1.934828e-01
Iteration	140		Cost: 1.934470e-01
Iteration	141		Cost: 1.930246e-01
Iteration	142		Cost: 1.928470e-01
Iteration	143		Cost: 1.921011e-01
Iteration	144		Cost: 1.918886e-01
Iteration	145		Cost: 1.915949e-01
Iteration	146		Cost: 1.915563e-01
Iteration	147		Cost: 1.912242e-01
Iteration	148		Cost: 1.911722e-01
Iteration	149		Cost: 1.909908e-01
Iteration	150		Cost: 1.908000e-01
Iteration	151		Cost: 1.904710e-01
Iteration	152		Cost: 1.903946e-01
Iteration	153		Cost: 1.902309e-01
Iteration	154		Cost: 1.901956e-01
Iteration	155		Cost: 1.897420e-01
Iteration	156		Cost: 1.897320e-01
Iteration	157		Cost: 1.894898e-01
Iteration	158		Cost: 1.891643e-01
Iteration	159		Cost: 1.891019e-01
Iteration	160		Cost: 1.889144e-01
Iteration	161		Cost: 1.887883e-01
Iteration	162		Cost: 1.885876e-01
Iteration	163		Cost: 1.883254e-01
Iteration	164		Cost: 1.882543e-01
Iteration	165		Cost: 1.882217e-01
Iteration	166		Cost: 1.881893e-01
Iteration	...		

```

plot(1:m, error_train, 1:m, error_val);
title(sprintf('Polynomial Regression Learning Curve (lambda = %f)', lambda));
xlabel('Number of training examples')
ylabel('Error')
axis([0 13 0 100])
legend('Train', 'Cross Validation')

```



To better understand the problems with the unregularized  $\lambda = 0$  model, you can see that the learning curve (Figure 5) shows the same effect where the low training error is low, but the cross validation error is high. There is a gap between the training and cross validation errors, indicating a high variance problem. One way to combat the overfitting (high-variance) problem is to add regularization to the model. In the next section, you will get to try different  $\lambda$  parameters to see how regularization can lead to a better model.

### 3.2 Optional (ungraded) exercise: Adjusting the regularization parameter

In this section, you will get to observe how the regularization parameter affects the bias-variance of regularized polynomial regression. You should now modify the the `lambda` parameter in the code below and try  $\lambda = 1, 100$ .

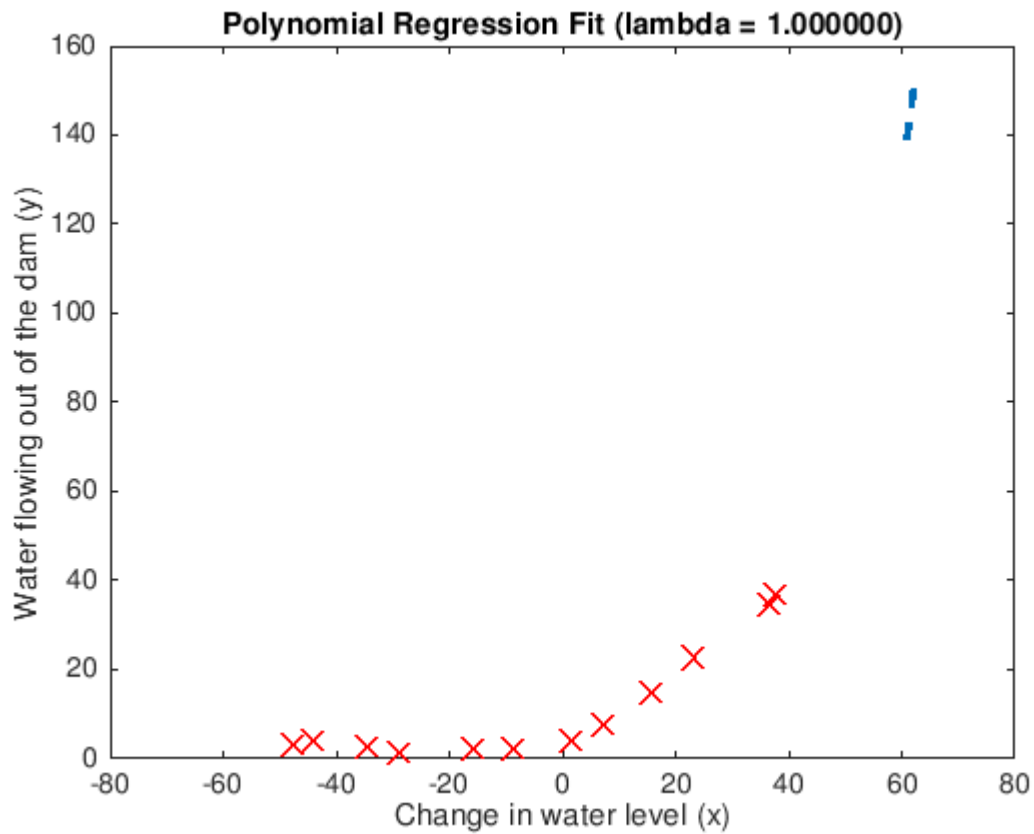
```
% Choose the value of lambda
lambda = 1;
[theta] = trainLinearReg(X_poly, y, lambda);
```

```
Iteration    1 | Cost: 8.320954e+01
Iteration    2 | Cost: 2.907694e+01
Iteration    3 | Cost: 1.613078e+01
Iteration    4 | Cost: 7.846949e+00
Iteration    5 | Cost: 7.728636e+00
Iteration    6 | Cost: 7.597593e+00
Iteration    7 | Cost: 7.525779e+00
Iteration    8 | Cost: 7.459900e+00
Iteration    9 | Cost: 7.377098e+00
Iteration   10 | Cost: 7.313100e+00
Iteration   11 | Cost: 7.295318e+00
Iteration   12 | Cost: 7.275583e+00
```

Iteration	13	Cost: 7.272255e+00
Iteration	14	Cost: 7.271615e+00
Iteration	15	Cost: 7.269168e+00
Iteration	16	Cost: 7.268895e+00
Iteration	17	Cost: 7.268688e+00
Iteration	18	Cost: 7.268467e+00
Iteration	19	Cost: 7.268207e+00
Iteration	20	Cost: 7.268174e+00
Iteration	21	Cost: 7.268158e+00
Iteration	22	Cost: 7.268155e+00
Iteration	23	Cost: 7.268151e+00
Iteration	24	Cost: 7.268151e+00
Iteration	25	Cost: 7.268150e+00
Iteration	26	Cost: 7.268150e+00
Iteration	27	Cost: 7.268149e+00
Iteration	28	Cost: 7.268149e+00
Iteration	29	Cost: 7.268148e+00
Iteration	30	Cost: 7.268148e+00
Iteration	31	Cost: 7.268148e+00
Iteration	32	Cost: 7.268148e+00
Iteration	33	Cost: 7.268148e+00
Iteration	34	Cost: 7.268148e+00
Iteration	35	Cost: 7.268148e+00
Iteration	36	Cost: 7.268148e+00
Iteration	37	Cost: 7.268148e+00
Iteration	38	Cost: 7.268148e+00
Iteration	39	Cost: 7.268148e+00
Iteration	40	Cost: 7.268148e+00
Iteration	41	Cost: 7.268148e+00
Iteration	42	Cost: 7.268148e+00
Iteration	43	Cost: 7.268148e+00
Iteration	44	Cost: 7.268148e+00
Iteration	45	Cost: 7.268148e+00
Iteration	46	Cost: 7.268148e+00
Iteration	47	Cost: 7.268148e+00
Iteration	48	Cost: 7.268148e+00
Iteration	49	Cost: 7.268148e+00
Iteration	50	Cost: 7.268148e+00
Iteration	51	Cost: 7.268148e+00
Iteration	52	Cost: 7.268148e+00
Iteration	53	Cost: 7.268148e+00
Iteration	54	Cost: 7.268148e+00
Iteration	55	Cost: 7.268148e+00
Iteration	56	Cost: 7.268148e+00
Iteration	57	Cost: 7.268148e+00
Iteration	58	Cost: 7.268148e+00
Iteration	59	Cost: 7.268148e+00
Iteration	60	Cost: 7.268148e+00
Iteration	61	Cost: 7.268148e+00
Iteration	62	Cost: 7.268148e+00
Iteration	63	Cost: 7.268148e+00
Iteration	64	Cost: 7.268148e+00
Iteration	65	Cost: 7.268148e+00
Iteration	66	Cost: 7.268148e+00

```
% Plot training data and fit
plot(X, y, 'rx', 'MarkerSize', 10, 'LineWidth', 1.5);
plotFit(min(X), max(X), mu, sigma, theta, p);
xlabel('Change in water level (x)');
ylabel('Water flowing out of the dam (y)');
title(sprintf('Polynomial Regression Fit (lambda = %f)', lambda));
```





```
[error_train, error_val] = learningCurve(X_poly, y, X_poly_val, yval, lambda);
```

Iteration	1	Cost: 5.280051e-01
Iteration	2	Cost: 2.083531e-01
Iteration	3	Cost: 9.810873e-02
Iteration	4	Cost: 1.501116e-03
Iteration	5	Cost: 1.089480e-03
Iteration	6	Cost: 8.985589e-29
Iteration	7	Cost: 4.737339e-29
Iteration	8	Cost: 3.340815e-30
Iteration	9	Cost: 2.363551e-30
Iteration	10	Cost: 5.395241e-31
Iteration	11	Cost: 2.908085e-31
Iteration	12	Cost: 1.938140e-31
Iteration	13	Cost: 8.418143e-32
Iteration	14	Cost: 6.910454e-32
Iteration	1	Cost: 2.032751e-01
Iteration	2	Cost: 1.041953e-01
Iteration	3	Cost: 7.367762e-02
Iteration	4	Cost: 7.279642e-02
Iteration	5	Cost: 7.269797e-02
Iteration	6	Cost: 7.269533e-02
Iteration	7	Cost: 7.269502e-02
Iteration	8	Cost: 7.269437e-02
Iteration	9	Cost: 7.269436e-02
Iteration	10	Cost: 7.269436e-02
Iteration	11	Cost: 7.269436e-02
Iteration	12	Cost: 7.269436e-02
Iteration	13	Cost: 7.269436e-02
Iteration	14	Cost: 7.269436e-02
Iteration	15	Cost: 7.269436e-02
Iteration	16	Cost: 7.269436e-02

Iteration	17	Cost: 7.269436e-02
Iteration	18	Cost: 7.269436e-02
Iteration	19	Cost: 7.269436e-02
Iteration	20	Cost: 7.269436e-02
Iteration	21	Cost: 7.269436e-02
Iteration	23	Cost: 7.269436e-02
Iteration	24	Cost: 7.269436e-02
Iteration	1	Cost: 3.958682e+01
Iteration	2	Cost: 2.172738e+01
Iteration	3	Cost: 2.007128e+01
Iteration	4	Cost: 1.908475e+01
Iteration	5	Cost: 1.903782e+01
Iteration	6	Cost: 1.872107e+01
Iteration	7	Cost: 1.855211e+01
Iteration	8	Cost: 1.852112e+01
Iteration	9	Cost: 1.850030e+01
Iteration	10	Cost: 1.849891e+01
Iteration	11	Cost: 1.849887e+01
Iteration	12	Cost: 1.849880e+01
Iteration	13	Cost: 1.849879e+01
Iteration	14	Cost: 1.849879e+01
Iteration	15	Cost: 1.849879e+01
Iteration	16	Cost: 1.849879e+01
Iteration	17	Cost: 1.849879e+01
Iteration	18	Cost: 1.849879e+01
Iteration	19	Cost: 1.849879e+01
Iteration	21	Cost: 1.849879e+01
Iteration	1	Cost: 1.883439e+01
Iteration	2	Cost: 1.695119e+01
Iteration	3	Cost: 1.546680e+01
Iteration	4	Cost: 1.486258e+01
Iteration	5	Cost: 1.462699e+01
Iteration	6	Cost: 1.460173e+01
Iteration	7	Cost: 1.458789e+01
Iteration	8	Cost: 1.458160e+01
Iteration	9	Cost: 1.457865e+01
Iteration	10	Cost: 1.457606e+01
Iteration	11	Cost: 1.457596e+01
Iteration	12	Cost: 1.457591e+01
Iteration	13	Cost: 1.457590e+01
Iteration	14	Cost: 1.457588e+01
Iteration	15	Cost: 1.457587e+01
Iteration	16	Cost: 1.457586e+01
Iteration	17	Cost: 1.457586e+01
Iteration	18	Cost: 1.457586e+01
Iteration	19	Cost: 1.457586e+01
Iteration	20	Cost: 1.457586e+01
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Iteration	33	Cost: 1.457586e+01
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Iteration	39	Cost: 1.457586e+01
Iteration	40	Cost: 1.457586e+01
Iteration	41	Cost: 1.457586e+01
Iteration	42	Cost: 1.457586e+01
Iteration	43	Cost: 1.457586e+01
Iteration	1	Cost: 9.507932e+01
Iteration	2	Cost: 3.745281e+01
Iteration	3	Cost: 1.603853e+01
Iteration	4	Cost: 1.259101e+01
Iteration	5	Cost: 1.224802e+01
Iteration	6	Cost: 1.203688e+01
Iteration	7	Cost: 1.177695e+01
Iteration	8	Cost: 1.170176e+01
Iteration	9	Cost: 1.167281e+01
Iteration	10	Cost: 1.166567e+01
Iteration	11	Cost: 1.166407e+01
Iteration	12	Cost: 1.166172e+01
Iteration	13	Cost: 1.166153e+01
Iteration	14	Cost: 1.166101e+01
Iteration	15	Cost: 1.166087e+01
Iteration	16	Cost: 1.166077e+01
Iteration	17	Cost: 1.166076e+01
Iteration	18	Cost: 1.166074e+01
Iteration	19	Cost: 1.166073e+01
Iteration	20	Cost: 1.166072e+01
Iteration	21	Cost: 1.166072e+01
Iteration	22	Cost: 1.166072e+01
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Iteration	55	Cost: 1.166072e+01
Iteration	56	Cost: 1.166072e+01
Iteration	57	Cost: 1.166072e+01
Iteration	58	Cost: 1.166072e+01
Iteration	59	Cost: 1.166072e+01
Iteration	61	Cost: 1.166072e+01

Iteration	1	Cost: 7.115385e+01
Iteration	2	Cost: 2.111452e+01
Iteration	3	Cost: 1.314175e+01
Iteration	4	Cost: 1.054644e+01
Iteration	5	Cost: 1.036773e+01
Iteration	6	Cost: 1.034120e+01
Iteration	7	Cost: 1.026977e+01
Iteration	8	Cost: 1.022714e+01
Iteration	9	Cost: 1.019759e+01
Iteration	10	Cost: 1.015385e+01
Iteration	11	Cost: 1.014049e+01
Iteration	12	Cost: 1.013163e+01
Iteration	13	Cost: 1.013124e+01
Iteration	14	Cost: 1.012855e+01
Iteration	15	Cost: 1.012593e+01
Iteration	16	Cost: 1.011958e+01
Iteration	17	Cost: 1.011929e+01
Iteration	18	Cost: 1.011892e+01
Iteration	19	Cost: 1.011888e+01
Iteration	20	Cost: 1.011885e+01
Iteration	21	Cost: 1.011883e+01
Iteration	22	Cost: 1.011882e+01
Iteration	23	Cost: 1.011882e+01
Iteration	24	Cost: 1.011882e+01
Iteration	25	Cost: 1.011882e+01
Iteration	26	Cost: 1.011882e+01
Iteration	27	Cost: 1.011882e+01
Iteration	28	Cost: 1.011882e+01
Iteration	29	Cost: 1.011882e+01
Iteration	30	Cost: 1.011882e+01
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Iteration	32	Cost: 1.011882e+01
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Iteration	39	Cost: 1.011882e+01
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Iteration	41	Cost: 1.011882e+01
Iteration	42	Cost: 1.011882e+01
Iteration	43	Cost: 1.011882e+01
Iteration	44	Cost: 1.011882e+01
Iteration	45	Cost: 1.011882e+01
Iteration	46	Cost: 1.011882e+01
Iteration	47	Cost: 1.011882e+01
Iteration	48	Cost: 1.011882e+01
Iteration	49	Cost: 1.011882e+01
Iteration	50	Cost: 1.011882e+01
Iteration	51	Cost: 1.011882e+01
Iteration	53	Cost: 1.011882e+01
Iteration	55	Cost: 1.011882e+01
Iteration	56	Cost: 1.011882e+01
Iteration	1	Cost: 7.518060e+01
Iteration	2	Cost: 1.559044e+01
Iteration	3	Cost: 1.513533e+01
Iteration	4	Cost: 1.209122e+01
Iteration	5	Cost: 1.079247e+01
Iteration	6	Cost: 1.037089e+01
Iteration	7	Cost: 9.830827e+00
Iteration	8	Cost: 9.592523e+00
Iteration	9	Cost: 9.566945e+00
Iteration	10	Cost: 9.458758e+00
Iteration	11	Cost: 9.456354e+00

Iteration	12	Cost: 9.445971e+00
Iteration	13	Cost: 9.439737e+00
Iteration	14	Cost: 9.432534e+00
Iteration	15	Cost: 9.423417e+00
Iteration	16	Cost: 9.420646e+00
Iteration	17	Cost: 9.420083e+00
Iteration	18	Cost: 9.419240e+00
Iteration	19	Cost: 9.418908e+00
Iteration	20	Cost: 9.417683e+00
Iteration	21	Cost: 9.417024e+00
Iteration	22	Cost: 9.416462e+00
Iteration	23	Cost: 9.416375e+00
Iteration	24	Cost: 9.416327e+00
Iteration	25	Cost: 9.416324e+00
Iteration	26	Cost: 9.416323e+00
Iteration	27	Cost: 9.416321e+00
Iteration	28	Cost: 9.416320e+00
Iteration	29	Cost: 9.416320e+00
Iteration	30	Cost: 9.416319e+00
Iteration	31	Cost: 9.416318e+00
Iteration	32	Cost: 9.416318e+00
Iteration	33	Cost: 9.416317e+00
Iteration	34	Cost: 9.416317e+00
Iteration	35	Cost: 9.416317e+00
Iteration	36	Cost: 9.416317e+00
Iteration	37	Cost: 9.416317e+00
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Iteration	39	Cost: 9.416317e+00
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Iteration	59	Cost: 9.416317e+00
Iteration	60	Cost: 9.416317e+00
Iteration	61	Cost: 9.416317e+00
Iteration	63	Cost: 9.416317e+00
Iteration	64	Cost: 9.416317e+00
Iteration	65	Cost: 9.416317e+00
Iteration	66	Cost: 9.416317e+00
Iteration	67	Cost: 9.416317e+00
Iteration	68	Cost: 9.416317e+00
Iteration	1	Cost: 6.611004e+01
Iteration	2	Cost: 1.195226e+01
Iteration	3	Cost: 9.740804e+00
Iteration	4	Cost: 8.828668e+00
Iteration	5	Cost: 8.560404e+00
Iteration	6	Cost: 8.381595e+00
Iteration	7	Cost: 8.344767e+00
Iteration	8	Cost: 8.300061e+00
Iteration	9	Cost: 8.284688e+00

Iteration	10	Cost: 8.279706e+00
Iteration	11	Cost: 8.266926e+00
Iteration	12	Cost: 8.260051e+00
Iteration	13	Cost: 8.259467e+00
Iteration	14	Cost: 8.257623e+00
Iteration	15	Cost: 8.256702e+00
Iteration	16	Cost: 8.256529e+00
Iteration	17	Cost: 8.256320e+00
Iteration	18	Cost: 8.256245e+00
Iteration	19	Cost: 8.256228e+00
Iteration	20	Cost: 8.256226e+00
Iteration	21	Cost: 8.256225e+00
Iteration	22	Cost: 8.256224e+00
Iteration	23	Cost: 8.256224e+00
Iteration	24	Cost: 8.256224e+00
Iteration	25	Cost: 8.256224e+00
Iteration	26	Cost: 8.256224e+00
Iteration	27	Cost: 8.256224e+00
Iteration	28	Cost: 8.256224e+00
Iteration	29	Cost: 8.256224e+00
Iteration	30	Cost: 8.256224e+00
Iteration	31	Cost: 8.256224e+00
Iteration	32	Cost: 8.256224e+00
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Iteration	35	Cost: 8.256224e+00
Iteration	36	Cost: 8.256224e+00
Iteration	37	Cost: 8.256224e+00
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Iteration	19	Cost: 7.064405e+00
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Iteration	21	Cost: 7.064400e+00
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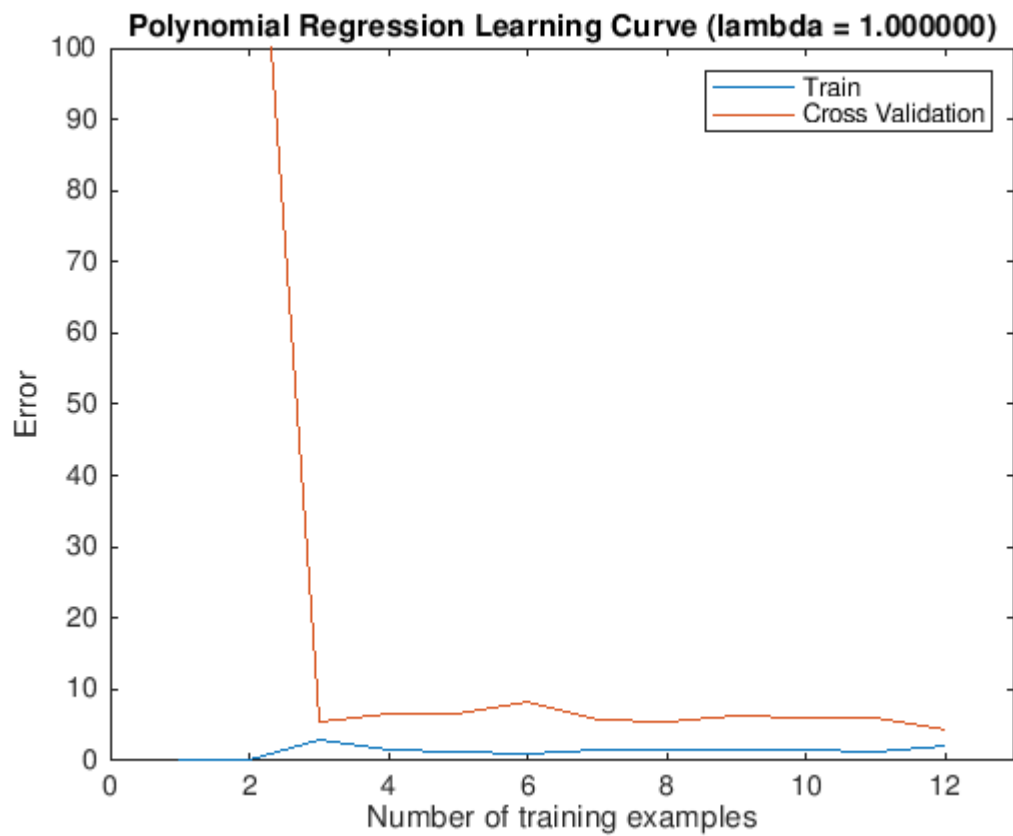
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Iteration	40	Cost: 6.423784e+00
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Iteration	12	Cost: 7.275583e+00
Iteration	13	Cost: 7.272255e+00
Iteration	14	Cost: 7.271615e+00
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Iteration	17	Cost: 7.268688e+00
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Iteration	37	Cost: 7.268148e+00

Iteration	38		Cost: 7.268148e+00
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Iteration	40		Cost: 7.268148e+00
Iteration	41		Cost: 7.268148e+00
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Iteration	64		Cost: 7.268148e+00
Iteration	65		Cost: 7.268148e+00
Iteration	66		Cost: 7.268148e+00

```
plot(1:m, error_train, 1:m, error_val);  
title(sprintf('Polynomial Regression Learning Curve (lambda = %f)', lambda));  
xlabel('Number of training examples')  
ylabel('Error')  
axis([0 13 0 100])  
legend('Train', 'Cross Validation')
```



For each of these values, the code should generate a polynomial fit to the data and also a learning curve.

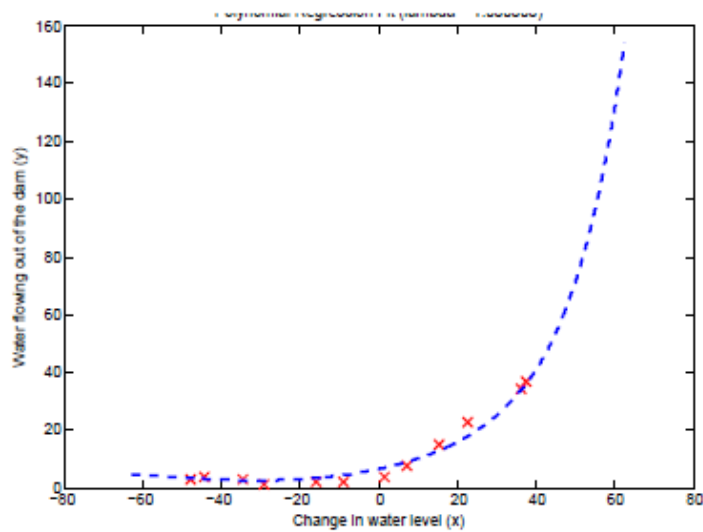


Figure 6: Polynomial fit,  $\lambda = 1$

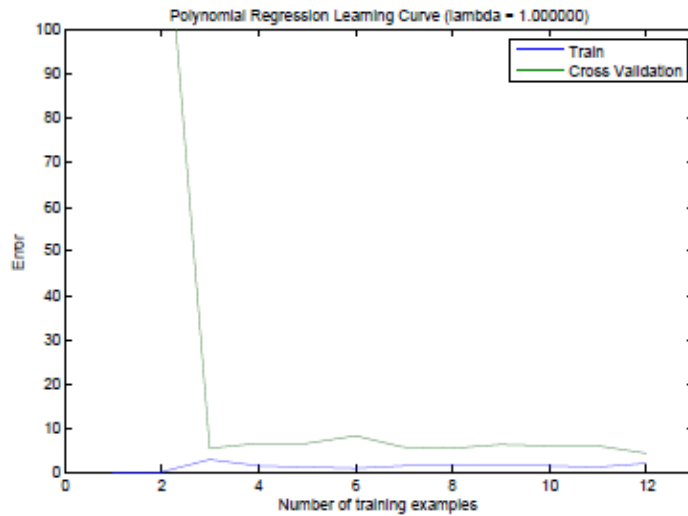


Figure 7: Polynomial learning curve,  $\lambda = 1$

For  $\lambda = 1$ , you should see a polynomial fit that follows the data trend well (Figure 6) and a learning curve (Figure 7) showing that both the cross validation and training error converge to a relatively low value. This shows the  $\lambda = 1$  regularized polynomial regression model does not have the high bias or high-variance problems. In effect, it achieves a good trade-off between bias and variance.

For  $\lambda = 100$ , you should see a polynomial fit (Figure 8) that does not follow the data well. In this case, there is too much regularization and the model is unable to fit the training data.

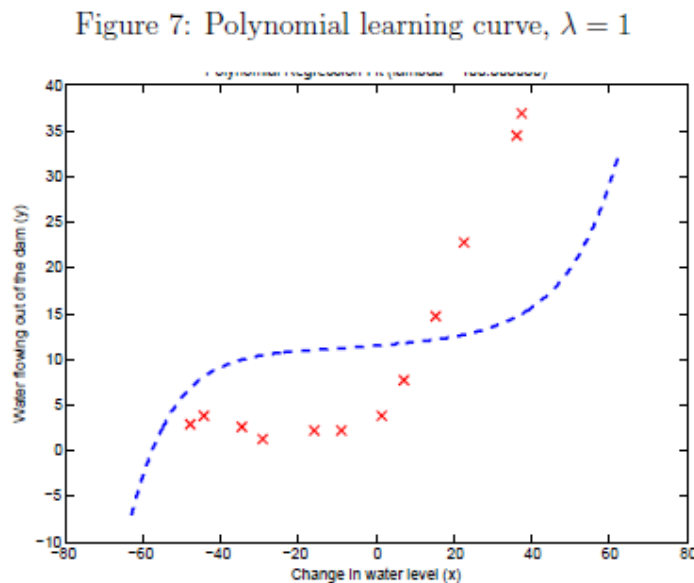


Figure 8: Polynomial fit,  $\lambda = 100$

### 3.3 Selecting lambda using a cross validation set

From the previous parts of the exercise, you observed that the value of  $\lambda$  can significantly affect the results of regularized polynomial regression on the training and cross validation set. In particular, a model without regularization ( $\lambda = 0$ ) fits the training set well, but does not generalize. Conversely, a model with too much regularization ( $\lambda = 100$ ) does not fit the training set and testing set well. A good choice of  $\lambda$  (e.g.  $\lambda = 1$ ) can provide a good fit to the data.

In this section, you will implement an automated method to select the parameter. Concretely, you will use a cross validation set to evaluate how good each  $\lambda$  value is. After selecting the best  $\lambda$  value using the cross validation set, we can then evaluate the model on the test set to estimate how well the model will perform on actual unseen data. Your task is to complete the code in `validationCurve.m`. Specifically, you should use the `trainLinearReg` function to train the model using different values of  $\lambda$  and compute the training error and cross validation error. The function will try  $\lambda$  in the following range: {0, 0.001, 0.003, 0.01, 0.03, 0.1, 0.3, 1, 3, 10}.

After you have completed the code, the code below will run your function and plot a cross validation curve of error v.s  $\lambda$  that allows you select which  $\lambda$  parameter to use. You should see a plot similar to Figure 9.

```
[lambda_vec, error_train, error_val] = validationCurve(X_poly, y, X_poly_val, yval);
```

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Iteration	2		Cost: 2.687496e+01
Iteration	3		Cost: 1.327780e+01
Iteration	4		Cost: 3.455324e+00
Iteration	5		Cost: 2.870493e+00
Iteration	6		Cost: 2.404364e+00
Iteration	7		Cost: 2.372779e+00
Iteration	8		Cost: 1.771555e+00
Iteration	9		Cost: 1.210317e+00
Iteration	10		Cost: 9.411622e-01
Iteration	11		Cost: 7.981808e-01
Iteration	12		Cost: 7.556890e-01
Iteration	13		Cost: 6.697776e-01
Iteration	14		Cost: 4.869518e-01
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Iteration	16		Cost: 4.428080e-01
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Iteration	40	Cost: 2.519101e-01
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Iteration	42	Cost: 2.512185e-01
Iteration	43	Cost: 2.505467e-01
Iteration	44	Cost: 2.503816e-01
Iteration	45	Cost: 2.501629e-01
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Iteration	54	Cost: 2.278730e-01
Iteration	55	Cost: 2.278083e-01
Iteration	56	Cost: 2.277903e-01
Iteration	57	Cost: 2.277236e-01
Iteration	58	Cost: 2.275362e-01
Iteration	59	Cost: 2.273722e-01
Iteration	60	Cost: 2.271478e-01
Iteration	61	Cost: 2.269241e-01
Iteration	62	Cost: 2.268479e-01
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Iteration	78	Cost: 2.183557e-01
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Iteration	92	Cost: 2.120567e-01
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Iteration	97	Cost: 2.115167e-01
Iteration	98	Cost: 2.114027e-01
Iteration	99	Cost: 2.113492e-01
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Iteration	102	Cost: 2.106924e-01
Iteration	103	Cost: 2.103854e-01
Iteration	104	Cost: 2.096211e-01

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Iteration	163	Cost: 1.883254e-01
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Iteration	165	Cost: 1.882217e-01
Iteration	166	Cost: 1.881893e-01
Iteration	167	Cost: 1.881428e-01
Iteration	168	Cost: 1.880951e-01
Iteration	169	Cost: 1.880156e-01

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Iteration	183	Cost: 1.864189e-01
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Iteration	188	Cost: 1.860338e-01
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Iteration	194	Cost: 1.846662e-01
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Iteration	197	Cost: 1.843992e-01
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Iteration	6	Cost: 2.410018e+00
Iteration	7	Cost: 2.378879e+00
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Iteration	9	Cost: 1.211503e+00
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Iteration	12	Cost: 7.550362e-01
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Iteration	15	Cost: 5.342269e-01
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Iteration	6	Cost: 2.421323e+00
Iteration	7	Cost: 2.391085e+00
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Iteration	132	Cost: 1.443470e+00
Iteration	133	Cost: 1.443470e+00
Iteration	134	Cost: 1.443470e+00
Iteration	135	Cost: 1.443470e+00
Iteration	136	Cost: 1.443470e+00
Iteration	137	Cost: 1.443470e+00
Iteration	138	Cost: 1.443470e+00
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Iteration	140	Cost: 1.443470e+00
Iteration	141	Cost: 1.443470e+00
Iteration	142	Cost: 1.443470e+00
Iteration	143	Cost: 1.443470e+00
Iteration	144	Cost: 1.443470e+00

Iteration	145	Cost: 1.443470e+00
Iteration	146	Cost: 1.443470e+00
Iteration	147	Cost: 1.443470e+00
Iteration	148	Cost: 1.443470e+00
Iteration	149	Cost: 1.443470e+00
Iteration	150	Cost: 1.443470e+00
Iteration	151	Cost: 1.443470e+00
Iteration	152	Cost: 1.443470e+00
Iteration	153	Cost: 1.443470e+00
Iteration	154	Cost: 1.443470e+00
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Iteration	156	Cost: 1.443470e+00
Iteration	157	Cost: 1.443470e+00
Iteration	158	Cost: 1.443470e+00
Iteration	159	Cost: 1.443470e+00
Iteration	160	Cost: 1.443470e+00
Iteration	161	Cost: 1.443470e+00
Iteration	162	Cost: 1.443470e+00
Iteration	163	Cost: 1.443470e+00
Iteration	164	Cost: 1.443470e+00
Iteration	165	Cost: 1.443470e+00
Iteration	166	Cost: 1.443470e+00
Iteration	167	Cost: 1.443470e+00
Iteration	168	Cost: 1.443470e+00
Iteration	169	Cost: 1.443470e+00
Iteration	170	Cost: 1.443470e+00
Iteration	171	Cost: 1.443470e+00
Iteration	172	Cost: 1.443470e+00
Iteration	173	Cost: 1.443470e+00
Iteration	174	Cost: 1.443470e+00
Iteration	175	Cost: 1.443470e+00
Iteration	176	Cost: 1.443470e+00
Iteration	178	Cost: 1.443470e+00
Iteration	179	Cost: 1.443470e+00
Iteration	180	Cost: 1.443470e+00
Iteration	1	Cost: 8.287440e+01
Iteration	2	Cost: 2.753557e+01
Iteration	3	Cost: 1.416686e+01
Iteration	4	Cost: 5.488365e+00
Iteration	5	Cost: 4.682558e+00
Iteration	6	Cost: 4.060120e+00
Iteration	7	Cost: 4.049813e+00
Iteration	8	Cost: 3.938558e+00
Iteration	9	Cost: 3.836442e+00
Iteration	10	Cost: 3.716714e+00
Iteration	11	Cost: 3.445850e+00
Iteration	12	Cost: 3.183467e+00
Iteration	13	Cost: 3.154350e+00
Iteration	14	Cost: 3.128190e+00
Iteration	15	Cost: 3.126324e+00
Iteration	16	Cost: 3.122261e+00
Iteration	17	Cost: 3.121275e+00
Iteration	18	Cost: 3.117681e+00
Iteration	19	Cost: 3.116196e+00
Iteration	20	Cost: 3.115676e+00
Iteration	21	Cost: 3.111715e+00
Iteration	22	Cost: 3.107123e+00
Iteration	23	Cost: 3.106259e+00
Iteration	24	Cost: 3.104494e+00
Iteration	25	Cost: 3.104270e+00
Iteration	26	Cost: 3.103957e+00
Iteration	27	Cost: 3.103880e+00
Iteration	28	Cost: 3.103074e+00
Iteration	29	Cost: 3.102418e+00
Iteration	30	Cost: 3.102116e+00

Iteration	31	Cost: 3.102019e+00
Iteration	32	Cost: 3.101895e+00
Iteration	33	Cost: 3.101862e+00
Iteration	34	Cost: 3.101774e+00
Iteration	35	Cost: 3.101729e+00
Iteration	36	Cost: 3.101712e+00
Iteration	37	Cost: 3.101701e+00
Iteration	38	Cost: 3.101665e+00
Iteration	39	Cost: 3.101635e+00
Iteration	40	Cost: 3.101610e+00
Iteration	41	Cost: 3.101601e+00
Iteration	42	Cost: 3.101597e+00
Iteration	43	Cost: 3.101597e+00
Iteration	44	Cost: 3.101596e+00
Iteration	45	Cost: 3.101596e+00
Iteration	46	Cost: 3.101595e+00
Iteration	47	Cost: 3.101593e+00
Iteration	48	Cost: 3.101592e+00
Iteration	49	Cost: 3.101592e+00
Iteration	50	Cost: 3.101592e+00
Iteration	51	Cost: 3.101592e+00
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Iteration	57	Cost: 3.101591e+00
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Iteration	61	Cost: 3.101591e+00
Iteration	62	Cost: 3.101591e+00
Iteration	63	Cost: 3.101591e+00
Iteration	64	Cost: 3.101591e+00
Iteration	65	Cost: 3.101591e+00
Iteration	66	Cost: 3.101591e+00
Iteration	67	Cost: 3.101591e+00
Iteration	68	Cost: 3.101591e+00
Iteration	69	Cost: 3.101591e+00
Iteration	70	Cost: 3.101591e+00
Iteration	71	Cost: 3.101591e+00
Iteration	72	Cost: 3.101591e+00
Iteration	73	Cost: 3.101591e+00
Iteration	74	Cost: 3.101591e+00
Iteration	75	Cost: 3.101591e+00
Iteration	76	Cost: 3.101591e+00
Iteration	77	Cost: 3.101591e+00
Iteration	78	Cost: 3.101591e+00
Iteration	79	Cost: 3.101591e+00
Iteration	80	Cost: 3.101591e+00
Iteration	81	Cost: 3.101591e+00
Iteration	82	Cost: 3.101591e+00
Iteration	83	Cost: 3.101591e+00
Iteration	84	Cost: 3.101591e+00
Iteration	85	Cost: 3.101591e+00
Iteration	86	Cost: 3.101591e+00
Iteration	87	Cost: 3.101591e+00
Iteration	88	Cost: 3.101591e+00
Iteration	89	Cost: 3.101591e+00
Iteration	90	Cost: 3.101591e+00
Iteration	91	Cost: 3.101591e+00
Iteration	92	Cost: 3.101591e+00
Iteration	93	Cost: 3.101591e+00
Iteration	94	Cost: 3.101591e+00
Iteration	95	Cost: 3.101591e+00



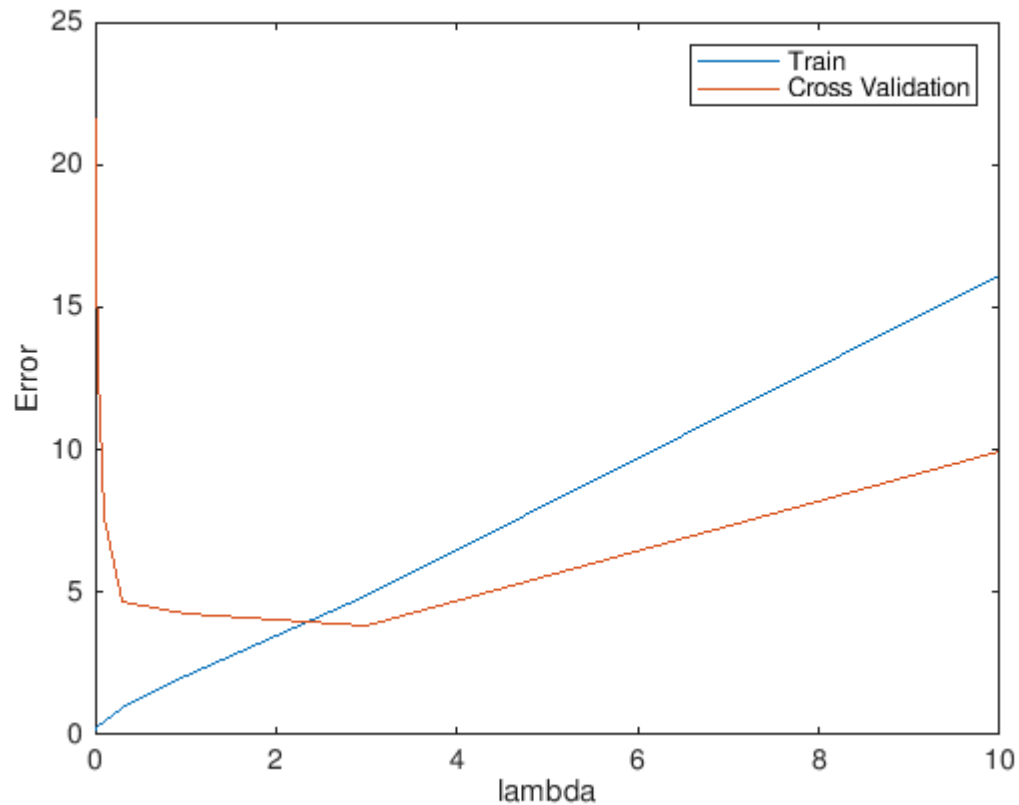
Iteration	96	Cost: 3.101591e+00
Iteration	97	Cost: 3.101591e+00
Iteration	98	Cost: 3.101591e+00
Iteration	99	Cost: 3.101591e+00
Iteration	100	Cost: 3.101591e+00
Iteration	101	Cost: 3.101591e+00
Iteration	102	Cost: 3.101591e+00
Iteration	103	Cost: 3.101591e+00
Iteration	104	Cost: 3.101591e+00
Iteration	105	Cost: 3.101591e+00
Iteration	1	Cost: 8.320954e+01
Iteration	2	Cost: 2.907694e+01
Iteration	3	Cost: 1.613078e+01
Iteration	4	Cost: 7.846949e+00
Iteration	5	Cost: 7.728636e+00
Iteration	6	Cost: 7.597593e+00
Iteration	7	Cost: 7.525779e+00
Iteration	8	Cost: 7.459900e+00
Iteration	9	Cost: 7.377098e+00
Iteration	10	Cost: 7.313100e+00
Iteration	11	Cost: 7.295318e+00
Iteration	12	Cost: 7.275583e+00
Iteration	13	Cost: 7.272255e+00
Iteration	14	Cost: 7.271615e+00
Iteration	15	Cost: 7.269168e+00
Iteration	16	Cost: 7.268895e+00
Iteration	17	Cost: 7.268688e+00
Iteration	18	Cost: 7.268467e+00
Iteration	19	Cost: 7.268207e+00
Iteration	20	Cost: 7.268174e+00
Iteration	21	Cost: 7.268158e+00
Iteration	22	Cost: 7.268155e+00
Iteration	23	Cost: 7.268151e+00
Iteration	24	Cost: 7.268151e+00
Iteration	25	Cost: 7.268150e+00
Iteration	26	Cost: 7.268150e+00
Iteration	27	Cost: 7.268149e+00
Iteration	28	Cost: 7.268149e+00
Iteration	29	Cost: 7.268148e+00
Iteration	30	Cost: 7.268148e+00
Iteration	31	Cost: 7.268148e+00
Iteration	32	Cost: 7.268148e+00
Iteration	33	Cost: 7.268148e+00
Iteration	34	Cost: 7.268148e+00
Iteration	35	Cost: 7.268148e+00
Iteration	36	Cost: 7.268148e+00
Iteration	37	Cost: 7.268148e+00
Iteration	38	Cost: 7.268148e+00
Iteration	39	Cost: 7.268148e+00
Iteration	40	Cost: 7.268148e+00
Iteration	41	Cost: 7.268148e+00
Iteration	42	Cost: 7.268148e+00
Iteration	43	Cost: 7.268148e+00
Iteration	44	Cost: 7.268148e+00
Iteration	45	Cost: 7.268148e+00
Iteration	46	Cost: 7.268148e+00
Iteration	47	Cost: 7.268148e+00
Iteration	48	Cost: 7.268148e+00
Iteration	49	Cost: 7.268148e+00
Iteration	50	Cost: 7.268148e+00
Iteration	51	Cost: 7.268148e+00
Iteration	52	Cost: 7.268148e+00
Iteration	53	Cost: 7.268148e+00
Iteration	54	Cost: 7.268148e+00
Iteration	55	Cost: 7.268148e+00

Iteration	56	Cost: 7.268148e+00
Iteration	57	Cost: 7.268148e+00
Iteration	58	Cost: 7.268148e+00
Iteration	59	Cost: 7.268148e+00
Iteration	60	Cost: 7.268148e+00
Iteration	61	Cost: 7.268148e+00
Iteration	62	Cost: 7.268148e+00
Iteration	63	Cost: 7.268148e+00
Iteration	64	Cost: 7.268148e+00
Iteration	65	Cost: 7.268148e+00
Iteration	66	Cost: 7.268148e+00
Iteration	1	Cost: 8.416707e+01
Iteration	2	Cost: 3.345965e+01
Iteration	3	Cost: 2.112694e+01
Iteration	4	Cost: 1.621542e+01
Iteration	5	Cost: 1.605198e+01
Iteration	6	Cost: 1.596514e+01
Iteration	7	Cost: 1.596285e+01
Iteration	8	Cost: 1.592089e+01
Iteration	9	Cost: 1.589157e+01
Iteration	10	Cost: 1.589011e+01
Iteration	11	Cost: 1.587849e+01
Iteration	12	Cost: 1.587363e+01
Iteration	13	Cost: 1.586793e+01
Iteration	14	Cost: 1.586791e+01
Iteration	15	Cost: 1.586776e+01
Iteration	16	Cost: 1.586772e+01
Iteration	17	Cost: 1.586769e+01
Iteration	18	Cost: 1.586769e+01
Iteration	19	Cost: 1.586769e+01
Iteration	20	Cost: 1.586769e+01
Iteration	21	Cost: 1.586769e+01
Iteration	22	Cost: 1.586769e+01
Iteration	23	Cost: 1.586769e+01
Iteration	24	Cost: 1.586769e+01
Iteration	25	Cost: 1.586769e+01
Iteration	26	Cost: 1.586769e+01
Iteration	27	Cost: 1.586769e+01
Iteration	28	Cost: 1.586769e+01
Iteration	29	Cost: 1.586769e+01
Iteration	30	Cost: 1.586769e+01
Iteration	31	Cost: 1.586769e+01
Iteration	32	Cost: 1.586769e+01
Iteration	33	Cost: 1.586769e+01
Iteration	34	Cost: 1.586769e+01
Iteration	35	Cost: 1.586769e+01
Iteration	37	Cost: 1.586769e+01
Iteration	1	Cost: 8.751844e+01
Iteration	2	Cost: 4.781977e+01
Iteration	3	Cost: 3.633140e+01
Iteration	4	Cost: 3.345113e+01
Iteration	5	Cost: 3.340324e+01
Iteration	6	Cost: 3.337310e+01
Iteration	7	Cost: 3.337236e+01
Iteration	8	Cost: 3.337221e+01
Iteration	9	Cost: 3.337220e+01
Iteration	10	Cost: 3.337220e+01
Iteration	11	Cost: 3.337220e+01
Iteration	12	Cost: 3.337220e+01
Iteration	13	Cost: 3.337220e+01
Iteration	14	Cost: 3.337220e+01
Iteration	15	Cost: 3.337220e+01
Iteration	16	Cost: 3.337220e+01
Iteration	17	Cost: 3.337220e+01
Iteration	18	Cost: 3.337220e+01

```

plot(lambda_vec, error_train, lambda_vec, error_val);
legend('Train', 'Cross Validation');
xlabel('lambda');
ylabel('Error');

```



```

for i = 1:length(lambda_vec)
    if i == 1
        fprintf('lambda\t\tTrain Error\tValidation Error\n');
    end
    fprintf('%f\t%f\t%f\n',lambda_vec(i), error_train(i), error_val(i));
end

```

```

lambda  Train Error Validation Error
0.000000 0.183992 21.606375
0.001000 0.168849 19.419796
0.003000 0.179776 18.109898
0.010000 0.222494 17.065930
0.030000 0.281850 12.829251
0.100000 0.459318 7.587013
0.300000 0.921760 4.636833
1.000000 2.076188 4.260626
3.000000 4.901351 3.822907
10.000000 16.092213 9.945509

```

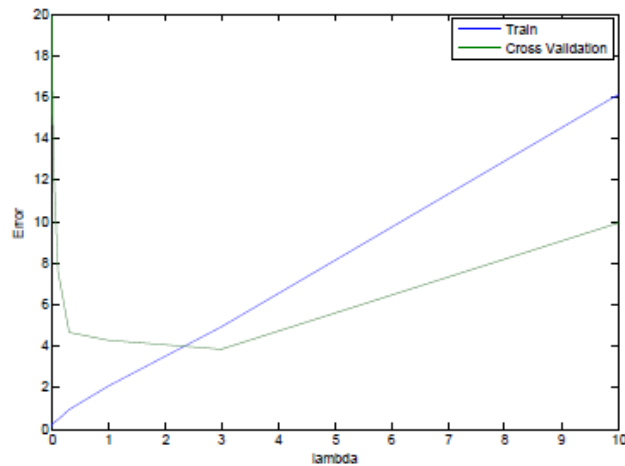


Figure 9: Selecting  $\lambda$  using a cross validation set

In this figure, we can see that the best value of  $\lambda$  is around 3. Due to randomness in the training and validation splits of the dataset, the cross validation error can sometimes be lower than the training error.

*You should now submit your solutions. Enter `submit` at the command prompt, then enter or confirm your login and token when prompted.*

### 3.4 Optional (ungraded) exercise: Computing test set error

In the previous part of the exercise, you implemented code to compute the cross validation error for various values of the regularization parameter  $\lambda$ . However, to get a better indication of the model's performance in the real world, it is important to evaluate the 'final' model on a test set that was not used in any part of training (that is, it was neither used to select the  $\lambda$  parameters, nor to learn the model parameters  $\theta$ ).

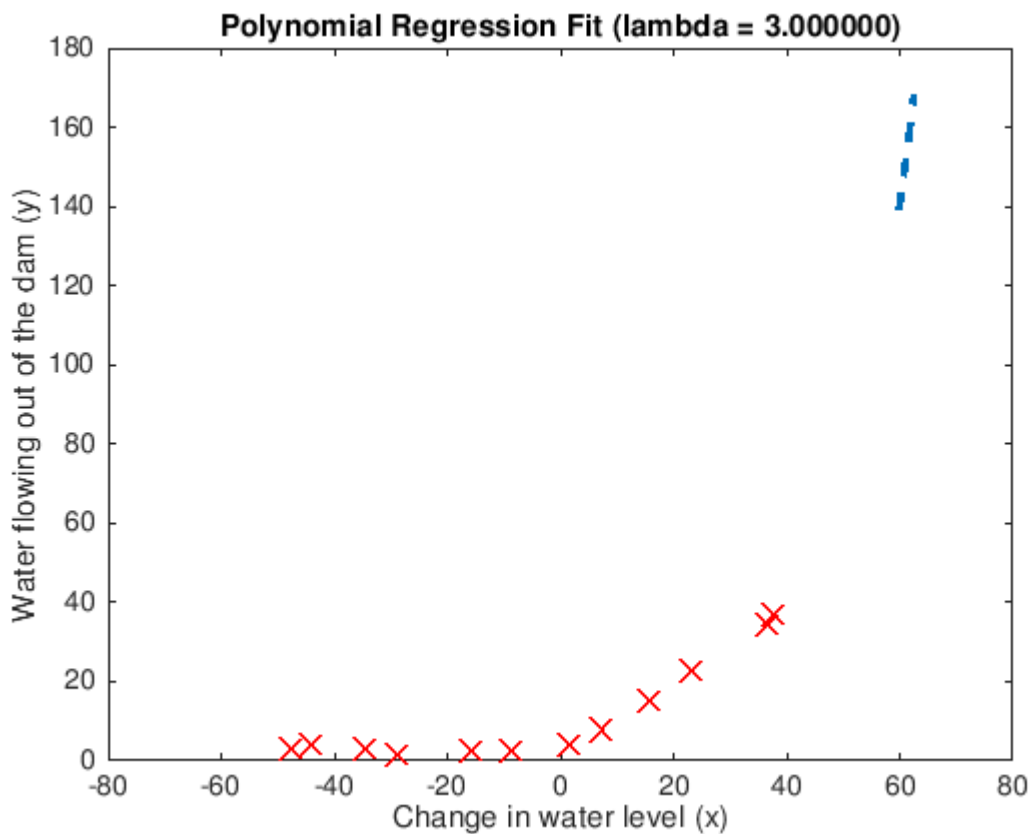
For this optional (ungraded) exercise, you should compute the test error using the best value of  $\lambda$  you found. In our cross validation, we obtained a test error of 3.8599 for  $\lambda = 3$ . You do not need to submit any solutions for this optional (ungraded) exercise.

```
%%%%%%%%% Add your code to compute the test error below %%%%%%%%%%%
lambda = 3;
[theta] = trainLinearReg(X_poly, y, lambda);
```

```
Iteration    1 | Cost: 8.416707e+01
Iteration    2 | Cost: 3.345965e+01
Iteration    3 | Cost: 2.112694e+01
Iteration    4 | Cost: 1.621542e+01
Iteration    5 | Cost: 1.605198e+01
Iteration    6 | Cost: 1.596514e+01
Iteration    7 | Cost: 1.596285e+01
Iteration    8 | Cost: 1.592089e+01
Iteration    9 | Cost: 1.589157e+01
Iteration   10 | Cost: 1.589011e+01
Iteration   11 | Cost: 1.587849e+01
Iteration   12 | Cost: 1.587363e+01
Iteration   13 | Cost: 1.586793e+01
```

Iteration	14	Cost: 1.586791e+01
Iteration	15	Cost: 1.586776e+01
Iteration	16	Cost: 1.586772e+01
Iteration	17	Cost: 1.586769e+01
Iteration	18	Cost: 1.586769e+01
Iteration	19	Cost: 1.586769e+01
Iteration	20	Cost: 1.586769e+01
Iteration	21	Cost: 1.586769e+01
Iteration	22	Cost: 1.586769e+01
Iteration	23	Cost: 1.586769e+01
Iteration	24	Cost: 1.586769e+01
Iteration	25	Cost: 1.586769e+01
Iteration	26	Cost: 1.586769e+01
Iteration	27	Cost: 1.586769e+01
Iteration	28	Cost: 1.586769e+01
Iteration	29	Cost: 1.586769e+01
Iteration	30	Cost: 1.586769e+01
Iteration	31	Cost: 1.586769e+01
Iteration	32	Cost: 1.586769e+01
Iteration	33	Cost: 1.586769e+01
Iteration	34	Cost: 1.586769e+01
Iteration	35	Cost: 1.586769e+01
Iteration	37	Cost: 1.586769e+01

```
% Plot training data and fit
plot(X, y, 'rx', 'MarkerSize', 10, 'LineWidth', 1.5);
plotFit(min(X), max(X), mu, sigma, theta, p);
xlabel('Change in water level (x)');
ylabel('Water flowing out of the dam (y)');
title(sprintf('Polynomial Regression Fit (lambda = %f)', lambda));
```



```
[error_train, error_test] = learningTestCurve(X_poly, y, X_poly_test, ytest, lambda);
```

Iteration	1	Cost: 9.061563e-01
Iteration	2	Cost: 5.521793e-03
Iteration	3	Cost: 5.471332e-03
Iteration	4	Cost: 3.507246e-04
Iteration	5	Cost: 2.448155e-04
Iteration	6	Cost: 1.126018e-04
Iteration	7	Cost: 9.643465e-06
Iteration	8	Cost: 2.205237e-07
Iteration	9	Cost: 1.378984e-07
Iteration	10	Cost: 2.215491e-08
Iteration	11	Cost: 2.020947e-08
Iteration	12	Cost: 4.298838e-09
Iteration	13	Cost: 4.533971e-27
Iteration	14	Cost: 3.406309e-31
Iteration	15	Cost: 5.957063e-32
Iteration	16	Cost: 3.234364e-34
Iteration	17	Cost: 1.491033e-60
Iteration	18	Cost: 1.901694e-61
Iteration	19	Cost: 7.805281e-64
Iteration	20	Cost: 3.203587e-66
Iteration	21	Cost: 1.314875e-68
Iteration	22	Cost: 5.396754e-71
Iteration	23	Cost: 2.215035e-73
Iteration	24	Cost: 9.091356e-76
Iteration	25	Cost: 3.731442e-78
Iteration	26	Cost: 1.531527e-80
Iteration	27	Cost: 6.285977e-83
Iteration	28	Cost: 2.580006e-85
Iteration	29	Cost: 1.058934e-87
Iteration	30	Cost: 4.346271e-90
Iteration	31	Cost: 1.783877e-92
Iteration	32	Cost: 7.321716e-95
Iteration	33	Cost: 3.005114e-97
Iteration	34	Cost: 1.233414e-99
Iteration	35	Cost: 5.062406e-102
Iteration	36	Cost: 2.077806e-104
Iteration	37	Cost: 8.528115e-107
Iteration	38	Cost: 3.500266e-109
Iteration	39	Cost: 1.436644e-111
Iteration	40	Cost: 5.896538e-114
Iteration	41	Cost: 2.420166e-116
Iteration	42	Cost: 9.933292e-119
Iteration	43	Cost: 4.077005e-121
Iteration	44	Cost: 1.673359e-123
Iteration	45	Cost: 6.868110e-126
Iteration	46	Cost: 2.818936e-128
Iteration	47	Cost: 1.157000e-130
Iteration	48	Cost: 4.748772e-133
Iteration	49	Cost: 1.949079e-135
Iteration	50	Cost: 7.999768e-138
Iteration	51	Cost: 3.283412e-140
Iteration	52	Cost: 1.347639e-142
Iteration	53	Cost: 5.531227e-145
Iteration	54	Cost: 2.270228e-147
Iteration	55	Cost: 9.317889e-150
Iteration	56	Cost: 3.824420e-152
Iteration	57	Cost: 1.569689e-154
Iteration	58	Cost: 6.442607e-157
Iteration	59	Cost: 2.644293e-159
Iteration	60	Cost: 1.085320e-161
Iteration	61	Cost: 4.454569e-164
Iteration	62	Cost: 1.828326e-166

Iteration	63	Cost: 7.504154e-169
Iteration	64	Cost: 3.079993e-171
Iteration	65	Cost: 1.264148e-173
Iteration	66	Cost: 5.188548e-176
Iteration	67	Cost: 2.129580e-178
Iteration	68	Cost: 8.740613e-181
Iteration	69	Cost: 3.587484e-183
Iteration	70	Cost: 1.472441e-185
Iteration	71	Cost: 6.043465e-188
Iteration	72	Cost: 2.480470e-190
Iteration	73	Cost: 1.018080e-192
Iteration	74	Cost: 4.178593e-195
Iteration	75	Cost: 1.715055e-197
Iteration	76	Cost: 7.039246e-200
Iteration	77	Cost: 2.889177e-202
Iteration	78	Cost: 1.185829e-204
Iteration	79	Cost: 4.867099e-207
Iteration	80	Cost: 1.997645e-209
Iteration	81	Cost: 8.199101e-212
Iteration	82	Cost: 3.365226e-214
Iteration	83	Cost: 1.381218e-216
Iteration	84	Cost: 5.669051e-219
Iteration	85	Cost: 2.326796e-221
Iteration	86	Cost: 9.550066e-224
Iteration	87	Cost: 3.919714e-226
Iteration	88	Cost: 1.608801e-228
Iteration	89	Cost: 6.603139e-231
Iteration	90	Cost: 2.710182e-233
Iteration	91	Cost: 1.112363e-235
Iteration	92	Cost: 4.565565e-238
Iteration	93	Cost: 1.873883e-240
Iteration	94	Cost: 7.691138e-243
Iteration	95	Cost: 3.156739e-245
Iteration	96	Cost: 1.295647e-247
Iteration	97	Cost: 5.317833e-250
Iteration	98	Cost: 2.182643e-252
Iteration	99	Cost: 8.958406e-255
Iteration	100	Cost: 3.676874e-257
Iteration	101	Cost: 1.509131e-259
Iteration	102	Cost: 6.194052e-262
Iteration	103	Cost: 2.542277e-264
Iteration	104	Cost: 1.043448e-266
Iteration	105	Cost: 4.282712e-269
Iteration	106	Cost: 1.757790e-271
Iteration	107	Cost: 7.214645e-274
Iteration	108	Cost: 2.961168e-276
Iteration	109	Cost: 1.215377e-278
Iteration	110	Cost: 4.988374e-281
Iteration	111	Cost: 2.047421e-283
Iteration	112	Cost: 8.403401e-286
Iteration	113	Cost: 3.449079e-288
Iteration	114	Cost: 1.415635e-290
Iteration	115	Cost: 5.810308e-293
Iteration	116	Cost: 2.384774e-295
Iteration	117	Cost: 9.788029e-298
Iteration	118	Cost: 4.017383e-300
Iteration	119	Cost: 1.648889e-302
Iteration	120	Cost: 6.767672e-305
Iteration	121	Cost: 2.777713e-307
Iteration	122	Cost: 1.140080e-309
Iteration	123	Cost: 0.000000e+00
Iteration	125	Cost: 0.000000e+00
Iteration	127	Cost: 0.000000e+00
Iteration	1	Cost: 4.377204e-01
Iteration	2	Cost: 1.043792e-01

Iteration	3	Cost: 9.652732e-02
Iteration	4	Cost: 9.652732e-02
Iteration	1	Cost: 5.829284e+01
Iteration	2	Cost: 4.414537e+01
Iteration	3	Cost: 4.252973e+01
Iteration	4	Cost: 4.235442e+01
Iteration	5	Cost: 4.229886e+01
Iteration	6	Cost: 4.227781e+01
Iteration	7	Cost: 4.227638e+01
Iteration	8	Cost: 4.227637e+01
Iteration	9	Cost: 4.227612e+01
Iteration	10	Cost: 4.227606e+01
Iteration	11	Cost: 4.227606e+01
Iteration	12	Cost: 4.227606e+01
Iteration	13	Cost: 4.227606e+01
Iteration	14	Cost: 4.227606e+01
Iteration	15	Cost: 4.227606e+01
Iteration	16	Cost: 4.227606e+01
Iteration	17	Cost: 4.227606e+01
Iteration	18	Cost: 4.227606e+01
Iteration	19	Cost: 4.227606e+01
Iteration	20	Cost: 4.227606e+01
Iteration	21	Cost: 4.227606e+01
Iteration	22	Cost: 4.227606e+01
Iteration	23	Cost: 4.227606e+01
Iteration	24	Cost: 4.227606e+01
Iteration	1	Cost: 4.938395e+01
Iteration	2	Cost: 4.241493e+01
Iteration	3	Cost: 4.041742e+01
Iteration	4	Cost: 3.743596e+01
Iteration	5	Cost: 3.653168e+01
Iteration	6	Cost: 3.638706e+01
Iteration	7	Cost: 3.636015e+01
Iteration	8	Cost: 3.634363e+01
Iteration	9	Cost: 3.633905e+01
Iteration	10	Cost: 3.633904e+01
Iteration	11	Cost: 3.633904e+01
Iteration	12	Cost: 3.633904e+01
Iteration	13	Cost: 3.633904e+01
Iteration	14	Cost: 3.633904e+01
Iteration	15	Cost: 3.633904e+01
Iteration	16	Cost: 3.633904e+01
Iteration	17	Cost: 3.633904e+01
Iteration	18	Cost: 3.633904e+01
Iteration	19	Cost: 3.633904e+01
Iteration	20	Cost: 3.633904e+01
Iteration	21	Cost: 3.633904e+01
Iteration	22	Cost: 3.633904e+01
Iteration	23	Cost: 3.633904e+01
Iteration	24	Cost: 3.633904e+01
Iteration	25	Cost: 3.633904e+01
Iteration	26	Cost: 3.633904e+01
Iteration	28	Cost: 3.633904e+01
Iteration	1	Cost: 1.023732e+02
Iteration	2	Cost: 5.465598e+01
Iteration	3	Cost: 3.841327e+01
Iteration	4	Cost: 3.042877e+01
Iteration	5	Cost: 3.001668e+01
Iteration	6	Cost: 2.998451e+01
Iteration	7	Cost: 2.958554e+01
Iteration	8	Cost: 2.938406e+01
Iteration	9	Cost: 2.920359e+01
Iteration	10	Cost: 2.913416e+01
Iteration	11	Cost: 2.910149e+01
Iteration	12	Cost: 2.909674e+01



Iteration	13	Cost: 2.909665e+01
Iteration	14	Cost: 2.909664e+01
Iteration	15	Cost: 2.909662e+01
Iteration	16	Cost: 2.909662e+01
Iteration	17	Cost: 2.909662e+01
Iteration	18	Cost: 2.909662e+01
Iteration	19	Cost: 2.909662e+01
Iteration	20	Cost: 2.909662e+01
Iteration	21	Cost: 2.909662e+01
Iteration	22	Cost: 2.909662e+01
Iteration	23	Cost: 2.909662e+01
Iteration	24	Cost: 2.909662e+01
Iteration	25	Cost: 2.909662e+01
Iteration	26	Cost: 2.909662e+01
Iteration	27	Cost: 2.909662e+01
Iteration	28	Cost: 2.909662e+01
Iteration	29	Cost: 2.909662e+01
Iteration	30	Cost: 2.909662e+01
Iteration	31	Cost: 2.909662e+01
Iteration	32	Cost: 2.909662e+01
Iteration	33	Cost: 2.909662e+01
Iteration	34	Cost: 2.909662e+01
Iteration	35	Cost: 2.909662e+01
Iteration	36	Cost: 2.909662e+01
Iteration	37	Cost: 2.909662e+01
Iteration	38	Cost: 2.909662e+01
Iteration	39	Cost: 2.909662e+01
Iteration	40	Cost: 2.909662e+01
Iteration	1	Cost: 7.974612e+01
Iteration	2	Cost: 3.681932e+01
Iteration	3	Cost: 3.082928e+01
Iteration	4	Cost: 2.744507e+01
Iteration	5	Cost: 2.725356e+01
Iteration	6	Cost: 2.649727e+01
Iteration	7	Cost: 2.589117e+01
Iteration	8	Cost: 2.582864e+01
Iteration	9	Cost: 2.579753e+01
Iteration	10	Cost: 2.579302e+01
Iteration	11	Cost: 2.578799e+01
Iteration	12	Cost: 2.578711e+01
Iteration	13	Cost: 2.578693e+01
Iteration	14	Cost: 2.578657e+01
Iteration	15	Cost: 2.578654e+01
Iteration	16	Cost: 2.578654e+01
Iteration	17	Cost: 2.578654e+01
Iteration	18	Cost: 2.578654e+01
Iteration	19	Cost: 2.578654e+01
Iteration	20	Cost: 2.578654e+01
Iteration	21	Cost: 2.578654e+01
Iteration	22	Cost: 2.578654e+01
Iteration	23	Cost: 2.578654e+01
Iteration	24	Cost: 2.578654e+01
Iteration	25	Cost: 2.578654e+01
Iteration	27	Cost: 2.578654e+01
Iteration	1	Cost: 8.304494e+01
Iteration	2	Cost: 3.043031e+01
Iteration	3	Cost: 2.286042e+01
Iteration	4	Cost: 2.269376e+01
Iteration	5	Cost: 2.269259e+01
Iteration	6	Cost: 2.269255e+01
Iteration	7	Cost: 2.269255e+01
Iteration	8	Cost: 2.269255e+01
Iteration	9	Cost: 2.269255e+01
Iteration	10	Cost: 2.269255e+01
Iteration	11	Cost: 2.269255e+01

Iteration	12	Cost: 2.269255e+01
Iteration	13	Cost: 2.269255e+01
Iteration	14	Cost: 2.269255e+01
Iteration	15	Cost: 2.269255e+01
Iteration	16	Cost: 2.269255e+01
Iteration	17	Cost: 2.269255e+01
Iteration	19	Cost: 2.269255e+01
Iteration	20	Cost: 2.269255e+01
Iteration	22	Cost: 2.269255e+01
Iteration	23	Cost: 2.269255e+01
Iteration	25	Cost: 2.269255e+01
Iteration	26	Cost: 2.269255e+01
Iteration	28	Cost: 2.269255e+01
Iteration	29	Cost: 2.269255e+01
Iteration	31	Cost: 2.269255e+01
Iteration	1	Cost: 7.294146e+01
Iteration	2	Cost: 2.595715e+01
Iteration	3	Cost: 2.022269e+01
Iteration	4	Cost: 1.992933e+01
Iteration	5	Cost: 1.992020e+01
Iteration	6	Cost: 1.992017e+01
Iteration	7	Cost: 1.992017e+01
Iteration	8	Cost: 1.992017e+01
Iteration	9	Cost: 1.992017e+01
Iteration	10	Cost: 1.992017e+01
Iteration	11	Cost: 1.992017e+01
Iteration	12	Cost: 1.992017e+01
Iteration	13	Cost: 1.992017e+01
Iteration	14	Cost: 1.992017e+01
Iteration	15	Cost: 1.992017e+01
Iteration	16	Cost: 1.992017e+01
Iteration	17	Cost: 1.992017e+01
Iteration	18	Cost: 1.992017e+01
Iteration	19	Cost: 1.992017e+01
Iteration	20	Cost: 1.992017e+01
Iteration	21	Cost: 1.992017e+01
Iteration	22	Cost: 1.992017e+01
Iteration	23	Cost: 1.992017e+01
Iteration	24	Cost: 1.992017e+01
Iteration	25	Cost: 1.992017e+01
Iteration	26	Cost: 1.992017e+01
Iteration	27	Cost: 1.992017e+01
Iteration	28	Cost: 1.992017e+01
Iteration	1	Cost: 6.775954e+01
Iteration	2	Cost: 2.291626e+01
Iteration	3	Cost: 1.941334e+01
Iteration	4	Cost: 1.903775e+01
Iteration	5	Cost: 1.860473e+01
Iteration	6	Cost: 1.856597e+01
Iteration	7	Cost: 1.853606e+01
Iteration	8	Cost: 1.852402e+01
Iteration	9	Cost: 1.851899e+01
Iteration	10	Cost: 1.851584e+01
Iteration	11	Cost: 1.851537e+01
Iteration	12	Cost: 1.851509e+01
Iteration	13	Cost: 1.851505e+01
Iteration	14	Cost: 1.851498e+01
Iteration	15	Cost: 1.851492e+01
Iteration	16	Cost: 1.851491e+01
Iteration	17	Cost: 1.851490e+01
Iteration	18	Cost: 1.851490e+01
Iteration	19	Cost: 1.851490e+01
Iteration	20	Cost: 1.851490e+01
Iteration	21	Cost: 1.851490e+01
Iteration	22	Cost: 1.851490e+01

Iteration	23	Cost: 1.851490e+01
Iteration	24	Cost: 1.851490e+01
Iteration	25	Cost: 1.851490e+01
Iteration	26	Cost: 1.851490e+01
Iteration	27	Cost: 1.851490e+01
Iteration	28	Cost: 1.851490e+01
Iteration	29	Cost: 1.851490e+01
Iteration	30	Cost: 1.851490e+01
Iteration	31	Cost: 1.851490e+01
Iteration	32	Cost: 1.851490e+01
Iteration	33	Cost: 1.851490e+01
Iteration	34	Cost: 1.851490e+01
Iteration	35	Cost: 1.851490e+01
Iteration	36	Cost: 1.851490e+01
Iteration	37	Cost: 1.851490e+01
Iteration	1	Cost: 8.076748e+01
Iteration	2	Cost: 3.723754e+01
Iteration	3	Cost: 1.907921e+01
Iteration	4	Cost: 1.744677e+01
Iteration	5	Cost: 1.704092e+01
Iteration	6	Cost: 1.684336e+01
Iteration	7	Cost: 1.676114e+01
Iteration	8	Cost: 1.671684e+01
Iteration	9	Cost: 1.669977e+01
Iteration	10	Cost: 1.669149e+01
Iteration	11	Cost: 1.668929e+01
Iteration	12	Cost: 1.668720e+01
Iteration	13	Cost: 1.668643e+01
Iteration	14	Cost: 1.668610e+01
Iteration	15	Cost: 1.668597e+01
Iteration	16	Cost: 1.668591e+01
Iteration	17	Cost: 1.668589e+01
Iteration	18	Cost: 1.668588e+01
Iteration	19	Cost: 1.668588e+01
Iteration	20	Cost: 1.668588e+01
Iteration	21	Cost: 1.668588e+01
Iteration	22	Cost: 1.668588e+01
Iteration	23	Cost: 1.668588e+01
Iteration	24	Cost: 1.668588e+01
Iteration	25	Cost: 1.668588e+01
Iteration	26	Cost: 1.668588e+01
Iteration	27	Cost: 1.668588e+01
Iteration	28	Cost: 1.668588e+01
Iteration	29	Cost: 1.668588e+01
Iteration	30	Cost: 1.668588e+01
Iteration	31	Cost: 1.668588e+01
Iteration	32	Cost: 1.668588e+01
Iteration	33	Cost: 1.668588e+01
Iteration	34	Cost: 1.668588e+01
Iteration	35	Cost: 1.668588e+01
Iteration	1	Cost: 7.371899e+01
Iteration	2	Cost: 3.189996e+01
Iteration	3	Cost: 1.633102e+01
Iteration	4	Cost: 1.536679e+01
Iteration	5	Cost: 1.529069e+01
Iteration	6	Cost: 1.524931e+01
Iteration	7	Cost: 1.523110e+01
Iteration	8	Cost: 1.520781e+01
Iteration	9	Cost: 1.520336e+01
Iteration	10	Cost: 1.519775e+01
Iteration	11	Cost: 1.519487e+01
Iteration	12	Cost: 1.519444e+01
Iteration	13	Cost: 1.519308e+01
Iteration	14	Cost: 1.519308e+01
Iteration	15	Cost: 1.519307e+01

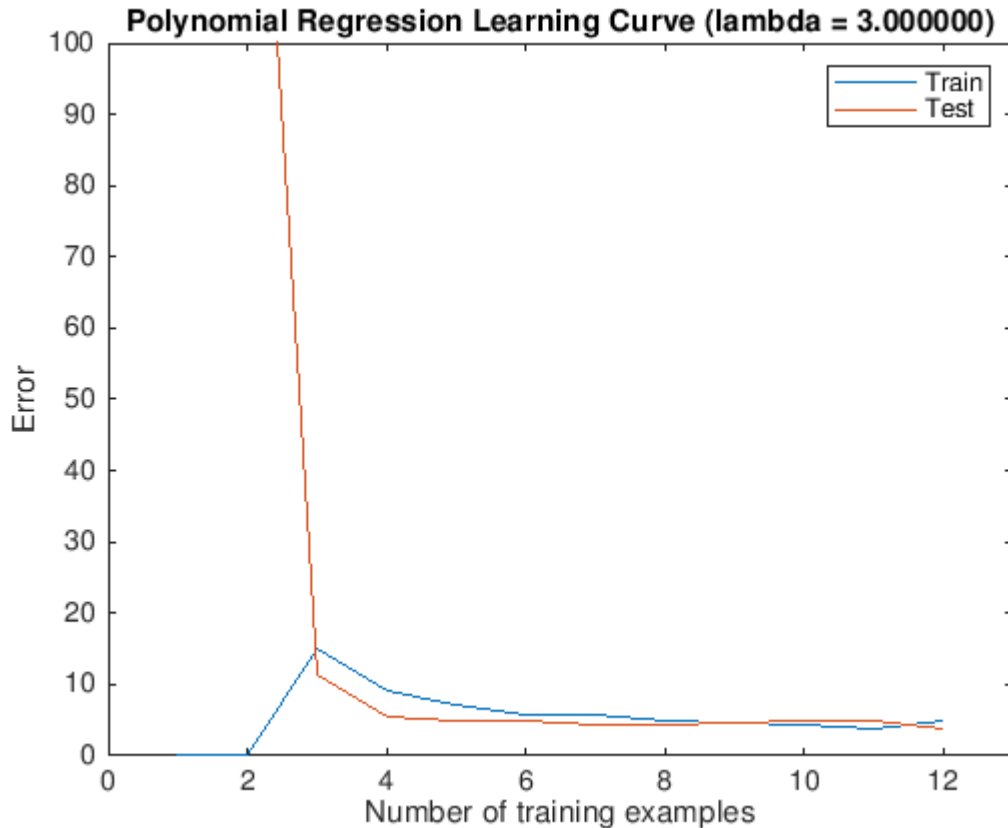
Iteration	16	Cost: 1.519306e+01
Iteration	17	Cost: 1.519306e+01
Iteration	18	Cost: 1.519306e+01
Iteration	19	Cost: 1.519306e+01
Iteration	20	Cost: 1.519306e+01
Iteration	21	Cost: 1.519306e+01
Iteration	22	Cost: 1.519306e+01
Iteration	23	Cost: 1.519306e+01
Iteration	24	Cost: 1.519306e+01
Iteration	25	Cost: 1.519306e+01
Iteration	26	Cost: 1.519306e+01
Iteration	27	Cost: 1.519306e+01
Iteration	28	Cost: 1.519306e+01
Iteration	29	Cost: 1.519306e+01
Iteration	30	Cost: 1.519306e+01
Iteration	31	Cost: 1.519306e+01
Iteration	32	Cost: 1.519306e+01
Iteration	33	Cost: 1.519306e+01
Iteration	34	Cost: 1.519306e+01
Iteration	35	Cost: 1.519306e+01
Iteration	36	Cost: 1.519306e+01
Iteration	37	Cost: 1.519306e+01
Iteration	38	Cost: 1.519306e+01
Iteration	1	Cost: 8.416707e+01
Iteration	2	Cost: 3.345965e+01
Iteration	3	Cost: 2.112694e+01
Iteration	4	Cost: 1.621542e+01
Iteration	5	Cost: 1.605198e+01
Iteration	6	Cost: 1.596514e+01
Iteration	7	Cost: 1.596285e+01
Iteration	8	Cost: 1.592089e+01
Iteration	9	Cost: 1.589157e+01
Iteration	10	Cost: 1.589011e+01
Iteration	11	Cost: 1.587849e+01
Iteration	12	Cost: 1.587363e+01
Iteration	13	Cost: 1.586793e+01
Iteration	14	Cost: 1.586791e+01
Iteration	15	Cost: 1.586776e+01
Iteration	16	Cost: 1.586772e+01
Iteration	17	Cost: 1.586769e+01
Iteration	18	Cost: 1.586769e+01
Iteration	19	Cost: 1.586769e+01
Iteration	20	Cost: 1.586769e+01
Iteration	21	Cost: 1.586769e+01
Iteration	22	Cost: 1.586769e+01
Iteration	23	Cost: 1.586769e+01
Iteration	24	Cost: 1.586769e+01
Iteration	25	Cost: 1.586769e+01
Iteration	26	Cost: 1.586769e+01
Iteration	27	Cost: 1.586769e+01
Iteration	28	Cost: 1.586769e+01
Iteration	29	Cost: 1.586769e+01
Iteration	30	Cost: 1.586769e+01
Iteration	31	Cost: 1.586769e+01
Iteration	32	Cost: 1.586769e+01
Iteration	33	Cost: 1.586769e+01
Iteration	34	Cost: 1.586769e+01
Iteration	35	Cost: 1.586769e+01
Iteration	37	Cost: 1.586769e+01

```

plot(1:m, error_train, 1:m, error_test);
title(sprintf('Polynomial Regression Learning Curve (lambda = %f)', lambda));
xlabel('Number of training examples')
ylabel('Error')

```

```
axis([0 13 0 100])
legend('Train', 'Test')
```



### 3.5 Optional (ungraded) exercise: Plotting learning curves with randomly selected examples

In practice, especially for small training sets, when you plot learning curves to debug your algorithms, it is often helpful to average across multiple sets of randomly selected examples to determine the training error and cross validation error. Concretely, to determine the training error and cross validation error for  $i$  examples, you should first randomly select  $i$  examples from the training set and  $i$  examples from the cross validation set. You will then learn the parameters  $\theta$  using the randomly chosen training set and evaluate the parameters  $\theta$  on the randomly chosen training set and cross validation set. The above steps should then be repeated multiple times (say 50) and the averaged error should be used to determine the training error and cross validation error for  $i$  examples.

For this optional (ungraded) exercise, you should implement the above strategy for computing the learning curves in `learningCurve.m` and use the code below to call your modified function and generate the plot.

```
lambda = 0.01;
[error_train, error_val] = learningCurve(X_poly, y, X_poly_val, yval, lambda);
```

Iteration	1	Cost: 3.405390e-01
Iteration	2	Cost: 4.988078e-03
Iteration	3	Cost: 2.151804e-04
Iteration	4	Cost: 1.111526e-04
Iteration	5	Cost: 5.971823e-05
Iteration	6	Cost: 1.149113e-06
Iteration	7	Cost: 1.118191e-06

Iteration	8	Cost: 5.589559e-07
Iteration	9	Cost: 2.324464e-08
Iteration	10	Cost: 2.323681e-08
Iteration	11	Cost: 2.302666e-08
Iteration	12	Cost: 1.565767e-09
Iteration	13	Cost: 1.565301e-09
Iteration	14	Cost: 1.550797e-09
Iteration	15	Cost: 1.155016e-09
Iteration	16	Cost: 3.935095e-11
Iteration	17	Cost: 7.975049e-12
Iteration	18	Cost: 3.409301e-12
Iteration	19	Cost: 3.922709e-13
Iteration	20	Cost: 1.698440e-14
Iteration	21	Cost: 4.687336e-15
Iteration	22	Cost: 6.861766e-18
Iteration	23	Cost: 6.835508e-18
Iteration	24	Cost: 6.798111e-18
Iteration	25	Cost: 6.620210e-18
Iteration	26	Cost: 4.598923e-18
Iteration	27	Cost: 2.294184e-18
Iteration	28	Cost: 1.296869e-18
Iteration	29	Cost: 3.290841e-19
Iteration	30	Cost: 4.838789e-22
Iteration	31	Cost: 4.818622e-22
Iteration	32	Cost: 4.790295e-22
Iteration	33	Cost: 4.648769e-22
Iteration	34	Cost: 3.089710e-22
Iteration	35	Cost: 1.287347e-22
Iteration	36	Cost: 6.830497e-23
Iteration	37	Cost: 6.395066e-23
Iteration	38	Cost: 5.532981e-24
Iteration	39	Cost: 8.958818e-26
Iteration	40	Cost: 4.293080e-27
Iteration	41	Cost: 1.153867e-35
Iteration	42	Cost: 8.766474e-36
Iteration	43	Cost: 2.308782e-38
Iteration	44	Cost: 6.599136e-66
Iteration	45	Cost: 9.729824e-69
Iteration	46	Cost: 3.520809e-70
Iteration	47	Cost: 2.997065e-99
Iteration	48	Cost: 5.669035e-100
Iteration	49	Cost: 6.515388e-129
Iteration	50	Cost: 1.748404e-133
Iteration	51	Cost: 3.101442e-158
Iteration	52	Cost: 7.517268e-163
Iteration	53	Cost: 1.264575e-186
Iteration	54	Cost: 2.887328e-192
Iteration	55	Cost: 1.306844e-214
Iteration	56	Cost: 4.076765e-221
Iteration	57	Cost: 4.103311e-243
Iteration	58	Cost: 4.011396e-251
Iteration	59	Cost: 1.241270e-271
Iteration	60	Cost: 2.345621e-280
Iteration	61	Cost: 6.563317e-300
Iteration	62	Cost: 4.406174e-310
Iteration	63	Cost: 0.000000e+00
Iteration	1	Cost: 5.523568e-02
Iteration	2	Cost: 3.367312e-03
Iteration	3	Cost: 3.036905e-03
Iteration	4	Cost: 3.001266e-03
Iteration	5	Cost: 2.090248e-03
Iteration	6	Cost: 1.932836e-03
Iteration	7	Cost: 1.930413e-03
Iteration	8	Cost: 1.930097e-03
Iteration	9	Cost: 1.930032e-03

Iteration	10	Cost: 1.930016e-03
Iteration	11	Cost: 1.930016e-03
Iteration	12	Cost: 1.930015e-03
Iteration	13	Cost: 1.930015e-03
Iteration	14	Cost: 1.930015e-03
Iteration	15	Cost: 1.930014e-03
Iteration	16	Cost: 1.930013e-03
Iteration	17	Cost: 1.930013e-03
Iteration	18	Cost: 1.930013e-03
Iteration	19	Cost: 1.930013e-03
Iteration	20	Cost: 1.930013e-03
Iteration	21	Cost: 1.930013e-03
Iteration	22	Cost: 1.930013e-03
Iteration	23	Cost: 1.930013e-03
Iteration	24	Cost: 1.930013e-03
Iteration	25	Cost: 1.930013e-03
Iteration	26	Cost: 1.930013e-03
Iteration	27	Cost: 1.930013e-03
Iteration	28	Cost: 1.930013e-03
Iteration	29	Cost: 1.930013e-03
Iteration	30	Cost: 1.930013e-03
Iteration	31	Cost: 1.930013e-03
Iteration	32	Cost: 1.930013e-03
Iteration	33	Cost: 1.930013e-03
Iteration	34	Cost: 1.930013e-03
Iteration	35	Cost: 1.930013e-03
Iteration	36	Cost: 1.930013e-03
Iteration	37	Cost: 1.930013e-03
Iteration	38	Cost: 1.930013e-03
Iteration	39	Cost: 1.930013e-03
Iteration	40	Cost: 1.930013e-03
Iteration	41	Cost: 1.930013e-03
Iteration	42	Cost: 1.930013e-03
Iteration	43	Cost: 1.930013e-03
Iteration	44	Cost: 1.930013e-03
Iteration	45	Cost: 1.930013e-03
Iteration	46	Cost: 1.930013e-03
Iteration	47	Cost: 1.930013e-03
Iteration	48	Cost: 1.930013e-03
Iteration	50	Cost: 1.930013e-03
Iteration	1	Cost: 3.032734e+01
Iteration	2	Cost: 1.226927e+00
Iteration	3	Cost: 7.383164e-01
Iteration	4	Cost: 2.727993e-01
Iteration	5	Cost: 2.622976e-01
Iteration	6	Cost: 2.616915e-01
Iteration	7	Cost: 2.612460e-01
Iteration	8	Cost: 2.600987e-01
Iteration	9	Cost: 2.597820e-01
Iteration	10	Cost: 2.293193e-01
Iteration	11	Cost: 2.245222e-01
Iteration	12	Cost: 2.233166e-01
Iteration	13	Cost: 2.216354e-01
Iteration	14	Cost: 2.211828e-01
Iteration	15	Cost: 2.208628e-01
Iteration	16	Cost: 2.207706e-01
Iteration	17	Cost: 2.207157e-01
Iteration	18	Cost: 2.206993e-01
Iteration	19	Cost: 2.206900e-01
Iteration	20	Cost: 2.206839e-01
Iteration	21	Cost: 2.206780e-01
Iteration	22	Cost: 2.206654e-01
Iteration	23	Cost: 2.206531e-01
Iteration	24	Cost: 2.206316e-01
Iteration	25	Cost: 2.206177e-01

Iteration	26	Cost: 2.206126e-01
Iteration	27	Cost: 2.205934e-01
Iteration	28	Cost: 2.205838e-01
Iteration	29	Cost: 2.205405e-01
Iteration	30	Cost: 2.205062e-01
Iteration	31	Cost: 2.203766e-01
Iteration	32	Cost: 2.202748e-01
Iteration	33	Cost: 2.201954e-01
Iteration	34	Cost: 2.201533e-01
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Iteration	193	Cost: 1.352881e-01
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Iteration	195	Cost: 1.352877e-01
Iteration	196	Cost: 1.352876e-01
Iteration	197	Cost: 1.352874e-01
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Iteration	199	Cost: 1.352873e-01
Iteration	200	Cost: 1.352873e-01
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Iteration	3	Cost: 1.918807e+00
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Iteration	5	Cost: 3.343811e-01
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Iteration	8	Cost: 1.614093e-01
Iteration	9	Cost: 1.607878e-01
Iteration	10	Cost: 1.603904e-01
Iteration	11	Cost: 1.595788e-01
Iteration	12	Cost: 1.584840e-01
Iteration	13	Cost: 1.578635e-01
Iteration	14	Cost: 1.577248e-01
Iteration	15	Cost: 1.575202e-01
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Iteration	18	Cost: 1.570784e-01
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Iteration	105	Cost: 1.400176e-01
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Iteration	9	Cost: 1.070866e+00
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Iteration	53	Cost: 2.240634e-01
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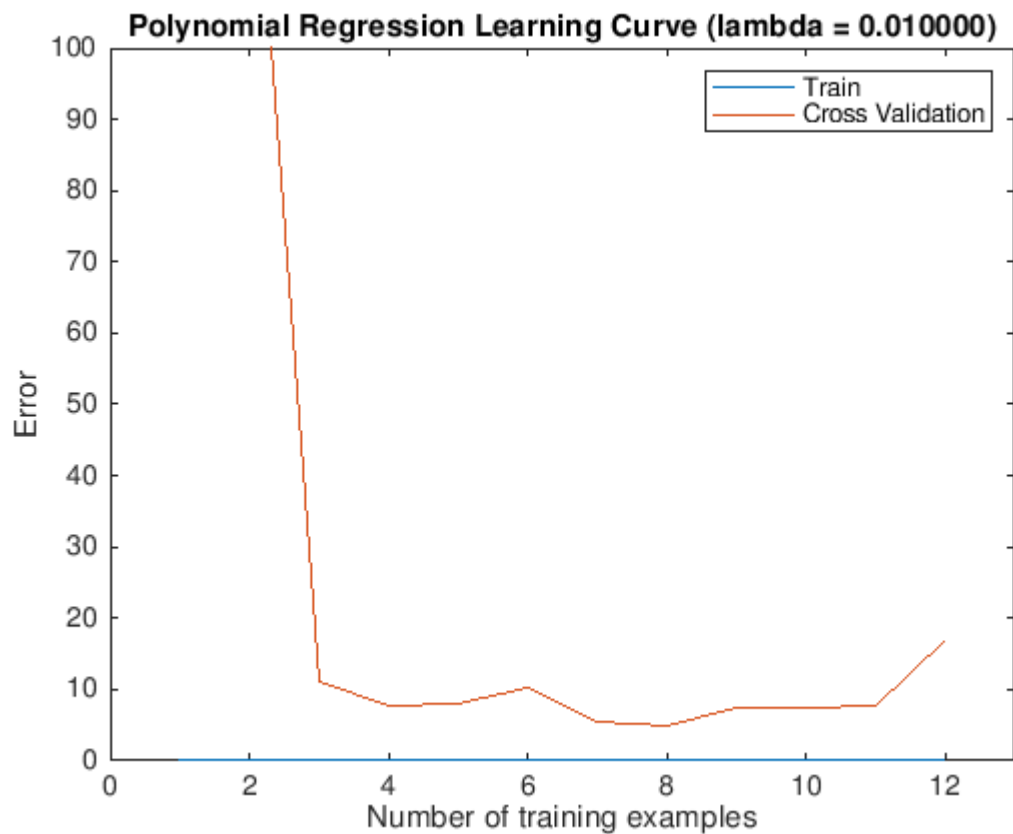
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Iteration	154	Cost: 3.729829e-01
Iteration	155	Cost: 3.729804e-01
Iteration	156	Cost: 3.729791e-01
Iteration	157	Cost: 3.729635e-01
Iteration	158	Cost: 3.729634e-01
Iteration	159	Cost: 3.729619e-01
Iteration	160	Cost: 3.729617e-01
Iteration	161	Cost: 3.729609e-01
Iteration	162	Cost: 3.729601e-01
Iteration	163	Cost: 3.729579e-01
Iteration	164	Cost: 3.729575e-01
Iteration	165	Cost: 3.729523e-01...

```

plot(1:m, error_train, 1:m, error_val);

title(sprintf('Polynomial Regression Learning Curve (lambda = %f)', lambda));
xlabel('Number of training examples')
ylabel('Error')
axis([0 13 0 100])
legend('Train', 'Cross Validation')

```



For reference, Figure 10 shows the learning curve we obtained for polynomial regression with  $\lambda = 0.01$ .

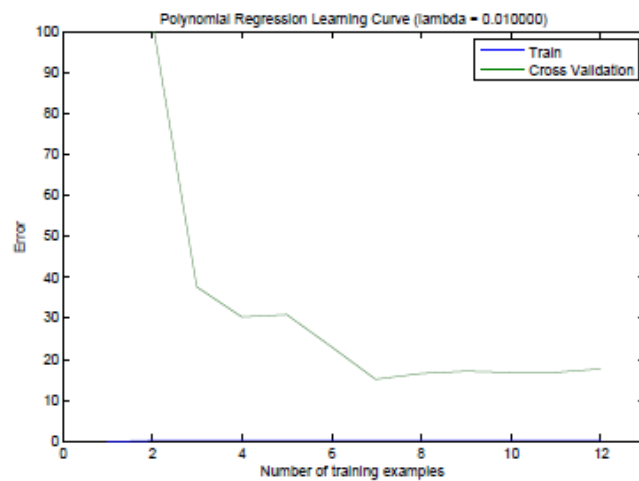


Figure 10: Optional (ungraded) exercise: Learning curve with randomly selected examples

Your figure may differ slightly due to the random selection of examples.

*You do not need to submit any solutions for this optional (ungraded) exercise.*

## Submission and Grading

After completing various parts of the assignment, be sure to use the submit function system to submit your solutions to our servers. The following is a breakdown of how each part of this exercise is scored.

Part	Submitted File	Points
Regularized Linear Regression Cost Function	linearRegCostFunction.m	25 points
Regularized Linear Regression Gradient	linearRegCostFunction.m	25 points
Learning Curve	learningCurve.m	20 points
Polynomial Feature Mapping	polyFeatures.m	10 points
Cross Validation Curve	validationCurve.m	20 points
Total Points		100 points

You are allowed to submit your solutions multiple times, and we will take only the highest score into consideration.