# Machine Learning: Programming Exercise 8

## Anomaly Detection and Recommender Systems

In this exercise, you will implement the anomaly detection algorithm and apply it to detect failing servers on a network. In the second part, you will use collaborative filtering to build a recommender system for movies.

### Files needed for this exercise

- `ex8.mlx` - MATLAB Live Script that steps you through the exercise
- `ex8data1.mat` - First example Dataset for anomaly detection
- `ex8data2.mat` - Second example Dataset for anomaly detection
- `ex8_movies.mat` - Movie Review Dataset
- `ex8_movieParams.mat` - Parameters provided for debugging
- `multivariateGaussian.m` - Computes the probability density function for a Gaussian distribution
- `visualizeFit.m` - 2D plot of a Gaussian distribution and a dataset
- `checkCostFunction.m` - Gradient checking for collaborative filtering
- `computeNumericalGradient.m` - Numerically compute gradients
- `fmincg.m` - Function minimization routine (similar to `fminunc`)
- `loadMovieList.m` - Loads the list of movies into a cell-array
- movie_ids.txt - List of movies
- `normalizeRatings.m` - Mean normalization for collaborative filtering
- `submit.m` - Submission script that sends your solutions to our servers
- `*estimateGaussian.m` - Estimate the parameters of a Gaussian distribution with a diagonal covariance matrix
- `*selectThreshold.m` - Find a threshold for anomaly detection
- `*cofiCostFunc.m` - Implement the cost function for collaborative filtering

**** indicates files you will need to complete***

### 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. Anomaly Detection

In this exercise, you will implement an anomaly detection algorithm to detect anomalous behavior in server computers. The features measure the throughput (mb/s) and latency (ms) of response of each server. While your servers were operating, you collected $m = 307$ examples of how they were behaving, and thus have an unlabeled dataset $\{x^{(1)}, \ldots, x^{(m)}\}$. You suspect that the vast majority of these examples are 'normal' (non-anomalous) examples of the servers operating normally, but there might also be some examples of servers acting anomalously within this dataset.

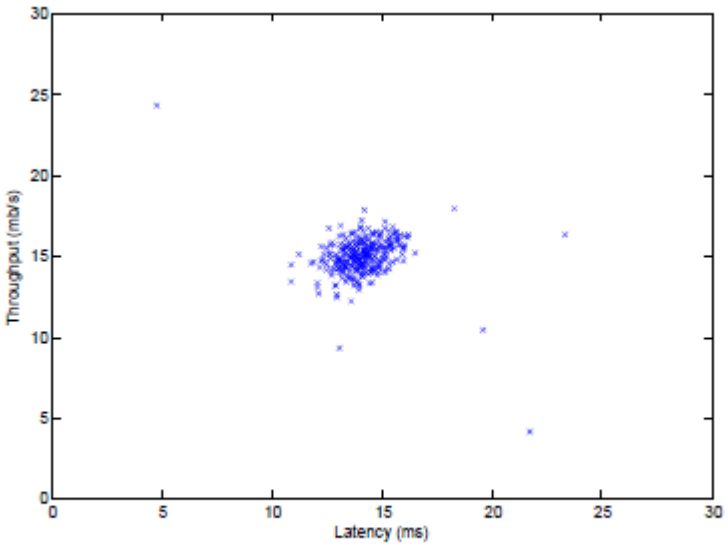
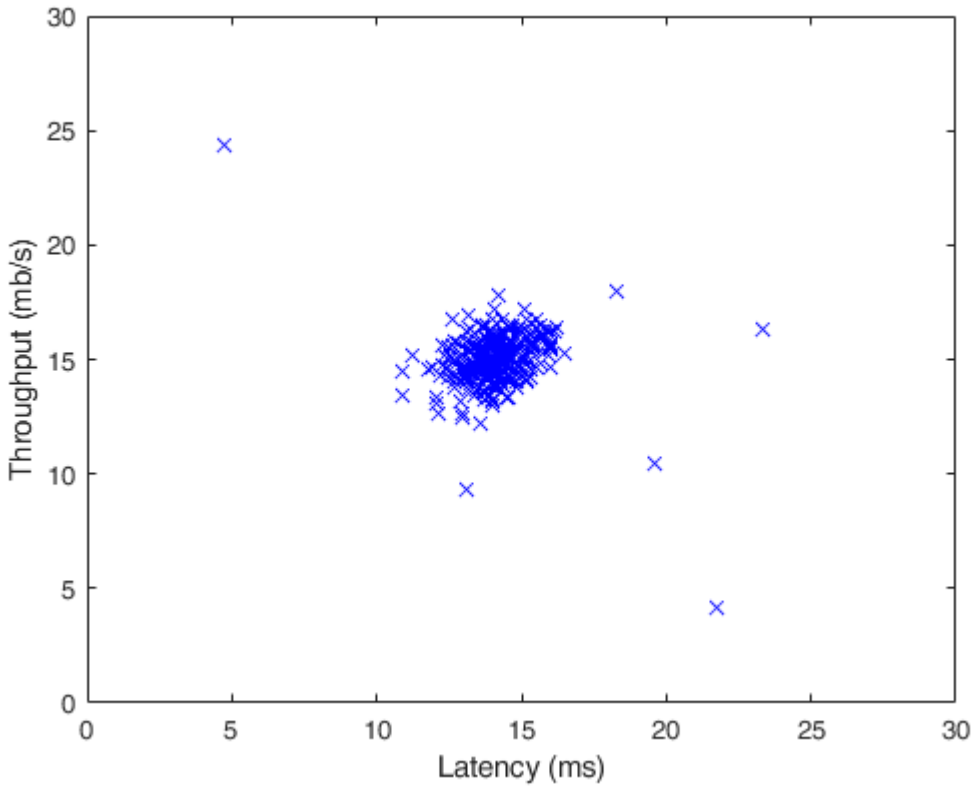



Figure 1: The first dataset.

You will use a Gaussian model to detect anomalous examples in your dataset. You will first start on a 2D dataset that will allow you to visualize what the algorithm is doing. On that dataset you will fit a Gaussian distribution and then find values that have very low probability and hence can be considered anomalies. After that, you will apply the anomaly detection algorithm to a larger dataset with many dimensions. The code below will visualize the dataset as shown in Figure 1.

```
% The following command loads the dataset. You should now have the variables X, Xval, y
load('ex8data1.mat');

% Visualize the example dataset
plot(X(:, 1), X(:, 2), 'bx');
axis([0 30 0 30]);
xlabel('Latency (ms)');
ylabel('Throughput (mb/s)');
```




## 1.1 Gaussian distribution

To perform anomaly detection, you will first need to fit a model to the data's distribution. Given a training set $\{x^{(1)}, \ldots, x^{(m)}\}$ (where $x^{(i)} \in \mathbb{R}^n$), you want to estimate the Gaussian distribution for each of the features $x_i$. For each feature $i = 1 \ldots n$ you need to find parameters $\mu_i$ and $\sigma_i^2$ that fit the data in the *i*-th dimension $\{x_i^{(1)}, \ldots, x_i^{(m)}\}$ (the *i*-th dimension of each example).

The Gaussian distribution is given by

$$p(x; \mu, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

where $\mu$ is the mean and $\sigma^2$ controls the variance.

## 1.2 Estimating parameters for a Gaussian

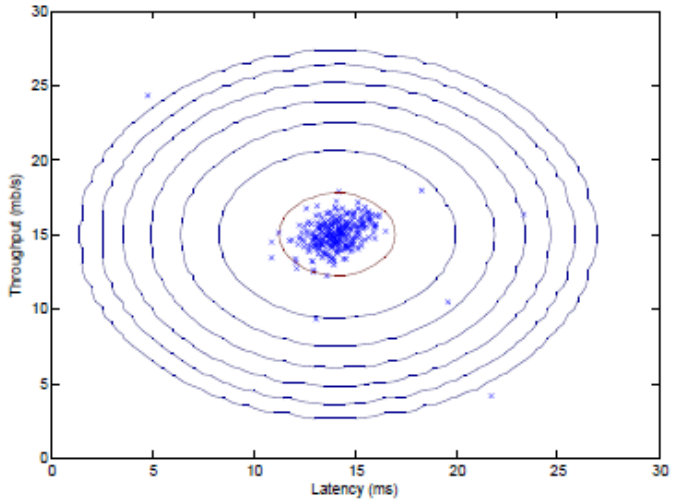
You can estimate the parameters, $(\mu_i, \sigma_i^2)$, of the *i*-th feature by using the following equations. To estimate the mean, you will use:

$$\mu_i = \frac{1}{m}\sum_{j=1}^{m} x^{(j)},$$

and for the variance you will use:

$$\sigma_i^2 = \frac{1}{m}\sum_{j=1}^{m} (x^{(j)} - \mu_j)^2.$$

Your task is to complete the code in `estimateGaussian.m`. This function takes as input the data matrix `X` and should output an *n*-dimension vector `mu` that holds the mean of all the *n* features and another *n*-dimension vector `sigma2` that holds the variances of all the features. You can implement this using a `for` loop over every feature and every training example (though a vectorized implementation might be more efficient; feel free to use a vectorized implementation if you prefer). Note that in MATLAB, the `var` function will (by default) use $\frac{1}{m-1}$, instead of $\frac{1}{m}$ when computing $\sigma_i^2$.



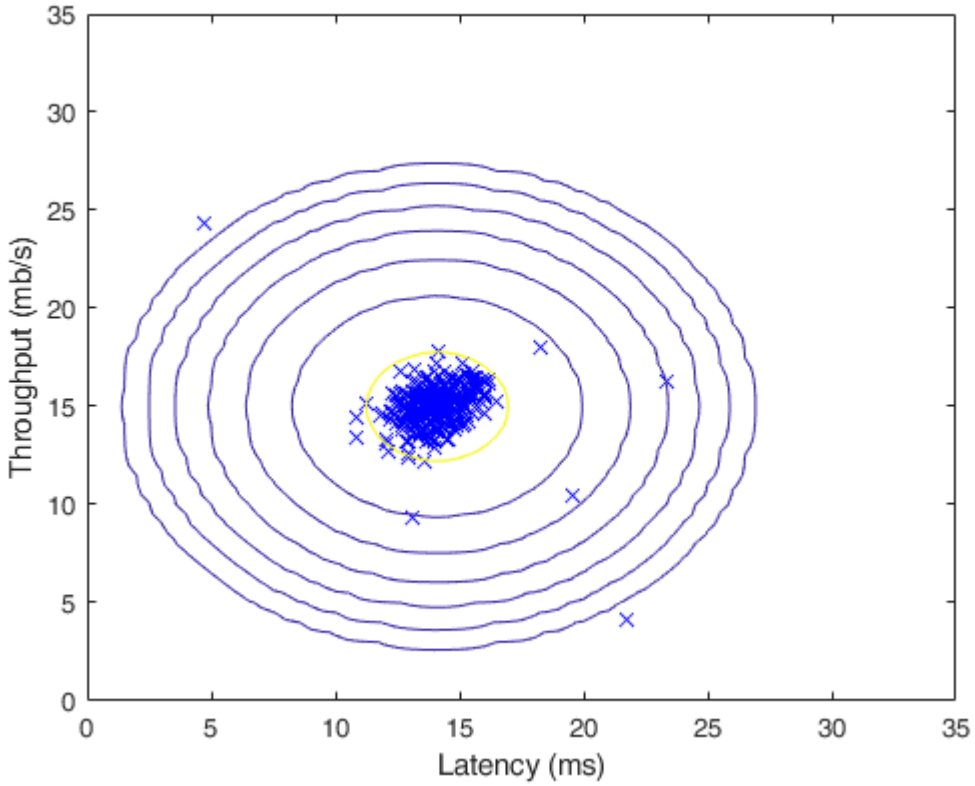

Once you have completed the code in `estimateGaussian.m`, the code below will visualize the contours of the fitted Gaussian distribution. You should get a plot similar to Figure 2. From your plot, you can see that most of the examples are in the region with the highest probability, while the anomalous examples are in the regions with lower probabilities.

```
%  Estimate mu and sigma2
[mu, sigma2] = estimateGaussian(X);

%  Returns the density of the multivariate normal at each data point (row) of X
p = multivariateGaussian(X, mu, sigma2);

%  Visualize the fit
visualizeFit(X,  mu, sigma2);
xlabel('Latency (ms)');
```

```
ylabel('Throughput (mb/s)');
```




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

### 1.3 Selecting the threshold, $\epsilon$

Now that you have estimated the Gaussian parameters, you can investigate which examples have a very high probability given this distribution and which examples have a very low probability. The low probability examples are more likely to be the anomalies in our dataset. One way to determine which examples are anomalies is to select a threshold based on a cross validation set. In this part of the exercise, you will implement an algorithm to select the threshold $\epsilon$ using the $F_1$ score on a cross validation set.

You should now complete the code in `selectThreshold.m`. For this, we will use a cross validation set $\{(x_{cv}^{(1)}, y_{cv}^{(1)}), \ldots, (x_{cv}^{(m)}, y_{cv}^{(m)})\}$, where the label $y = 1$ corresponds to an anomalous example, and $y = 0$ corresponds to a normal example. For each cross validation example, we will compute $p(x_{cv}^{(i)})$. The vector of all of these probabilities $p(x_{cv}^{(1)}), \ldots, p(x_{cv}^{(m)})$ is passed to `selectThreshold.m` in the vector `pval`. The corresponding labels $y_{cv}^{(1)}, \ldots, y_{cv}^{(m)}$ is passed to the same function in the vector `yval`.

The function `selectThreshold.m` should return two values; the first is the selected threshold $\epsilon$. If an example $x$ has a low probability $p(x) < \epsilon$, then it is considered to be an anomaly. The function should also return the $F_1$ score, which tells you how well you're doing on finding the ground truth anomalies given a certain threshold.

For many different values of $\epsilon$, you will compute the resulting $F_1$ score by computing how many examples the current threshold classifies correctly and incorrectly.

The $F_1$ score is computed using precision (*prec*) and recall (*rec*):

$$F_1 = \frac{2(prec)(rec)}{prec + rec},$$

You compute precision and recall by:

$$prec = \frac{tp}{tp + fp}$$

$$rec = \frac{tp}{tp + fn}$$

where

- $tp$ is the number of true positives: the ground truth label says it's an anomaly and our algorithm correctly classified it as an anomaly.
- $fp$ is the number of false positives: the ground truth label says it's not an anomaly, but our algorithm incorrectly classified it as an anomaly.
- $fn$ is the number of false negatives: the ground truth label says it's an anomaly, but our algorithm incorrectly classified it as not being anomalous.

In the provided code `selectThreshold.m`, there is already a loop that will try many different values of $\epsilon$ and select the "best" based $\epsilon$ on the $F_1$ score. You should now complete the code in `selectThreshold.m`. You can implement the computation of the $F_1$ score using a `for` loop over all the cross validation examples (to compute the values $tp$, $fp$, and $fn$. You should see a value for epsilon of about `8.99e-05`.

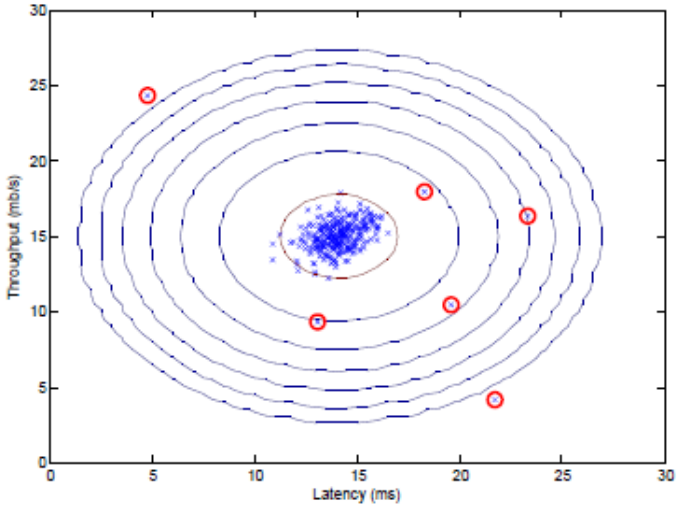



Figure 3: The classified anomalies.

**Implementation Note**: In order to compute $tp$, $fp$, and $fn$, you may be able to use a vectorized implementation rather than loop over all the examples. This can be implemented by MATLAB's equality test between a vector and a single number. If you have several binary values in an *n*-dimensional binary vector $v \in \{0, 1\}^n$, you can find out how many values in this vector are 0 by using: `sum(v == 0)`. You can also apply a logical *and* operator to such binary vectors. For instance, let `cvPredictions` be a binary vector of the size of your cross validation set, where the *i*-th element is 1 if your algorithm considers $x_{cv}^{(i)}$ an anomaly, and 0 otherwise. You can then, for example, compute the number of false positives using: `fp = sum((cvPredictions == 1) & (yval == 0))`.

Once you have completed the code in `selectThreshold.m`, the code below will detect and circle the anomalies in the plot (Figure 3).

```
pval = multivariateGaussian(Xval, mu, sigma2);

[epsilon, F1] = selectThreshold(yval, pval);
fprintf('Best epsilon found using cross-validation: %e\n', epsilon);
```

```
Best epsilon found using cross-validation: 8.990853e-05
```

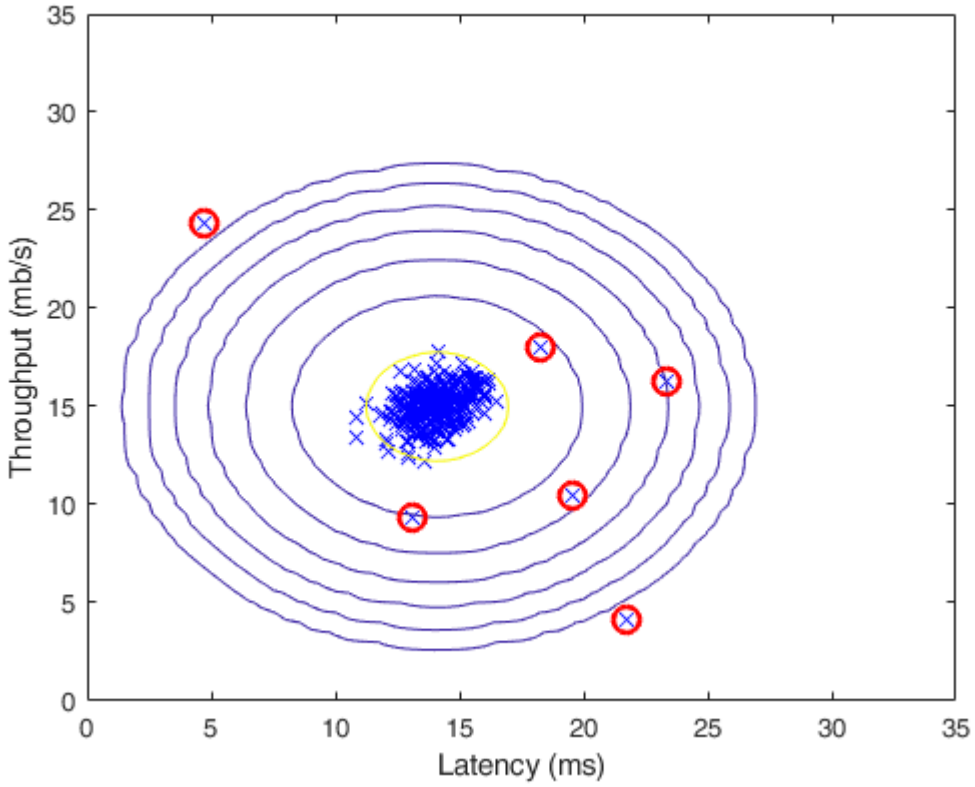
```
fprintf('Best F1 on Cross Validation Set:  %f\n', F1);
```

```
Best F1 on Cross Validation Set:  0.875000
```

```


%  Find the outliers in the training set and plot the
outliers = find(p < epsilon);

%  Visualize the fit
visualizeFit(X,  mu, sigma2);
xlabel('Latency (ms)');
ylabel('Throughput (mb/s)');
%  Draw a red circle around those outliers
hold on
plot(X(outliers, 1), X(outliers, 2), 'ro', 'LineWidth', 2, 'MarkerSize', 10);
hold off
```




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

### 1.4 High dimensional dataset

The code in this section will run the anomaly detection algorithm you implemented on a more realistic and much harder dataset. In this dataset, each example is described by 11 features, capturing many more properties of your compute servers. The code below will use your code to estimate the Gaussian parameters ($\mu_i$ and $\sigma_i^2$), evaluate the probabilities for both the training data `X` from which you estimated the Gaussian parameters, and do so for the the cross-validation set `Xval`. Finally, it will use `selectThreshold` to find the best threshold $\epsilon$. You should see a value `epsilon` of about `1.38e-18`, and 117 anomalies found.

```
%  Loads the second dataset. You should now have the variables X, Xval, yval in your en
load('ex8data2.mat');

%  Apply the same steps to the larger dataset
[mu, sigma2] = estimateGaussian(X);

%  Training set
p = multivariateGaussian(X, mu, sigma2);

%  Cross-validation set
pval = multivariateGaussian(Xval, mu, sigma2);
```

```
%  Find the best threshold
[epsilon, F1] = selectThreshold(yval, pval);
fprintf('Best epsilon found using cross-validation: %e\n', epsilon);
```

```
Best epsilon found using cross-validation: 1.377229e-18
```

```
fprintf('Best F1 on Cross Validation Set:  %f\n', F1);
```

```
Best F1 on Cross Validation Set:  0.615385
```

```
fprintf('# Outliers found: %d\n', sum(p < epsilon));
```

```
# Outliers found: 117
```

## 2. Recommender Systems

In this part of the exercise, you will implement the collaborative filtering learning algorithm and apply it to a dataset of movie ratings*. This dataset consists of ratings on a scale of 1 to 5. The dataset has $n_u = 943$ users, and $n_m = 1682$ movies. In the next parts of this exercise, you will implement the function `cofiCostFunc.m` that computes the collaborative fitlering objective function and gradient. After implementing the cost function and gradient, you will use `fmincg.m` to learn the parameters for collaborative filtering.

*MovieLens 100k Dataset from GroupLens Research.

### 2.1 Movie ratings dataset

The code in this section will load the dataset `ex8_movies.mat`, providing the variables Y and R in your MATLAB environment. The matrix Y (a `num_movies` × `num_users` matrix) stores the ratings $y^{(i,j)}$ (from 1 to 5). The matrix R is an binary-valued indicator matrix, where `R(i,j) = 1` if user `j` gave a rating to movie `i`, and `R(i,j) = 0` otherwise. The objective of collaborative filtering is to predict movie ratings for the movies that users have not yet rated, that is, the entries with `R(i,j) = 0`. This will allow us to recommend the movies with the highest predicted ratings to the user.

To help you understand the matrix Y, the code below will compute the average movie rating for the first movie (Toy Story) and output the average rating to the screen. Throughout this part of the exercise, you will also be working with the matrices, X and `Theta`:

$$\texttt{X} = \begin{bmatrix} - (x^{(1)})^T - \\ - (x^{(2)})^T - \\ \vdots \\ - (x^{(n_m)})^T - \end{bmatrix}, \quad \texttt{Theta} = \begin{bmatrix} - (\theta^{(1)})^T - \\ - (\theta^{(2)})^T - \\ \vdots \\ - (\theta^{(n_u)})^T - \end{bmatrix}.$$

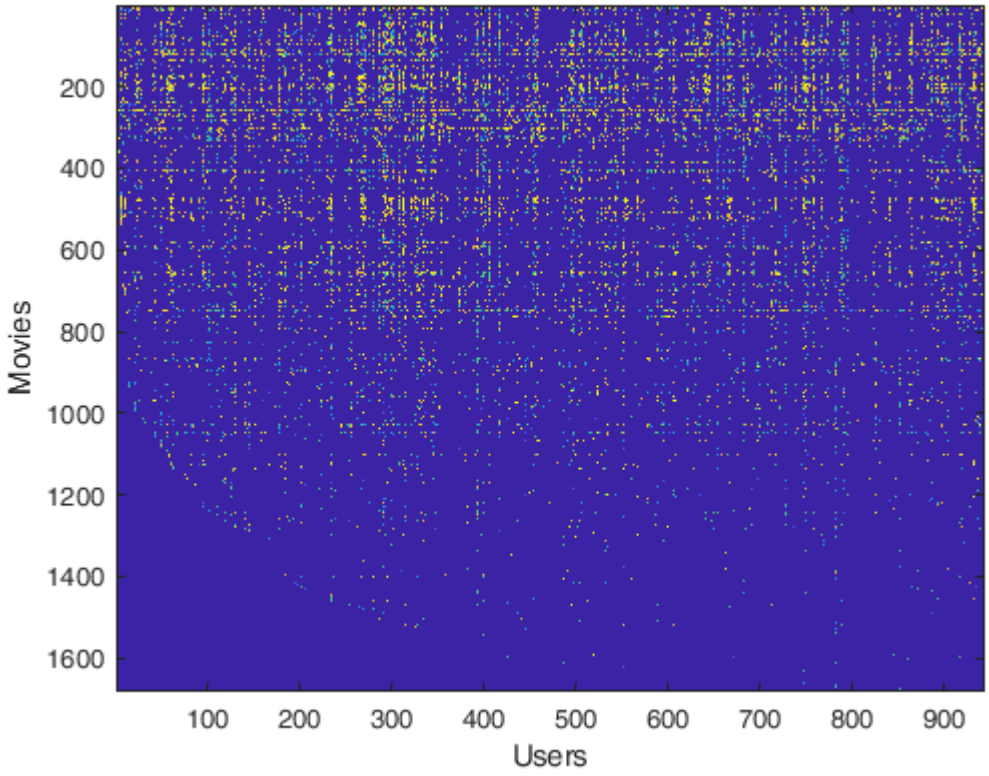
```
% Load data
load('ex8_movies.mat');
```

- Y is a 1682 x 943 matrix, containing ratings (1 - 5) of 1682 movies on 943 users
- R is a 1682 x 943 matrix, where `R(i,j)` = 1 if and only if user `j` gave a rating to movie `i`

```
% From the matrix, we can compute statistics like average rating.
fprintf('Average rating for movie 1 (Toy Story): %f / 5\n\n', mean(Y(1, R(1, :))));
```

```
Average rating for movie 1 (Toy Story): 3.878319 / 5
```

```
%  We can "visualize" the ratings matrix by plotting it with imagesc
imagesc(Y);
ylabel('Movies');
xlabel('Users');
```




The *i*-th row of X corresponds to the feature vector $x^{(i)}$ for the *i*-th movie, and the *j*-th row of Theta corresponds to one parameter vector $\theta^{(j)}$, for the *j*-th user. Both $x^{(i)}$ and $\theta^{(j)}$ are *n*-dimensional vectors. For the purposes of this exercise, you will use $n = 100$, and therefore, $x^{(i)} \in \mathbb{R}^{100}$ and $\theta^{(j)} \in \mathbb{R}^{100}$. Correspondingly, X is a $n_m \times 100$ matrix and Theta is a $n_u \times 100$ matrix.

## 2.2 Collaborative filtering learning algorithm

Now, you will start implementing the collaborative filtering learning algorithm. You will start by implementing the cost function (without regularization). The collaborative filtering algorithm in the setting of movie recommendations considers a set of *n*-dimensional parameter vectors $x^{(1)}, \ldots, x^{(n_m)}$ and $\theta^{(1)}, \ldots, \theta^{(n_u)}$, where the model predicts the rating for movie *i* by user *j* as $y^{(i,j)} = (\theta^{(j)})^T x^{(i)}$. Given a dataset that consists of a set of ratings produced by some users on some movies, you wish to learn the parameter vectors $x^{(1)}, \ldots, x^{(n_m)}, \theta^{(1)}, \ldots, \theta^{(n_u)}$ that produce the best fit (minimizes the squared error).

You will complete the code in `cofiCostFunc.m` to compute the cost function and gradient for collaborative filtering. Note that the parameters to the function (i.e., the values that you are trying to learn) are `X` and `Theta`. In order to use an off-the-shelf minimizer such as `fmincg`, the cost function has been set up to unroll the parameters into a single vector `params`. You had previously used the same vector unrolling method in the neural networks programming exercise.

### 2.2.1 Collaborative filtering cost function

The collaborative filtering cost function (without regularization) is given by

$$J\left(x^{(i)}, \ldots, x^{(n_m)}, \theta^{(1)}, \ldots, \theta^{(n_u)}\right) = \frac{1}{2} \sum_{(i,j):r(i,j)=1} \left((\theta^{(j)})^T x^{(i)} - y^{(i,j)}\right)^2$$

You should now modify `cofiCostFunc.m` to return this cost in the variable `J`. Note that you should be accumulating the cost for user *j* and movie *i* only if $R(i, j) = 1$. After you have completed the function, the code below will run your cost function. You should expect to see an output of `22.22`.

**Implementation Note:** We strongly encourage you to use a vectorized implementation to compute `J`, since it will later by called many times by the optimization package `fmincg`. As usual, it might be easiest to first write a non-vectorized implementation (to make sure you have the right answer), and the modify it to become a vectorized implementation (checking that the vectorization steps don't change your algorithm's output). To come up with a vectorized implementation, the following tip might be helpful: You can use the `R` matrix to set selected entries to 0. For example, `R.*M` will do an element-wise multiplication between `M` and `R`; since `R` only has elements with values either 0 or 1, this has the effect of setting the elements of `M` to 0 only when the corresponding value in `R` is 0. Hence, `sum(sum(R.*M))` is the sum of all the elements of `M` for which the corresponding element in `R` equals 1.

```
%  Load pre-trained weights (X, Theta, num_users, num_movies, num_features)
load('ex8_movieParams.mat');

%  Reduce the data set size so that this runs faster
num_users = 4; num_movies = 5; num_features = 3;
X = X(1:num_movies, 1:num_features);
Theta = Theta(1:num_users, 1:num_features);
Y = Y(1:num_movies, 1:num_users);
R = R(1:num_movies, 1:num_users);

%  Evaluate cost function
J = cofiCostFunc([X(:); Theta(:)],  Y, R, num_users, num_movies,num_features, 0);
fprintf('Cost at loaded parameters: %f ',J);
```

```
Cost at loaded parameters: 22.224604
```

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

### 2.2.2 Collaborative filtering gradient

Now, you should implement the gradient (without regularization). Specically, you should complete the code in `cofiCostFunc.m` to return the variables `X_grad` and `Theta_grad`. Note that `X_grad` should be a matrix of the same size as `X` and similarly, `Theta_grad` is a matrix of the same size as `Theta`. The gradients of the cost function is given by:

$$\frac{\partial J}{\partial x_k^{(i)}} = \sum_{j:r(i,j)=1} ((\theta^{(j)})^T x^{(i)} - y^{(i,j)})\theta_k^{(j)}$$

$$\frac{\partial J}{\partial \theta_k^{(j)}} = \sum_{i:r(i,j)=1} ((\theta^{(j)})^T x^{(i)} - y^{(i,j)})x_k^{(i)}$$

Note that the function returns the gradient for both sets of variables by unrolling them into a single vector. After you have completed the code to compute the gradients, the code below will run a gradient check (`checkCostFunction`) to numerically check the implementation of your gradients. (This is similar to the numerical check that you used in the neural networks exercise.) If your implementation is correct, you should find that the analytical and numerical gradients match up closely.

**Implementation Note**: You can get full credit for this assignment without using a vectorized implementation, but your code will run much more slowly (a small number of hours), and so we recommend that you try to vectorize your implementation. To get started, you can implement the gradient with a `for` loop over movies (for computing $\frac{\partial J}{\partial x_k^{(i)}}$) and a `for` loop over users (for computing $\frac{\partial J}{\partial \theta_k^{(j)}}$). When you first implement the gradient, you might start with an unvectorized version, by implementing another inner `for` loop that computes each element in the summation. After you have completed the gradient computation this way, you should try to vectorize your implementation (vectorize the inner `for` loops), so that you're left with only two `for` loops (one for looping over movies to compute $\frac{\partial J}{\partial x_k^{(i)}}$ for each movie, and one for looping over users to compute $\frac{\partial J}{\partial \theta_k^{(j)}}$ for each user).

To perform the vectorization, you might find this helpful: You should come up with a way to compute all the derivatives associated with $x_1^{(i)}, x_2^{(i)}, \ldots, x_n^{(i)}$, (i.e., the derivative terms associated with the feature vector $x^{(i)}$) at the same time. Let us define the derivatives for the feature vector of the *i*-th movie as:

$$(\mathrm{X}_{\mathrm{grad}}(\mathrm{i},:))^T = \begin{bmatrix} \frac{\partial J}{\partial x_1^{(i)}} \\ \frac{\partial J}{\partial x_2^{(i)}} \\ \vdots \\ \frac{\partial J}{\partial x_n^{(i)}} \end{bmatrix} = \sum\nolimits_{j:r(i,j)=1} \left((\theta^{(j)})^T x^{(i)} - y^{(i,j)}\right) \theta^{(j)}$$

To vectorize the above expression, you can start by indexing into `Theta` and `Y` to select only the elements of interest (that is, those with $r(i, j) = 1$). Intuitively, when you consider the features for the *i*-th movie, you only

need to be concerned about the users who had given ratings to the movie, and this allows you to remove all the other users from Theta and Y.

Concretely, you can set `idx = find(R(i,:)==1)` to be a list of all the users that have rated movie *i*. This will allow you to create the temporary matrices `Theta_temp = Theta(idx,:)` and `Y_temp = Y(i,idx)` that index into Theta and Y to give you only the set of users which have rated the *i*-th movie. This will allow you to write the derivatives as:

$$\mathrm{X}_{\mathrm{grad}}(i,:) = \left(\mathrm{X}(i,:) * \mathrm{Theta}_{\mathrm{temp}}^{T} - \mathrm{Y}_{\mathrm{temp}}\right) * \mathrm{Theta}_{\mathrm{temp}}.$$

(Note: The vectorized computation above returns a row-vector instead.) After you have vectorized the computations of the derivatives with respect to $x^{(i)}$, you should use a similar method to vectorize the derivatives with respect to $\theta^{(j)}$ as well.

```
%  Check gradients by running checkNNGradients
checkCostFunction;
```

```
    0.9845    0.9845
   -1.2717   -1.2717
   -1.7052   -1.7052
         0         0
   -3.7928   -3.7928
    1.9492    1.9492
    1.3028    1.3028
         0         0
   -4.7722   -4.7722
    0.9211    0.9211
    1.1007    1.1007
         0         0
    1.3446    1.3446
    1.2473    1.2473
    0.8016    0.8016
    0.9625    0.9625
    0.9625    0.9625
    0.2862    0.2862
   -0.4118   -0.4118
   -0.6227   -0.6227
   -0.3178   -0.3178
   -1.4399   -1.4399
    0.6779    0.6779
   -3.1014   -3.1014
   -2.1479   -2.1479
   -2.3931   -2.3931
   -2.4436   -2.4436

The above two columns you get should be very similar.
(Left-Your Numerical Gradient, Right-Analytical Gradient)

If your cost function implementation is correct, then
the relative difference will be small (less than 1e-9).

Relative Difference: 1.11346e-12
```

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

### 2.2.3 Regularized cost function

The cost function for collaborative filtering with regularization is given by

$$J\left(x^{(i)},\ldots,x^{(n_m)},\theta^{(1)},\ldots,\theta^{(n_u)}\right)=\frac{1}{2}\sum_{(i,j):r(i,j)=1}((\theta^{(j)})^Tx^{(i)}-y^{(i,j)})^2+\left(\frac{\lambda}{2}\sum_{j=1}^{n_u}\sum_{k=1}^{n}(\theta_k^{(j)})^2\right)+\left(\frac{\lambda}{2}\sum_{i=1}^{n_m}\sum_{k=1}^{n}(x_k^{(i)})^2\right)$$

You should now add regularization to your original computations of the cost function, *J*. After you are done, the code below will run your regularized cost function, and you should expect to see a cost of about `31.34`.

```
%  Evaluate cost function
J = cofiCostFunc([X(:); Theta(:)], Y, R, num_users, num_movies, num_features, 1.5);
fprintf('Cost at loaded parameters (lambda = 1.5): %f',J);
```

```
Cost at loaded parameters (lambda = 1.5): 31.344056
```

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

### 2.2.4 Regularized gradient

Now that you have implemented the regularized cost function, you should proceed to implement regularization for the gradient. You should add to your implementation in `cofiCostFunc.m` to return the regularized gradient by adding the contributions from the regularization terms. Note that the gradients for the regularized cost function is given by:

$$\frac{\partial J}{\partial x_k^{(i)}}=\sum_{j:r(i,j)=1}((\theta^{(j)})^Tx^{(i)}-y^{(i,j)})\theta_k^{(j)}+\lambda x_k^{(i)}$$

$$\frac{\partial J}{\partial \theta_k^{(j)}}=\sum_{i:r(i,j)=1}((\theta^{(j)})^Tx^{(i)}-y^{(i,j)})x_k^{(i)}+\lambda \theta_k^{(j)}$$

This means that you just need to add $\lambda x^{(i)}$ to the `X_grad(i,:)` variable described earlier, and add $\lambda\theta^{(j)}$ to the `Theta_grad(j,:)` variable described earlier. After you have completed the code to compute the gradients, the code below will run another gradient check (`checkCostFunction`) to numerically check the implementation of your gradients.

```
%  Check gradients by running checkNNGradients
checkCostFunction(1.5);
```

```
    3.4242    3.4242
    6.1585    6.1585
    1.2582    1.2582
    1.9691    1.9691
    1.2582    1.2582
    2.1379    2.1379
   -0.3135   -0.3135
    5.4827    5.4827
    2.6294    2.6294
    2.0589    2.0589
    1.8886    1.8886
    2.9244    2.9244
```

```
   -4.5459   -4.5459
   -0.6346   -0.6346
   -0.6762   -0.6762
   -0.8616   -0.8616
    5.1261    5.1261
   -2.7808   -2.7808
   -0.8750   -0.8750
   -2.4140   -2.4140
   -2.6094   -2.6094
    0.6716    0.6716
   -1.0020   -1.0020
    2.2311    2.2311
   -0.8498   -0.8498
   -2.6674   -2.6674
    2.9236    2.9236

The above two columns you get should be very similar.
(Left-Your Numerical Gradient, Right-Analytical Gradient)

If your cost function implementation is correct, then
the relative difference will be small (less than 1e-9).

Relative Difference: 1.75986e-12
```

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

### 2.3 Learning movie recommendations

After you have finished implementing the collaborative ltering cost function and gradient, you can now start training your algorithm to make movie recommendations for yourself. In the code below, you can enter your own movie preferences, so that later when the algorithm runs, you can get your own movie recommendations! We have filled out some values according to our own preferences, but you should change this according to your own tastes. The list of all movies and their number in the dataset can be found listed in the file movie idx.txt.

```
% Load movvie list
movieList = loadMovieList();

% Initialize my ratings
my_ratings = zeros(1682, 1);

% Check the file movie_idx.txt for id of each movie in our dataset
% For example, Toy Story (1995) has ID 1, so to rate it "4", you can set
my_ratings(1) = 1;
% Or suppose did not enjoy Silence of the Lambs (1991), you can set
my_ratings(98) = 1;

% We have selected a few movies we liked / did not like and the ratings we gave are as
my_ratings(3) = 1;
my_ratings(120)= 1;
my_ratings(504) = 1;
my_ratings(64)= 1;
my_ratings(66)= 1;
my_ratings(609) = 1;
my_ratings(13) = 1;
```

```
my_ratings(226) = 1;
my_ratings(455)= 1;
my_ratings(5) = 1;
my_ratings(124)= 1;
my_ratings(508) = 1;
my_ratings(67)= 1;
my_ratings(79)= 1;
my_ratings(701) = 1;
my_ratings(17) = 1;
my_ratings(240) = 1;
my_ratings(425)= 1;
my_ratings(1) = 1;
my_ratings(150)= 1;
my_ratings(604) = 1;
my_ratings(84)= 1;
my_ratings(36)= 1;
my_ratings(809) = 1;
my_ratings(43) = 1;
my_ratings(626) = 1;
my_ratings(855)= 1;

fprintf('\n\nNew user ratings:\n');
```

```
New user ratings:
```

```
for i = 1:length(my_ratings)
    if my_ratings(i) > 0
        fprintf('Rated %d for %s\n', my_ratings(i), movieList{i});
    end
end
```

```
Rated 1 for Toy Story (1995)
Rated 1 for Four Rooms (1995)
Rated 1 for Copycat (1995)
Rated 1 for Mighty Aphrodite (1995)
Rated 1 for From Dusk Till Dawn (1996)
Rated 1 for Mad Love (1995)
Rated 1 for Disclosure (1994)
Rated 1 for Shawshank Redemption, The (1994)
Rated 1 for While You Were Sleeping (1995)
Rated 1 for Ace Ventura: Pet Detective (1994)
Rated 1 for Fugitive, The (1993)
Rated 1 for Robert A. Heinlein's The Puppet Masters (1994)
Rated 1 for Silence of the Lambs, The (1991)
Rated 1 for Striptease (1996)
Rated 1 for Lone Star (1996)
Rated 1 for Swingers (1996)
Rated 1 for Die Hard 2 (1990)
Rated 1 for Beavis and Butt-head Do America (1996)
Rated 1 for Bob Roberts (1992)
Rated 1 for Jackie Chan's First Strike (1996)
Rated 1 for Bonnie and Clyde (1967)
Rated 1 for People vs. Larry Flynt, The (1996)
Rated 1 for It Happened One Night (1934)
Rated 1 for Father of the Bride (1950)
Rated 1 for So Dear to My Heart (1949)
Rated 1 for Wonderful, Horrible Life of Leni Riefenstahl, The (1993)
Rated 1 for Rising Sun (1993)
Rated 1 for Diva (1981)
```

### 2.3.1 Recommendations

After the additional ratings have been added to the dataset, the code below will proceed to train the collaborative filtering model. This will learn the parameters X and Theta.

```
%  Load data
load('ex8_movies.mat');

%  Y is a 1682x943 matrix, containing ratings (1-5) of 1682 movies by 943 users
%  R is a 1682x943 matrix, where R(i,j) = 1 if and only if user j gave a rating to movi
%  Add our own ratings to the data matrix
Y = [my_ratings Y];
R = [(my_ratings ~= 0) R];

%  Normalize Ratings
[Ynorm, Ymean] = normalizeRatings(Y, R);

%  Useful Values
num_users = size(Y, 2);
num_movies = size(Y, 1);
num_features = 10;

% Set Initial Parameters (Theta, X)
X = randn(num_movies, num_features);
Theta = randn(num_users, num_features);
initial_parameters = [X(:); Theta(:)];

% Set options for fmincg
options = optimset('GradObj','on','MaxIter',100);

% Set Regularization
lambda = 1;
theta = fmincg(@(t)(cofiCostFunc(t, Ynorm, R, num_users, num_movies, num_features,lamba
```

```
Iteration     1 | Cost: 2.130577e+05
Iteration     2 | Cost: 1.315644e+05
Iteration     3 | Cost: 8.016154e+04
Iteration     4 | Cost: 6.296153e+04
Iteration     5 | Cost: 5.536330e+04
Iteration     6 | Cost: 5.092473e+04
Iteration     7 | Cost: 4.816057e+04
Iteration     8 | Cost: 4.545415e+04
Iteration     9 | Cost: 4.375668e+04
Iteration    10 | Cost: 4.155424e+04
Iteration    11 | Cost: 4.053754e+04
Iteration    12 | Cost: 3.966576e+04
Iteration    13 | Cost: 3.785635e+04
Iteration    14 | Cost: 3.603902e+04
Iteration    15 | Cost: 3.513054e+04
Iteration    16 | Cost: 3.445254e+04
Iteration    17 | Cost: 3.390751e+04
Iteration    18 | Cost: 3.278036e+04
Iteration    19 | Cost: 3.184985e+04
Iteration    20 | Cost: 3.131003e+04
Iteration    21 | Cost: 3.094990e+04
Iteration    22 | Cost: 3.052527e+04
Iteration    23 | Cost: 3.012898e+04
```

```
Iteration    24 | Cost: 2.971727e+04
Iteration    25 | Cost: 2.938344e+04
Iteration    26 | Cost: 2.913142e+04
Iteration    27 | Cost: 2.885986e+04
Iteration    28 | Cost: 2.870532e+04
Iteration    29 | Cost: 2.864174e+04
Iteration    30 | Cost: 2.847465e+04
Iteration    31 | Cost: 2.838313e+04
Iteration    32 | Cost: 2.831022e+04
Iteration    33 | Cost: 2.821678e+04
Iteration    34 | Cost: 2.808867e+04
Iteration    35 | Cost: 2.799438e+04
Iteration    36 | Cost: 2.794095e+04
Iteration    37 | Cost: 2.788280e+04
Iteration    38 | Cost: 2.773684e+04
Iteration    39 | Cost: 2.762933e+04
Iteration    40 | Cost: 2.756596e+04
Iteration    41 | Cost: 2.748338e+04
Iteration    42 | Cost: 2.744715e+04
Iteration    43 | Cost: 2.742560e+04
Iteration    44 | Cost: 2.739474e+04
Iteration    45 | Cost: 2.736754e+04
Iteration    46 | Cost: 2.735673e+04
Iteration    47 | Cost: 2.731510e+04
Iteration    48 | Cost: 2.727430e+04
Iteration    49 | Cost: 2.723627e+04
Iteration    50 | Cost: 2.719905e+04
Iteration    51 | Cost: 2.716078e+04
Iteration    52 | Cost: 2.711259e+04
Iteration    53 | Cost: 2.709418e+04
Iteration    54 | Cost: 2.707739e+04
Iteration    55 | Cost: 2.705684e+04
Iteration    56 | Cost: 2.703567e+04
Iteration    57 | Cost: 2.701314e+04
Iteration    58 | Cost: 2.700030e+04
Iteration    59 | Cost: 2.699551e+04
Iteration    60 | Cost: 2.697546e+04
Iteration    61 | Cost: 2.696793e+04
Iteration    62 | Cost: 2.696549e+04
Iteration    63 | Cost: 2.695853e+04
Iteration    64 | Cost: 2.695561e+04
Iteration    65 | Cost: 2.693502e+04
Iteration    66 | Cost: 2.690678e+04
Iteration    67 | Cost: 2.688290e+04
Iteration    68 | Cost: 2.687164e+04
Iteration    69 | Cost: 2.687067e+04
Iteration    70 | Cost: 2.685993e+04
Iteration    71 | Cost: 2.685327e+04
Iteration    72 | Cost: 2.685053e+04
Iteration    73 | Cost: 2.684665e+04
Iteration    74 | Cost: 2.684354e+04
Iteration    75 | Cost: 2.683787e+04
Iteration    76 | Cost: 2.682936e+04
Iteration    77 | Cost: 2.681691e+04
Iteration    78 | Cost: 2.680647e+04
Iteration    79 | Cost: 2.679770e+04
Iteration    80 | Cost: 2.677098e+04
Iteration    81 | Cost: 2.674620e+04
Iteration    82 | Cost: 2.673292e+04
Iteration    83 | Cost: 2.672754e+04
Iteration    84 | Cost: 2.672119e+04
Iteration    85 | Cost: 2.671634e+04
Iteration    86 | Cost: 2.670976e+04
Iteration    87 | Cost: 2.670294e+04
Iteration    88 | Cost: 2.670012e+04
```

```
Iteration    89 | Cost: 2.669717e+04
Iteration    90 | Cost: 2.669316e+04
Iteration    91 | Cost: 2.668937e+04
Iteration    92 | Cost: 2.668688e+04
Iteration    93 | Cost: 2.668501e+04
Iteration    94 | Cost: 2.667898e+04
Iteration    95 | Cost: 2.666629e+04
Iteration    96 | Cost: 2.665386e+04
Iteration    97 | Cost: 2.664616e+04
Iteration    98 | Cost: 2.664153e+04
Iteration    99 | Cost: 2.663150e+04
Iteration   100 | Cost: 2.662800e+04
```

```
% Unfold the returned theta back into U and W
X = reshape(theta(1:num_movies*num_features), num_movies, num_features);
Theta = reshape(theta(num_movies*num_features+1:end), num_users, num_features);
```

To predict the rating of movie *i* for user*j*, you need to compute $(\theta^{(j)})^T x^{(i)}$ The code below computes the ratings for all the movies and users and displays the movies that it recommends (Figure 4), according to ratings that were entered earlier in the script. Note that you might obtain a different set of the predictions due to different random initializations.

```
Top recommendations for you:
Predicting rating 9.0 for movie Titanic (1997)
Predicting rating 8.9 for movie Star Wars (1977)
Predicting rating 8.8 for movie Shawshank Redemption, The (1994)
Predicting rating 8.5 for movie As Good As It Gets (1997)
Predicting rating 8.5 for movie Good Will Hunting (1997)
Predicting rating 8.5 for movie Usual Suspects, The (1995)
Predicting rating 8.5 for movie Schindler's List (1993)
Predicting rating 8.4 for movie Raiders of the Lost Ark (1981)
Predicting rating 8.4 for movie Empire Strikes Back, The (1980)
Predicting rating 8.4 for movie Braveheart (1995)

Original ratings provided:
Rated 4 for Toy Story (1995)
Rated 3 for Twelve Monkeys (1995)
Rated 5 for Usual Suspects, The (1995)
Rated 4 for Outbreak (1995)
Rated 5 for Shawshank Redemption, The (1994)
Rated 3 for While You Were Sleeping (1995)
Rated 5 for Forrest Gump (1994)
Rated 2 for Silence of the Lambs, The (1991)
Rated 4 for Alien (1979)
Rated 5 for Die Hard 2 (1990)
Rated 5 for Sphere (1998)
```

Figure 4: Movie recommendations

```
p = X * Theta';
my_predictions = p(:,1) + Ymean;

movieList = loadMovieList();

[r, ix] = sort(my_predictions,'descend');
```

```
for i=1:800
    j = ix(i);
    if i == 1
        fprintf('\nTop recommendations for you:\n');
    end
    fprintf('Predicting rating %.1f for movie %s\n', my_predictions(j), movieList{j});
end
```

```
Top recommendations for you:
Predicting rating 5.5 for movie Boys, Les (1997)
Predicting rating 5.1 for movie Apostle, The (1997)
Predicting rating 5.0 for movie Everest (1998)
Predicting rating 5.0 for movie Angel Baby (1995)
Predicting rating 5.0 for movie Star Kid (1997)
Predicting rating 5.0 for movie Saint of Fort Washington, The (1993)
Predicting rating 5.0 for movie Marlene Dietrich: Shadow and Light (1996)
Predicting rating 5.0 for movie Great Day in Harlem, A (1994)
Predicting rating 5.0 for movie Prefontaine (1997)
Predicting rating 5.0 for movie Entertaining Angels: The Dorothy Day Story (1996)
Predicting rating 5.0 for movie Someone Else's America (1995)
Predicting rating 5.0 for movie Aiqing wansui (1994)
Predicting rating 5.0 for movie Santa with Muscles (1996)
Predicting rating 5.0 for movie They Made Me a Criminal (1939)
Predicting rating 5.0 for movie Inventing the Abbotts (1997)
Predicting rating 5.0 for movie Radioland Murders (1994)
Predicting rating 5.0 for movie Love and Death on Long Island (1997)
Predicting rating 4.9 for movie American Dream (1990)
Predicting rating 4.9 for movie Bitter Moon (1992)
Predicting rating 4.9 for movie Rocket Man (1997)
Predicting rating 4.8 for movie Underneath, The (1995)
Predicting rating 4.8 for movie Schizopolis (1996)
Predicting rating 4.8 for movie Duoluo tianshi (1995)
Predicting rating 4.8 for movie Street Fighter (1994)
Predicting rating 4.7 for movie Safe (1995)
Predicting rating 4.6 for movie Crooklyn (1994)
Predicting rating 4.6 for movie Mixed Nuts (1994)
Predicting rating 4.6 for movie Roommates (1995)
Predicting rating 4.6 for movie Frisk (1995)
Predicting rating 4.5 for movie Keys to Tulsa (1997)
Predicting rating 4.5 for movie Oscar & Lucinda (1997)
Predicting rating 4.5 for movie Kaspar Hauser (1993)
Predicting rating 4.5 for movie Ruby in Paradise (1993)
Predicting rating 4.5 for movie Mina Tannenbaum (1994)
Predicting rating 4.5 for movie Innocents, The (1961)
Predicting rating 4.4 for movie Romper Stomper (1992)
Predicting rating 4.4 for movie Hollow Reed (1996)
Predicting rating 4.4 for movie Slingshot, The (1993)
Predicting rating 4.3 for movie Doom Generation, The (1995)
Predicting rating 4.3 for movie Excess Baggage (1997)
Predicting rating 4.3 for movie Bitter Sugar (Azucar Amargo) (1996)
Predicting rating 4.2 for movie Promesse, La (1996)
Predicting rating 4.2 for movie Underworld (1997)
Predicting rating 4.2 for movie Two or Three Things I Know About Her (1966)
Predicting rating 4.2 for movie Ma vie en rose (My Life in Pink) (1997)
Predicting rating 4.2 for movie Ready to Wear (Pret-A-Porter) (1994)
Predicting rating 4.1 for movie Deceiver (1997)
Predicting rating 4.1 for movie Surviving the Game (1994)
Predicting rating 4.1 for movie My Man Godfrey (1936)
Predicting rating 4.0 for movie Stalker (1979)
Predicting rating 4.0 for movie Wallace & Gromit: The Best of Aardman Animation (1996)
Predicting rating 4.0 for movie Faster Pussycat! Kill! Kill! (1965)
Predicting rating 4.0 for movie Big Bang Theory, The (1994)
Predicting rating 4.0 for movie Cérémonie, La (1995)
```

```
Predicting rating 4.0 for movie Brothers in Trouble (1995)
Predicting rating 4.0 for movie Celestial Clockwork (1994)
Predicting rating 4.0 for movie Spanish Prisoner, The (1997)
Predicting rating 4.0 for movie Tokyo Fist (1995)
Predicting rating 4.0 for movie Nightwatch (1997)
Predicting rating 4.0 for movie Damsel in Distress, A (1937)
Predicting rating 4.0 for movie Mamma Roma (1962)
Predicting rating 4.0 for movie Witness (1985)
Predicting rating 4.0 for movie I Don't Want to Talk About It (De eso no se habla) (1993)
Predicting rating 4.0 for movie Farmer & Chase (1995)
Predicting rating 4.0 for movie Wings of Courage (1995)
Predicting rating 4.0 for movie Object of My Affection, The (1998)
Predicting rating 4.0 for movie Jupiter's Wife (1994)
Predicting rating 4.0 for movie Gate of Heavenly Peace, The (1995)
Predicting rating 4.0 for movie Killer: A Journal of Murder (1995)
Predicting rating 4.0 for movie Substance of Fire, The (1996)
Predicting rating 4.0 for movie He Walked by Night (1948)
Predicting rating 4.0 for movie Butcher Boy, The (1998)
Predicting rating 4.0 for movie Lady of Burlesque (1943)
Predicting rating 4.0 for movie Desert Winds (1995)
Predicting rating 4.0 for movie Window to Paris (1994)
Predicting rating 4.0 for movie Death in Brunswick (1991)
Predicting rating 4.0 for movie Butcher Boy, The (1998)
Predicting rating 4.0 for movie Shooting Fish (1997)
Predicting rating 4.0 for movie Female Perversions (1996)
Predicting rating 4.0 for movie Anna (1996)
Predicting rating 4.0 for movie Big Lebowski, The (1998)
Predicting rating 4.0 for movie Joy Luck Club, The (1993)
Predicting rating 3.9 for movie Great Race, The (1965)
Predicting rating 3.9 for movie Rosencrantz and Guildenstern Are Dead (1990)
Predicting rating 3.9 for movie Jude (1996)
Predicting rating 3.9 for movie Dead Man (1995)
Predicting rating 3.9 for movie Tough and Deadly (1995)
Predicting rating 3.9 for movie C'est arrivé près de chez vous (1992)
Predicting rating 3.9 for movie Whole Wide World, The (1996)
Predicting rating 3.9 for movie Friday (1995)
Predicting rating 3.9 for movie Some Mother's Son (1996)
Predicting rating 3.8 for movie Race the Sun (1996)
Predicting rating 3.8 for movie Fresh (1994)
Predicting rating 3.8 for movie Fear of a Black Hat (1993)
Predicting rating 3.8 for movie Flirt (1995)
Predicting rating 3.8 for movie I'll Do Anything (1994)
Predicting rating 3.8 for movie Misérables, Les (1995)
Predicting rating 3.8 for movie Garden of Finzi-Contini, The (Giardino dei Finzi-Contini, Il) (1970)
Predicting rating 3.8 for movie Braindead (1992)
Predicting rating 3.8 for movie S.F.W. (1994)
Predicting rating 3.8 for movie Stranger in the House (1997)
Predicting rating 3.8 for movie Nina Takes a Lover (1994)
Predicting rating 3.8 for movie Mark of Zorro, The (1940)
Predicting rating 3.7 for movie Threesome (1994)
Predicting rating 3.7 for movie Panther (1995)
Predicting rating 3.7 for movie Stonewall (1995)
Predicting rating 3.7 for movie War Room, The (1993)
Predicting rating 3.7 for movie Lightning Jack (1994)
Predicting rating 3.7 for movie Ladybird Ladybird (1994)
Predicting rating 3.7 for movie For Whom the Bell Tolls (1943)
Predicting rating 3.7 for movie Pather Panchali (1955)
Predicting rating 3.7 for movie April Fool's Day (1986)
Predicting rating 3.7 for movie Apt Pupil (1998)
Predicting rating 3.7 for movie Zeus and Roxanne (1997)
Predicting rating 3.7 for movie Crossfire (1947)
Predicting rating 3.7 for movie Endless Summer 2, The (1994)
Predicting rating 3.7 for movie Letter From Death Row, A (1998)
Predicting rating 3.6 for movie Mute Witness (1994)
Predicting rating 3.6 for movie Celluloid Closet, The (1995)
```

```
Predicting rating 3.6 for movie Beat the Devil (1954)
Predicting rating 3.6 for movie Critical Care (1997)
Predicting rating 3.6 for movie His Girl Friday (1940)
Predicting rating 3.6 for movie Miami Rhapsody (1995)
Predicting rating 3.6 for movie Collectionneuse, La (1967)
Predicting rating 3.6 for movie Good Man in Africa, A (1994)
Predicting rating 3.6 for movie Gay Divorcee, The (1934)
Predicting rating 3.6 for movie World of Apu, The (Apur Sansar) (1959)
Predicting rating 3.6 for movie Henry V (1989)
Predicting rating 3.5 for movie Cabin Boy (1994)
Predicting rating 3.5 for movie In the Company of Men (1997)
Predicting rating 3.5 for movie As Good As It Gets (1997)
Predicting rating 3.5 for movie Grosse Fatigue (1994)
Predicting rating 3.5 for movie Once Were Warriors (1994)
Predicting rating 3.5 for movie Hurricane Streets (1998)
Predicting rating 3.5 for movie Drunks (1995)
Predicting rating 3.5 for movie Thirty-Two Short Films About Glenn Gould (1993)
Predicting rating 3.5 for movie Gold Diggers: The Secret of Bear Mountain (1995)
Predicting rating 3.5 for movie Love and a .45 (1994)
Predicting rating 3.5 for movie Picture Bride (1995)
Predicting rating 3.5 for movie Colonel Chabert, Le (1994)
Predicting rating 3.5 for movie In the Line of Duty 2 (1987)
Predicting rating 3.5 for movie Show, The (1995)
Predicting rating 3.4 for movie Feast of July (1995)
Predicting rating 3.4 for movie Paradise Lost: The Child Murders at Robin Hood Hills (1996)
Predicting rating 3.4 for movie Jackie Brown (1997)
Predicting rating 3.4 for movie Three Wishes (1995)
Predicting rating 3.4 for movie Next Karate Kid, The (1994)
Predicting rating 3.4 for movie Delta of Venus (1994)
Predicting rating 3.4 for movie Hear My Song (1991)
Predicting rating 3.4 for movie Loch Ness (1995)
Predicting rating 3.4 for movie Nadja (1994)
Predicting rating 3.4 for movie Inkwell, The (1994)
Predicting rating 3.4 for movie Of Human Bondage (1934)
Predicting rating 3.4 for movie Mallrats (1995)
Predicting rating 3.4 for movie In the Realm of the Senses (Ai no corrida) (1976)
Predicting rating 3.4 for movie Hard Eight (1996)
Predicting rating 3.4 for movie Tango Lesson, The (1997)
Predicting rating 3.4 for movie Carpool (1996)
Predicting rating 3.4 for movie I'm Not Rappaport (1996)
Predicting rating 3.4 for movie Horseman on the Roof, The (Hussard sur le toit, Le) (1995)
Predicting rating 3.3 for movie Faust (1994)
Predicting rating 3.3 for movie My Life as a Dog (Mitt liv som hund) (1985)
Predicting rating 3.3 for movie Die xue shuang xiong (Killer, The) (1989)
Predicting rating 3.3 for movie Washington Square (1997)
Predicting rating 3.3 for movie Bewegte Mann, Der (1994)
Predicting rating 3.3 for movie Grand Day Out, A (1992)
Predicting rating 3.3 for movie Nil By Mouth (1997)
Predicting rating 3.3 for movie North (1994)
Predicting rating 3.3 for movie Wild Bill (1995)
Predicting rating 3.3 for movie Aladdin and the King of Thieves (1996)
Predicting rating 3.3 for movie 8 Heads in a Duffel Bag (1997)
Predicting rating 3.3 for movie I Love Trouble (1994)
Predicting rating 3.3 for movie Better Off Dead... (1985)
Predicting rating 3.3 for movie Rough Magic (1995)
Predicting rating 3.3 for movie Caught (1996)
Predicting rating 3.2 for movie Much Ado About Nothing (1993)
Predicting rating 3.2 for movie House of Yes, The (1997)
Predicting rating 3.2 for movie Girl 6 (1996)
Predicting rating 3.2 for movie Farewell My Concubine (1993)
Predicting rating 3.2 for movie Beyond Rangoon (1995)
Predicting rating 3.2 for movie Bye Bye, Love (1995)
Predicting rating 3.2 for movie Children of the Revolution (1996)
Predicting rating 3.2 for movie Far From Home: The Adventures of Yellow Dog (1995)
Predicting rating 3.2 for movie Mrs. Brown (Her Majesty, Mrs. Brown) (1997)
```

```
Predicting rating 3.2 for movie Mediterraneo (1991)
Predicting rating 3.2 for movie Forbidden Planet (1956)
Predicting rating 3.2 for movie In the Bleak Midwinter (1995)
Predicting rating 3.2 for movie Bad Taste (1987)
Predicting rating 3.1 for movie Touch of Evil (1958)
Predicting rating 3.1 for movie SubUrbia (1997)
Predicting rating 3.1 for movie Mr. Wrong (1996)
Predicting rating 3.1 for movie Wild Reeds (1994)
Predicting rating 3.1 for movie Secret Adventures of Tom Thumb, The (1993)
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Predicting rating 2.1 for movie Clear and Present Danger (1994)
Predicting rating 2.1 for movie Terminator 2: Judgment Day (1991)
Predicting rating 2.1 for movie Nowhere (1997)
Predicting rating 2.1 for movie Hunt for Red October, The (1990)
Predicting rating 2.1 for movie Exit to Eden (1994)
Predicting rating 2.1 for movie Secret Garden, The (1993)
Predicting rating 2.1 for movie To Kill a Mockingbird (1962)
Predicting rating 2.1 for movie Madness of King George, The (1994)
Predicting rating 2.1 for movie Ghost and Mrs. Muir, The (1947)
Predicting rating 2.1 for movie Love! Valour! Compassion! (1997)
Predicting rating 2.1 for movie Bullets Over Broadway (1994)
Predicting rating 2.1 for movie Four Days in September (1997)
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Predicting rating 2.1 for movie Swept from the Sea (1997)
Predicting rating 2.1 for movie Jackal, The (1997)
Predicting rating 2.1 for movie My Left Foot (1989)
Predicting rating 2.1 for movie Little Big League (1994)
Predicting rating 2.1 for movie Head Above Water (1996)
Predicting rating 2.1 for movie Room with a View, A (1986)
Predicting rating 2.1 for movie Ice Storm, The (1997)
Predicting rating 2.1 for movie Pushing Hands (1992)
Predicting rating 2.1 for movie Nénette et Boni (1996)
Predicting rating 2.1 for movie Ponette (1996)
Predicting rating 2.1 for movie Substitute, The (1996)
Predicting rating 2.1 for movie Cat on a Hot Tin Roof (1958)
Predicting rating 2.1 for movie Emma (1996)
Predicting rating 2.0 for movie Spirits of the Dead (Tre passi nel delirio) (1968)
Predicting rating 2.0 for movie Moonlight and Valentino (1995)
Predicting rating 2.0 for movie Eddie (1996)
Predicting rating 2.0 for movie Dangerous Beauty (1998)
Predicting rating 2.0 for movie Gaslight (1944)
Predicting rating 2.0 for movie Very Brady Sequel, A (1996)
Predicting rating 2.0 for movie Wings of the Dove, The (1997)
Predicting rating 2.0 for movie Daytrippers, The (1996)
Predicting rating 2.0 for movie Two if by Sea (1996)
Predicting rating 2.0 for movie It's My Party (1995)
Predicting rating 2.0 for movie Spanking the Monkey (1994)
Predicting rating 2.0 for movie Three Colors: Blue (1993)
Predicting rating 2.0 for movie Waiting for Guffman (1996)
Predicting rating 2.0 for movie Spy Hard (1996)
Predicting rating 2.0 for movie Picnic (1955)
Predicting rating 2.0 for movie Heavenly Creatures (1994)
Predicting rating 2.0 for movie My Fellow Americans (1996)
Predicting rating 2.0 for movie MURDER and murder (1996)
Predicting rating 2.0 for movie Highlander III: The Sorcerer (1994)
Predicting rating 2.0 for movie Foreign Student (1994)
Predicting rating 2.0 for movie Penny Serenade (1941)
Predicting rating 2.0 for movie Sprung (1997)
Predicting rating 2.0 for movie Brother's Kiss, A (1997)
Predicting rating 2.0 for movie Here Comes Cookie (1935)
Predicting rating 2.0 for movie Apocalypse Now (1979)
Predicting rating 2.0 for movie Hush (1998)
Predicting rating 2.0 for movie Raw Deal (1948)
Predicting rating 2.0 for movie Kika (1993)
Predicting rating 2.0 for movie War at Home, The (1996)
Predicting rating 2.0 for movie Sliding Doors (1998)
Predicting rating 2.0 for movie Shopping (1994)
Predicting rating 2.0 for movie Coldblooded (1995)
Predicting rating 2.0 for movie Favor, The (1994)
Predicting rating 2.0 for movie Two Deaths (1995)
Predicting rating 2.0 for movie Deceiver (1997)
Predicting rating 2.0 for movie Nemesis 2: Nebula (1995)
Predicting rating 2.0 for movie Etz Hadomim Tafus (Under the Domin Tree) (1994)
Predicting rating 2.0 for movie Small Faces (1995)
Predicting rating 2.0 for movie Niagara, Niagara (1997)
Predicting rating 2.0 for movie Ripe (1996)
Predicting rating 2.0 for movie Stranger, The (1994)
Predicting rating 2.0 for movie Angel on My Shoulder (1946)
Predicting rating 2.0 for movie Shadowlands (1993)
Predicting rating 2.0 for movie Everyone Says I Love You (1996)
Predicting rating 2.0 for movie Underground (1995)
Predicting rating 2.0 for movie Booty Call (1997)
Predicting rating 2.0 for movie Nothing Personal (1995)
Predicting rating 2.0 for movie Akira (1988)
Predicting rating 2.0 for movie Unhook the Stars (1996)
Predicting rating 2.0 for movie Jane Eyre (1996)
Predicting rating 2.0 for movie Little Princess, The (1939)
Predicting rating 2.0 for movie Sting, The (1973)
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Predicting rating 2.0 for movie Commandments (1997)
Predicting rating 2.0 for movie Mr. Smith Goes to Washington (1939)
Predicting rating 2.0 for movie Pagemaster, The (1994)
Predicting rating 2.0 for movie Return of Martin Guerre, The (Retour de Martin Guerre, Le) (1982)
Predicting rating 2.0 for movie Brazil (1985)
Predicting rating 2.0 for movie Newton Boys, The (1998)
Predicting rating 2.0 for movie Being Human (1993)
Predicting rating 2.0 for movie Smilla's Sense of Snow (1997)
Predicting rating 2.0 for movie Amos & Andrew (1993)
Predicting rating 2.0 for movie Seven Years in Tibet (1997)
Predicting rating 2.0 for movie Rebecca (1940)
Predicting rating 2.0 for movie Twilight (1998)
Predicting rating 2.0 for movie Hoop Dreams (1994)
Predicting rating 2.0 for movie Backbeat (1993)
Predicting rating 2.0 for movie When the Cats Away (Chacun cherche son chat) (1996)
Predicting rating 2.0 for movie Fifth Element, The (1997)
Predicting rating 2.0 for movie Spawn (1997)
Predicting rating 2.0 for movie This Is Spinal Tap (1984)
Predicting rating 1.9 for movie Professional, The (1994)
Predicting rating 1.9 for movie Fast, Cheap & Out of Control (1997)
Predicting rating 1.9 for movie Apollo 13 (1995)
Predicting rating 1.9 for movie Maya Lin: A Strong Clear Vision (1994)
Predicting rating 1.9 for movie Bronx Tale, A (1993)
Predicting rating 1.9 for movie Widows' Peak (1994)
Predicting rating 1.9 for movie Ed's Next Move (1996)
Predicting rating 1.9 for movie East of Eden (1955)
Predicting rating 1.9 for movie City of Lost Children, The (1995)
Predicting rating 1.9 for movie Absolute Power (1997)
Predicting rating 1.9 for movie Long Kiss Goodnight, The (1996)
Predicting rating 1.9 for movie Benny & Joon (1993)
Predicting rating 1.9 for movie Nikita (La Femme Nikita) (1990)
Predicting rating 1.9 for movie Murder, My Sweet (1944)
Predicting rating 1.9 for movie Marvin's Room (1996)
Predicting rating 1.9 for movie Around the World in 80 Days (1956)
Predicting rating 1.9 for movie Once Upon a Time in the West (1969)
Predicting rating 1.9 for movie Last of the Mohicans, The (1992)
Predicting rating 1.9 for movie Taxi Driver (1976)
Predicting rating 1.9 for movie In & Out (1997)
Predicting rating 1.9 for movie Balto (1995)
Predicting rating 1.9 for movie Mouse Hunt (1997)
Predicting rating 1.9 for movie Wrong Trousers, The (1993)
Predicting rating 1.9 for movie Dial M for Murder (1954)
Predicting rating 1.9 for movie Grosse Pointe Blank (1997)
Predicting rating 1.9 for movie Another Stakeout (1993)
Predicting rating 1.9 for movie Conspiracy Theory (1997)
Predicting rating 1.9 for movie Faces (1968)
Predicting rating 1.9 for movie Shawshank Redemption, The (1994)
Predicting rating 1.9 for movie Mars Attacks! (1996)
Predicting rating 1.9 for movie Little Princess, A (1995)
Predicting rating 1.9 for movie Terminator, The (1984)
Predicting rating 1.9 for movie Picture Perfect (1997)
Predicting rating 1.9 for movie Basketball Diaries, The (1995)
Predicting rating 1.9 for movie Cool Hand Luke (1967)
Predicting rating 1.9 for movie Lawrence of Arabia (1962)
Predicting rating 1.9 for movie Lawnmower Man 2: Beyond Cyberspace (1996)
Predicting rating 1.9 for movie Godfather: Part II, The (1974)
Predicting rating 1.9 for movie Escape from New York (1981)
Predicting rating 1.9 for movie Sneakers (1992)
Predicting rating 1.9 for movie It's a Wonderful Life (1946)
Predicting rating 1.9 for movie Christmas Carol, A (1938)
Predicting rating 1.9 for movie Last Man Standing (1996)
Predicting rating 1.9 for movie Lamerica (1994)
Predicting rating 1.9 for movie Big Night (1996)
Predicting rating 1.9 for movie Lone Star (1996)
Predicting rating 1.9 for movie Losing Isaiah (1995)
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Predicting rating 1.9 for movie All About Eve (1950)
Predicting rating 1.9 for movie Bastard Out of Carolina (1996)
Predicting rating 1.9 for movie Sword in the Stone, The (1963)
Predicting rating 1.9 for movie Wag the Dog (1997)
Predicting rating 1.9 for movie Heavy Metal (1981)
Predicting rating 1.9 for movie Best of the Best 3: No Turning Back (1995)
Predicting rating 1.9 for movie Twin Town (1997)
Predicting rating 1.9 for movie Judge Dredd (1995)
Predicting rating 1.8 for movie Rainmaker, The (1997)
Predicting rating 1.8 for movie Adventures of Robin Hood, The (1938)
Predicting rating 1.8 for movie 20,000 Leagues Under the Sea (1954)
Predicting rating 1.8 for movie Touch (1997)
Predicting rating 1.8 for movie Chasers (1994)
Predicting rating 1.8 for movie Fargo (1996)
Predicting rating 1.8 for movie Escape to Witch Mountain (1975)
Predicting rating 1.8 for movie Quiz Show (1994)
Predicting rating 1.8 for movie Carried Away (1996)
Predicting rating 1.8 for movie Walking and Talking (1996)
Predicting rating 1.8 for movie Brassed Off (1996)
Predicting rating 1.8 for movie Amazing Panda Adventure, The (1995)
Predicting rating 1.8 for movie Naked (1993)
Predicting rating 1.8 for movie Dead Poets Society (1989)
Predicting rating 1.8 for movie 2001: A Space Odyssey (1968)
Predicting rating 1.8 for movie Chasing Amy (1997)
Predicting rating 1.8 for movie Scarlet Letter, The (1995)
Predicting rating 1.8 for movie Powder (1995)
Predicting rating 1.8 for movie Boys of St. Vincent, The (1993)
Predicting rating 1.8 for movie Heavyweights (1994)
Predicting rating 1.8 for movie Open Season (1996)
Predicting rating 1.8 for movie Great Dictator, The (1940)
Predicting rating 1.8 for movie Meet Me in St. Louis (1944)
```

```
for i = 1:length(my_ratings)
    if i == 1
        fprintf('\n\nOriginal ratings provided:\n');
    end
    if my_ratings(i) > 0
        fprintf('Rated %d for %s\n', my_ratings(i), movieList{i});
    end
end
```

```
Original ratings provided:
Rated 1 for Toy Story (1995)
Rated 1 for Four Rooms (1995)
Rated 1 for Copycat (1995)
Rated 1 for Mighty Aphrodite (1995)
Rated 1 for From Dusk Till Dawn (1996)
Rated 1 for Mad Love (1995)
Rated 1 for Disclosure (1994)
Rated 1 for Shawshank Redemption, The (1994)
Rated 1 for While You Were Sleeping (1995)
Rated 1 for Ace Ventura: Pet Detective (1994)
Rated 1 for Fugitive, The (1993)
Rated 1 for Robert A. Heinlein's The Puppet Masters (1994)
Rated 1 for Silence of the Lambs, The (1991)
Rated 1 for Striptease (1996)
Rated 1 for Lone Star (1996)
Rated 1 for Swingers (1996)
Rated 1 for Die Hard 2 (1990)
Rated 1 for Beavis and Butt-head Do America (1996)
Rated 1 for Bob Roberts (1992)
Rated 1 for Jackie Chan's First Strike (1996)
Rated 1 for Bonnie and Clyde (1967)
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Rated 1 for People vs. Larry Flynt, The (1996)
Rated 1 for It Happened One Night (1934)
Rated 1 for Father of the Bride (1950)
Rated 1 for So Dear to My Heart (1949)
Rated 1 for Wonderful, Horrible Life of Leni Riefenstahl, The (1993)
Rated 1 for Rising Sun (1993)
Rated 1 for Diva (1981)
```

## 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 |
|---|---|---|
| Estimate Gaussian Parameters | `estimateGuassian.m` | 15 points |
| Select Threshold | `selectThreshold.m` | 15 points |
| Collaborative Filtering Cost | `cofiCostFunc.m` | 20 points |
| Collaborative Filtering Gradient | `cofiCostFunc.m` | 30 points |
| Regularized Cost | `cofiCostFunc.m` | 10 points |
| Gradient with regularization | `cofiCostFunc.m` | 10 points |
| Total Points | | 100 points |

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