

Image features exercise

Complete and hand in this completed worksheet (including its outputs and any supporting code outside of the worksheet) with your assignment submission. For more details see the [assignments page \(https://compsci682-fa19.github.io/assignments2019/assignment1\)](https://compsci682-fa19.github.io/assignments2019/assignment1) on the course website.

We have seen that we can achieve reasonable performance on an image classification task by training a linear classifier on the pixels of the input image. In this exercise we will show that we can improve our classification performance by training linear classifiers not on raw pixels but on features that are computed from the raw pixels.

All of your work for this exercise will be done in this notebook.

```
In [1]: from __future__ import print_function
import random
import numpy as np
from cs682.data_utils import load_CIFAR10
import matplotlib.pyplot as plt

%matplotlib inline
plt.rcParams['figure.figsize'] = (10.0, 8.0) # set default size of plots
plt.rcParams['image.interpolation'] = 'nearest'
plt.rcParams['image.cmap'] = 'gray'

# for auto-reloading external modules
# see http://stackoverflow.com/questions/1907993/autoreload-of-modules-in-ipython
%load_ext autoreload
%autoreload 2
```

Load data

Similar to previous exercises, we will load CIFAR-10 data from disk.

```
In [2]: from cs682.features import color_histogram_hsv, hog_feature

def get_CIFAR10_data(num_training=49000, num_validation=1000, num_test=1000):
    # Load the raw CIFAR-10 data
    cifar10_dir = 'cs682/datasets/cifar-10-batches-py'

    X_train, y_train, X_test, y_test = load_CIFAR10(cifar10_dir)

    # Subsample the data
    mask = list(range(num_training, num_training + num_validation))
    X_val = X_train[mask]
    y_val = y_train[mask]
    mask = list(range(num_training))
    X_train = X_train[mask]
    y_train = y_train[mask]
    mask = list(range(num_test))
    X_test = X_test[mask]
    y_test = y_test[mask]

    return X_train, y_train, X_val, y_val, X_test, y_test

# Cleaning up variables to prevent loading data multiple times (which may cause memory issue)
try:
    del X_train, y_train
    del X_test, y_test
    print('Clear previously loaded data.')
except:
    pass

X_train, y_train, X_val, y_val, X_test, y_test = get_CIFAR10_data()
```

Extract Features

For each image we will compute a Histogram of Oriented Gradients (HOG) as well as a color histogram using the hue channel in HSV color space. We form our final feature vector for each image by concatenating the HOG and color histogram feature vectors.

Roughly speaking, HOG should capture the texture of the image while ignoring color information, and the color histogram represents the color of the input image while ignoring texture. As a result, we expect that using both together ought to work better than using either alone. Verifying this assumption would be a good thing to try for your interests.

The `hog_feature` and `color_histogram_hsv` functions both operate on a single image and return a feature vector for that image. The `extract_features` function takes a set of images and a list of feature functions and evaluates each feature function on each image, storing the results in a matrix where each column is the concatenation of all feature vectors for a single image.

```
In [31]: from cs682.features import *

num_color_bins = 100 # Number of bins in the color histogram
feature_fns = [hog_feature, lambda img: color_histogram_hsv(img, nbin
=num_color_bins)]
X_train_feats = extract_features(X_train, feature_fns, verbose=True)
X_val_feats = extract_features(X_val, feature_fns)
X_test_feats = extract_features(X_test, feature_fns)

# Preprocessing: Subtract the mean feature
mean_feat = np.mean(X_train_feats, axis=0, keepdims=True)
X_train_feats -= mean_feat
X_val_feats -= mean_feat
X_test_feats -= mean_feat

# Preprocessing: Divide by standard deviation. This ensures that each
# feature
# has roughly the same scale.
std_feat = np.std(X_train_feats, axis=0, keepdims=True)
X_train_feats /= std_feat
X_val_feats /= std_feat
X_test_feats /= std_feat

# Preprocessing: Add a bias dimension
X_train_feats = np.hstack([X_train_feats, np.ones((X_train_feats.shape[0], 1))])
X_val_feats = np.hstack([X_val_feats, np.ones((X_val_feats.shape[0], 1))])
X_test_feats = np.hstack([X_test_feats, np.ones((X_test_feats.shape[0], 1))])
```

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```

Train SVM on features

Using the multiclass SVM code developed earlier in the assignment, train SVMs on top of the features extracted above; this should achieve better results than training SVMs directly on top of raw pixels.

```

In [32]: # Use the validation set to tune the learning rate and regularization
          strength

          from cs682.classifiers.linear_classifier import LinearSVM

          learning_rates = [1e-9, 1e-8, 1e-7]
          regularization_strengths = [5e4, 5e5, 5e6]

          results = {}
          best_val = -1
          best_svm = None

          #####
          #####
          # TODO:
          #
          # Use the validation set to set the learning rate and regularization
          # strength. #
          # This should be identical to the validation that you did for the SVM; save #
          # the best trained classifier in best_svm. You might also want to play #
          # with different numbers of bins in the color histogram. If you are careful #
          # you should be able to get accuracy of near 0.44 on the validation set. #
          #####
          #####
          learning_rates = [1e-9, 5e-5]
          regularization_strengths = [2e4, 5e6]
          num_iters = 20
          for it in range(num_iters):
              for jt in range(num_iters):
                  svm = LinearSVM()
                  learning_rate = learning_rates[0] + it * ((learning_rates[1] - learning_rates[0]) / num_iters)
                  reg = regularization_strengths[0] + jt * ((regularization_strengths[1] - regularization_strengths[0]) / num_iters)
                  loss_hist = svm.train(X_train_feats, y_train, learning_rate=learning_rate, reg=reg,
                                      num_iters=3000, verbose=False)
                  y_train_pred = svm.predict(X_train_feats)
                  y_val_pred = svm.predict(X_val_feats)
                  training_accuracy = np.mean(y_train == y_train_pred)
                  validation_accuracy = np.mean(y_val == y_val_pred)
                  results[(learning_rate, reg)] = (training_accuracy, validation_accuracy)
                  print('lr %e reg %e train accuracy: %f val accuracy: %f' % (learning_rate, reg, training_accuracy, validation_accuracy))
                  if validation_accuracy > best_val:
                      best_val = validation_accuracy
                      best_svm = svm

          #####
          #####

```

```
#                                     END OF YOUR CODE
#
#####

# Print out results.
for lr, reg in sorted(results):
    train_accuracy, val_accuracy = results[(lr, reg)]
    print('lr %e reg %e train accuracy: %f val accuracy: %f' % (
        lr, reg, train_accuracy, val_accuracy))

print('best validation accuracy achieved during cross-validation: %f'
      % best_val)
```

```

lr 1.000000e-09 reg 2.000000e+04 train accuracy: 0.094327 val accuracy: 0.088000
lr 1.000000e-09 reg 2.690000e+05 train accuracy: 0.093878 val accuracy: 0.101000
lr 1.000000e-09 reg 5.180000e+05 train accuracy: 0.090612 val accuracy: 0.099000
lr 1.000000e-09 reg 7.670000e+05 train accuracy: 0.117347 val accuracy: 0.126000
lr 1.000000e-09 reg 1.016000e+06 train accuracy: 0.104735 val accuracy: 0.105000
lr 1.000000e-09 reg 1.265000e+06 train accuracy: 0.203122 val accuracy: 0.205000
lr 1.000000e-09 reg 1.514000e+06 train accuracy: 0.340469 val accuracy: 0.338000
lr 1.000000e-09 reg 1.763000e+06 train accuracy: 0.406388 val accuracy: 0.435000
lr 1.000000e-09 reg 2.012000e+06 train accuracy: 0.412490 val accuracy: 0.427000
lr 1.000000e-09 reg 2.261000e+06 train accuracy: 0.412857 val accuracy: 0.433000
lr 1.000000e-09 reg 2.510000e+06 train accuracy: 0.414143 val accuracy: 0.442000
lr 1.000000e-09 reg 2.759000e+06 train accuracy: 0.413286 val accuracy: 0.435000
lr 1.000000e-09 reg 3.008000e+06 train accuracy: 0.414408 val accuracy: 0.436000
lr 1.000000e-09 reg 3.257000e+06 train accuracy: 0.417571 val accuracy: 0.432000
lr 1.000000e-09 reg 3.506000e+06 train accuracy: 0.412571 val accuracy: 0.429000
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lr 1.000000e-09 reg 4.004000e+06 train accuracy: 0.415633 val accuracy: 0.430000
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lr 1.750065e-05 reg 4.751000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 2.000000e+04 train accuracy: 0.333755 val accuracy: 0.345000
lr 2.000060e-05 reg 2.690000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 5.180000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 7.670000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 1.016000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 1.265000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 1.514000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 1.763000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 2.012000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 2.261000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.000060e-05 reg 2.510000e+06 train accuracy: 0.100265 val accuracy: 0.087000
```

lr 2.000060e-05	reg 2.759000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.000060e-05	reg 3.008000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.000060e-05	reg 3.257000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.000060e-05	reg 3.506000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.000060e-05	reg 3.755000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.000060e-05	reg 4.004000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.000060e-05	reg 4.253000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.000060e-05	reg 4.502000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.000060e-05	reg 4.751000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 2.000000e+04	train accuracy: 0.332041	val accuracy: 0.339000
lr 2.250055e-05	reg 2.690000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 5.180000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 7.670000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 1.016000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 1.265000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 1.514000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 1.763000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 2.012000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 2.261000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 2.510000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 2.759000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 3.008000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 3.257000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 3.506000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 3.755000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 4.004000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 4.253000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 4.502000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.250055e-05	reg 4.751000e+06	train accuracy: 0.100265	val accuracy: 0.087000

```
cy: 0.087000
lr 2.500050e-05 reg 2.000000e+04 train accuracy: 0.322959 val accuracy: 0.328000
lr 2.500050e-05 reg 2.690000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 5.180000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 7.670000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 1.016000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 1.265000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 1.514000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 1.763000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 2.012000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 2.261000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 2.510000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 2.759000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 3.008000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 3.257000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 3.506000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 3.755000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 4.004000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 4.253000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 4.502000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500050e-05 reg 4.751000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.750045e-05 reg 2.000000e+04 train accuracy: 0.312980 val accuracy: 0.333000
lr 2.750045e-05 reg 2.690000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.750045e-05 reg 5.180000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.750045e-05 reg 7.670000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.750045e-05 reg 1.016000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.750045e-05 reg 1.265000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.750045e-05 reg 1.514000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.750045e-05 reg 1.763000e+06 train accuracy: 0.100265 val accuracy: 0.087000
```

lr 2.750045e-05	reg 2.012000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 2.261000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 2.510000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 2.759000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 3.008000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 3.257000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 3.506000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 3.755000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 4.004000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 4.253000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 4.502000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 2.750045e-05	reg 4.751000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 2.000000e+04	train accuracy: 0.293490	val accuracy: 0.281000
lr 3.000040e-05	reg 2.690000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 5.180000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 7.670000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 1.016000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 1.265000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 1.514000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 1.763000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 2.012000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 2.261000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 2.510000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 2.759000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 3.008000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 3.257000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 3.506000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 3.755000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.000040e-05	reg 4.004000e+06	train accuracy: 0.100265	val accuracy: 0.087000

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cy: 0.087000
lr 3.000040e-05 reg 4.253000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.000040e-05 reg 4.502000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.000040e-05 reg 4.751000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 2.000000e+04 train accuracy: 0.268898 val accuracy: 0.257000
lr 3.250035e-05 reg 2.690000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 5.180000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 7.670000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 1.016000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 1.265000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 1.514000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 1.763000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 2.012000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 2.261000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 2.510000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 2.759000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 3.008000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 3.257000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 3.506000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 3.755000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 4.004000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 4.253000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 4.502000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.250035e-05 reg 4.751000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.500030e-05 reg 2.000000e+04 train accuracy: 0.279959 val accuracy: 0.310000
lr 3.500030e-05 reg 2.690000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.500030e-05 reg 5.180000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.500030e-05 reg 7.670000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.500030e-05 reg 1.016000e+06 train accuracy: 0.100265 val accuracy: 0.087000

```


lr 3.500030e-05	reg 1.265000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 1.514000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 1.763000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 2.012000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 2.261000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 2.510000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 2.759000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 3.008000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 3.257000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 3.506000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 3.755000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 4.004000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 4.253000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 4.502000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.500030e-05	reg 4.751000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 2.000000e+04	train accuracy: 0.257163	val accuracy: 0.226000
lr 3.750025e-05	reg 2.690000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 5.180000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 7.670000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 1.016000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 1.265000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 1.514000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 1.763000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 2.012000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 2.261000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 2.510000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 2.759000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 3.008000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 3.750025e-05	reg 3.257000e+06	train accuracy: 0.100265	val accuracy: 0.087000

```
cy: 0.087000
lr 3.750025e-05 reg 3.506000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.750025e-05 reg 3.755000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.750025e-05 reg 4.004000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.750025e-05 reg 4.253000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.750025e-05 reg 4.502000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 3.750025e-05 reg 4.751000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 2.000000e+04 train accuracy: 0.264980 val accuracy: 0.251000
lr 4.000020e-05 reg 2.690000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 5.180000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 7.670000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 1.016000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 1.265000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 1.514000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 1.763000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 2.012000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 2.261000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 2.510000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 2.759000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 3.008000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 3.257000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 3.506000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 3.755000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 4.004000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 4.253000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 4.502000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.000020e-05 reg 4.751000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.250015e-05 reg 2.000000e+04 train accuracy: 0.275612 val accuracy: 0.293000
lr 4.250015e-05 reg 2.690000e+05 train accuracy: 0.100265 val accuracy: 0.087000
```

lr 4.250015e-05	reg 5.180000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 7.670000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 1.016000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 1.265000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 1.514000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 1.763000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 2.012000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 2.261000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 2.510000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 2.759000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 3.008000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 3.257000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 3.506000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 3.755000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 4.004000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 4.253000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 4.502000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.250015e-05	reg 4.751000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 2.000000e+04	train accuracy: 0.209286	val accuracy: 0.195000
lr 4.500010e-05	reg 2.690000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 5.180000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 7.670000e+05	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 1.016000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 1.265000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 1.514000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 1.763000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 2.012000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 2.261000e+06	train accuracy: 0.100265	val accuracy: 0.087000
lr 4.500010e-05	reg 2.510000e+06	train accuracy: 0.100265	val accuracy: 0.087000

```
cy: 0.087000
lr 4.500010e-05 reg 2.759000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.500010e-05 reg 3.008000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.500010e-05 reg 3.257000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.500010e-05 reg 3.506000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.500010e-05 reg 3.755000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.500010e-05 reg 4.004000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.500010e-05 reg 4.253000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.500010e-05 reg 4.502000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.500010e-05 reg 4.751000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 2.000000e+04 train accuracy: 0.217122 val accuracy: 0.231000
lr 4.750005e-05 reg 2.690000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 5.180000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 7.670000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 1.016000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 1.265000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 1.514000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 1.763000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 2.012000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 2.261000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 2.510000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 2.759000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 3.008000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 3.257000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 3.506000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 3.755000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 4.004000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 4.253000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 4.750005e-05 reg 4.502000e+06 train accuracy: 0.100265 val accuracy: 0.087000
```

```
lr 4.750005e-05 reg 4.751000e+06 train accuracy: 0.100265 val accuracy: 0.087000
lr 1.000000e-09 reg 2.000000e+04 train accuracy: 0.094327 val accuracy: 0.088000
lr 1.000000e-09 reg 2.690000e+05 train accuracy: 0.093878 val accuracy: 0.101000
lr 1.000000e-09 reg 5.180000e+05 train accuracy: 0.090612 val accuracy: 0.099000
lr 1.000000e-09 reg 7.670000e+05 train accuracy: 0.117347 val accuracy: 0.126000
lr 1.000000e-09 reg 1.016000e+06 train accuracy: 0.104735 val accuracy: 0.105000
lr 1.000000e-09 reg 1.265000e+06 train accuracy: 0.203122 val accuracy: 0.205000
lr 1.000000e-09 reg 1.514000e+06 train accuracy: 0.340469 val accuracy: 0.338000
lr 1.000000e-09 reg 1.763000e+06 train accuracy: 0.406388 val accuracy: 0.435000
lr 1.000000e-09 reg 2.012000e+06 train accuracy: 0.412490 val accuracy: 0.427000
lr 1.000000e-09 reg 2.261000e+06 train accuracy: 0.412857 val accuracy: 0.433000
lr 1.000000e-09 reg 2.510000e+06 train accuracy: 0.414143 val accuracy: 0.442000
lr 1.000000e-09 reg 2.759000e+06 train accuracy: 0.413286 val accuracy: 0.435000
lr 1.000000e-09 reg 3.008000e+06 train accuracy: 0.414408 val accuracy: 0.436000
lr 1.000000e-09 reg 3.257000e+06 train accuracy: 0.417571 val accuracy: 0.432000
lr 1.000000e-09 reg 3.506000e+06 train accuracy: 0.412571 val accuracy: 0.429000
lr 1.000000e-09 reg 3.755000e+06 train accuracy: 0.411653 val accuracy: 0.430000
lr 1.000000e-09 reg 4.004000e+06 train accuracy: 0.415633 val accuracy: 0.430000
lr 1.000000e-09 reg 4.253000e+06 train accuracy: 0.414327 val accuracy: 0.434000
lr 1.000000e-09 reg 4.502000e+06 train accuracy: 0.414878 val accuracy: 0.432000
lr 1.000000e-09 reg 4.751000e+06 train accuracy: 0.414408 val accuracy: 0.431000
lr 2.500950e-06 reg 2.000000e+04 train accuracy: 0.406776 val accuracy: 0.419000
lr 2.500950e-06 reg 2.690000e+05 train accuracy: 0.291653 val accuracy: 0.269000
lr 2.500950e-06 reg 5.180000e+05 train accuracy: 0.100265 val accuracy: 0.087000
lr 2.500950e-06 reg 7.670000e+05 train accuracy: 0.100265 val accuracy: 0.087000
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best validation accuracy achieved during cross-validation: 0.442000
```

```
In [33]: # Evaluate your trained SVM on the test set
y_test_pred = best_svm.predict(X_test_feats)
test_accuracy = np.mean(y_test == y_test_pred)
print(test_accuracy)
```

```
0.405
```

```
In [34]: # An important way to gain intuition about how an algorithm works is
to
# visualize the mistakes that it makes. In this visualization, we show
examples
# of images that are misclassified by our current system. The first column
# shows images that our system labeled as "plane" but whose true label is
# something other than "plane".

examples_per_class = 8
classes = ['plane', 'car', 'bird', 'cat', 'deer', 'dog', 'frog', 'horse', 'ship', 'truck']
for cls, cls_name in enumerate(classes):
    idxs = np.where((y_test != cls) & (y_test_pred == cls))[0]
    idxs = np.random.choice(idxs, examples_per_class, replace=False)
    for i, idx in enumerate(idxs):
        plt.subplot(examples_per_class, len(classes), i * len(classes) + cls + 1)
        plt.imshow(X_test[idx].astype('uint8'))
        plt.axis('off')
        if i == 0:
            plt.title(cls_name)
plt.show()
```



Inline question 1:

Describe the misclassification results that you see. Do they make sense?

They kind of make sense. For example, misclassifications in plane category were most probably because there is a lot of sky and bluish tinge in those images. Similarly, in car category, it put some ships and trucks, which look a lot like a car in some angles. So, yes. It does make sense.

Neural Network on image features

Earlier in this assignment we saw that training a two-layer neural network on raw pixels achieved better classification performance than linear classifiers on raw pixels. In this notebook we have seen that linear classifiers on image features outperform linear classifiers on raw pixels.

For completeness, we should also try training a neural network on image features. This approach should outperform all previous approaches: you should easily be able to achieve over 55% classification accuracy on the test set; our best model achieves about 60% classification accuracy.

```
In [12]: # Preprocessing: Remove the bias dimension
# Make sure to run this cell only ONCE
print(X_train_feats.shape)
X_train_feats = X_train_feats[:, :-1]
X_val_feats = X_val_feats[:, :-1]
X_test_feats = X_test_feats[:, :-1]

print(X_train_feats.shape)

(49000, 155)
(49000, 154)
```

```

In [35]: from cs682.classifiers.neural_net import TwoLayerNet

# input_dim = X_train_feats.shape[1]
# hidden_dim = 500
# num_classes = 10

# net = TwoLayerNet(input_dim, hidden_dim, num_classes)
# best_net = None

#####
#####
# TODO: Train a two-layer neural network on image features. You may want to
# cross-validate various parameters as in previous sections. Store your best
# model in the best_net variable.
#
#####
#####
best_net = None # store the best model into this
input_size = X_train_feats.shape[1]
learning_rates = [1e-1, 9e-1]
regularization_strengths = [1e-2, 1e-1]
hiddenSizes = range(500,501)
num_classes = 10
results = {}
best_val = -1
best_lr = -1
best_reg = -1
best_hidden_size = -1
inner_iterations = 3000
batch_size = 200
learning_rate_decay=0.95

num_iters = 10
for it in range(num_iters):
    for jt in range(num_iters):
        for kt in range(len(hiddenSizes)-1):
            learning_rate = learning_rates[0] + it * ((learning_rates[1] - learning_rates[0]) / num_iters)
            reg = regularization_strengths[0] + jt * ((regularization_strengths[1] - regularization_strengths[0]) / num_iters)
            hidden_size = hiddenSizes[kt]

            net = TwoLayerNet(input_size, hidden_size, num_classes)
            # Train the network
            stats = net.train(X_train_feats, y_train, X_val_feats, y_val,
                             learning_rate, learning_rate_decay,
                             reg, inner_iterations, batch_size, verbose=False)

            y_train_pred = net.predict(X_train_feats)
            y_val_pred = net.predict(X_val_feats)
            training_accuracy = np.mean(y_train == y_train_pred)
            validation_accuracy = np.mean(y_val == y_val_pred)

```

```
        results[(learning_rate, reg, hidden_size)] = (training_accuracy, validation_accuracy)
        print('lr %e reg %e hidden %f train accuracy: %f val accuracy: %f' % (
            learning_rate, reg, hidden_size, training_accuracy, validation_accuracy))
        if validation_accuracy > best_val:
            best_val = validation_accuracy
            best_net = net
            best_lr = learning_rate
            best_reg = reg
            best_hidden_size = hidden_size

    print('best validation accuracy achieved during cross-validation: lr %e reg %e hidden %f val accuracy: %f, ' % (learning_rate, reg, hidden_size, best_val))

#####
#####
#                                     END OF YOUR CODE
#
#####
#####
```

lr 1.000000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.535571 val accuracy: 0.527000
lr 1.000000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.518347 val accuracy: 0.519000
lr 1.000000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.506531 val accuracy: 0.530000
lr 1.000000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.484878 val accuracy: 0.490000
lr 1.000000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.463102 val accuracy: 0.473000
lr 1.000000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.450286 val accuracy: 0.486000
lr 1.000000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.431265 val accuracy: 0.435000
lr 1.000000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.413959 val accuracy: 0.430000
lr 1.000000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.400408 val accuracy: 0.378000
lr 1.000000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.391490 val accuracy: 0.394000
lr 1.800000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.540531 val accuracy: 0.537000
lr 1.800000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.511408 val accuracy: 0.522000
lr 1.800000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.501224 val accuracy: 0.505000
lr 1.800000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.483980 val accuracy: 0.503000
lr 1.800000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.466776 val accuracy: 0.486000
lr 1.800000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.451306 val accuracy: 0.451000
lr 1.800000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.423694 val accuracy: 0.422000
lr 1.800000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.414306 val accuracy: 0.417000
lr 1.800000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.397408 val accuracy: 0.390000
lr 1.800000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.392673 val accuracy: 0.393000
lr 2.600000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.536510 val accuracy: 0.544000
lr 2.600000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.510878 val accuracy: 0.513000
lr 2.600000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.495347 val accuracy: 0.498000
lr 2.600000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.481449 val accuracy: 0.486000
lr 2.600000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.464551 val accuracy: 0.480000
lr 2.600000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.438592 val accuracy: 0.446000
lr 2.600000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.429776 val accuracy: 0.444000
lr 2.600000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.412286 val accuracy: 0.419000
lr 2.600000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.

373531 val accuracy: 0.358000
lr 2.600000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.
388224 val accuracy: 0.379000
lr 3.400000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.
540286 val accuracy: 0.526000
lr 3.400000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.
507163 val accuracy: 0.526000
lr 3.400000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.
491918 val accuracy: 0.502000
lr 3.400000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.
481408 val accuracy: 0.495000
lr 3.400000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.
429735 val accuracy: 0.438000
lr 3.400000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.
421510 val accuracy: 0.424000
lr 3.400000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.
389082 val accuracy: 0.373000
lr 3.400000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.
409429 val accuracy: 0.401000
lr 3.400000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.
363571 val accuracy: 0.374000
lr 3.400000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.
397327 val accuracy: 0.394000
lr 4.200000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.
528735 val accuracy: 0.506000
lr 4.200000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.
505061 val accuracy: 0.517000
lr 4.200000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.
474694 val accuracy: 0.480000
lr 4.200000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.
470306 val accuracy: 0.469000
lr 4.200000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.
453776 val accuracy: 0.474000
lr 4.200000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.
415816 val accuracy: 0.454000
lr 4.200000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.
415551 val accuracy: 0.410000
lr 4.200000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.
411898 val accuracy: 0.418000
lr 4.200000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.
358020 val accuracy: 0.377000
lr 4.200000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.
366939 val accuracy: 0.378000
lr 5.000000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.
522673 val accuracy: 0.509000
lr 5.000000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.
507429 val accuracy: 0.498000
lr 5.000000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.
485857 val accuracy: 0.483000
lr 5.000000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.
478367 val accuracy: 0.480000
lr 5.000000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.
449388 val accuracy: 0.487000
lr 5.000000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.
424204 val accuracy: 0.428000
lr 5.000000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.
394429 val accuracy: 0.407000

lr 5.000000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.401245 val accuracy: 0.430000
lr 5.000000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.377184 val accuracy: 0.369000
lr 5.000000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.370224 val accuracy: 0.384000
lr 5.800000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.532592 val accuracy: 0.517000
lr 5.800000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.490490 val accuracy: 0.503000
lr 5.800000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.474857 val accuracy: 0.488000
lr 5.800000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.457735 val accuracy: 0.461000
lr 5.800000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.454490 val accuracy: 0.449000
lr 5.800000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.430184 val accuracy: 0.436000
lr 5.800000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.397306 val accuracy: 0.386000
lr 5.800000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.387082 val accuracy: 0.384000
lr 5.800000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.383347 val accuracy: 0.397000
lr 5.800000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.349592 val accuracy: 0.328000
lr 6.600000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.529449 val accuracy: 0.519000
lr 6.600000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.483755 val accuracy: 0.481000
lr 6.600000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.472143 val accuracy: 0.477000
lr 6.600000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.471653 val accuracy: 0.488000
lr 6.600000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.444184 val accuracy: 0.471000
lr 6.600000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.396796 val accuracy: 0.379000
lr 6.600000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.390980 val accuracy: 0.384000
lr 6.600000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.374551 val accuracy: 0.381000
lr 6.600000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.360286 val accuracy: 0.356000
lr 6.600000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.330510 val accuracy: 0.347000
lr 7.400000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.515816 val accuracy: 0.496000
lr 7.400000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.481735 val accuracy: 0.488000
lr 7.400000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.478878 val accuracy: 0.497000
lr 7.400000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.452041 val accuracy: 0.458000
lr 7.400000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.441837 val accuracy: 0.437000
lr 7.400000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.

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414633 val accuracy: 0.429000
lr 7.400000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.
386449 val accuracy: 0.392000
lr 7.400000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.
354980 val accuracy: 0.321000
lr 7.400000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.
385469 val accuracy: 0.388000
lr 7.400000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.
293714 val accuracy: 0.294000
lr 8.200000e-01 reg 1.000000e-02 hidden 500.000000 train accuracy: 0.
518102 val accuracy: 0.506000
lr 8.200000e-01 reg 1.900000e-02 hidden 500.000000 train accuracy: 0.
474327 val accuracy: 0.466000
lr 8.200000e-01 reg 2.800000e-02 hidden 500.000000 train accuracy: 0.
459673 val accuracy: 0.464000
lr 8.200000e-01 reg 3.700000e-02 hidden 500.000000 train accuracy: 0.
441980 val accuracy: 0.435000
lr 8.200000e-01 reg 4.600000e-02 hidden 500.000000 train accuracy: 0.
429857 val accuracy: 0.442000
lr 8.200000e-01 reg 5.500000e-02 hidden 500.000000 train accuracy: 0.
375796 val accuracy: 0.349000
lr 8.200000e-01 reg 6.400000e-02 hidden 500.000000 train accuracy: 0.
367265 val accuracy: 0.360000
lr 8.200000e-01 reg 7.300000e-02 hidden 500.000000 train accuracy: 0.
385367 val accuracy: 0.379000
lr 8.200000e-01 reg 8.200000e-02 hidden 500.000000 train accuracy: 0.
353633 val accuracy: 0.354000
lr 8.200000e-01 reg 9.100000e-02 hidden 500.000000 train accuracy: 0.
325265 val accuracy: 0.321000
best validation accuracy achieved during cross-validation: lr 8.20000
0e-01 reg 9.100000e-02 hidden 500.000000 val accuracy: 0.544000,

```

```

In [36]: # Run your best neural net classifier on the test set. You should be
         able
         # to get more than 55% accuracy.

test_acc = (best_net.predict(X_test_feats) == y_test).mean()
print(test_acc)

```

```
0.517
```

```
In [ ]:
```