In [ ]:
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import numpy as np

class Softmax(object):

  def __init__(self, dims=[10, 3073]):
    self.init_weights(dims=dims)

  def init_weights(self, dims):
    """
      Initializes the weight matrix of the Softmax classifier.
      Note that it has shape (C, D) where C is the number of
      classes and D is the feature size.
      """
    self.W = np.random.normal(size=dims) * 0.0001

  def loss(self, X, y):
    """
    Calculates the softmax loss.

    Inputs have dimension D, there are C classes, and we operate on minibatches
    of N examples.

    Inputs:
    - X: A numpy array of shape (N, D) containing a minibatch of data.
    - y: A numpy array of shape (N,) containing training labels; y[i] = c means
      that X[i] has label c, where 0 <= c < C.

    Returns a tuple of:
    - loss as single float
    """

    # Initialize the loss to zero.
    loss = 0.0

    # ================================================================ #
    # YOUR CODE HERE:
    #   Calculate the normalized softmax loss.  Store it as the variable loss.
    #   (That is, calculate the sum of the losses of all the training
    #   set margins, and then normalize the loss by the number of
    #   training examples.)
    # ================================================================ #
    for i in np.arange(X.shape[0]):
      loss += np.log(np.sum(np.exp(np.matmul(self.W, X[i])))) - np.matmul(self.W[
y[i]].transpose(), X[i])

    loss /= X.shape[0]
    # ================================================================ #
    # END YOUR CODE HERE
    # ================================================================ #

    return loss

  def loss_and_grad(self, X, y):
    """
      Same as self.loss(X, y), except that it also returns the gradient.

      Output: grad -- a matrix of the same dimensions as W containing
              the gradient of the loss with respect to W.
      """

    # Initialize the loss and gradient to zero.
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    loss = 0.0
    grad = np.zeros_like(self.W)

    # ================================================================ #
    # YOUR CODE HERE:
    #   Calculate the softmax loss and the gradient. Store the gradient
    #   as the variable grad.
    # ================================================================ #
    for i in np.arange(X.shape[0]):
      loss += np.log(np.sum(np.exp(np.matmul(self.W, X[i])))) - np.matmul(self.W[
y[i]].transpose(), X[i])
    loss /= X.shape[0]

    for i in range(X.shape[0]):
      denominator = np.sum(np.exp(np.matmul(self.W, X[i])))
      for j in range(self.W.shape[0]):
        if j == y[i]:
          grad[j] += -X[i] + np.exp(np.dot(self.W[j], X[i])) * X[i] / denominator
        else:
          grad[j] += np.exp(np.dot(self.W[j], X[i])) * X[i] / denominator
    grad /= X.shape[0]
    # ================================================================ #
    # END YOUR CODE HERE
    # ================================================================ #

    return loss, grad

  def grad_check_sparse(self, X, y, your_grad, num_checks=10, h=1e-5):
    """
    sample a few random elements and only return numerical
    in these dimensions.
    """

    for i in np.arange(num_checks):
      ix = tuple([np.random.randint(m) for m in self.W.shape])

      oldval = self.W[ix]
      self.W[ix] = oldval + h # increment by h
      fxph = self.loss(X, y)
      self.W[ix] = oldval - h # decrement by h
      fxmh = self.loss(X,y) # evaluate f(x - h)
      self.W[ix] = oldval # reset

      grad_numerical = (fxph - fxmh) / (2 * h)
      grad_analytic = your_grad[ix]
      rel_error = abs(grad_numerical - grad_analytic) / (abs(grad_numerical) + ab
s(grad_analytic))
      print('numerical: %f analytic: %f, relative error: %e' % (grad_numerical, g
rad_analytic, rel_error))

  def fast_loss_and_grad(self, X, y):
    """
    A vectorized implementation of loss_and_grad. It shares the same
      inputs and ouptuts as loss_and_grad.
    """
    loss = 0.0
    grad = np.zeros(self.W.shape) # initialize the gradient as zero

    # ================================================================ #
    # YOUR CODE HERE:
    #   Calculate the softmax loss and gradient WITHOUT any for loops.
    # ================================================================ #
```

```
    loss = np.sum(np.log(np.sum(np.exp(np.matmul(self.W, X.T)), axis=0)) - np.sum
(self.W[y] * X, axis=1))
    loss /= X.shape[0]

    base = np.exp(np.matmul(self.W, X.T)) / np.sum(np.exp(np.matmul(X, self.W.T
)), axis=1)
    print(base.shape)
    y[0] = 12
    base[y,np.arange(X.shape[0])] -= 1
    print(base[y])
    grad = np.matmul(base, X)
    grad /= X.shape[0]
    # ================================================================ #
    # END YOUR CODE HERE
    # ================================================================ #

    return loss, grad

  def train(self, X, y, learning_rate=1e-3, num_iters=100,
            batch_size=200, verbose=False):
    """
    Train this linear classifier using stochastic gradient descent.

    Inputs:
    - X: A numpy array of shape (N, D) containing training data; there are N
      training samples each of dimension D.
    - y: A numpy array of shape (N,) containing training labels; y[i] = c
      means that X[i] has label 0 <= c < C for C classes.
    - learning_rate: (float) learning rate for optimization.
    - num_iters: (integer) number of steps to take when optimizing
    - batch_size: (integer) number of training examples to use at each step.
    - verbose: (boolean) If true, print progress during optimization.

    Outputs:
    A list containing the value of the loss function at each training iteration.
    """
    num_train, dim = X.shape
    num_classes = np.max(y) + 1 # assume y takes values 0...K-1 where K is number
 of classes

    self.init_weights(dims=[np.max(y) + 1, X.shape[1]]) # initializes the weights
 of self.W

    # Run stochastic gradient descent to optimize W
    loss_history = []

    for it in np.arange(num_iters):
      X_batch = None
      y_batch = None

      # ================================================================ #
      # YOUR CODE HERE:
      #   Sample batch_size elements from the training data for use in
      #      gradient descent.  After sampling,
      #     - X_batch should have shape: (dim, batch_size)
      #     - y_batch should have shape: (batch_size,)
      #   The indices should be randomly generated to reduce correlations
      #   in the dataset.  Use np.random.choice.  It's okay to sample with
      #   replacement.
      # ================================================================ #
      indices = np.random.choice(X.shape[0], batch_size)
      X_batch = X[indices,:]
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        y_batch = y[indices]
        # ================================================================ #
        # END YOUR CODE HERE
        # ================================================================ #

        # evaluate loss and gradient
        loss, grad = self.fast_loss_and_grad(X_batch, y_batch)
        loss_history.append(loss)

        # ================================================================ #
        # YOUR CODE HERE:
        #   Update the parameters, self.W, with a gradient step
        # ================================================================ #
        self.W -= learning_rate * grad

        # ================================================================ #
        # END YOUR CODE HERE
        # ================================================================ #

        if verbose and it % 100 == 0:
          print('iteration {} / {}: loss {}'.format(it, num_iters, loss))

      return loss_history

    def predict(self, X):
      """
      Inputs:
      - X: N x D array of training data. Each row is a D-dimensional point.

      Returns:
      - y_pred: Predicted labels for the data in X. y_pred is a 1-dimensional
        array of length N, and each element is an integer giving the predicted
        class.
      """
      y_pred = np.zeros(X.shape[0])
      # ================================================================ #
      # YOUR CODE HERE:
      #   Predict the labels given the training data.
      # ================================================================ #
      y_pred = np.argsort(np.matmul(X, self.W.transpose()), axis=1)[:X.shape[0], se
lf.W.shape[0] - 1]
      # ================================================================ #
      # END YOUR CODE HERE
      # ================================================================ #

      return y_pred
```