classifiers_step_by_step

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3 Linear Classifier with Gradient Descent

In this lab, we will explore the implementation of a linear classifier from scratch. The topics covered include:

- Initialization of weights and bias
- Matrix multiplication of inputs (X) and weights (theta) with bias
- Loss (cost) function calculation
- Gradient Descent (both batch and stochastic)
- Weight update
- Use case for binomial and multinomial classification using sigmoid and softmax

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3.1 0. Import necessary libraries

[1]:
```
import os
import time
import numpy as np
from sklearn.datasets import make_classification
from sklearn.model_selection import train_test_split
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
import torch
from torch.utils.data import DataLoader, Subset
from torchvision import datasets, transforms

import torch.nn as nn
# import torchvision.transforms as transforms
# import torchvision.datasets as datasets
from torchvision import models
```

3.2 1. Initialization of Weights and Bias

Before training, we need to initialize our weights (`theta`) and bias (`b`). This can be done randomly or using a small constant value. In most cases, initializing weights with small random values works best to break symmetry, while bias can be initialized to zero.

3.3 2. Matrix Multiplication of X and θ with Bias

In linear models, the prediction is computed as the dot product between the input features X and the weight vector θ, plus the bias b. Mathematically, this is expressed as:

$$y = X\theta + b$$

To incorporate the bias term into the matrix multiplication, we can augment the input matrix X and the weight vector θ.

3.3.1 i. Augmenting X

Add a column of ones to the input matrix X to account for the bias term. Let X have dimensions $m \times n$ (where m is the number of samples and n is the number of features). The augmented matrix X_{bias} will have dimensions $m \times (n+1)$:

$$X_{\text{bias}} = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1n} \\ 1 & x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

3.3.2 ii. Augmenting θ

Extend θ to include the bias term. The extended vector θ_{bias} will have dimensions $(n+1) \times c$ (where c is the no. of classes):

$$\theta_{\text{bias}} = \begin{bmatrix} b \\ \theta_1 \\ \theta_2 \\ \vdots \\ \theta_n \end{bmatrix}$$

3.3.3 iii. Matrix Multiplication

With the augmented matrix X_{bias} and the extended vector θ_{bias}, the prediction y can be computed as:

$$y = X_{\text{bias}}\theta_{\text{bias}}$$

This approach simplifies the computation by integrating the bias term directly into the matrix multiplication, which can be more efficient and straightforward in practice, especially when using matrix operations libraries.

[2]:
```python
# Add bias term (column of 1s) to X
def add_bias_term(X):
    return np.c_[np.ones((X.shape[0], 1)), X]
```

[3]:
```python
# Initialize weights with X updated to handle bias
def initialize_parameters(X, y, multiclass):
    n_features = X.shape[1]  # Number of features from the input X with bias␣
↪term
    if multiclass:
        n_classes = y.shape[1]
        theta = np.random.randn(n_features, n_classes) * 0.01  # Small random␣
↪weights
    else:
        theta = np.random.randn(n_features, 1) * 0.01  # Small random weights
    return theta
```

[4]:
```python
# Linear prediction
def linear_prediction(X, theta):
    return np.dot(X, theta)
```

3.4 3. Loss Functions for Classification

For classification tasks, different loss functions are used depending on whether the task is binary classification or multinomial classification.

3.4.1 Binary Classification (Sigmoid/Logistic Regression)

The loss function used is binary cross-entropy, also known as log loss. It is defined as:

$$J(\theta) = -\frac{1}{m} \sum_{i=1}^{m} [y_i \log(\hat{y}_i) + (1 - y_i) \log(1 - \hat{y}_i)]$$

where: - m is the number of samples. - y_i is the true label for the i-th sample. - $\hat{y}_i$ is the predicted probability for the i-th sample.

3.4.2 Multinomial Classification (Softmax)

For multinomial classification, especially after one-hot encoding the labels, the loss function is categorical cross-entropy. It is defined as:

$$J(\theta) = -\frac{1}{m} \sum_{i=1}^{m} \sum_{k=1}^{K} y_{ik} \log(\hat{y}_{ik})$$

where: - m is the number of samples. - K is the number of classes. - y_{ik} is the one-hot encoded label for the i-th sample and k-th class (binary indicator: 0 or 1). - $\hat{y}_{ik}$ is the predicted probability of class k for the i-th sample.

In one-hot encoding, y_{ik} is 1 if the i-th sample belongs to class k, and 0 otherwise. This loss function measures how well the predicted probabilities match the one-hot encoded true labels.

```
[5]: # Binary Cross Entropy Loss
def binary_cross_entropy_loss(y_true, y_pred):
    m = y_true.shape[0]
    epsilon = 1e-15  # To avoid log(0) this is a very small value
    y_pred = np.clip(y_pred, epsilon, 1 - epsilon)
    return -np.sum(y_true * np.log(y_pred) + (1 - y_true) * np.log(1 - y_pred))
 ↪/ m

# Categorical Cross Entropy Loss
def categorical_cross_entropy_loss(y_true, y_pred):
    m = y_true.shape[0]
    epsilon = 1e-15  # To avoid log(0)
    y_pred = np.clip(y_pred, epsilon, 1 - epsilon)
    return -np.sum(y_true * np.log(y_pred)) / m
```

3.5 4. Gradient Descent for Minimizing the Loss Function with weight updates

Gradient descent is used to minimize the loss function by iteratively updating the weights based on the gradient of the loss function.

3.5.1 Batch Gradient Descent

In Batch Gradient Descent, the gradient is computed using all examples in the dataset:

$$\theta = \theta - \alpha \frac{\partial J(\theta)}{\partial \theta}$$

where: - α is the learning rate. - $\frac{\partial J(\theta)}{\partial \theta}$ is the gradient of the loss function with respect to the weights.

3.5.2 Stochastic Gradient Descent (SGD)

In Stochastic Gradient Descent, the gradient is computed using only one example at a time:

$$\theta = \theta - \alpha \frac{\partial J(\theta)}{\partial \theta}$$

where: - α is the learning rate. - $\frac{\partial J(\theta)}{\partial \theta}$ is the gradient of the loss function with respect to the weights, computed for a single example.

In both cases, the update rule for weights is the same, but the difference lies in how the gradient is computed: either over the entire dataset (Batch Gradient Descent) or a single example (Stochastic Gradient Descent).

3.6 5. Weight Update

After calculating the gradient, we update the weights using the formula mentioned above. Depending on whether we are using batch gradient descent or stochastic gradient descent, the weight update happens differently.

[6]:
```python
def gradient_descent_step(X, y, predictions, theta, learning_rate, multiclass):
    m = X.shape[0]
    # predictions = linear_prediction(X, theta)
    if multiclass:
        # predictions = softmax(predictions)
        gradients = (1/m) * np.dot(X.T, (predictions - y))
    else:
        # predictions = sigmoid(predictions)
        gradients = (1/m) * np.dot(X.T, (predictions - y))
    theta = theta - learning_rate * gradients
    return theta
```

[7]:
```python
# Stochastic Gradient Descent (SGD) Step
def stochastic_gradient_descent_step(X, y, theta, learning_rate, multiclass):
    m = X.shape[0]
    for i in range(m):
        xi = X[i:i+1]
        yi = y[i:i+1]
        # print (theta.shape)
        prediction = linear_prediction(xi, theta)
        if multiclass:
            prediction = softmax(prediction)
        else:
            prediction = sigmoid(prediction)
        # print(prediction.shape)
        # print(xi.T.shape)
        # print(yi.shape)
        gradients = np.dot(xi.T, (prediction - yi))
        theta = theta - learning_rate * gradients
    return theta
```

3.7 Activation: Binomial Classification (Sigmoid)

In binary classification, the sigmoid function is applied to the linear output to obtain the predicted probability. The sigmoid function $\sigma(z)$ is defined as:

$$\hat{y} = \sigma(X\theta) = \frac{1}{1 + e^{-X\theta}}$$

where: - $\hat{y}$ is the predicted probability. - $X\theta$ represents the linear combination of the input features X and the weights θ. - e is the base of the natural logarithm.

The sigmoid function maps the linear output to a probability value between 0 and 1, which can then be used to make a classification decision.

3.8 Activation: Multinomial Classification (Softmax)

In multinomial classification, the softmax function is used to compute probabilities across multiple classes. The softmax function $\text{softmax}(z_i)$ for class k is defined as:

$$\hat{y}_{ik} = \frac{e^{(X\theta_k)}}{\sum_{j=1}^{K} e^{(X\theta_j)}}$$

where: - $\hat{y}_{ik}$ is the predicted probability of the i-th sample belonging to class k. - $X\theta_k$ is the linear combination of the input features X and the weights θ_k for class k. - K is the total number of classes. - The denominator is the sum of the exponentials of the linear combinations for all classes, ensuring that the probabilities sum up to 1.

The softmax function converts the linear outputs into a probability distribution over multiple classes, which is useful for making predictions in multiclass classification problems.

[8]:
```
# Sigmoid function for binary classification
def sigmoid(z):
    return 1 / (1 + np.exp(-z))

# Softmax function for multi-class
def softmax(z):
    exp_scores = np.exp(z - np.max(z, axis=1, keepdims=True))  # For numerical␣
 ↪stability
    return exp_scores / np.sum(exp_scores, axis=1, keepdims=True)
```

3.8.1 OKAY LETS GO A HEAD AND TRAIN OUR MODEL !!

[9]:
```
# Training function
def train_model(X, y, learning_rate=0.01, iterations=1000, batch=True,␣
 ↪multiclass=False):
    # Add bias term to X
    X = add_bias_term(X)

    # Initialize theta
    theta = initialize_parameters(X, y, multiclass)

    # Track loss over iterations
    losses = []

    for i in range(iterations):
        # Compute predictions and loss
        if multiclass:
            predictions = softmax(linear_prediction(X, theta))
            loss = categorical_cross_entropy_loss(y, predictions)
```

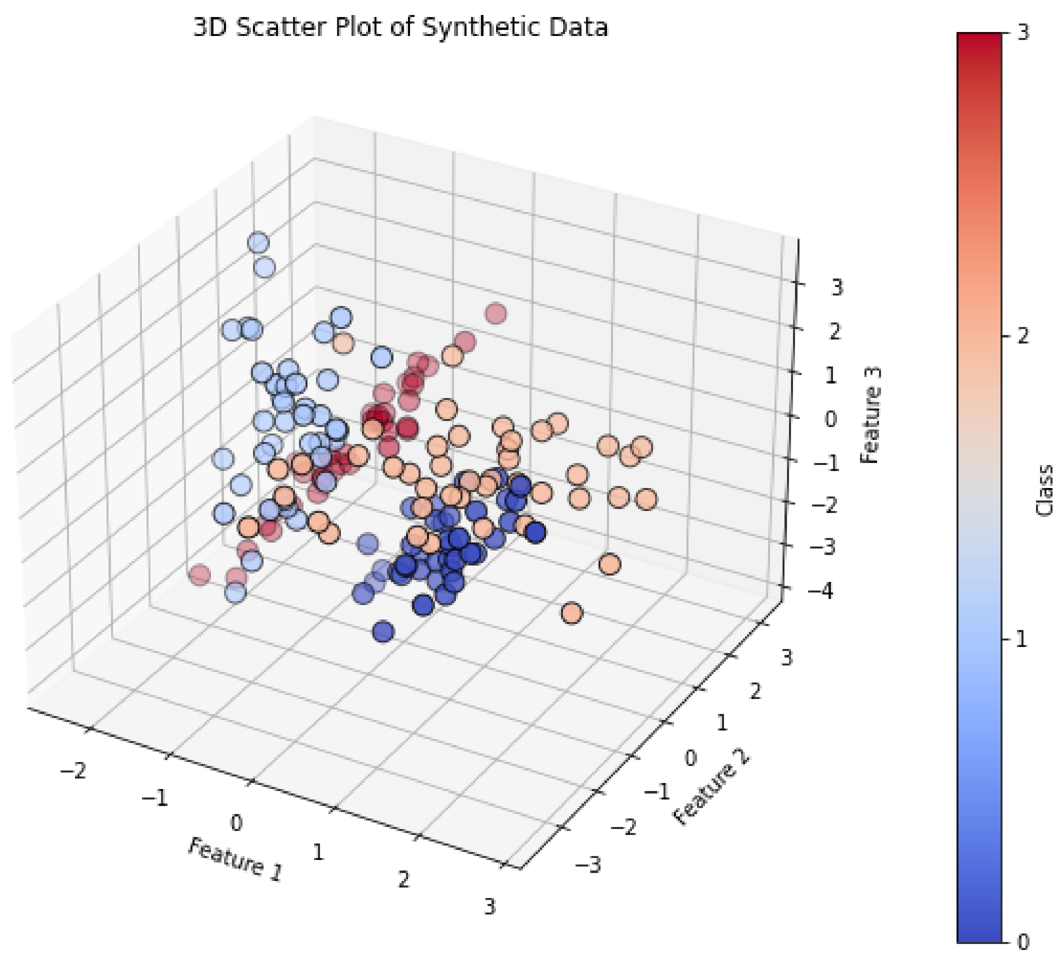
```
        else:
            predictions = sigmoid(linear_prediction(X, theta))
            loss = binary_cross_entropy_loss(y, predictions)

        losses.append(loss)

        # Update weights
        if batch:
            theta = gradient_descent_step(X, y, predictions, theta,␣
 ↪learning_rate, multiclass)
        else:
            # Use stochastic gradient descent
            theta = stochastic_gradient_descent_step(X, y, theta,␣
 ↪learning_rate, multiclass)

        # Print loss every 100 iterations
        if i % 100 == 0:
            print(f"Iteration {i}/{iterations}, Loss: {loss:.4f}")

    return theta, losses
```

3.8.2 Lets generate some data!!

[10]:
```
# Set multiclass to True or False
multiclass = True  # Set to True for multiclass classification

if multiclass:
    # For multiclass classification
    X_syn, y_syn = make_classification(n_samples=200, n_features=3,␣
 ↪n_informative=3,
                                   n_redundant=0, n_clusters_per_class=1,␣
 ↪n_classes=4, random_state=100)
    # Convert y to one-hot encoding
    y_syn = np.eye(np.max(y_syn) + 1)[y_syn]
else:
    # For binary classification
    X_syn, y_syn = make_classification(n_samples=200, n_features=2,␣
 ↪n_classes=2, n_informative=2, n_redundant=0, random_state=100)
    y_syn = y_syn.reshape(-1, 1)  # Reshape y to be a column vector

# Split into training and test sets
X_train_syn, X_test_syn, y_train_syn, y_test_syn = train_test_split(X_syn,␣
 ↪y_syn, test_size=0.2, random_state=100)
```

[11]:
```
if multiclass:
    fig = plt.figure(figsize=(10, 8))
```

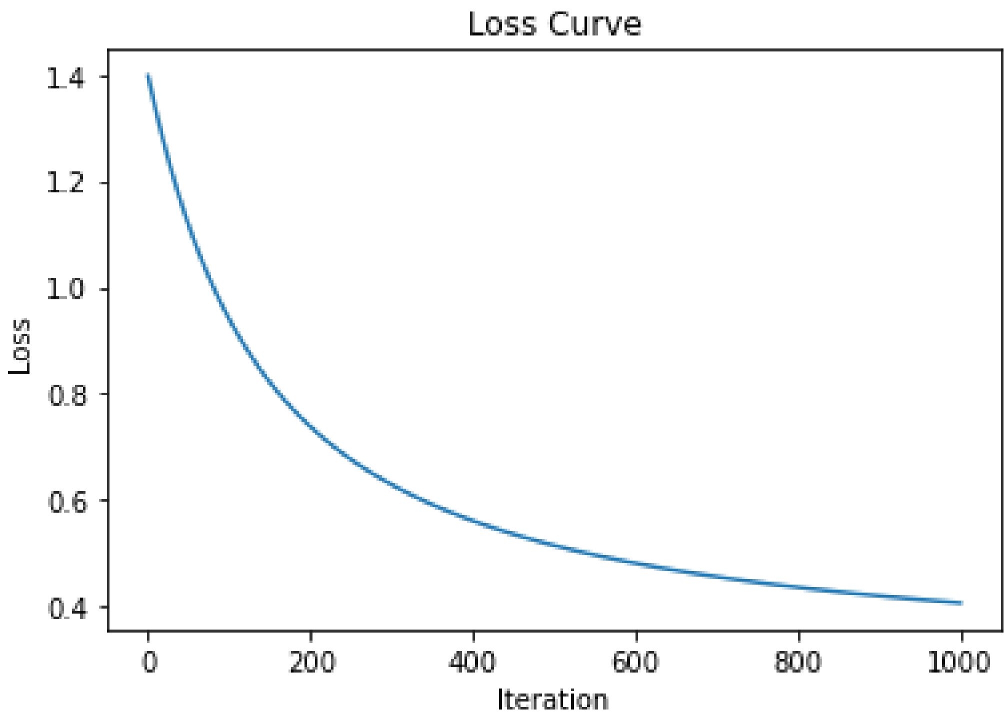
```python
    ax = fig.add_subplot(111, projection='3d')
    # Convert one-hot encoding to class labels for plotting
    y_train_labels = np.argmax(y_train_syn, axis=1)

    # Use the 3 features for the scatter plot
    scatter = ax.scatter(X_train_syn[:, 0], X_train_syn[:, 1], X_train_syn[:,␣
↪2],
                         c=y_train_labels, cmap='coolwarm', edgecolor='k',␣
↪s=100)

    # Add labels
    ax.set_title("3D Scatter Plot of Synthetic Data")
    ax.set_xlabel("Feature 1")
    ax.set_ylabel("Feature 2")
    ax.set_zlabel("Feature 3")

    # Add color bar to represent class labels
    cbar = fig.colorbar(scatter, ax=ax, pad=0.1)
    cbar.set_label('Class')

    # Set ticks to be integers corresponding to class labels
    cbar.set_ticks(np.arange(np.min(y_train_labels), np.max(y_train_labels) +␣
↪1))

    plt.show()
else:
    plt.figure(figsize=(10, 8))
    plt.scatter(X_train_syn[:, 0], X_train_syn[:, 1], c=y_train_syn,␣
↪cmap='coolwarm', edgecolor='k', s=100)
    plt.title("Scatter Plot of Training Data")
    plt.xlabel("Feature 1")
    plt.ylabel("Feature 2")
    plt.show()
```



[12]:
```
start_time = time.time()
theta, losses = train_model(X_train_syn, y_train_syn, learning_rate=0.01,␣
    ↪iterations=1000, batch=True, multiclass=multiclass)
print(f"Time Taken Using Batch gradient descent :{time.time() - start_time}")
```

```
Iteration 0/1000, Loss: 1.3973
Iteration 100/1000, Loss: 0.9391
Iteration 200/1000, Loss: 0.7377
Iteration 300/1000, Loss: 0.6285
Iteration 400/1000, Loss: 0.5605
Iteration 500/1000, Loss: 0.5143
Iteration 600/1000, Loss: 0.4807
Iteration 700/1000, Loss: 0.4554
Iteration 800/1000, Loss: 0.4354
Iteration 900/1000, Loss: 0.4194
Time Taken Using Batch gradient descent :0.14931321144104004
```

[13]:
```python
plt.plot(losses)
plt.xlabel('Iteration')
plt.ylabel('Loss')
plt.title('Loss Curve')
plt.show()
```



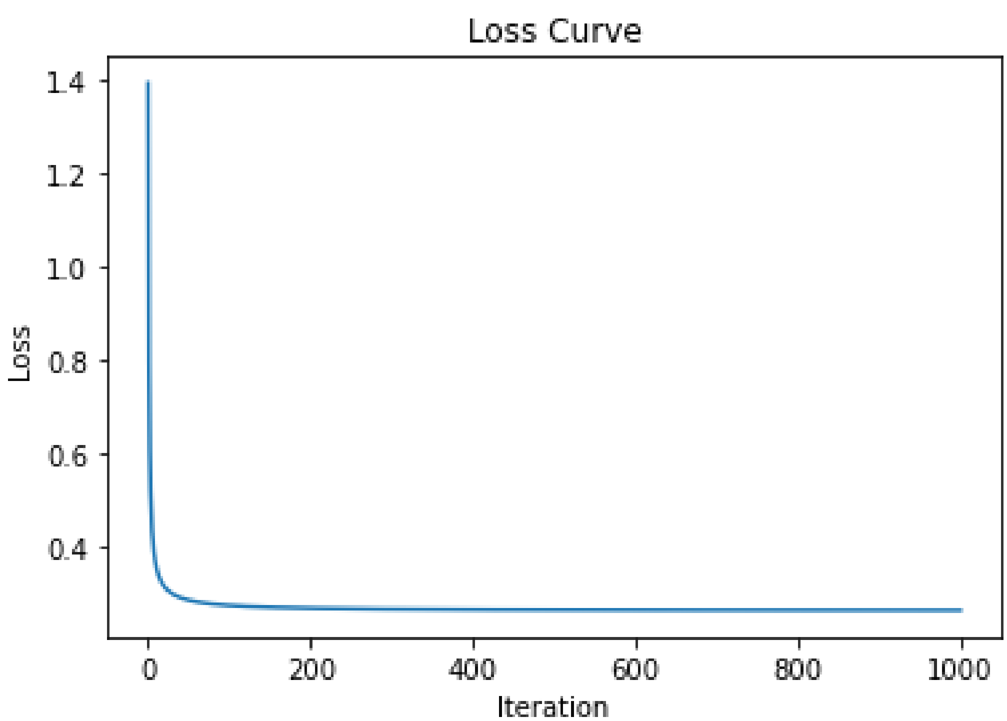
[14]:
```python
# Add bias term to test data
X_test_bias = add_bias_term(X_test_syn)

if multiclass:
    predictions = softmax(linear_prediction(X_test_bias, theta))
    predicted_classes = np.argmax(predictions, axis=1)
    true_classes = np.argmax(y_test_syn, axis=1)
else:
    predictions = sigmoid(linear_prediction(X_test_bias, theta))
    predicted_classes = (predictions >= 0.5).astype(int)
    true_classes = y_test_syn

# Calculate accuracy
accuracy = np.mean(predicted_classes.flatten() == true_classes.flatten())
print(f"Test Accuracy: {accuracy * 100:.2f}%")
```

```
Test Accuracy: 90.00%
```

[15]:
```
start_time = time.time()
theta, losses = train_model(X_train_syn, y_train_syn, learning_rate=0.01,
  ↪iterations=1000, batch=False, multiclass=multiclass)
print(f"Time Taken Using Stochastic gradient descent :{time.time() -
  ↪start_time}")
```

```
Iteration 0/1000, Loss: 1.3929
Iteration 100/1000, Loss: 0.2756
Iteration 200/1000, Loss: 0.2695
Iteration 300/1000, Loss: 0.2675
Iteration 400/1000, Loss: 0.2666
Iteration 500/1000, Loss: 0.2660
Iteration 600/1000, Loss: 0.2657
Iteration 700/1000, Loss: 0.2654
Iteration 800/1000, Loss: 0.2653
Iteration 900/1000, Loss: 0.2652
Time Taken Using Stochastic gradient descent :5.1505231857299805
```

[22]:
```
plt.plot(losses)
plt.xlabel('Iteration')
plt.ylabel('Loss')
plt.title('Loss Curve')
plt.show()
```



[23]:
```
# Add bias term to test data
X_test_bias = add_bias_term(X_test_syn)

if multiclass:
    predictions = softmax(linear_prediction(X_test_bias, theta))
    predicted_classes = np.argmax(predictions, axis=1)
    true_classes = np.argmax(y_test_syn, axis=1)
else:
    predictions = sigmoid(linear_prediction(X_test_bias, theta))
    predicted_classes = (predictions >= 0.5).astype(int)
    true_classes = y_test_syn

# Calculate accuracy
accuracy = np.mean(predicted_classes.flatten() == true_classes.flatten())
print(f"Test Accuracy: {accuracy * 100:.2f}%")
```

```
Test Accuracy: 92.50%
```

3.9 For Image what could be possible changes??

[24]:
```
# For our puffer surver we need to browse via a proxy!!

# Set HTTP and HTTPS proxy
os.environ['http_proxy'] = 'http://192.41.170.23:3128'
os.environ['https_proxy'] = 'http://192.41.170.23:3128'
```

[25]:
```
# Check if GPU is available
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")
print(f"Using device: {device}")
```

```
Using device: cpu
```

```
/opt/conda/lib/python3.9/site-packages/torch/cuda/__init__.py:118: UserWarning:
CUDA initialization: The NVIDIA driver on your system is too old (found version
11060). Please update your GPU driver by downloading and installing a new
version from the URL: http://www.nvidia.com/Download/index.aspx Alternatively,
go to: https://pytorch.org to install a PyTorch version that has been compiled
with your version of the CUDA driver. (Triggered internally at
../c10/cuda/CUDAFunctions.cpp:108.)
  return torch._C._cuda_getDeviceCount() > 0
```

[26]:
```
cifar_train = datasets.CIFAR10('data', train=True, download=True␣
 ↪,transform=transforms.ToTensor())
cifar_test = datasets.CIFAR10('data', train=False, download=True␣
 ↪,transform=transforms.ToTensor())
```

```
Files already downloaded and verified
Files already downloaded and verified
```

[27]:
```python
# Function to subsample CIFAR-10 dataset
def subsample_dataset(dataset, sample_size=1000):
    indices = np.random.choice(len(dataset), sample_size, replace=False)
    subset = Subset(dataset, indices)
    return subset

# Subsample the training and test datasets
sample_size = 1000
train_subset = subsample_dataset(cifar_train, sample_size=sample_size)
test_subset = subsample_dataset(cifar_test, sample_size=int(sample_size * 0.4))

# Load data into PyTorch DataLoader
train_loader = DataLoader(train_subset, batch_size=sample_size, shuffle=True)
test_loader = DataLoader(test_subset, batch_size=int(sample_size * 0.4),␣
 ↪shuffle=False)

# Fetch all data and labels for easier handling
X_train, y_train = next(iter(train_loader))
X_test, y_test = next(iter(test_loader))

print("Before Flattening")
print(f"Training data shape: {X_train.shape}")
print(f"Test data shape: {X_test.shape}")

# Reshape the images to 2D for the KNN algorithm
X_train = X_train.view(X_train.size(0), -1).to(device)  # Flatten
X_test = X_test.view(X_test.size(0), -1).to(device)
y_train = y_train.to(device)
y_test = y_test.to(device)

print("After Flattening")
print(f"Training data shape: {X_train.shape}")
print(f"Test data shape: {X_test.shape}")
```

```
Before Flattening
Training data shape: torch.Size([1000, 3, 32, 32])
Test data shape: torch.Size([400, 3, 32, 32])
After Flattening
Training data shape: torch.Size([1000, 3072])
Test data shape: torch.Size([400, 3072])
```

[28]:
```python
class ImageLinearClassifier:
    def __init__(self, input_size, n_classes):
        self.W = np.random.randn(n_classes, input_size) * 0.01  # Small random␣
 ↪weights (10,3072)
        self.b = np.zeros((n_classes, 1))  # Bias initialized to zero (10,1)
```

```
    def predict(self, X):
        # Reshape X to (input_size, batch_size)
        X=X.T  # Transpose to shape (3072,1000)
        return np.dot(self.W, X) + self.b

    def compute_loss(self, X, y):
        """
            X: (batch_size, input_size) = (1000, 3072)
            y: (batch_size,) = (1000,) with class labels (0-9)
        """
        m = X.shape[0]
        z = self.predict(X)
        probs = self.softmax(z)
        log_likelihood = -np.log(probs[y, range(m)])
        return np.sum(log_likelihood) / m

    def softmax(self, z):
        exp_z = np.exp(z - np.max(z, axis=0, keepdims=True))  # Numerical␣
 ↪stability
        return exp_z / np.sum(exp_z, axis=0, keepdims=True)

    def gradient_descent(self, X, y, learning_rate=0.001):
        # Compute the gradient and update W, b
        m = X.shape[0]
        z = self.predict(X)
        probs = self.softmax(z)
        probs[y, range(m)] -= 1  # Gradient of softmax loss wrt z
        dW = np.dot(probs, X) / m  #Gradient wrt weights
        db = np.sum(probs, axis=1, keepdims=True) / m

        # Update weights and bias
        self.W -= learning_rate * dW
        self.b -= learning_rate * db
```

[29]:
```
def train(classifier, X_train, y_train, epochs, learning_rate):
    losses = []
    for i in range(epochs):
        loss = classifier.compute_loss(X_train, y_train)
        losses.append(loss)
        print(f'Epoch {i+1}, Loss: {loss}')
        classifier.gradient_descent(X_train, y_train, learning_rate)
    return losses
```

[30]:
```
print(f"Training data: {len(cifar_train)}")
print(f"Test data: {len(cifar_test)}")

image, label = cifar_train[0]
```

```
# Now you can check the shape of the image
print(f"Image shape: {image.shape}")
```

```
Training data: 50000
Test data: 10000
Image shape: torch.Size([3, 32, 32])
```

[31]:

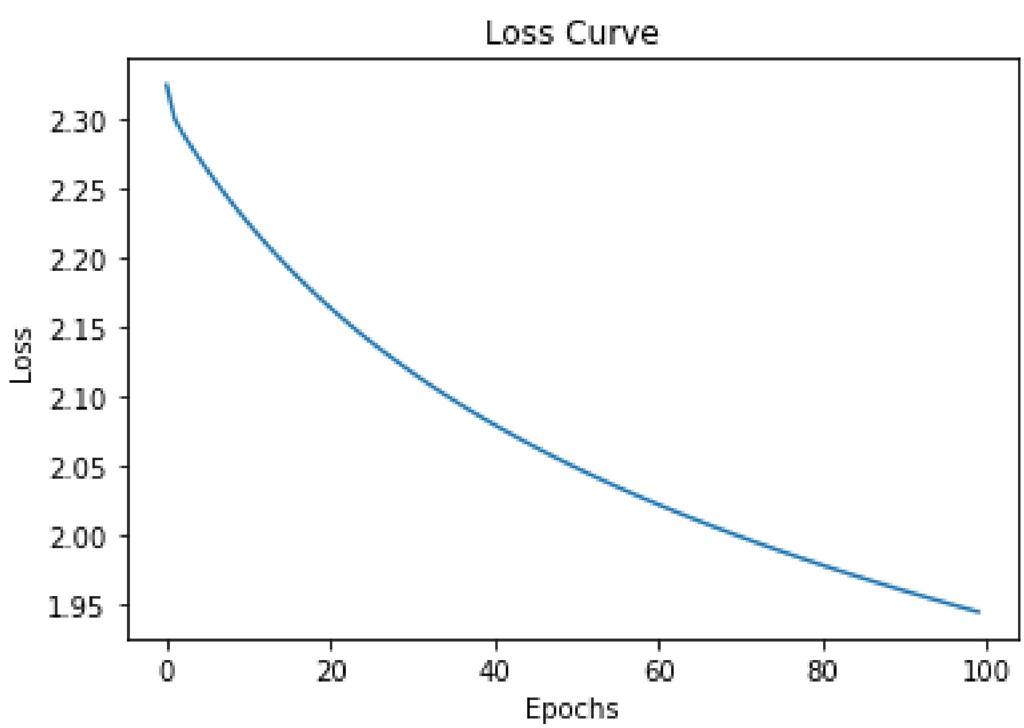
```
# Example usage
n_classes = 10  # For CIFAR-10
image_size = 32 * 32 * 3  # CIFAR-10 images are 32x32x3
classifier = ImageLinearClassifier(input_size=image_size, n_classes=n_classes)

# X_train is shape (image_size, batch_size) and y_train is (batch_size,)
losses = train(classifier, X_train, y_train, epochs=100, learning_rate=0.01)
```

```
Epoch 1, Loss: 2.3244961981300367
Epoch 2, Loss: 2.2997889815893306
Epoch 3, Loss: 2.289259543337674
Epoch 4, Loss: 2.2801174848191055
Epoch 5, Loss: 2.2713609350461
Epoch 6, Loss: 2.262906242493645
Epoch 7, Loss: 2.2547342921396396
Epoch 8, Loss: 2.2468314493952577
Epoch 9, Loss: 2.239185109292782
Epoch 10, Loss: 2.231783285579562
Epoch 11, Loss: 2.224614558107142
Epoch 12, Loss: 2.217668054751691
Epoch 13, Loss: 2.2109334354131662
Epoch 14, Loss: 2.2044008748110646
Epoch 15, Loss: 2.1980610440313995
Epoch 16, Loss: 2.1919050911519107
Epoch 17, Loss: 2.1859246212841756
Epoch 18, Loss: 2.1801116763302115
Epoch 19, Loss: 2.174458714703721
Epoch 20, Loss: 2.16895859122133
Epoch 21, Loss: 2.163604537329091
Epoch 22, Loss: 2.158390141794516
Epoch 23, Loss: 2.1533093319642607
Epoch 24, Loss: 2.1483563556618948
Epoch 25, Loss: 2.1435257637785807
Epoch 26, Loss: 2.1388123935914547
Epoch 27, Loss: 2.1342113528296007
Epoch 28, Loss: 2.1297180044954005
Epoch 29, Loss: 2.1253279524392354
Epoch 30, Loss: 2.121037027677783
Epoch 31, Loss: 2.1168412754400796
Epoch 32, Loss: 2.112736942920921
Epoch 33, Loss: 2.1087204677177533
```

```
Epoch 34, Loss: 2.1047884669247896
Epoch 35, Loss: 2.100937726856475
Epoch 36, Loss: 2.097165193371493
Epoch 37, Loss: 2.09346796276809
Epoch 38, Loss: 2.089843273221514
Epoch 39, Loss: 2.0862884967347086
Epoch 40, Loss: 2.0828011315740347
Epoch 41, Loss: 2.079378795162563
Epoch 42, Loss: 2.0760192174044594
Epoch 43, Loss: 2.072720234415001
Epoch 44, Loss: 2.0694797826319036
Epoch 45, Loss: 2.066295893284762
Epoch 46, Loss: 2.063166687200586
Epoch 47, Loss: 2.0600903699245765
Epoch 48, Loss: 2.0570652271364205
Epoch 49, Loss: 2.054089620343528
Epoch 50, Loss: 2.0511619828336873
Epoch 51, Loss: 2.0482808158707098
Epoch 52, Loss: 2.045444685117578
Epoch 53, Loss: 2.042652217272638
Epoch 54, Loss: 2.0399020969052306
Epoch 55, Loss: 2.0371930634780577
Epoch 56, Loss: 2.0345239085443767
Epoch 57, Loss: 2.0318934731089033
Epoch 58, Loss: 2.0293006451420066
Epoch 59, Loss: 2.026744357237483
Epoch 60, Loss: 2.0242235844048304
Epoch 61, Loss: 2.021737341987524
Epoch 62, Loss: 2.019284683699393
Epoch 63, Loss: 2.0168646997716815
Epoch 64, Loss: 2.0144765152038984
Epoch 65, Loss: 2.0121192881120042
Epoch 66, Loss: 2.0097922081679105
Epoch 67, Loss: 2.007494495124667
Epoch 68, Loss: 2.005225397422096
Epoch 69, Loss: 2.002984190867946
Epoch 70, Loss: 2.0007701773900095
Epoch 71, Loss: 1.998582683854897
Epoch 72, Loss: 1.9964210609494848
Epoch 73, Loss: 1.994284682121282
Epoch 74, Loss: 1.9921729425742292
Epoch 75, Loss: 1.99008525831665
Epoch 76, Loss: 1.9880210652583017
Epoch 77, Loss: 1.9859798183536554
Epoch 78, Loss: 1.9839609907887301
Epoch 79, Loss: 1.9819640732089676
Epoch 80, Loss: 1.9799885729857998
Epoch 81, Loss: 1.9780340135197056
```

```
Epoch 82, Loss: 1.9760999335776916
Epoch 83, Loss: 1.9741858866632642
Epoch 84, Loss: 1.9722914404170768
Epoch 85, Loss: 1.9704161760465466
Epoch 86, Loss: 1.9685596877828515
Epoch 87, Loss: 1.9667215823637958
Epoch 88, Loss: 1.9649014785411427
Epoch 89, Loss: 1.9630990066110918
Epoch 90, Loss: 1.96131380796665
Epoch 91, Loss: 1.9595455346707313
Epoch 92, Loss: 1.9577938490488873
Epoch 93, Loss: 1.9560584233006288
Epoch 94, Loss: 1.9543389391283645
Epoch 95, Loss: 1.9526350873830467
Epoch 96, Loss: 1.9509465677256517
Epoch 97, Loss: 1.9492730883036848
Epoch 98, Loss: 1.9476143654419438
Epoch 99, Loss: 1.945970123346818
Epoch 100, Loss: 1.9443400938234363
```

[32]:
```python
plt.plot(losses)
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.title('Loss Curve')
plt.show()
```



3.10 Key Components:

1. Input Layer: The input data, similar to your previous setup.
2. Hidden Layer(s): These layers will have weights, biases, and non-linear activations like ReLU.
3. Output Layer: This will have a softmax activation for classification.
4. Loss Function: Cross-entropy loss for classification.
5. Backpropagation: To update weights using gradients from the loss.

3.11 MLP Structure Example:

1. Input Layer: (3072 neurons, corresponding to image size 32x32x3 in CIFAR-10)
2. Hidden Layer 1: Fully connected, with a non-linear activation like ReLU.
3. Hidden Layer 2: Another fully connected layer (optional).
4. Output Layer: A fully connected layer with 10 neurons (for 10 classes) and softmax activation.

[33]:
```python
class MLPClassifier:
    def __init__(self, input_size, hidden_size, output_size):
        # Weight initialization
        self.W1 = np.random.randn(hidden_size, input_size) * 0.01  #␣
 ↪(hidden_size, input_size)
        self.b1 = np.zeros((hidden_size, 1))  # (hidden_size, 1)
        self.W2 = np.random.randn(output_size, hidden_size) * 0.01  #␣
 ↪(output_size, hidden_size)
        self.b2 = np.zeros((output_size, 1))  # (output_size, 1)

    def relu(self, z):
        return np.maximum(0, z)

    def relu_derivative(self, z):
        return np.where(z > 0, 1, 0)

    def softmax(self, z):
        exp_z = np.exp(z - np.max(z, axis=0, keepdims=True))  # Numerical␣
 ↪stability
        return exp_z / np.sum(exp_z, axis=0, keepdims=True)

    def forward(self, X):
        """
        Forward pass through the network.
        X: input data of shape (input_size, batch_size)
        """
        # Layer 1 (hidden layer)
        self.Z1 = np.dot(self.W1, X) + self.b1  # (hidden_size, batch_size)
        self.A1 = self.relu(self.Z1)  # Apply ReLU activation

        ## ADD ANOTHER HIDDEN LAYER IN YOUR TAKE HOME EXERCISE
```

```
        # Layer 2 (output layer)
        self.Z2 = np.dot(self.W2, self.A1) + self.b2  # (output_size,␣
↪batch_size)
        self.A2 = self.softmax(self.Z2)  # Apply softmax activation
        return self.A2

    def compute_loss(self, A2, y):
        """
        Compute cross-entropy loss.
        A2: output from softmax, shape (output_size, batch_size)
        y: true labels, shape (batch_size,)
        """
        m = y.shape[0]  # batch size
        log_likelihood = -np.log(A2[y, range(m)])
        loss = np.sum(log_likelihood) / m
        return loss

    def backward(self, X, y, learning_rate=0.01):
        """
        Perform backward propagation and update weights.
        X: input data of shape (input_size, batch_size)
        y: true labels of shape (batch_size,)
        """
        m = X.shape[1]  # Batch size

        # Gradient of the loss w.r.t. Z2
        dZ2 = self.A2  # Softmax probabilities
        dZ2[y, range(m)] -= 1  # Subtract 1 from the correct class probabilities
        dZ2 /= m

        # Gradients for W2 and b2
        dW2 = np.dot(dZ2, self.A1.T)  # (output_size, hidden_size)
        db2 = np.sum(dZ2, axis=1, keepdims=True)  # (output_size, 1)

        # Gradients for the hidden layer (backprop through ReLU)
        dA1 = np.dot(self.W2.T, dZ2)  # (hidden_size, batch_size)
        dZ1 = dA1 * self.relu_derivative(self.Z1)  # Backprop through ReLU

        # Gradients for W1 and b1
        dW1 = np.dot(dZ1, X.T)  # (hidden_size, input_size)
        db1 = np.sum(dZ1, axis=1, keepdims=True)  # (hidden_size, 1)

        # Update weights and biases
        self.W1 -= learning_rate * dW1
        self.b1 -= learning_rate * db1
        self.W2 -= learning_rate * dW2
```

```
        self.b2 -= learning_rate * db2

    def train(self, X_train, y_train, epochs=100, learning_rate=0.01):
        """
        Train the network.
        X_train: input data, shape (input_size, batch_size)
        y_train: true labels, shape (batch_size,)
        """
        losses = []
        for i in range(epochs):
            # Forward pass
            A2 = self.forward(X_train)

            # Compute the loss
            loss = self.compute_loss(A2, y_train)
            print(f'Epoch {i+1}, Loss: {loss}')
            losses.append(loss)

            # Backward pass
            self.backward(X_train, y_train, learning_rate)
        return losses
```

[34]:

```
input_size = 3072  # CIFAR-10 images are 32x32x3
hidden_size = 100  # Arbitrary hidden layer size
output_size = 10  # 10 classes for CIFAR-10

mlp = MLPClassifier(input_size, hidden_size, output_size)

X_train_copy = X_train.T

losses = mlp.train(X_train_copy, y_train, epochs=100, learning_rate=0.1)
```

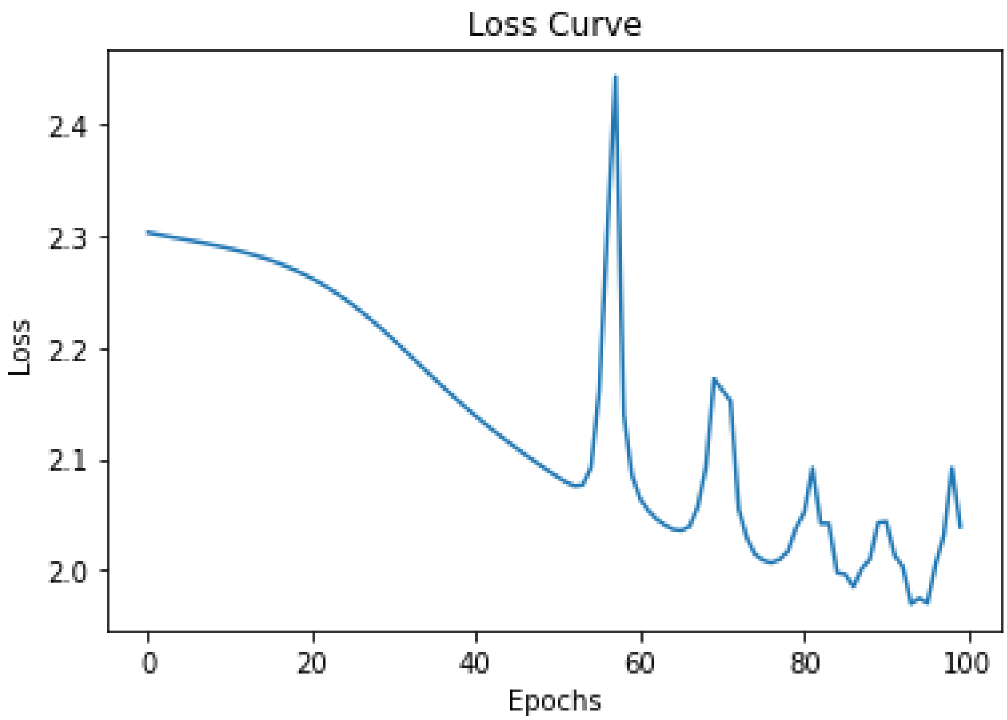
```
Epoch 1, Loss: 2.3030842819548556
Epoch 2, Loss: 2.3015363917786082
Epoch 3, Loss: 2.3001489169449023
Epoch 4, Loss: 2.2988126765041725
Epoch 5, Loss: 2.2974839138784398
Epoch 6, Loss: 2.2961367103012567
Epoch 7, Loss: 2.2947441601867316
Epoch 8, Loss: 2.2933161857146662
Epoch 9, Loss: 2.2918307818550905
Epoch 10, Loss: 2.2902501004056566
Epoch 11, Loss: 2.2885728603025077
Epoch 12, Loss: 2.2867710420391965
Epoch 13, Loss: 2.28482650068963
Epoch 14, Loss: 2.2827300708284843
Epoch 15, Loss: 2.280460710587007
```

```
Epoch 16, Loss: 2.2779983382655264
Epoch 17, Loss: 2.275326904526805
Epoch 18, Loss: 2.2724156703272897
Epoch 19, Loss: 2.2692446092081937
Epoch 20, Loss: 2.265783052904521
Epoch 21, Loss: 2.2620051510956265
Epoch 22, Loss: 2.2579024896852204
Epoch 23, Loss: 2.2534667474726295
Epoch 24, Loss: 2.248682941816581
Epoch 25, Loss: 2.2435555664856865
Epoch 26, Loss: 2.238090286404641
Epoch 27, Loss: 2.2322957284771894
Epoch 28, Loss: 2.2262025786151445
Epoch 29, Loss: 2.2198324810472227
Epoch 30, Loss: 2.2132179915121273
Epoch 31, Loss: 2.206416949219848
Epoch 32, Loss: 2.1994763747070616
Epoch 33, Loss: 2.192437497097516
Epoch 34, Loss: 2.1853609016848776
Epoch 35, Loss: 2.1782909408264683
Epoch 36, Loss: 2.1712730117358614
Epoch 37, Loss: 2.1643497285573385
Epoch 38, Loss: 2.157556602481427
Epoch 39, Loss: 2.1509162284781893
Epoch 40, Loss: 2.1444427930730012
Epoch 41, Loss: 2.1381434886247273
Epoch 42, Loss: 2.132020210285066
Epoch 43, Loss: 2.1260657210102036
Epoch 44, Loss: 2.120274094185845
Epoch 45, Loss: 2.1146335261458753
Epoch 46, Loss: 2.109128955132295
Epoch 47, Loss: 2.103754483315264
Epoch 48, Loss: 2.098500736771581
Epoch 49, Loss: 2.0933548635043633
Epoch 50, Loss: 2.0883227338421984
Epoch 51, Loss: 2.0834511096716968
Epoch 52, Loss: 2.078984017258503
Epoch 53, Loss: 2.0756599452569615
Epoch 54, Loss: 2.0766689980371162
Epoch 55, Loss: 2.0922967733155784
Epoch 56, Loss: 2.1605329255061276
Epoch 57, Loss: 2.3063294360181126
Epoch 58, Loss: 2.4432081865291178
Epoch 59, Loss: 2.1402261809858656
Epoch 60, Loss: 2.0850022093239007
Epoch 61, Loss: 2.063904411841294
Epoch 62, Loss: 2.0534114278925797
Epoch 63, Loss: 2.0458858579825296
```

```
Epoch 64, Loss: 2.040643518047492
Epoch 65, Loss: 2.036787965923209
Epoch 66, Loss: 2.035744161692922
Epoch 67, Loss: 2.0393307334187862
Epoch 68, Loss: 2.0568660448642038
Epoch 69, Loss: 2.0926139243383277
Epoch 70, Loss: 2.1718530733184362
Epoch 71, Loss: 2.161771067275567
Epoch 72, Loss: 2.152213679004437
Epoch 73, Loss: 2.0549837227282937
Epoch 74, Loss: 2.028929863298653
Epoch 75, Loss: 2.0141321556124683
Epoch 76, Loss: 2.0089562882497916
Epoch 77, Loss: 2.0067044504295204
Epoch 78, Loss: 2.0097589556757574
Epoch 79, Loss: 2.0169725989662055
Epoch 80, Loss: 2.0382322836450326
Epoch 81, Loss: 2.0519732200847813
Epoch 82, Loss: 2.091827524119243
Epoch 83, Loss: 2.042009079822729
Epoch 84, Loss: 2.041895822834455
Epoch 85, Loss: 1.9978903533093897
Epoch 86, Loss: 1.9963852140600225
Epoch 87, Loss: 1.9850632734249232
Epoch 88, Loss: 2.0013546612603754
Epoch 89, Loss: 2.009867436888828
Epoch 90, Loss: 2.0426687524440896
Epoch 91, Loss: 2.0438123110144897
Epoch 92, Loss: 2.01328808574113
Epoch 93, Loss: 2.003191913323788
Epoch 94, Loss: 1.970003500667602
Epoch 95, Loss: 1.974904061402372
Epoch 96, Loss: 1.9705977217876876
Epoch 97, Loss: 2.0057133630704165
Epoch 98, Loss: 2.0313346602072584
Epoch 99, Loss: 2.0918011395176954
Epoch 100, Loss: 2.039101904821624
```

[35]:

```
plt.plot(losses)
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.title('Loss Curve')
plt.show()
```



3.12 TAKE AWAY EXERCISE

- In the picture above the learning rate is high so the model is not able to find a minima and is overshooting.
- Use a learning rate scheduler in the above implementation, increase the no. of epochs and train on full data.
- Also increase the complexity of structure by adding another hidden layer

[30]:
```
# your code here
```

[38]:
```
class MLPClassifier:
    def __init__(self, input_size, hidden_size, output_size, hidden_size_2):
        # Initialize weights and biases for two hidden layers
        self.W1 = np.random.randn(hidden_size, input_size) * 0.01
        self.b1 = np.zeros((hidden_size, 1))
        self.W2 = np.random.randn(hidden_size_2, hidden_size) * 0.01
        self.b2 = np.zeros((hidden_size_2, 1))
        self.W3 = np.random.randn(output_size, hidden_size_2) * 0.01
        self.b3 = np.zeros((output_size, 1))

    def relu(self, z):
        return np.maximum(0, z)

    def relu_derivative(self, z):
```

```
        return np.where(z > 0, 1, 0)

    def softmax(self, z):
        exp_z = np.exp(z - np.max(z, axis=0, keepdims=True))  # Numerical␣
↪stability
        return exp_z / np.sum(exp_z, axis=0, keepdims=True)

    def forward(self, X):
        self.Z1 = np.dot(self.W1, X) + self.b1
        self.A1 = self.relu(self.Z1)
        self.Z2 = np.dot(self.W2, self.A1) + self.b2
        self.A2 = self.relu(self.Z2)
        self.Z3 = np.dot(self.W3, self.A2) + self.b3
        self.A3 = self.softmax(self.Z3)
        return self.A3

    def compute_loss(self, A3, y):
        m = y.shape[0]
        log_likelihood = -np.log(A3[y, range(m)])
        loss = np.sum(log_likelihood) / m
        return loss

    def backward(self, X, y, learning_rate):
        m = X.shape[1]
        dZ3 = self.A3
        dZ3[y, range(m)] -= 1
        dZ3 /= m

        dW3 = np.dot(dZ3, self.A2.T)
        db3 = np.sum(dZ3, axis=1, keepdims=True)

        dA2 = np.dot(self.W3.T, dZ3)
        dZ2 = dA2 * self.relu_derivative(self.Z2)

        dW2 = np.dot(dZ2, self.A1.T)
        db2 = np.sum(dZ2, axis=1, keepdims=True)

        dA1 = np.dot(self.W2.T, dZ2)
        dZ1 = dA1 * self.relu_derivative(self.Z1)

        dW1 = np.dot(dZ1, X.T)
        db1 = np.sum(dZ1, axis=1, keepdims=True)

        # Update weights and biases
        self.W1 -= learning_rate * dW1
        self.b1 -= learning_rate * db1
        self.W2 -= learning_rate * dW2
```

```
        self.b2 -= learning_rate * db2
        self.W3 -= learning_rate * dW3
        self.b3 -= learning_rate * db3

    def train(self, X_train, y_train, epochs=100, initial_lr=0.01,␣
↪step_size=10, lr_decay=0.1, early_stopping_patience=10):
        """
        Train the model with a step learning rate scheduler and early stopping.

        Parameters:
        - epochs: Number of epochs for training.
        - initial_lr: Starting learning rate.
        - step_size: After how many epochs to reduce the learning rate.
        - lr_decay: The factor by which to multiply the learning rate after␣
↪step_size epochs.
        """
        losses = []
        best_loss = float('inf')
        patience_counter = 0
        learning_rate = initial_lr

        for i in range(epochs):
            # Forward pass
            A3 = self.forward(X_train)
            # Compute loss
            loss = self.compute_loss(A3, y_train)
            print(f'Epoch {i+1}, Loss: {loss}, Learning Rate: {learning_rate}')
            losses.append(loss)

            # Check for early stopping condition
            if loss < best_loss:
                best_loss = loss
                patience_counter = 0
            else:
                patience_counter += 1
                if patience_counter >= early_stopping_patience:
                    print(f"Early stopping at epoch {i+1}")
                    break

            # Backward pass and weight updates
            self.backward(X_train, y_train, learning_rate)

            # Step Learning Rate Scheduler
            if (i+1) % step_size == 0:
                learning_rate *= lr_decay

        return losses
```

[46]:
```
train_loader = DataLoader(cifar_train, batch_size=64, shuffle=True)
X_train, y_train = next(iter(train_loader))

print("Before Flattening")
print(f"Training data shape: {X_train.shape}")

# Reshape the images to 2D for the KNN algorithm
X_train = X_train.view(X_train.size(0), -1)  # Flatten
X_train = X_train.T.to(device)
y_train = y_train.to(device)

print("After Flattening")
print(f"Training data shape: {X_train.shape}")
```

```
Before Flattening
Training data shape: torch.Size([64, 3, 32, 32])
After Flattening
Training data shape: torch.Size([3072, 64])
```

[66]:
```
# Training the model using the step learning rate scheduler
model = MLPClassifier(input_size=32*32*3, hidden_size=128, hidden_size_2=64,␣
↪output_size=10)
losses = model.train(X_train, y_train, epochs=1000, initial_lr=0.01,␣
↪step_size=100, lr_decay=0.5, early_stopping_patience=10)
```

```
Epoch 1, Loss: 2.3024745706888172, Learning Rate: 0.01
Epoch 2, Loss: 2.30233318353272, Learning Rate: 0.01
Epoch 3, Loss: 2.302192092327501, Learning Rate: 0.01
Epoch 4, Loss: 2.3020512184434656, Learning Rate: 0.01
Epoch 5, Loss: 2.301910698371731, Learning Rate: 0.01
Epoch 6, Loss: 2.301770550944966, Learning Rate: 0.01
Epoch 7, Loss: 2.3016307471512496, Learning Rate: 0.01
Epoch 8, Loss: 2.3014912063666877, Learning Rate: 0.01
Epoch 9, Loss: 2.3013519876400643, Learning Rate: 0.01
Epoch 10, Loss: 2.301213095284651, Learning Rate: 0.01
Epoch 11, Loss: 2.301074487061726, Learning Rate: 0.01
Epoch 12, Loss: 2.300936105104025, Learning Rate: 0.01
Epoch 13, Loss: 2.300798030744547, Learning Rate: 0.01
Epoch 14, Loss: 2.3006601792323473, Learning Rate: 0.01
Epoch 15, Loss: 2.3005226712229323, Learning Rate: 0.01
Epoch 16, Loss: 2.300385519720482, Learning Rate: 0.01
Epoch 17, Loss: 2.300248697250098, Learning Rate: 0.01
Epoch 18, Loss: 2.3001122342679405, Learning Rate: 0.01
Epoch 19, Loss: 2.2999760619700456, Learning Rate: 0.01
Epoch 20, Loss: 2.2998402279592933, Learning Rate: 0.01
Epoch 21, Loss: 2.2997046359101727, Learning Rate: 0.01
Epoch 22, Loss: 2.299569292311642, Learning Rate: 0.01
```

```
Epoch 23, Loss: 2.2994342950118947, Learning Rate: 0.01
Epoch 24, Loss: 2.299299614109505, Learning Rate: 0.01
Epoch 25, Loss: 2.299165240061179, Learning Rate: 0.01
Epoch 26, Loss: 2.299031124152446, Learning Rate: 0.01
Epoch 27, Loss: 2.2988972201419244, Learning Rate: 0.01
Epoch 28, Loss: 2.2987634538667323, Learning Rate: 0.01
Epoch 29, Loss: 2.2986299496076397, Learning Rate: 0.01
Epoch 30, Loss: 2.298496729550528, Learning Rate: 0.01
Epoch 31, Loss: 2.2983637949213307, Learning Rate: 0.01
Epoch 32, Loss: 2.298231156862896, Learning Rate: 0.01
Epoch 33, Loss: 2.298098730458618, Learning Rate: 0.01
Epoch 34, Loss: 2.297966596286144, Learning Rate: 0.01
Epoch 35, Loss: 2.2978348154920685, Learning Rate: 0.01
Epoch 36, Loss: 2.2977033124084447, Learning Rate: 0.01
Epoch 37, Loss: 2.297572136030042, Learning Rate: 0.01
Epoch 38, Loss: 2.29744121971299, Learning Rate: 0.01
Epoch 39, Loss: 2.297310603157541, Learning Rate: 0.01
Epoch 40, Loss: 2.297180231260405, Learning Rate: 0.01
Epoch 41, Loss: 2.2970501762718385, Learning Rate: 0.01
Epoch 42, Loss: 2.2969203131957627, Learning Rate: 0.01
Epoch 43, Loss: 2.2967907026145618, Learning Rate: 0.01
Epoch 44, Loss: 2.2966613099034143, Learning Rate: 0.01
Epoch 45, Loss: 2.2965321440427355, Learning Rate: 0.01
Epoch 46, Loss: 2.29640321687172, Learning Rate: 0.01
Epoch 47, Loss: 2.2962745028150833, Learning Rate: 0.01
Epoch 48, Loss: 2.2961460487480876, Learning Rate: 0.01
Epoch 49, Loss: 2.296017823602359, Learning Rate: 0.01
Epoch 50, Loss: 2.2958897262076174, Learning Rate: 0.01
Epoch 51, Loss: 2.2957619331352834, Learning Rate: 0.01
Epoch 52, Loss: 2.2956344476779997, Learning Rate: 0.01
Epoch 53, Loss: 2.2955072160441747, Learning Rate: 0.01
Epoch 54, Loss: 2.295380244926892, Learning Rate: 0.01
Epoch 55, Loss: 2.2952535717581335, Learning Rate: 0.01
Epoch 56, Loss: 2.2951271184164685, Learning Rate: 0.01
Epoch 57, Loss: 2.295000836815534, Learning Rate: 0.01
Epoch 58, Loss: 2.2948747734138433, Learning Rate: 0.01
Epoch 59, Loss: 2.294748902462565, Learning Rate: 0.01
Epoch 60, Loss: 2.2946232941508127, Learning Rate: 0.01
Epoch 61, Loss: 2.2944979569122923, Learning Rate: 0.01
Epoch 62, Loss: 2.2943728570066275, Learning Rate: 0.01
Epoch 63, Loss: 2.294247991672849, Learning Rate: 0.01
Epoch 64, Loss: 2.294123234378228, Learning Rate: 0.01
Epoch 65, Loss: 2.293998635179289, Learning Rate: 0.01
Epoch 66, Loss: 2.293874284141575, Learning Rate: 0.01
Epoch 67, Loss: 2.29375019648890l, Learning Rate: 0.01
Epoch 68, Loss: 2.293626344350314, Learning Rate: 0.01
Epoch 69, Loss: 2.293502654117604, Learning Rate: 0.01
Epoch 70, Loss: 2.293379173795622, Learning Rate: 0.01
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Epoch 71, Loss: 2.2932559515012967, Learning Rate: 0.01
Epoch 72, Loss: 2.2931329421240934, Learning Rate: 0.01
Epoch 73, Loss: 2.293010124066777, Learning Rate: 0.01
Epoch 74, Loss: 2.2928875044013592, Learning Rate: 0.01
Epoch 75, Loss: 2.292765072430335, Learning Rate: 0.01
Epoch 76, Loss: 2.2926428551365157, Learning Rate: 0.01
Epoch 77, Loss: 2.2925208644947865, Learning Rate: 0.01
Epoch 78, Loss: 2.292399057245729, Learning Rate: 0.01
Epoch 79, Loss: 2.292277478471553, Learning Rate: 0.01
Epoch 80, Loss: 2.292156140113035, Learning Rate: 0.01
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Epoch 82, Loss: 2.2919141942095878, Learning Rate: 0.01
Epoch 83, Loss: 2.291793580488328, Learning Rate: 0.01
Epoch 84, Loss: 2.291673209833389, Learning Rate: 0.01
Epoch 85, Loss: 2.2915530807516564, Learning Rate: 0.01
Epoch 86, Loss: 2.291433181961388, Learning Rate: 0.01
Epoch 87, Loss: 2.2913134919147846, Learning Rate: 0.01
Epoch 88, Loss: 2.2911940229792345, Learning Rate: 0.01
Epoch 89, Loss: 2.29107482262415, Learning Rate: 0.01
Epoch 90, Loss: 2.2909558172242543, Learning Rate: 0.01
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Epoch 103, Loss: 2.2895456896493727, Learning Rate: 0.005
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Epoch 740, Loss: 2.2790045971808834, Learning Rate: 7.8125e-05
Epoch 741, Loss: 2.279003809423666, Learning Rate: 7.8125e-05
Epoch 742, Loss: 2.2790030216887054, Learning Rate: 7.8125e-05
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Epoch 794, Loss: 2.2789620697235278, Learning Rate: 7.8125e-05
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[67]:

```
plt.plot(losses)
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.title('Loss Curve')
plt.show()
```