

Лабораторная работа № 1

Перцептроны. Процедура обучения Розенблатта

Цель работы: исследование свойств перцептрона Розенблатта и его применение для решения задачи распознавания образов

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```
import numpy as np
import torch
import torch.nn as nn
import matplotlib.pyplot as plt
```

1 набор данных

```
px = [1.4, 1.3, 1.4, 2.2, 4.9, -4]
py = [-0.3, 0.4, 0.4, 0.2, -2.9, -4]

classes = [1, 1, 1, 1, 0, 0]
```

Созданы тензоры `x_train` и `y_train` на основе координат точек и меток классов

```
x_train = torch.FloatTensor(np.array(list(zip(px, py))))
y_train = torch.FloatTensor(np.array(classes))
```

Определен класс `Perceptron`, модель включает в себя параметры весов и параметры смещения. Метод `forward` определяет процесс прямого прохода (forward pass) через перцептрон.

```
class Perceptron(nn.Module):
    def __init__(self, in_features: int, out_features: int, bias: bool = True):
        super().__init__()
        self.weights = nn.Parameter(torch.randn(in_features, out_features))
        self.bias = bias
        if bias:
            self.bias_term = nn.Parameter(torch.randn(out_features))

    def forward(self, x):
        x = x @ self.weights
        if self.bias:
```

```
        x += self.bias_term
    return x
```

Создается Perceptron с двумя входными нейронами и одним выходным, функция потерь MAE и в качестве оптимизатора выступает стохастический градиентный спуск (SGD) с коэффициентом обучения 0.05. Оптимизатор использует параметры модели perceptron для обновления их значений в процессе обучения с целью минимизации функции потерь.

```
perceptron = Perceptron(2, 1)
loss_function = nn.L1Loss()
optimizer = torch.optim.SGD(perceptron.parameters(), lr=0.05)
```

Определена функция fit, которая представляет цикл обучения для модели машинного обучения. Внутри цикла происходит прямой проход через модель, вычисление функции потерь с использованием сигмоидной функции, обратное распространение ошибки, обновление параметров модели с помощью оптимизатора и сохранение значений функции потерь на каждой эпохе.

```
def fit(model, x_train, y_train, criterion, optimizer, epochs):
    losses = [] # Здесь будут сохраняться значения функции потерь на
    каждой эпохе
    log_template = "Epoch {ep:03d} train_loss: {t_loss:0.4f}"

    for epoch in range(epochs):
        optimizer.zero_grad()
        outp = model(x_train)

        probabilities = torch.sigmoid(outp.view(-1))
        loss = criterion(probabilities, y_train)

        loss.backward()
        losses.append(loss.detach().flatten()[0])
        optimizer.step()

        print(log_template.format(ep=epoch+1, t_loss=loss))

    return losses
```

Обучение перцептрона на данных x_train с метками y_train в течение 1000 эпох.

```
losses = fit(perceptron, x_train, y_train, loss_function, optimizer,
1000)
```

```
Epoch 001 train_loss: 0.5095
Epoch 002 train_loss: 0.5070
Epoch 003 train_loss: 0.5045
Epoch 004 train_loss: 0.5019
Epoch 005 train_loss: 0.4993
Epoch 006 train_loss: 0.4966
```

```
Epoch 007 train_loss: 0.4939
Epoch 008 train_loss: 0.4911
Epoch 009 train_loss: 0.4883
Epoch 010 train_loss: 0.4854
Epoch 011 train_loss: 0.4825
Epoch 012 train_loss: 0.4795
Epoch 013 train_loss: 0.4765
Epoch 014 train_loss: 0.4734
Epoch 015 train_loss: 0.4703
Epoch 016 train_loss: 0.4671
Epoch 017 train_loss: 0.4639
Epoch 018 train_loss: 0.4606
Epoch 019 train_loss: 0.4573
Epoch 020 train_loss: 0.4539
Epoch 021 train_loss: 0.4505
Epoch 022 train_loss: 0.4470
Epoch 023 train_loss: 0.4435
Epoch 024 train_loss: 0.4400
Epoch 025 train_loss: 0.4364
Epoch 026 train_loss: 0.4328
Epoch 027 train_loss: 0.4291
Epoch 028 train_loss: 0.4254
Epoch 029 train_loss: 0.4217
Epoch 030 train_loss: 0.4180
Epoch 031 train_loss: 0.4142
Epoch 032 train_loss: 0.4104
Epoch 033 train_loss: 0.4066
Epoch 034 train_loss: 0.4028
Epoch 035 train_loss: 0.3990
Epoch 036 train_loss: 0.3952
Epoch 037 train_loss: 0.3913
Epoch 038 train_loss: 0.3875
Epoch 039 train_loss: 0.3837
Epoch 040 train_loss: 0.3799
Epoch 041 train_loss: 0.3761
Epoch 042 train_loss: 0.3723
Epoch 043 train_loss: 0.3685
Epoch 044 train_loss: 0.3648
Epoch 045 train_loss: 0.3611
Epoch 046 train_loss: 0.3574
Epoch 047 train_loss: 0.3538
Epoch 048 train_loss: 0.3502
Epoch 049 train_loss: 0.3466
Epoch 050 train_loss: 0.3431
Epoch 051 train_loss: 0.3397
Epoch 052 train_loss: 0.3363
Epoch 053 train_loss: 0.3329
Epoch 054 train_loss: 0.3297
Epoch 055 train_loss: 0.3264
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Epoch 056 train_loss: 0.3233
Epoch 057 train_loss: 0.3201
Epoch 058 train_loss: 0.3171
Epoch 059 train_loss: 0.3141
Epoch 060 train_loss: 0.3112
Epoch 061 train_loss: 0.3083
Epoch 062 train_loss: 0.3055
Epoch 063 train_loss: 0.3028
Epoch 064 train_loss: 0.3001
Epoch 065 train_loss: 0.2975
Epoch 066 train_loss: 0.2950
Epoch 067 train_loss: 0.2925
Epoch 068 train_loss: 0.2901
Epoch 069 train_loss: 0.2877
Epoch 070 train_loss: 0.2854
Epoch 071 train_loss: 0.2831
Epoch 072 train_loss: 0.2809
Epoch 073 train_loss: 0.2788
Epoch 074 train_loss: 0.2767
Epoch 075 train_loss: 0.2746
Epoch 076 train_loss: 0.2726
Epoch 077 train_loss: 0.2706
Epoch 078 train_loss: 0.2687
Epoch 079 train_loss: 0.2668
Epoch 080 train_loss: 0.2650
Epoch 081 train_loss: 0.2632
Epoch 082 train_loss: 0.2614
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Epoch 084 train_loss: 0.2580
Epoch 085 train_loss: 0.2563
Epoch 086 train_loss: 0.2547
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Epoch 089 train_loss: 0.2500
Epoch 090 train_loss: 0.2485
Epoch 091 train_loss: 0.2470
Epoch 092 train_loss: 0.2456
Epoch 093 train_loss: 0.2441
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Epoch 096 train_loss: 0.2400
Epoch 097 train_loss: 0.2386
Epoch 098 train_loss: 0.2373
Epoch 099 train_loss: 0.2360
Epoch 100 train_loss: 0.2347
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Epoch 103 train_loss: 0.2309
Epoch 104 train_loss: 0.2297
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Epoch 111 train_loss: 0.2216
Epoch 112 train_loss: 0.2205
Epoch 113 train_loss: 0.2194
Epoch 114 train_loss: 0.2183
Epoch 115 train_loss: 0.2172
Epoch 116 train_loss: 0.2162
Epoch 117 train_loss: 0.2151
Epoch 118 train_loss: 0.2141
Epoch 119 train_loss: 0.2130
Epoch 120 train_loss: 0.2120
Epoch 121 train_loss: 0.2110
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Epoch 124 train_loss: 0.2080
Epoch 125 train_loss: 0.2071
Epoch 126 train_loss: 0.2061
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Epoch 129 train_loss: 0.2033
Epoch 130 train_loss: 0.2023
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Epoch 521 train_loss: 0.0690
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Epoch 547 train_loss: 0.0660
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Epoch 596 train_loss: 0.0611
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Epoch 743 train_loss: 0.0499
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Epoch 792 train_loss: 0.0471
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Epoch 840 train_loss: 0.0446
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Epoch 841 train_loss: 0.0445
Epoch 842 train_loss: 0.0445
Epoch 843 train_loss: 0.0444
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Epoch 846 train_loss: 0.0443
Epoch 847 train_loss: 0.0442
Epoch 848 train_loss: 0.0442
Epoch 849 train_loss: 0.0441
Epoch 850 train_loss: 0.0441
Epoch 851 train_loss: 0.0440
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Epoch 887 train_loss: 0.0424
Epoch 888 train_loss: 0.0423
Epoch 889 train_loss: 0.0423
```

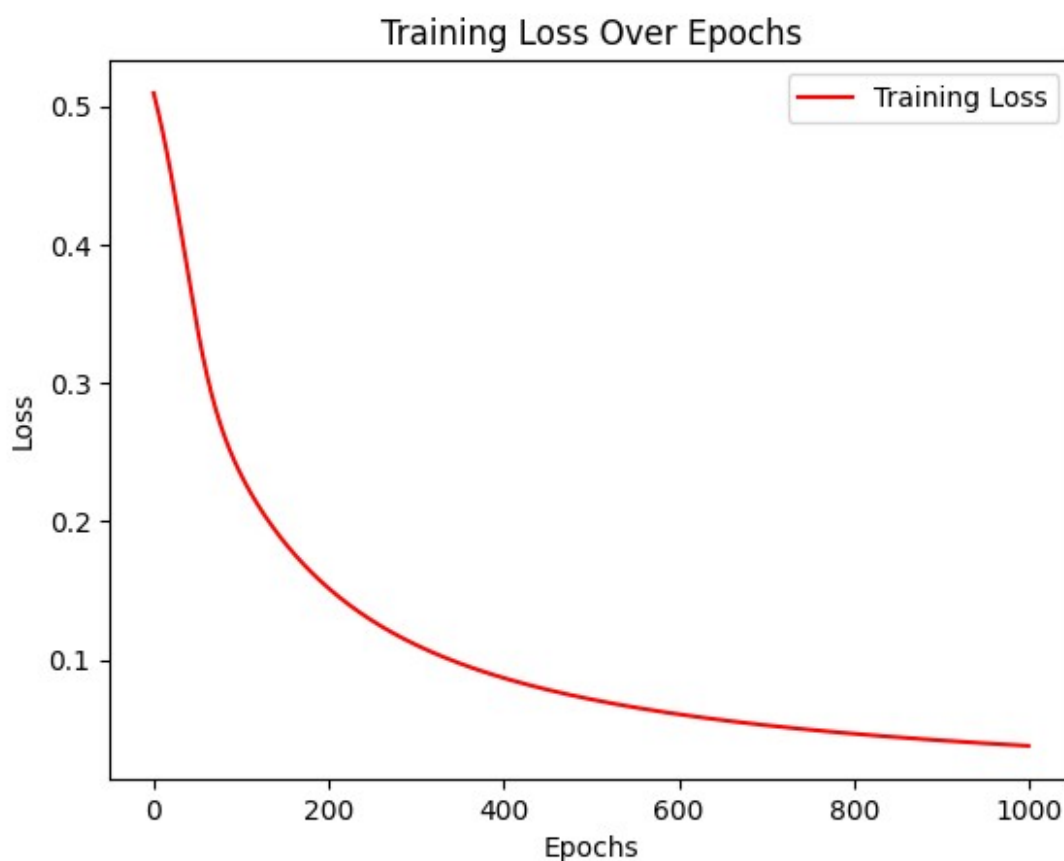
```
Epoch 890 train_loss: 0.0422
Epoch 891 train_loss: 0.0422
Epoch 892 train_loss: 0.0421
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Epoch 894 train_loss: 0.0421
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Epoch 896 train_loss: 0.0420
Epoch 897 train_loss: 0.0419
Epoch 898 train_loss: 0.0419
Epoch 899 train_loss: 0.0418
Epoch 900 train_loss: 0.0418
Epoch 901 train_loss: 0.0418
Epoch 902 train_loss: 0.0417
Epoch 903 train_loss: 0.0417
Epoch 904 train_loss: 0.0416
Epoch 905 train_loss: 0.0416
Epoch 906 train_loss: 0.0415
Epoch 907 train_loss: 0.0415
Epoch 908 train_loss: 0.0415
Epoch 909 train_loss: 0.0414
Epoch 910 train_loss: 0.0414
Epoch 911 train_loss: 0.0413
Epoch 912 train_loss: 0.0413
Epoch 913 train_loss: 0.0412
Epoch 914 train_loss: 0.0412
Epoch 915 train_loss: 0.0412
Epoch 916 train_loss: 0.0411
Epoch 917 train_loss: 0.0411
Epoch 918 train_loss: 0.0410
Epoch 919 train_loss: 0.0410
Epoch 920 train_loss: 0.0409
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Epoch 923 train_loss: 0.0408
Epoch 924 train_loss: 0.0408
Epoch 925 train_loss: 0.0407
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Epoch 933 train_loss: 0.0404
Epoch 934 train_loss: 0.0404
Epoch 935 train_loss: 0.0403
Epoch 936 train_loss: 0.0403
Epoch 937 train_loss: 0.0402
Epoch 938 train_loss: 0.0402
```

```
Epoch 939 train_loss: 0.0402
Epoch 940 train_loss: 0.0401
Epoch 941 train_loss: 0.0401
Epoch 942 train_loss: 0.0400
Epoch 943 train_loss: 0.0400
Epoch 944 train_loss: 0.0400
Epoch 945 train_loss: 0.0399
Epoch 946 train_loss: 0.0399
Epoch 947 train_loss: 0.0399
Epoch 948 train_loss: 0.0398
Epoch 949 train_loss: 0.0398
Epoch 950 train_loss: 0.0397
Epoch 951 train_loss: 0.0397
Epoch 952 train_loss: 0.0397
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Epoch 977 train_loss: 0.0387
Epoch 978 train_loss: 0.0387
Epoch 979 train_loss: 0.0386
Epoch 980 train_loss: 0.0386
Epoch 981 train_loss: 0.0386
Epoch 982 train_loss: 0.0385
Epoch 983 train_loss: 0.0385
Epoch 984 train_loss: 0.0384
Epoch 985 train_loss: 0.0384
Epoch 986 train_loss: 0.0384
Epoch 987 train_loss: 0.0383
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Epoch 988 train_loss: 0.0383
Epoch 989 train_loss: 0.0383
Epoch 990 train_loss: 0.0382
Epoch 991 train_loss: 0.0382
Epoch 992 train_loss: 0.0382
Epoch 993 train_loss: 0.0381
Epoch 994 train_loss: 0.0381
Epoch 995 train_loss: 0.0380
Epoch 996 train_loss: 0.0380
Epoch 997 train_loss: 0.0380
Epoch 998 train_loss: 0.0379
Epoch 999 train_loss: 0.0379
Epoch 1000 train_loss: 0.0379
```

Построен график функции ошибки

```
plt.plot(losses, color='red', label='Training Loss')
plt.legend()
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.title('Training Loss Over Epochs')
plt.show()
```



Сохранены текущие веса и смещение модели

```
current_weights = perceptron.weights.detach().clone()
w = current_weights.flatten().numpy()

current_bias = perceptron.bias_term.detach().clone()
b = current_bias.flatten().numpy()
```

Решение задачи линейной разделимости

```
X = np.linspace(-10, 10, 100)

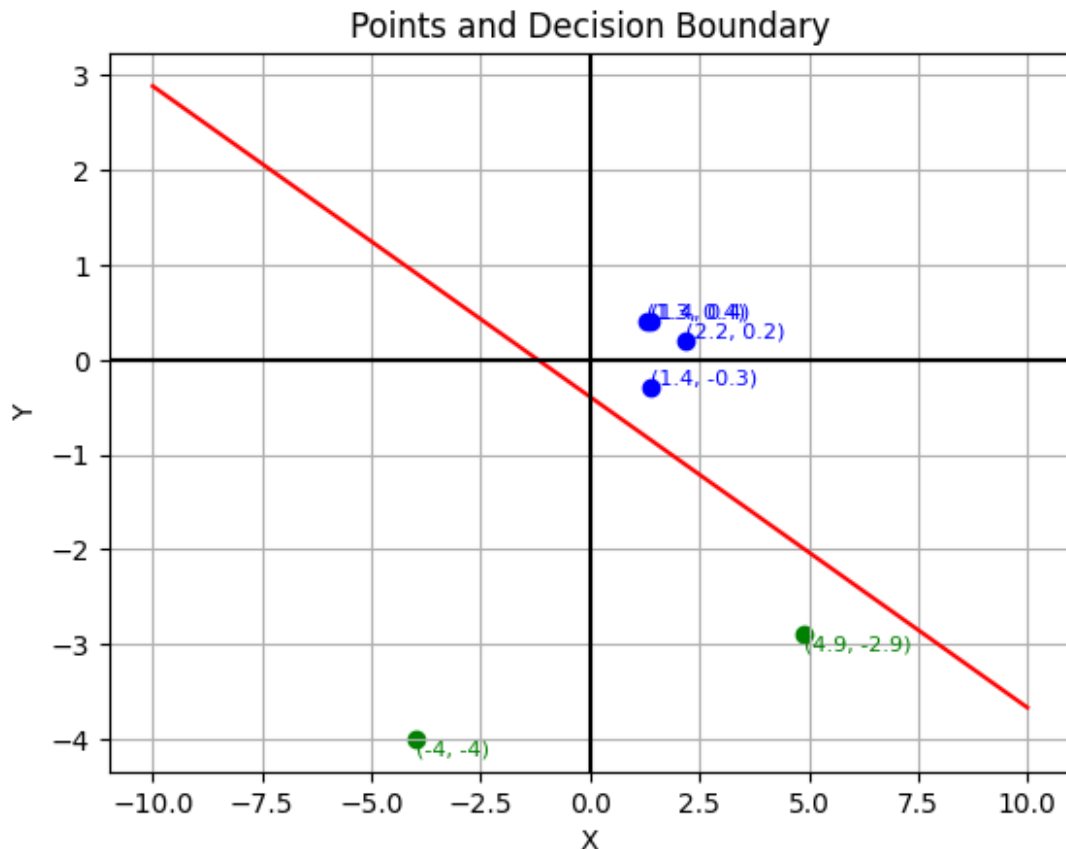
def discriminant(x):
    return (-x * w[0] - b[0]) / w[1]

plt.plot(X, discriminant(X), "red", label="Decision Boundary")

plt.grid(True, which='both')
plt.axhline(y=0, color='k')
plt.axvline(x=0, color='k')

for x, y, c in list(zip(px, py, y_train)):
    if c == 1:
        plt.scatter(x, y, c="blue", label="Class 1")
        plt.text(x, y, f'({x}, {y})', fontsize=8, color='blue',
verticalalignment='bottom')
    else:
        plt.scatter(x, y, c="green", label="Class 0")
        plt.text(x, y, f'({x}, {y})', fontsize=8, color='green',
verticalalignment='top')

# plt.legend()
plt.xlabel('X')
plt.ylabel('Y')
plt.title('Points and Decision Boundary')
plt.show()
```

2 набор данных

```
x2 = [-2.6, -4.1, 4.4, 0.7, -2.7, 3.2, -4.6, 1.4]
y2 = [-1, -3.7, 4.5, -4.5, -1.5, -4.9, -3.4, 2.3]

c2_1 = [0, 0, 0, 1, 0, 1, 0, 0]
c2_2 = [0, 0, 1, 0, 0, 1, 0, 1]

x_train2 = torch.FloatTensor(np.array(list(zip(x2, y2))))
y_train2 = torch.FloatTensor(np.array(list(zip(c2_1, c2_2))))

perceptron2 = Perceptron(2, 2)
loss_function = nn.L1Loss()
optimizer = torch.optim.SGD(perceptron2.parameters(), lr=0.05)

def fit2(model, x_train, y_train, criterion, optimizer, epochs):
    losses = []
    log_template = "\nEpoch {ep:03d} train_loss: {t_loss:0.4f}"
    for epoch in range(epochs):
        optimizer.zero_grad()
        outp = model(x_train)

        probaba = torch.sigmoid(outp)
```

```
    loss1 = criterion(probaba[:, 0], y_train[:, 0])
    loss2 = criterion(probaba[:, 1], y_train[:, 1])
    loss = loss1 + loss2

    loss.backward()
    losses.append(loss.detach().flatten()[0])
    optimizer.step()
    print(log_template.format(ep=epoch+1, t_loss=loss))
return losses
```

```
losses2 = fit2(perceptron2, x_train2, y_train2, loss_function,
optimizer, 1000)
```

Epoch 001 train_loss: 1.1707

Epoch 002 train_loss: 1.1666

Epoch 003 train_loss: 1.1627

Epoch 004 train_loss: 1.1588

Epoch 005 train_loss: 1.1550

Epoch 006 train_loss: 1.1513

Epoch 007 train_loss: 1.1477

Epoch 008 train_loss: 1.1441

Epoch 009 train_loss: 1.1406

Epoch 010 train_loss: 1.1372

Epoch 011 train_loss: 1.1338

Epoch 012 train_loss: 1.1305

Epoch 013 train_loss: 1.1273

Epoch 014 train_loss: 1.1241

Epoch 015 train_loss: 1.1209

Epoch 016 train_loss: 1.1178

Epoch 017 train_loss: 1.1147

Epoch 018 train_loss: 1.1117

Epoch 019 train_loss: 1.1087

Epoch 020 train_loss: 1.1057
Epoch 021 train_loss: 1.1028
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Epoch 032 train_loss: 1.0719
Epoch 033 train_loss: 1.0691
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Epoch 036 train_loss: 1.0609
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Epoch 071 train_loss: 0.9214

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Epoch 094 train_loss: 0.5898
Epoch 095 train_loss: 0.5754
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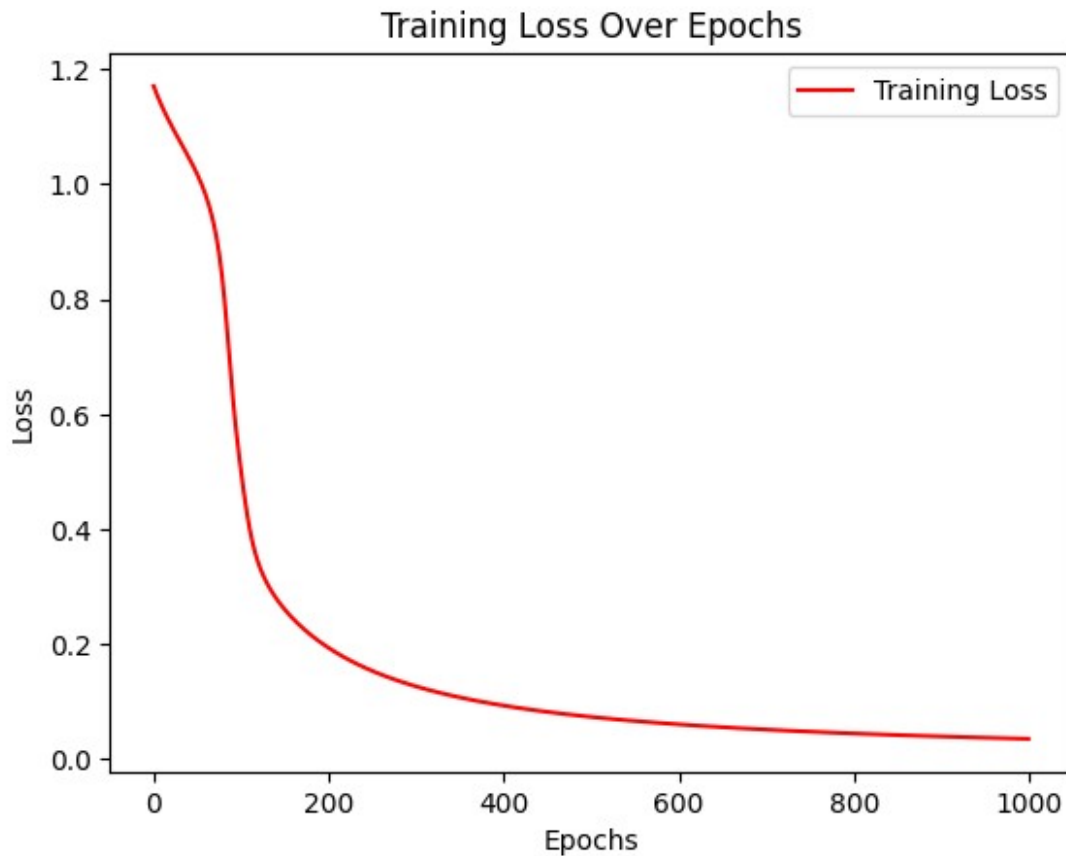
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Epoch 999 train_loss: 0.0357
Epoch 1000 train_loss: 0.0357

plt.plot(losses2, color='red', label='Training Loss')
plt.legend()
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.title('Training Loss Over Epochs')
plt.show()
```

```
current_weights = perceptron2.weights.detach().clone()
w = current_weights.numpy()

current_bias = perceptron2.bias_term.detach().clone()
b = current_bias.numpy()
```

Функция `decode_one_hot` преобразует массив двоичных значений, представляющих one-hot кодировку, обратно в целочисленные значения. Она объединяет два бита для каждого элемента массива и преобразует полученное двоичное значение в целое число.

```
def decode_one_hot(arr):
    arr_new = []

    for i, y in enumerate(arr):
        arr_new.append(int(str(y[0]) + str(y[1]), 2))

    return np.array(arr_new)

X = np.linspace(-10, 10, 100)

def discriminant1(x):
    return (-x * w[0][0] - b[0]) / w[1][0]
```

```

def discriminant2(x):
    return (-x * w[0][1] - b[0]) / w[1][1]

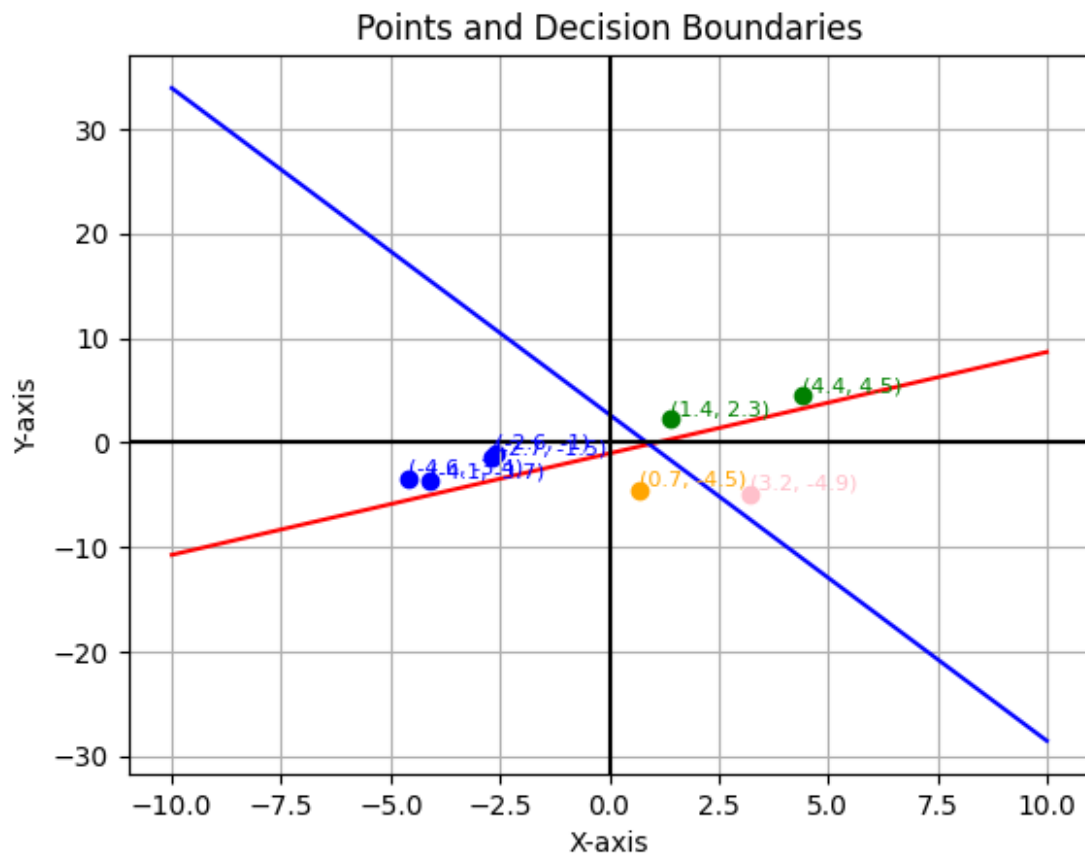
plt.plot(X, discriminant1(X), "red", label="Class 0 Discriminant")
plt.plot(X, discriminant2(X), "blue", label="Class 1 Discriminant")

plt.grid(True, which='both')
plt.axhline(y=0, color='k')
plt.axvline(x=0, color='k')

y_train2 = decode_one_hot(y_train2.to(torch.int).numpy())
for x, y, c in list(zip(x2, y2, y_train2)):
    if c == 0:
        plt.scatter(x, y, c="blue", label="Class 0")
        plt.text(x, y, f'({x}, {y})', fontsize=8, color='blue',
verticalalignment='bottom')
    elif c == 1:
        plt.scatter(x, y, c="green", label="Class 1")
        plt.text(x, y, f'({x}, {y})', fontsize=8, color='green',
verticalalignment='bottom')
    elif c == 2:
        plt.scatter(x, y, c="orange", label="Class 2")
        plt.text(x, y, f'({x}, {y})', fontsize=8, color='orange',
verticalalignment='bottom')
    else:
        plt.scatter(x, y, c="pink", label="Class 3")
        plt.text(x, y, f'({x}, {y})', fontsize=8, color='pink',
verticalalignment='bottom')

# plt.legend()
plt.xlabel('X-axis')
plt.ylabel('Y-axis')
plt.title('Points and Decision Boundaries')
plt.show()

```



Выводы: В ходе выполнения лабораторной работы я узнал, как эффективно использовать библиотеку PyTorch для реализации и обучения нейронных сетей. Это позволило лучше понять принципы машинного обучения и его применение в задачах классификации.