Министерство образования Республики Беларусь

Учреждение образования

«Брестский государственный технический университет»

Кафедра ИИТ

Лабораторная работа №2

По дисциплине: «Обработка изображений в ИС»

Тема: «Конструирование моделей на базе предобученных нейронных сетей»

Выполнила:

Студентка 4 курса

Группы ИИ-21

Шнур А.А.

Проверил:

Крощенко А.А.

Брест 2024

Цель: осуществлять обучение НС, сконструированных на базе предобученных архитектур НС.

Ход работы:

Вариант 15

В-т	**Выборка**	**Оптимизатор**	**Предобученная архитектура**
15	CIFAR-100	Adadelta	SqueezeNet 1.1

Код программы:

```
import torch
import torchvision
from torchvision import transforms, models
import torch.nn as nn
import numpy as np
import seaborn as sns
from tqdm import tqdm
import matplotlib.pyplot as plt
from sklearn.metrics import confusion_matrix

# Параметры загрузки данных
batch_size_train = 256
batch_size_test = 100

# Преобразования для CIFAR-100 с аугментацией данных
preprocess = transforms.Compose([
    transforms.RandomHorizontalFlip(),
    transforms.RandomCrop(32, padding=4),
    transforms.ToTensor(),
    transforms.Normalize(mean=[0.485, 0.456, 0.406], std=[0.229, 0.224, 0.225]),
])

# Загрузка данных CIFAR-100
train_loader = torch.utils.data.DataLoader(
    torchvision.datasets.CIFAR100(root='D:\\Лабы 4 курс\\ОиИС\\lab2\\data', train=True,
download=True,
                                  transform=preprocess),
    batch_size=batch_size_train, shuffle=True
)

test_loader = torch.utils.data.DataLoader(
    torchvision.datasets.CIFAR100(root='D:\\Лабы 4 курс\\ОиИС\\lab2\\data', train=False,
download=True,
                                  transform=preprocess),
    batch_size=batch_size_test, shuffle=False
)

# Загрузка предобученной SqueezeNet 1.1 и адаптация под CIFAR-100
model = models.squeezenet1_1(weights=models.SqueezeNet1_1_Weights.IMAGENET1K_V1)
model.classifier[1] = nn.Conv2d(512, 100, kernel_size=(1, 1))  # Изменение выходного слоя для
100 классов
model.num_classes = 100
```

```
# Функция для обучения модели
def train(device, model, train_loader, learning_rate=1.0, epochs=50,
model_save_path='best_model.pth'):
    model = model.to(device)
    criterion = nn.CrossEntropyLoss()
    optimizer = torch.optim.Adadelta(model.parameters(), lr=learning_rate)
    scheduler = torch.optim.lr_scheduler.StepLR(optimizer, step_size=10, gamma=0.5)  #
Понижение lr каждые 10 эпох
    history = []
    best_loss = float('inf')

    for epoch in tqdm(range(epochs), desc="Training Progress"):
        model.train()
        epoch_loss = 0.0
        for batch_idx, (x, y) in enumerate(train_loader):
            x, y = x.to(device), y.to(device)
            optimizer.zero_grad()
            pred = model(x)
            loss = criterion(pred, y)
            loss.backward()
            optimizer.step()
            epoch_loss += loss.item()

            # Промежуточный вывод для отслеживания прогресса по мини-батчам
            if batch_idx % 10 == 0:
                print(f"Epoch [{epoch + 1}/{epochs}], Batch [{batch_idx}/{len(train_loader)}],
Loss: {loss.item()}")

        average_loss = epoch_loss / len(train_loader)
        history.append(average_loss)
        scheduler.step()  # Обновление learning rate

        if average_loss < best_loss:
            best_loss = average_loss
            torch.save(model.state_dict(), model_save_path)
            print(f'Model saved with loss {best_loss:.4f} at epoch {epoch + 1}')
        print(f'Epoch {epoch + 1}, Average Loss: {average_loss:.4f}')

    plt.plot(range(1, epochs + 1), history)
    plt.xlabel('Epoch')
    plt.ylabel('Loss')
    plt.title('Training Loss per Epoch')
    plt.show()

# Функция для тестирования модели и построения матрицы ошибок
def test(model, device, test_loader):
    model.eval()
    correct = 0
    total = 0
    all_labels = []
    all_predictions = []
    num_classes = 100
    with torch.no_grad():
        for images, labels in test_loader:
            images, labels = images.to(device), labels.to(device)
            outputs = model(images)
            _, predicted = torch.max(outputs, 1)

            total += labels.size(0)
```

```
            correct += (predicted == labels).sum().item()

            all_labels.extend(labels.cpu().numpy())
            all_predictions.extend(predicted.cpu().numpy())

    accuracy = correct / total
    print(f"Accuracy on the test set: {accuracy:.2%}")

    cm = confusion_matrix(all_labels, all_predictions)
    cm_normalized = cm.astype('float') / cm.sum(axis=1)[:, np.newaxis]

    plt.figure(figsize=(20, 18))
    sns.heatmap(cm_normalized, annot=False, fmt='.2f', cmap='Blues', cbar=True)

    plt.xlabel('Predicted', fontsize=14)
    plt.ylabel('True', fontsize=14)
    plt.title('Confusion Matrix (Normalized)', fontsize=16)

    plt.xticks(np.arange(num_classes) + 0.5, labels=np.arange(num_classes), rotation=90,
fontsize=10)
    plt.yticks(np.arange(num_classes) + 0.5, labels=np.arange(num_classes), rotation=0,
fontsize=10)

    plt.tight_layout()
    plt.show()

# Инициализация и запуск обучения и тестирования
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
model.to(device)

# Запуск обучения
train(device, model, train_loader, learning_rate=1.0, epochs=25)

# Тестирование модели
model.load_state_dict(torch.load('best_model.pth'))
test(model, device, test_loader)
```

Среднее значение потерь для каждой эпохи и точность на тестовой выборке:

```
Downloading https://www.cs.toronto.edu/~kriz/cifar-100-python.tar.gz to D:\Лабы 4
курс\ОиИС\lab2\data/cifar-100-python.tar.gz
100%|██████████| 169M/169M [00:02<00:00, 74.4MB/s]
Extracting D:\Лабы 4 курс\ОиИС\lab2\data/cifar-100-python.tar.gz to D:\Лабы 4
курс\ОиИС\lab2\data
Files already downloaded and verified
Downloading: "https://download.pytorch.org/models/squeezenet1_1-b8a52dc0.pth" to
/root/.cache/torch/hub/checkpoints/squeezenet1_1-b8a52dc0.pth
100%|██████████| 4.73M/4.73M [00:00<00:00, 49.8MB/s]
Training Progress:   0%|          | 0/25 [00:00<?, ?it/s]
Epoch [1/25], Batch [0/196], Loss: 21.6106014251709
Epoch [1/25], Batch [10/196], Loss: 4.600142478942871
Epoch [1/25], Batch [20/196], Loss: 4.607020378112793
Epoch [1/25], Batch [30/196], Loss: 4.6031413078308105
Epoch [1/25], Batch [40/196], Loss: 4.597903728485107
Epoch [1/25], Batch [50/196], Loss: 4.59756326675415
Epoch [1/25], Batch [60/196], Loss: 4.5945820808410645
Epoch [1/25], Batch [70/196], Loss: 4.6003217697143555
Epoch [1/25], Batch [80/196], Loss: 4.600442409515381
Epoch [1/25], Batch [90/196], Loss: 4.594137668609619
Epoch [1/25], Batch [100/196], Loss: 4.597038745880127
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Epoch [1/25], Batch [110/196], Loss: 4.602277755737305
Epoch [1/25], Batch [120/196], Loss: 4.5987701416015625
Epoch [1/25], Batch [130/196], Loss: 4.604344844818115
Epoch [1/25], Batch [140/196], Loss: 4.597768306732178
Epoch [1/25], Batch [150/196], Loss: 4.569126605987549
Epoch [1/25], Batch [160/196], Loss: 4.515842437744141
Epoch [1/25], Batch [170/196], Loss: 4.557591438293457
Epoch [1/25], Batch [180/196], Loss: 4.594195365905762
Epoch [1/25], Batch [190/196], Loss: 4.586657524108887
Training Progress:   4%|▌         | 1/25 [01:24<33:46, 84.44s/it]
Model saved with loss 4.6975 at epoch 1
Epoch 1, Average Loss: 4.6975
Epoch [2/25], Batch [0/196], Loss: 4.5921759605407715
Epoch [2/25], Batch [10/196], Loss: 4.449706554412842
Epoch [2/25], Batch [20/196], Loss: 4.549580097198486
Epoch [2/25], Batch [30/196], Loss: 4.5486321449279785
Epoch [2/25], Batch [40/196], Loss: 4.536713123321533
Epoch [2/25], Batch [50/196], Loss: 4.4894490242004395
Epoch [2/25], Batch [60/196], Loss: 4.538067817687988
Epoch [2/25], Batch [70/196], Loss: 4.488898277282715
Epoch [2/25], Batch [80/196], Loss: 4.510069847106934
Epoch [2/25], Batch [90/196], Loss: 4.564204216003418
Epoch [2/25], Batch [100/196], Loss: 4.461141586303711
Epoch [2/25], Batch [110/196], Loss: 4.593387603759766
Epoch [2/25], Batch [120/196], Loss: 4.4770026206970215
Epoch [2/25], Batch [130/196], Loss: 4.441929340362549
Epoch [2/25], Batch [140/196], Loss: 4.4562530517578125
Epoch [2/25], Batch [150/196], Loss: 4.47421407699585
Epoch [2/25], Batch [160/196], Loss: 4.41464376449585
Epoch [2/25], Batch [170/196], Loss: 4.485645294189453
Epoch [2/25], Batch [180/196], Loss: 4.484821319580078
Epoch [2/25], Batch [190/196], Loss: 4.470389366149902
Training Progress:   8%|▉         | 2/25 [02:50<32:39, 85.17s/it]
Model saved with loss 4.5097 at epoch 2
Epoch 2, Average Loss: 4.5097
Epoch [3/25], Batch [0/196], Loss: 4.513958930969238
Epoch [3/25], Batch [10/196], Loss: 4.433712005615234
Epoch [3/25], Batch [20/196], Loss: 4.497776031494141
Epoch [3/25], Batch [30/196], Loss: 4.373252868652344
Epoch [3/25], Batch [40/196], Loss: 4.355649948120117
Epoch [3/25], Batch [50/196], Loss: 4.362421035766602
Epoch [3/25], Batch [60/196], Loss: 4.284133434295654
Epoch [3/25], Batch [70/196], Loss: 4.422453880310059
Epoch [3/25], Batch [80/196], Loss: 4.375551700592041
Epoch [3/25], Batch [90/196], Loss: 4.325893878936768
Epoch [3/25], Batch [100/196], Loss: 4.411043643951416
Epoch [3/25], Batch [110/196], Loss: 4.40197229385376
Epoch [3/25], Batch [120/196], Loss: 4.333016395568848
Epoch [3/25], Batch [130/196], Loss: 4.3057050704956055
Epoch [3/25], Batch [140/196], Loss: 4.3523054122924805
Epoch [3/25], Batch [150/196], Loss: 4.378509998321533
Epoch [3/25], Batch [160/196], Loss: 4.335581302642822
Epoch [3/25], Batch [170/196], Loss: 4.478213787078857
Epoch [3/25], Batch [180/196], Loss: 4.372671127319336
Epoch [3/25], Batch [190/196], Loss: 4.304111957550049
Training Progress:  12%|█▏        | 3/25 [04:14<31:07, 84.88s/it]
Model saved with loss 4.3759 at epoch 3
Epoch 3, Average Loss: 4.3759
Epoch [4/25], Batch [0/196], Loss: 4.311097145080566
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Epoch [4/25], Batch [10/196], Loss: 4.452680587768555
Epoch [4/25], Batch [20/196], Loss: 4.391745567321777
Epoch [4/25], Batch [30/196], Loss: 4.383526802062988
Epoch [4/25], Batch [40/196], Loss: 4.33633279800415
Epoch [4/25], Batch [50/196], Loss: 4.294257164001465
Epoch [4/25], Batch [60/196], Loss: 4.446527481079102
Epoch [4/25], Batch [70/196], Loss: 4.339521884918213
Epoch [4/25], Batch [80/196], Loss: 4.183706283569336
Epoch [4/25], Batch [90/196], Loss: 4.45637845993042
Epoch [4/25], Batch [100/196], Loss: 4.301537990570068
Epoch [4/25], Batch [110/196], Loss: 4.231672286987305
Epoch [4/25], Batch [120/196], Loss: 4.087931156158447
Epoch [4/25], Batch [130/196], Loss: 4.334202289581299
Epoch [4/25], Batch [140/196], Loss: 4.275662422180176
Epoch [4/25], Batch [150/196], Loss: 4.257157802581787
Epoch [4/25], Batch [160/196], Loss: 4.2229905128479
Epoch [4/25], Batch [170/196], Loss: 4.154943943023682
Epoch [4/25], Batch [180/196], Loss: 4.201357364654541
Epoch [4/25], Batch [190/196], Loss: 4.236985683441162
Training Progress:  16%|██        | 4/25 [05:39<29:45, 85.05s/it]
Model saved with loss 4.2653 at epoch 4
Epoch 4, Average Loss: 4.2653
Epoch [5/25], Batch [0/196], Loss: 4.238948345184326
Epoch [5/25], Batch [10/196], Loss: 4.294259071350098
Epoch [5/25], Batch [20/196], Loss: 4.110246181488037
Epoch [5/25], Batch [30/196], Loss: 4.1044392585754395
Epoch [5/25], Batch [40/196], Loss: 4.203535556793213
Epoch [5/25], Batch [50/196], Loss: 4.094635486602783
Epoch [5/25], Batch [60/196], Loss: 4.294687271118164
Epoch [5/25], Batch [70/196], Loss: 4.159101963043213
Epoch [5/25], Batch [80/196], Loss: 4.219420433044434
Epoch [5/25], Batch [90/196], Loss: 4.1295318603515625
Epoch [5/25], Batch [100/196], Loss: 3.962498903274536
Epoch [5/25], Batch [110/196], Loss: 4.1557722091674805
Epoch [5/25], Batch [120/196], Loss: 4.348452091217041
Epoch [5/25], Batch [130/196], Loss: 3.9984347820281982
Epoch [5/25], Batch [140/196], Loss: 4.414218902587891
Epoch [5/25], Batch [150/196], Loss: 4.253444671630859
Epoch [5/25], Batch [160/196], Loss: 4.026830196380615
Epoch [5/25], Batch [170/196], Loss: 4.142442226409912
Epoch [5/25], Batch [180/196], Loss: 4.0465312004089355
Epoch [5/25], Batch [190/196], Loss: 3.9589831829071045
Training Progress:  20%|██        | 5/25 [07:08<28:44, 86.20s/it]
Model saved with loss 4.1585 at epoch 5
Epoch 5, Average Loss: 4.1585
Epoch [6/25], Batch [0/196], Loss: 4.20662260055542
Epoch [6/25], Batch [10/196], Loss: 4.112669467926025
Epoch [6/25], Batch [20/196], Loss: 4.008995056152344
Epoch [6/25], Batch [30/196], Loss: 4.2667412757873535
Epoch [6/25], Batch [40/196], Loss: 4.035599708557129
Epoch [6/25], Batch [50/196], Loss: 4.104614734649658
Epoch [6/25], Batch [60/196], Loss: 3.870861053466797
Epoch [6/25], Batch [70/196], Loss: 4.133443832397461
Epoch [6/25], Batch [80/196], Loss: 4.023995399475098
Epoch [6/25], Batch [90/196], Loss: 4.004801273345947
Epoch [6/25], Batch [100/196], Loss: 4.196745872497559
Epoch [6/25], Batch [110/196], Loss: 3.9954099655151367
Epoch [6/25], Batch [120/196], Loss: 3.971142530441284
Epoch [6/25], Batch [130/196], Loss: 3.9431722164154053
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Epoch [6/25], Batch [140/196], Loss: 4.085458755493164
Epoch [6/25], Batch [150/196], Loss: 4.144186973571777
Epoch [6/25], Batch [160/196], Loss: 4.022668361663818
Epoch [6/25], Batch [170/196], Loss: 3.9832582473754883
Epoch [6/25], Batch [180/196], Loss: 3.978817939758301
Epoch [6/25], Batch [190/196], Loss: 4.108010292053223
Training Progress:  24%|██▍       | 6/25 [08:33<27:14, 86.00s/it]
Model saved with loss 4.0673 at epoch 6
Epoch 6, Average Loss: 4.0673
Epoch [7/25], Batch [0/196], Loss: 4.094375133514404
Epoch [7/25], Batch [10/196], Loss: 4.015654563903809
Epoch [7/25], Batch [20/196], Loss: 4.024716377258301
Epoch [7/25], Batch [30/196], Loss: 3.976025342941284
Epoch [7/25], Batch [40/196], Loss: 3.90679931640625
Epoch [7/25], Batch [50/196], Loss: 4.08661413192749
Epoch [7/25], Batch [60/196], Loss: 4.349062919616699
Epoch [7/25], Batch [70/196], Loss: 4.084483623504639
Epoch [7/25], Batch [80/196], Loss: 4.031923294067383
Epoch [7/25], Batch [90/196], Loss: 3.989565849304199
Epoch [7/25], Batch [100/196], Loss: 4.137994766235352
Epoch [7/25], Batch [110/196], Loss: 3.976189613342285
Epoch [7/25], Batch [120/196], Loss: 3.8737165927886963
Epoch [7/25], Batch [130/196], Loss: 3.872213363647461
Epoch [7/25], Batch [140/196], Loss: 4.084017753601074
Epoch [7/25], Batch [150/196], Loss: 4.025938034057617
Epoch [7/25], Batch [160/196], Loss: 3.968350648880005
Epoch [7/25], Batch [170/196], Loss: 3.9081296920776367
Epoch [7/25], Batch [180/196], Loss: 3.9646499156951904
Epoch [7/25], Batch [190/196], Loss: 3.946495294570923
Training Progress:  28%|██▊       | 7/25 [09:59<25:43, 85.74s/it]
Model saved with loss 3.9737 at epoch 7
Epoch 7, Average Loss: 3.9737
Epoch [8/25], Batch [0/196], Loss: 4.018457889556885
Epoch [8/25], Batch [10/196], Loss: 3.9572558403015137
Epoch [8/25], Batch [20/196], Loss: 3.7660956382751465
Epoch [8/25], Batch [30/196], Loss: 3.7284297943115234
Epoch [8/25], Batch [40/196], Loss: 3.957303285598755
Epoch [8/25], Batch [50/196], Loss: 3.9124138355255127
Epoch [8/25], Batch [60/196], Loss: 3.9227294921875
Epoch [8/25], Batch [70/196], Loss: 3.9815711975097656
Epoch [8/25], Batch [80/196], Loss: 4.112104892730713
Epoch [8/25], Batch [90/196], Loss: 4.201461315155029
Epoch [8/25], Batch [100/196], Loss: 3.9235832691192627
Epoch [8/25], Batch [110/196], Loss: 3.929335832595825
Epoch [8/25], Batch [120/196], Loss: 3.6597657203674316
Epoch [8/25], Batch [130/196], Loss: 3.8955581188201904
Epoch [8/25], Batch [140/196], Loss: 4.010858058929443
Epoch [8/25], Batch [150/196], Loss: 3.816088914871216
Epoch [8/25], Batch [160/196], Loss: 3.9207167625427246
Epoch [8/25], Batch [170/196], Loss: 3.988494873046875
Epoch [8/25], Batch [180/196], Loss: 3.798208236694336
Epoch [8/25], Batch [190/196], Loss: 4.013190269470215
Training Progress:  32%|███▏      | 8/25 [11:24<24:17, 85.71s/it]
Model saved with loss 3.8961 at epoch 8
Epoch 8, Average Loss: 3.8961
Epoch [9/25], Batch [0/196], Loss: 3.8912606239318848
Epoch [9/25], Batch [10/196], Loss: 3.9005823135375977
Epoch [9/25], Batch [20/196], Loss: 3.7842981815338135
Epoch [9/25], Batch [30/196], Loss: 3.6573987007141113
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Epoch [9/25], Batch [40/196], Loss: 4.063148498535156
Epoch [9/25], Batch [50/196], Loss: 3.8456501960754395
Epoch [9/25], Batch [60/196], Loss: 3.9028124809265137
Epoch [9/25], Batch [70/196], Loss: 3.812329053878784
Epoch [9/25], Batch [80/196], Loss: 3.7733120918273926
Epoch [9/25], Batch [90/196], Loss: 3.780057668685913
Epoch [9/25], Batch [100/196], Loss: 3.7792577743530273
Epoch [9/25], Batch [110/196], Loss: 3.865305185317993
Epoch [9/25], Batch [120/196], Loss: 3.570046901702881
Epoch [9/25], Batch [130/196], Loss: 3.8095951080322266
Epoch [9/25], Batch [140/196], Loss: 4.005258083343506
Epoch [9/25], Batch [150/196], Loss: 3.575026273727417
Epoch [9/25], Batch [160/196], Loss: 3.7570016384124756
Epoch [9/25], Batch [170/196], Loss: 3.4629311561584473
Epoch [9/25], Batch [180/196], Loss: 3.8610081672668457
Epoch [9/25], Batch [190/196], Loss: 3.81526255607605
Training Progress:  36%|███       | 9/25 [12:50<22:53, 85.85s/it]
Model saved with loss 3.8010 at epoch 9
Epoch 9, Average Loss: 3.8010
Epoch [10/25], Batch [0/196], Loss: 3.659308671951294
Epoch [10/25], Batch [10/196], Loss: 3.873201608657837
Epoch [10/25], Batch [20/196], Loss: 3.834136724472046
Epoch [10/25], Batch [30/196], Loss: 3.706122398376465
Epoch [10/25], Batch [40/196], Loss: 3.5111138820648193
Epoch [10/25], Batch [50/196], Loss: 3.778576135635376
Epoch [10/25], Batch [60/196], Loss: 3.814439296722412
Epoch [10/25], Batch [70/196], Loss: 3.8318705558776855
Epoch [10/25], Batch [80/196], Loss: 3.8715696334838867
Epoch [10/25], Batch [90/196], Loss: 3.5831358432769775
Epoch [10/25], Batch [100/196], Loss: 3.5751047134399414
Epoch [10/25], Batch [110/196], Loss: 3.6291496753692627
Epoch [10/25], Batch [120/196], Loss: 3.698025703430176
Epoch [10/25], Batch [130/196], Loss: 3.9163060188293457
Epoch [10/25], Batch [140/196], Loss: 3.848076581954956
Epoch [10/25], Batch [150/196], Loss: 3.7614657878875732
Epoch [10/25], Batch [160/196], Loss: 3.7100236415863037
Epoch [10/25], Batch [170/196], Loss: 3.7324259281158447
Epoch [10/25], Batch [180/196], Loss: 3.684030771255493
Epoch [10/25], Batch [190/196], Loss: 3.543670654296875
Training Progress:  40%|███       | 10/25 [14:17<21:30, 86.01s/it]
Model saved with loss 3.7266 at epoch 10
Epoch 10, Average Loss: 3.7266
Epoch [11/25], Batch [0/196], Loss: 3.871523141860962
Epoch [11/25], Batch [10/196], Loss: 3.56494402885437
Epoch [11/25], Batch [20/196], Loss: 3.447373390197754
Epoch [11/25], Batch [30/196], Loss: 3.622757911682129
Epoch [11/25], Batch [40/196], Loss: 3.358069658279419
Epoch [11/25], Batch [50/196], Loss: 3.46356201171875
Epoch [11/25], Batch [60/196], Loss: 3.5011134147644043
Epoch [11/25], Batch [70/196], Loss: 3.5105855464935303
Epoch [11/25], Batch [80/196], Loss: 3.372205972671509
Epoch [11/25], Batch [90/196], Loss: 3.522653818130493
Epoch [11/25], Batch [100/196], Loss: 3.733515977859497
Epoch [11/25], Batch [110/196], Loss: 3.4652693271636963
Epoch [11/25], Batch [120/196], Loss: 3.4946396350860596
Epoch [11/25], Batch [130/196], Loss: 3.3980934619903564
Epoch [11/25], Batch [140/196], Loss: 3.5734200477600098
Epoch [11/25], Batch [150/196], Loss: 3.5250418186187744
Epoch [11/25], Batch [160/196], Loss: 3.5559580326080322
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Epoch [11/25], Batch [170/196], Loss: 3.4637908935546875
Epoch [11/25], Batch [180/196], Loss: 3.369194507598877
Epoch [11/25], Batch [190/196], Loss: 3.4847443103790283
Training Progress:  44%|████      | 11/25 [15:42<20:00, 85.72s/it]
Model saved with loss 3.4830 at epoch 11
Epoch 11, Average Loss: 3.4830
Epoch [12/25], Batch [0/196], Loss: 3.3570799827575684
Epoch [12/25], Batch [10/196], Loss: 3.3065998554229736
Epoch [12/25], Batch [20/196], Loss: 3.494452476501465
Epoch [12/25], Batch [30/196], Loss: 3.3931775093078613
Epoch [12/25], Batch [40/196], Loss: 3.3828213214874268
Epoch [12/25], Batch [50/196], Loss: 3.435838222503662
Epoch [12/25], Batch [60/196], Loss: 3.39775013923645
Epoch [12/25], Batch [70/196], Loss: 3.3234612941741943
Epoch [12/25], Batch [80/196], Loss: 3.5241429805755615
Epoch [12/25], Batch [90/196], Loss: 3.4454617500305176
Epoch [12/25], Batch [100/196], Loss: 3.673464059829712
Epoch [12/25], Batch [110/196], Loss: 3.4321911334991455
Epoch [12/25], Batch [120/196], Loss: 3.367234945297241
Epoch [12/25], Batch [130/196], Loss: 3.463837146759033
Epoch [12/25], Batch [140/196], Loss: 3.261536121368408
Epoch [12/25], Batch [150/196], Loss: 3.4599287509918213
Epoch [12/25], Batch [160/196], Loss: 3.4363174438476562
Epoch [12/25], Batch [170/196], Loss: 3.4941511154174805
Epoch [12/25], Batch [180/196], Loss: 3.369061231613159
Epoch [12/25], Batch [190/196], Loss: 3.4268622398376465
Training Progress:  48%|████▊     | 12/25 [17:06<18:27, 85.22s/it]
Model saved with loss 3.4007 at epoch 12
Epoch 12, Average Loss: 3.4007
Epoch [13/25], Batch [0/196], Loss: 3.437885284423828
Epoch [13/25], Batch [10/196], Loss: 3.391786575317383
Epoch [13/25], Batch [20/196], Loss: 3.33286452293396
Epoch [13/25], Batch [30/196], Loss: 3.275444507598877
Epoch [13/25], Batch [40/196], Loss: 3.5993447303771973
Epoch [13/25], Batch [50/196], Loss: 3.204602003097534
Epoch [13/25], Batch [60/196], Loss: 3.4665780067443848
Epoch [13/25], Batch [70/196], Loss: 3.1398303508758545
Epoch [13/25], Batch [80/196], Loss: 3.5651168823242188
Epoch [13/25], Batch [90/196], Loss: 3.416707754135132
Epoch [13/25], Batch [100/196], Loss: 3.428778886795044
Epoch [13/25], Batch [110/196], Loss: 3.412130355834961
Epoch [13/25], Batch [120/196], Loss: 3.3385298252105713
Epoch [13/25], Batch [130/196], Loss: 3.463909387588501
Epoch [13/25], Batch [140/196], Loss: 3.3580594062805176
Epoch [13/25], Batch [150/196], Loss: 3.42218017578125
Epoch [13/25], Batch [160/196], Loss: 3.4290475845336914
Epoch [13/25], Batch [170/196], Loss: 3.4847445487976074
Epoch [13/25], Batch [180/196], Loss: 3.2514374256134033
Epoch [13/25], Batch [190/196], Loss: 3.4710299968719482
Training Progress:  52%|█████     | 13/25 [18:32<17:07, 85.62s/it]
Model saved with loss 3.3421 at epoch 13
Epoch 13, Average Loss: 3.3421
Epoch [14/25], Batch [0/196], Loss: 3.295016050338745
Epoch [14/25], Batch [10/196], Loss: 3.6567676067352295
Epoch [14/25], Batch [20/196], Loss: 3.4080300331115723
Epoch [14/25], Batch [30/196], Loss: 3.2642135620117188
Epoch [14/25], Batch [40/196], Loss: 3.2495522499084473
Epoch [14/25], Batch [50/196], Loss: 3.3214685916900635
Epoch [14/25], Batch [60/196], Loss: 3.344921588897705
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Epoch [14/25], Batch [70/196], Loss: 3.2774455547332764
Epoch [14/25], Batch [80/196], Loss: 3.3139920234680176
Epoch [14/25], Batch [90/196], Loss: 3.403474807739258
Epoch [14/25], Batch [100/196], Loss: 3.1365840435028076
Epoch [14/25], Batch [110/196], Loss: 3.232001543045044
Epoch [14/25], Batch [120/196], Loss: 3.433427095413208
Epoch [14/25], Batch [130/196], Loss: 3.3956143856048584
Epoch [14/25], Batch [140/196], Loss: 3.2229576110839844
Epoch [14/25], Batch [150/196], Loss: 3.321704626083374
Epoch [14/25], Batch [160/196], Loss: 3.293191909790039
Epoch [14/25], Batch [170/196], Loss: 3.223660469055176
Epoch [14/25], Batch [180/196], Loss: 3.4034934043884277
Epoch [14/25], Batch [190/196], Loss: 3.2125120162963867
Training Progress:  56%|█████     | 14/25 [19:59<15:43, 85.80s/it]
Model saved with loss 3.3008 at epoch 14
Epoch 14, Average Loss: 3.3008
Epoch [15/25], Batch [0/196], Loss: 3.508566379547119
Epoch [15/25], Batch [10/196], Loss: 3.3989970684051514
Epoch [15/25], Batch [20/196], Loss: 3.369919776916504
Epoch [15/25], Batch [30/196], Loss: 3.3252484798431396
Epoch [15/25], Batch [40/196], Loss: 3.2815256118774414
Epoch [15/25], Batch [50/196], Loss: 3.2807717323303223
Epoch [15/25], Batch [60/196], Loss: 3.3797149658203125
Epoch [15/25], Batch [70/196], Loss: 3.2520196437835693
Epoch [15/25], Batch [80/196], Loss: 3.3872013092041016
Epoch [15/25], Batch [90/196], Loss: 2.991212844848633
Epoch [15/25], Batch [100/196], Loss: 3.139004945755005
Epoch [15/25], Batch [110/196], Loss: 3.348233461380005
Epoch [15/25], Batch [120/196], Loss: 3.2339327335357666
Epoch [15/25], Batch [130/196], Loss: 3.368523359298706
Epoch [15/25], Batch [140/196], Loss: 3.051184892654419
Epoch [15/25], Batch [150/196], Loss: 3.348825454711914
Epoch [15/25], Batch [160/196], Loss: 3.11995267868042
Epoch [15/25], Batch [170/196], Loss: 3.3451273441314697
Epoch [15/25], Batch [180/196], Loss: 3.2976531982421875
Epoch [15/25], Batch [190/196], Loss: 3.2516181468963623
Training Progress:  60%|██████    | 15/25 [21:23<14:14, 85.40s/it]
Model saved with loss 3.2668 at epoch 15
Epoch 15, Average Loss: 3.2668
Epoch [16/25], Batch [0/196], Loss: 3.3639419078826904
Epoch [16/25], Batch [10/196], Loss: 3.1022093296051025
Epoch [16/25], Batch [20/196], Loss: 3.2405200004577637
Epoch [16/25], Batch [30/196], Loss: 3.1212501525878906
Epoch [16/25], Batch [40/196], Loss: 3.1788923740386963
Epoch [16/25], Batch [50/196], Loss: 3.364150047302246
Epoch [16/25], Batch [60/196], Loss: 3.05128812789917
Epoch [16/25], Batch [70/196], Loss: 3.1748955249786377
Epoch [16/25], Batch [80/196], Loss: 3.0359952449798584
Epoch [16/25], Batch [90/196], Loss: 3.3424787521362305
Epoch [16/25], Batch [100/196], Loss: 3.0511021614074707
Epoch [16/25], Batch [110/196], Loss: 3.1225743293762207
Epoch [16/25], Batch [120/196], Loss: 3.270440101623535
Epoch [16/25], Batch [130/196], Loss: 3.236124038696289
Epoch [16/25], Batch [140/196], Loss: 3.2432918548583984
Epoch [16/25], Batch [150/196], Loss: 3.2640531063079834
Epoch [16/25], Batch [160/196], Loss: 3.194125175476074
Epoch [16/25], Batch [170/196], Loss: 3.1027581691741943
Epoch [16/25], Batch [180/196], Loss: 3.1081364154815674
Epoch [16/25], Batch [190/196], Loss: 3.4533915519714355
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Training Progress:  64%|██████    | 16/25 [22:48<12:48, 85.39s/it]
Model saved with loss 3.2263 at epoch 16
Epoch 16, Average Loss: 3.2263
Epoch [17/25], Batch [0/196], Loss: 3.3903632164001465
Epoch [17/25], Batch [10/196], Loss: 3.125823736190796
Epoch [17/25], Batch [20/196], Loss: 3.3201208114624023
Epoch [17/25], Batch [30/196], Loss: 3.3770909309387207
Epoch [17/25], Batch [40/196], Loss: 3.1617579460144043
Epoch [17/25], Batch [50/196], Loss: 3.1144797801971436
Epoch [17/25], Batch [60/196], Loss: 3.374032497406006
Epoch [17/25], Batch [70/196], Loss: 3.2574803829193115
Epoch [17/25], Batch [80/196], Loss: 3.1367528438568115
Epoch [17/25], Batch [90/196], Loss: 3.2993006706237793
Epoch [17/25], Batch [100/196], Loss: 3.2506110668182373
Epoch [17/25], Batch [110/196], Loss: 3.27018666267395
Epoch [17/25], Batch [120/196], Loss: 3.2223072052001953
Epoch [17/25], Batch [130/196], Loss: 3.211010694503784
Epoch [17/25], Batch [140/196], Loss: 3.207857608795166
Epoch [17/25], Batch [150/196], Loss: 3.135324001312256
Epoch [17/25], Batch [160/196], Loss: 3.092083692550659
Epoch [17/25], Batch [170/196], Loss: 3.2621681690216064
Epoch [17/25], Batch [180/196], Loss: 3.2591934204101562
Epoch [17/25], Batch [190/196], Loss: 3.0658817291259766
Training Progress:  68%|██████    | 17/25 [24:12<11:19, 84.96s/it]
Model saved with loss 3.2132 at epoch 17
Epoch 17, Average Loss: 3.2132
Epoch [18/25], Batch [0/196], Loss: 3.472259759902954
Epoch [18/25], Batch [10/196], Loss: 2.7782249450683594
Epoch [18/25], Batch [20/196], Loss: 3.230299234390259
Epoch [18/25], Batch [30/196], Loss: 3.039667844772339
Epoch [18/25], Batch [40/196], Loss: 3.25117826461792
Epoch [18/25], Batch [50/196], Loss: 3.2625648975372314
Epoch [18/25], Batch [60/196], Loss: 3.2778990268707275
Epoch [18/25], Batch [70/196], Loss: 3.122042655944824
Epoch [18/25], Batch [80/196], Loss: 3.179166793823242
Epoch [18/25], Batch [90/196], Loss: 3.1857805252075195
Epoch [18/25], Batch [100/196], Loss: 2.9651877880096436
Epoch [18/25], Batch [110/196], Loss: 3.1339502334594727
Epoch [18/25], Batch [120/196], Loss: 2.888174057006836
Epoch [18/25], Batch [130/196], Loss: 3.121480703353882
Epoch [18/25], Batch [140/196], Loss: 3.107271432876587
Epoch [18/25], Batch [150/196], Loss: 3.247654676437378
Epoch [18/25], Batch [160/196], Loss: 2.9694297313690186
Epoch [18/25], Batch [170/196], Loss: 3.3080430030822754
Epoch [18/25], Batch [180/196], Loss: 3.307548761367798
Epoch [18/25], Batch [190/196], Loss: 3.3068745136260986
Training Progress:  72%|██████    | 18/25 [25:37<09:54, 84.87s/it]
Model saved with loss 3.1716 at epoch 18
Epoch 18, Average Loss: 3.1716
Epoch [19/25], Batch [0/196], Loss: 3.328946352005005
Epoch [19/25], Batch [10/196], Loss: 3.1546263694763184
Epoch [19/25], Batch [20/196], Loss: 3.196406602859497
Epoch [19/25], Batch [30/196], Loss: 3.3540399074554443
Epoch [19/25], Batch [40/196], Loss: 3.165977716445923
Epoch [19/25], Batch [50/196], Loss: 3.0668251514434814
Epoch [19/25], Batch [60/196], Loss: 3.097386360168457
Epoch [19/25], Batch [70/196], Loss: 3.23115873336792
Epoch [19/25], Batch [80/196], Loss: 3.0957107543945312
Epoch [19/25], Batch [90/196], Loss: 3.384371280670166
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Epoch [19/25], Batch [100/196], Loss: 3.118959665298462
Epoch [19/25], Batch [110/196], Loss: 3.2643046379089355
Epoch [19/25], Batch [120/196], Loss: 3.1575756072998047
Epoch [19/25], Batch [130/196], Loss: 3.172119617462158
Epoch [19/25], Batch [140/196], Loss: 3.332564353942871
Epoch [19/25], Batch [150/196], Loss: 3.0799577236175537
Epoch [19/25], Batch [160/196], Loss: 2.9367964267730713
Epoch [19/25], Batch [170/196], Loss: 2.965627908706665
Epoch [19/25], Batch [180/196], Loss: 2.9788644313812256
Epoch [19/25], Batch [190/196], Loss: 3.2624433040618896
Training Progress:  76%|███████   | 19/25 [27:01<08:27, 84.62s/it]
Model saved with loss 3.1380 at epoch 19
Epoch 19, Average Loss: 3.1380
Epoch [20/25], Batch [0/196], Loss: 3.48921537399292
Epoch [20/25], Batch [10/196], Loss: 3.3357584476470947
Epoch [20/25], Batch [20/196], Loss: 3.001044511795044
Epoch [20/25], Batch [30/196], Loss: 2.9560086727142334
Epoch [20/25], Batch [40/196], Loss: 3.151562213897705
Epoch [20/25], Batch [50/196], Loss: 2.978471279144287
Epoch [20/25], Batch [60/196], Loss: 3.1535069942474365
Epoch [20/25], Batch [70/196], Loss: 3.164590358734131
Epoch [20/25], Batch [80/196], Loss: 3.1478164196014404
Epoch [20/25], Batch [90/196], Loss: 3.1377336978912354
Epoch [20/25], Batch [100/196], Loss: 3.1473937034606934
Epoch [20/25], Batch [110/196], Loss: 3.1891136169433594
Epoch [20/25], Batch [120/196], Loss: 3.1158547401428223
Epoch [20/25], Batch [130/196], Loss: 3.1773340702056885
Epoch [20/25], Batch [140/196], Loss: 3.157862901687622
Epoch [20/25], Batch [150/196], Loss: 3.2348005771636963
Epoch [20/25], Batch [160/196], Loss: 3.358971357345581
Epoch [20/25], Batch [170/196], Loss: 3.0816121101379395
Epoch [20/25], Batch [180/196], Loss: 3.105466604232788
Epoch [20/25], Batch [190/196], Loss: 3.076634168624878
Training Progress:  80%|████████  | 20/25 [28:26<07:04, 84.84s/it]
Model saved with loss 3.1203 at epoch 20
Epoch 20, Average Loss: 3.1203
Epoch [21/25], Batch [0/196], Loss: 3.3148534297943115
Epoch [21/25], Batch [10/196], Loss: 3.131864547729492
Epoch [21/25], Batch [20/196], Loss: 3.0615503787994385
Epoch [21/25], Batch [30/196], Loss: 3.0873537063598633
Epoch [21/25], Batch [40/196], Loss: 3.0191547870635986
Epoch [21/25], Batch [50/196], Loss: 3.0613064765930176
Epoch [21/25], Batch [60/196], Loss: 2.919095039367676
Epoch [21/25], Batch [70/196], Loss: 3.0884857177734375
Epoch [21/25], Batch [80/196], Loss: 2.890630006790161
Epoch [21/25], Batch [90/196], Loss: 2.899358034133911
Epoch [21/25], Batch [100/196], Loss: 2.726929187774658
Epoch [21/25], Batch [110/196], Loss: 2.895756244659424
Epoch [21/25], Batch [120/196], Loss: 3.0512537956237793
Epoch [21/25], Batch [130/196], Loss: 3.1018426418304443
Epoch [21/25], Batch [140/196], Loss: 3.135718584060669
Epoch [21/25], Batch [150/196], Loss: 2.9881787300109863
Epoch [21/25], Batch [160/196], Loss: 3.1041111946105957
Epoch [21/25], Batch [170/196], Loss: 2.932828187942505
Epoch [21/25], Batch [180/196], Loss: 3.029043674468994
Epoch [21/25], Batch [190/196], Loss: 2.926041603088379
Training Progress:  84%|████████  | 21/25 [29:52<05:39, 84.90s/it]
Model saved with loss 2.9732 at epoch 21
Epoch 21, Average Loss: 2.9732
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Epoch [22/25], Batch [0/196], Loss: 2.990888833999634
Epoch [22/25], Batch [10/196], Loss: 2.718820095062256
Epoch [22/25], Batch [20/196], Loss: 2.7500507831573486
Epoch [22/25], Batch [30/196], Loss: 2.7725985050201416
Epoch [22/25], Batch [40/196], Loss: 2.9550492763519287
Epoch [22/25], Batch [50/196], Loss: 2.892911195755005
Epoch [22/25], Batch [60/196], Loss: 2.9004759788513184
Epoch [22/25], Batch [70/196], Loss: 2.9340786933898926
Epoch [22/25], Batch [80/196], Loss: 2.907075881958008
Epoch [22/25], Batch [90/196], Loss: 3.1450600624084473
Epoch [22/25], Batch [100/196], Loss: 2.8318207263946533
Epoch [22/25], Batch [110/196], Loss: 3.0678210258483887
Epoch [22/25], Batch [120/196], Loss: 2.9330451488494873
Epoch [22/25], Batch [130/196], Loss: 2.9234910011291504
Epoch [22/25], Batch [140/196], Loss: 3.1264524459838867
Epoch [22/25], Batch [150/196], Loss: 2.9128825664520264
Epoch [22/25], Batch [160/196], Loss: 2.886655807495117
Epoch [22/25], Batch [170/196], Loss: 2.823117256164551
Epoch [22/25], Batch [180/196], Loss: 2.9877679347991943
Epoch [22/25], Batch [190/196], Loss: 3.10341215133667
Training Progress:  88%|████████▊ | 22/25 [31:16<04:14, 84.68s/it]
Model saved with loss 2.9546 at epoch 22
Epoch 22, Average Loss: 2.9546
Epoch [23/25], Batch [0/196], Loss: 2.87499737739563
Epoch [23/25], Batch [10/196], Loss: 2.8885581493377686
Epoch [23/25], Batch [20/196], Loss: 2.9201016426086426
Epoch [23/25], Batch [30/196], Loss: 3.014294385910034
Epoch [23/25], Batch [40/196], Loss: 2.7792959213256836
Epoch [23/25], Batch [50/196], Loss: 2.7183167934417725
Epoch [23/25], Batch [60/196], Loss: 2.7125930786132812
Epoch [23/25], Batch [70/196], Loss: 3.060401678085327
Epoch [23/25], Batch [80/196], Loss: 3.0879065990448
Epoch [23/25], Batch [90/196], Loss: 2.977217674255371
Epoch [23/25], Batch [100/196], Loss: 2.9627535343170166
Epoch [23/25], Batch [110/196], Loss: 2.8731110095977783
Epoch [23/25], Batch [120/196], Loss: 2.8902220726013184
Epoch [23/25], Batch [130/196], Loss: 2.879558563232422
Epoch [23/25], Batch [140/196], Loss: 3.010706663131714
Epoch [23/25], Batch [150/196], Loss: 2.8525965213775635
Epoch [23/25], Batch [160/196], Loss: 2.808408737182617
Epoch [23/25], Batch [170/196], Loss: 2.933483600616455
Epoch [23/25], Batch [180/196], Loss: 2.947247266769409
Epoch [23/25], Batch [190/196], Loss: 2.8329803943634033
Training Progress:  92%|████████▎ | 23/25 [32:41<02:49, 84.75s/it]
Model saved with loss 2.9251 at epoch 23
Epoch 23, Average Loss: 2.9251
Epoch [24/25], Batch [0/196], Loss: 3.0334224700927734
Epoch [24/25], Batch [10/196], Loss: 2.6622512340545654
Epoch [24/25], Batch [20/196], Loss: 2.9139609336853027
Epoch [24/25], Batch [30/196], Loss: 2.8394775390625
Epoch [24/25], Batch [40/196], Loss: 2.7721943855285645
Epoch [24/25], Batch [50/196], Loss: 2.990398406982422
Epoch [24/25], Batch [60/196], Loss: 3.014869213104248
Epoch [24/25], Batch [70/196], Loss: 2.8904216289520264
Epoch [24/25], Batch [80/196], Loss: 2.909729242324829
Epoch [24/25], Batch [90/196], Loss: 2.7680206298828125
Epoch [24/25], Batch [100/196], Loss: 2.784339666366577
Epoch [24/25], Batch [110/196], Loss: 2.944568634033203
Epoch [24/25], Batch [120/196], Loss: 3.025315523147583
```

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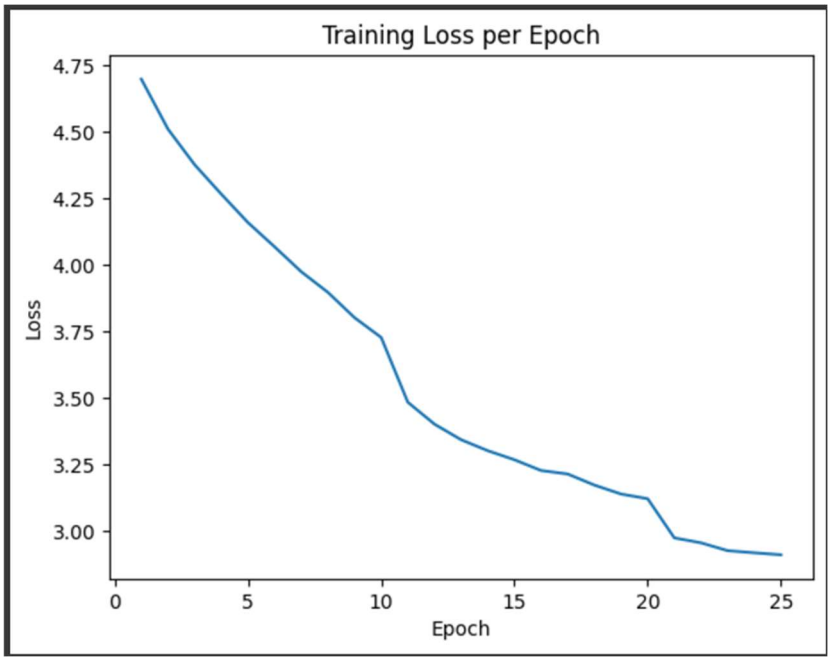
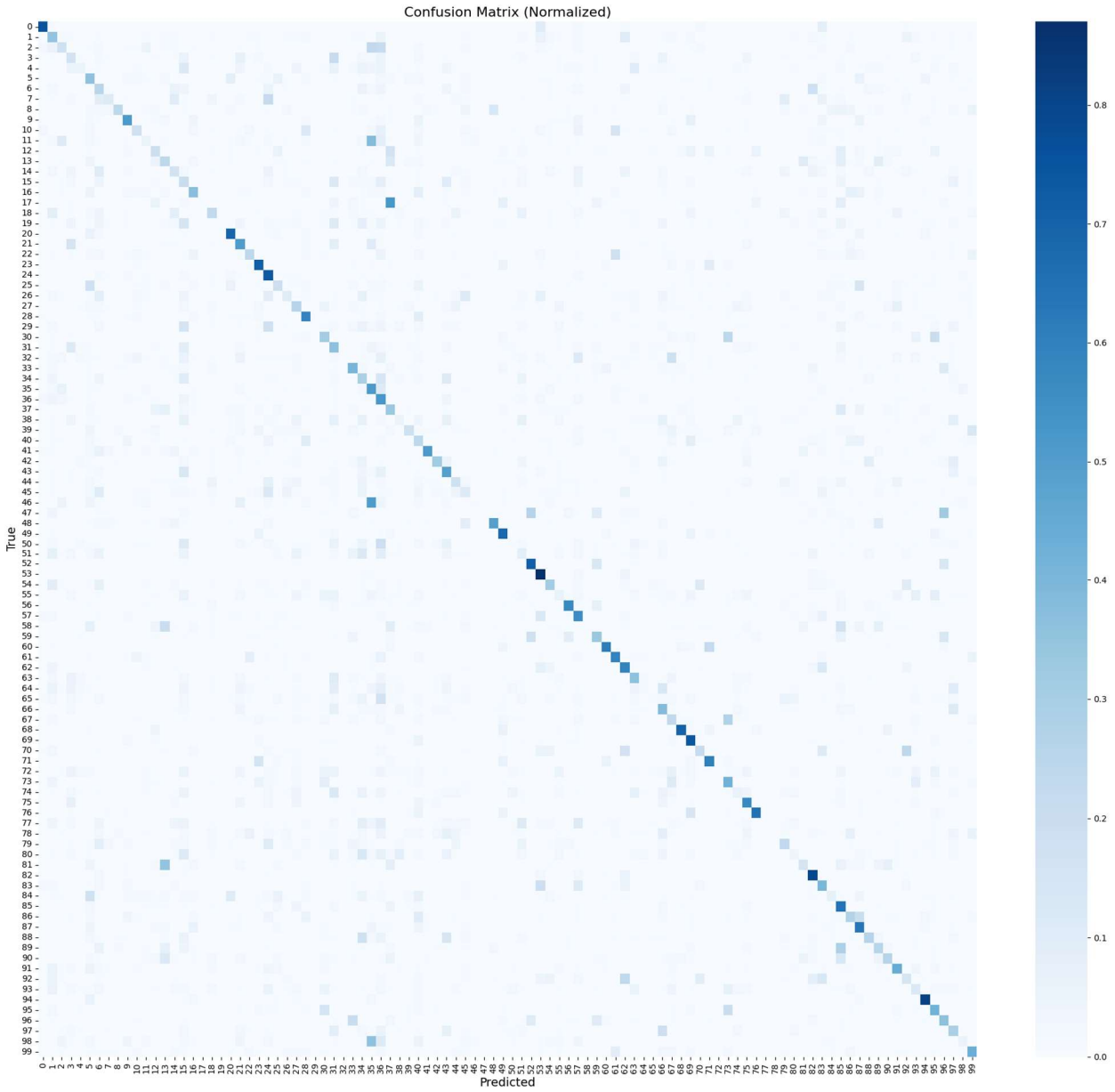
Epoch [24/25], Batch [130/196], Loss: 2.904090166091919
Epoch [24/25], Batch [140/196], Loss: 2.9039337635040283
Epoch [24/25], Batch [150/196], Loss: 2.9247541427612305
Epoch [24/25], Batch [160/196], Loss: 2.6830108165740967
Epoch [24/25], Batch [170/196], Loss: 3.032801628112793
Epoch [24/25], Batch [180/196], Loss: 2.9351444244384766
Epoch [24/25], Batch [190/196], Loss: 2.9502828121185303
Training Progress:  96%|█████████ | 24/25 [34:06<01:24, 84.99s/it]
Model saved with loss 2.9171 at epoch 24
Epoch 24, Average Loss: 2.9171
Epoch [25/25], Batch [0/196], Loss: 2.896562337875366
Epoch [25/25], Batch [10/196], Loss: 2.846888780593872
Epoch [25/25], Batch [20/196], Loss: 2.7675294876098633
Epoch [25/25], Batch [30/196], Loss: 2.610628128051758
Epoch [25/25], Batch [40/196], Loss: 2.860834836959839
Epoch [25/25], Batch [50/196], Loss: 2.876519203186035
Epoch [25/25], Batch [60/196], Loss: 2.6544644832611084
Epoch [25/25], Batch [70/196], Loss: 3.0036814212799072
Epoch [25/25], Batch [80/196], Loss: 2.990283489227295
Epoch [25/25], Batch [90/196], Loss: 2.8217334747314453
Epoch [25/25], Batch [100/196], Loss: 2.7381458282470703
Epoch [25/25], Batch [110/196], Loss: 2.7374188899993896
Epoch [25/25], Batch [120/196], Loss: 2.6940383911132812
Epoch [25/25], Batch [130/196], Loss: 2.9660420417785645
Epoch [25/25], Batch [140/196], Loss: 3.1283316612243652
Epoch [25/25], Batch [150/196], Loss: 2.936443567276001
Epoch [25/25], Batch [160/196], Loss: 2.989840030670166
Epoch [25/25], Batch [170/196], Loss: 2.7984228134155273
Epoch [25/25], Batch [180/196], Loss: 2.9567484855651855
Epoch [25/25], Batch [190/196], Loss: 2.691060781478882
Training Progress: 100%|██████████| 25/25 [35:31<00:00, 85.27s/it]
Model saved with loss 2.9096 at epoch 25
Epoch 25, Average Loss: 2.9096
```

График изменения ошибки:



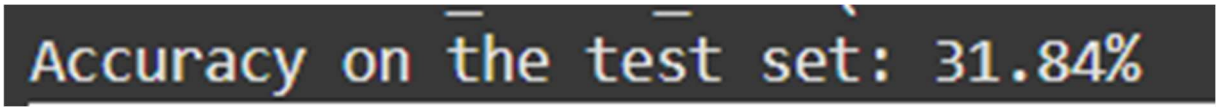



```
Accuracy on the test set: 31.84%
```

Получили:

Было:

Стало:



Вывод: в ходе лабораторной работы научилась осуществлять обучение НС, сконструированных на базе предобученных архитектур НС.