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ФАКУЛЬТЕТ «Информатика и системы управления»

КАФЕДРА «Теоретическая информатика и компьютерные технологии»

Домашняя работа №4

по курсу «Теория искусственных нейронных сетей»

«Использование генетического алгоритма для оптимизации гиперпараметров. Сравнительный анализ методов оптимизации»

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1 Цель

1. Изучение генетического алгоритма для оптимизации гиперпараметров.
2. Изучение основных методов оптимизации.

2 Задание

1. Требуется найти оптимальные гиперпараметры (lerning rate, количество эпох) для многослойного персептрона для решения задачи по классификации рукописных цифр.

2. Реализовать методы оптимизации: Adam, Momentum, SGD, Adagrad

3. Провести сравнительный анализ работы методов.

3 Реализация

Исходный код представлен в листинге 1 - 7.

Листинг 1: Подготовка датасета

```

from torchvision.datasets import MNIST
from torch.utils.data import DataLoader
from torch.utils.data import Subset
from matplotlib import pyplot as plt
import numpy as np
from IPython.display import clear_output
import sys

transform = lambda img: np.array(np.asarray(img).flatten())/256
train_dataset = MNIST('.', train=True, download=True, transform=
    transform)
test_dataset = MNIST('.', train=False, transform=transform)

train_loader = DataLoader(train_dataset, batch_size=32, shuffle=True)
test_loader = DataLoader(test_dataset, batch_size=32, shuffle=False)
```

Листинг 2: Функция тренировки

```

from tqdm import tqdm

```

```
def train(network, train_loader, test_loader, epochs, plot=True, verbose=True, loss=MSELoss()):
    train_loss_epochs = []
    test_loss_epochs = []
    train_accuracy_epochs = []
    test_accuracy_epochs = []

    try:
        for epoch in tqdm(range(epochs)):
            losses = []
            accuracies = []
            for X, y in train_loader:
                X = X.view(X.shape[0], -1).numpy()
                y = y.numpy()
                prediction = network.forward(X)
                loss_batch = loss.forward(prediction, y)
                losses.append(loss_batch)
                dLdx = loss.backward()

                network.backward(dLdx)
                network.step()
                accuracies.append((np.argmax(prediction, 1)==y).mean())
            train_loss_epochs.append(np.mean(losses))
            train_accuracy_epochs.append(np.mean(accuracies))

            losses = []
            accuracies = []
            for X, y in test_loader:
                X = X.view(X.shape[0], -1).numpy()
                y = y.numpy()
                prediction = network.forward(X)
                loss_batch = loss.forward(prediction, y)
                losses.append(loss_batch)
                accuracies.append((np.argmax(prediction, 1)==y).mean())
            test_loss_epochs.append(np.mean(losses))
            test_accuracy_epochs.append(np.mean(accuracies))
            clear_output(True)
            if verbose:
                sys.stdout.write('\rEpoch {0}... (Train/Test) Loss: {1:.3f}/{2:.3f}\tAccuracy: {3:.3f}/{4:.3f}'.format(
                            epoch, train_loss_epochs[-1], test_loss_epochs[-1],
                            train_accuracy_epochs[-1], test_accuracy_epochs[-1]))
```

```
            if plot:
                plt.figure(figsize=(12, 5))
                plt.subplot(1, 2, 1)
                plt.plot(train_loss_epochs, label='Train')
                plt.plot(test_loss_epochs, label='Test')
                plt.xlabel('Epochs', fontsize=16)
                plt.ylabel('Loss', fontsize=16)
                plt.legend(loc=0, fontsize=16)
                plt.grid('on')
                plt.subplot(1, 2, 2)
                plt.plot(train_accuracy_epochs, label='Train accuracy')
                plt.plot(test_accuracy_epochs, label='Test accuracy')
                plt.xlabel('Epochs', fontsize=16)
                plt.ylabel('Accuracy', fontsize=16)
                plt.legend(loc=0, fontsize=16)
                plt.grid('on')
                plt.show()
    except KeyboardInterrupt:
        pass
    return train_loss_epochs, \
           test_loss_epochs, \
           train_accuracy_epochs, \
           test_accuracy_epochs
```

Листинг 3: Функция активации и лосс функция

```

class ReLU:
def __init__(self):
    pass

def forward(self, X):
    self.X = X
    return np.maximum(X, 0)

def backward(self, dLdy):
    return (self.X > 0) * dLdy

def step(self):
    pass

class MSELoss:
    def __init__(self):
        pass

    def forward(self, X, y):
```

```
        self.X = X

        self.y = np.zeros((X.shape[0], X.shape[1]))
        self.y[np.arange(X.shape[0]), y] = 1

        return np.mean(np.square(self.X - self.y))

    def backward(self):
        return 2 * (self.X - self.y) / self.y.shape[0]
```

Листинг 4: Методы оптимизации

```

class Adam:
  def __init__(self, params, b1 = 0.9, b2 = 0.99, nu = 1., eta = 1e-8,
    lr=0.001):
      self.params = params
      self.b1 = b1
      self.b2 = b2
      self.nu = nu
      self.eta = eta
      self.lr = lr
      self.m = [np.zeros(p.shape) for p in self.params]
      self.v = [np.zeros(p.shape) for p in self.params]

  def step(self, gradW, gradb):
        grads = [gradW, gradb]
        for i, p in enumerate(self.params):
            self.m[i]=self.b1*self.m[i]+(1-self.b1)*grads[i]
            self.v[i]=self.b2*self.v[i]+(1-self.b2)*grads[i]**2
           m_ = self.m[i]/(1-self.b1**(i+1))
           v_ = self.v[i]/(1-self.b2**(i+1))

           p-=self.lr*self.nu/(np.sqrt(v_)+self.eta)*m_


class SGD:
  def __init__(self, params, lr=1e-2):
      self.params = params
      self.lr = lr

  def step(self,gradW, gradb):
      grads = [gradW, gradb]
      for i, p in enumerate(self.params):
          p -= self.lr * grads[i]

class NAG:
```

```
  def __init__(self, params, lr=1e-2, gamma=0.9):
      self.params = params
      self.lr=lr
      self.gamma=gamma
      self.momentum = [np.zeros(p.shape) for p in self.params]

  def step(self,gradW, gradb):
      grads = [gradW, gradb]
      for i, p in enumerate(self.params):
          self.momentum[i] = self.gamma * self.momentum[i] + self.lr *
   grads[i]
          p-=self.momentum[i]


class AdaGrad:
  def __init__(self, params, eta=1e-8, lr=1e-2):
      self.params=params
      self.eta = eta
      self.lr = lr

      self.G = [0] * len(self.params)

  def step(self,gradW, gradb):
      grads = [gradW, gradb]
      for i, p in enumerate(self.params):
          self.G[i] += grads[i] ** 2
          p -= self.lr / np.sqrt(self.G[i] + self.eta) * grads[i]
```

Листинг 5: Реализация нейронной сети

```

class Linear:
  def __init__(self, input_size, output_size, optimizer):
      self.W = np.random.randn(input_size, output_size)*0.01
      self.b = np.zeros(output_size)

      optimizer_class = optimizer[0]
      optimizer_options = optimizer[1] if len(optimizer) > 2 else {}
      optimizer = optimizer_class([self.W,self.b], **optimizer_options)
      self.optimizer=optimizer

  def forward(self, X):
      self.X = X
      return X.dot(self.W)+self.b

  def backward(self, dLdy):
      self.dLdW = self.X.T.dot(dLdy)
```

```
        self.dLdb = dLdy.sum(0)
        self.dLdx = dLdy.dot(self.W.T)
        return self.dLdx

    def step(self):
        self.optimizer.step(self.dLdW, self.dLdb)


class NeuralNetwork:
    def __init__(self, modules):
        self.modules = modules

    def forward(self, X):
        y = X
        for i in range(len(self.modules)):
            y = self.modules[i].forward(y)
        return y

    def backward(self, dLdy):
        for i in range(len(self.modules))[::-1]:
            dLdy = self.modules[i].backward(dLdy)

    def step(self):
        for i in range(len(self.modules)):
            self.modules[i].step()
```

Листинг 6: Реализация генетического алгоритма

```

    from dataclasses import dataclass

    @dataclass
    class HyperParams:
        lr: float
        epochs: int

        def __init__(self, lr, epoch):
            self.lr = lr
            self.epochs = int(epoch)

        def to_vec(self):
            return np.array([
                self.lr, self.epochs
            ])

    class Creature:
        def __init__(self, hp: HyperParams):
```

```
        self.hp = hp
        adam=[Adam,{'lr': hp.lr}]
        self.network = NeuralNetwork([
            Linear(784, 100,adam), ReLU(),
            Linear(100, 100,adam), ReLU(),
            Linear(100, 10,adam)
        ])
        self.loss = MSELoss()

        self.optimizer = 'Adam'

    def __repr__(self):
        return str(self.hp)


    def train(self, train_loader):
        for epoch in range(self.hp.epochs):
            for X, y in train_loader:
                X = X.view(X.shape[0], -1).numpy()
                y = y.numpy()
                prediction = self.network.forward(X)
                loss_batch = self.loss.forward(prediction, y)
                dLdx = self.loss.backward()

                self.network.backward(dLdx)
                self.network.step()

    def test(self, test_loader):
        accuracies=[]
        for X, y in test_loader:
            X = X.view(X.shape[0], -1).numpy()
            y = y.numpy()
            prediction = self.network.forward(X)
            loss_batch = self.loss.forward(prediction, y)
            accuracies.append((np.argmax(prediction, 1)==y).mean())
        return np.mean(accuracies)

    def fitnes(self, dl):
        return self.test(dl)


import pandas as pd
from itertools import product, chain
class Zoo:
    def __init__(self, dl_len=1000) -> None:
        self.dl = {
```

```
            'test': DataLoader(Subset(train_dataset, range(0, dl_len)), shuffle=True, batch_size=16),
            'train': DataLoader(Subset(train_dataset, range(dl_len, int(dl_len*1.2))), shuffle=True, batch_size=16),
        }

        lrs = [0.001,0.01, 0.1, 0.5]
        epochs = [10, 30]

        self.creatures = []
        self.pop_size = 0
        for lr, ep_num in product(lrs, epochs):
            self.creatures.append(Creature(HyperParams(lr=lr, epoch=ep_num)))
            self.pop_size += 1

    def train(self):
        for c in tqdm(self.creatures):
            c.train(self.dl['train'])

    def build_df(self, creatures: list[Creature]):
        df = pd.DataFrame({'creature': creatures})
        # df['accuracy'] = df.creature.map(lambda x: x.test(self.dl['test']))
        df['fitnes'] = df.creature.map(lambda x: x.fitnes(self.dl['test']))
        df.fitnes = df.fitnes
        df['cs'] = df.fitnes / df.fitnes.sum()
        df['cs'] = df['cs'] / sum(df.cs)
        df = df.sort_values(by=['fitnes'], axis=0, ascending=True)
        return df

    def selection(self):
        self.creatures = list(np.random.choice(
            self.df.creature,
            size=self.pop_size,
            p=self.df.cs
        ))

    def crossing_over(self):
        def cross(p1, p2):
            pc = 0.4
            genes1, genes2 = p1.hp.to_vec(), p2.hp.to_vec()
            while True:
                try:
                    ngenes1, ngenes2 = [], []
```

```
                    for g1, g2 in zip(genes1, genes2):
                        r = np.random.random()
                        if r < pc:
                            ngenes1.append(g1)
                            ngenes2.append(g2)
                        else:
                            c = np.random.random()
                            ngenes1.append(g1*c + (1-c)*g2)
                            ngenes2.append(g2*c + (1-c)*g1)
                except AssertionError:
                    continue
                else:
                    return [Creature(HyperParams(*ngenes1)), Creature(HyperParams(*ngenes2))]

        np.random.shuffle(self.creatures)  # type: ignore
        pairs = [tuple(self.creatures[i:i+2]) for i in range(0, 2*len(self.creatures)//2-1, 2)] + \
            [tuple(self.creatures[-2:])]
        offsprings = list(map(lambda x: cross(*x), pairs))
        self.creatures = list(chain(*offsprings))[:self.pop_size]

    def mutation(self):
        pm = 0.15

        def mutate(c):
            if np.random.random() > pm:
                return c
            gens = c.hp.to_vec()
            i = np.random.randint(0, len(gens))
            gens[i] = np.random.uniform(*MUTAGENS[i])
            try:
                return Creature(HyperParams(*gens))
            except:
                return c

        self.creatures = list(map(mutate, self.creatures))

    def replace_with_new_gen(self):
        new_df = self.build_df(self.creatures)

        all_df = pd.concat([self.df, new_df], axis=0)
        all_df.fitnes
        all_df.sort_values(by='fitnes', ascending=True, inplace=True)
        self.df = all_df.tail(self.pop_size)
        self.df.cs = self.df.fitnes / self.df.fitnes.sum()
```

```
            print(self.df)

    def evolve(self, N):
        best = []
        self.train()
        self.df = self.build_df(self.creatures)
        #
        for i in range(N):
            print(f'-> generation {i+1} of {N}')
            self.selection()
            self.crossing_over()
            self.mutation()
            self.train()
            self.replace_with_new_gen()
            best.append(self.df.iloc[-1].fitnes)
            # print(self.df)

        #

        print(self.df)
        row = self.df['fitnes'].idxmax()

        plt.plot(range(len(best)), best)
        return self.df.iloc[row].creature, self.df.iloc[row].fitnes

    MUTAGENS = [
            (0.001, 0.01),
            (10, 30),
        ]
```

Листинг 7: Пример запуска

```

sgd=[SGD, {'lr': 0.005}]

network = NeuralNetwork([
    Linear(784, 100, optimizer=sgd), ReLU(),
    Linear(100, 100,optimizer=sgd), ReLU(),
    Linear(100, 10,optimizer=sgd)
])
loss = MSELoss()
tr_mse_sgd, ts_mse_sgd, tr_ac_mse_sgd, ts_ac_mse_sgd = train(
    network,train_loader,test_loader, 10, plot=True, verbose=True,
  loss=loss)
```

4 Результаты

Результат представлен на рисунках 1 - 5.

```
                                           creature    fitnes        cs
5   HyperParams(lr=0.09687647963063076, epochs=23)  0.796627  0.124342
0   HyperParams(lr=0.19839015020036918, epochs=27)  0.797619  0.124497
2  HyperParams(lr=0.009377725074904707, epochs=21)  0.799603  0.124806
2                 HyperParams(lr=0.5, epochs=21)  0.801587  0.125116
0               HyperParams(lr=0.001, epochs=30)  0.801587  0.125116
0               HyperParams(lr=0.001, epochs=29)  0.801587  0.125116
6    HyperParams(lr=0.3088212076749669, epochs=21)  0.803571  0.125426
6  HyperParams(lr=0.005850987972820287, epochs=26)  0.804563  0.125581
                                           creature    fitnes        cs
5   HyperParams(lr=0.09687647963063076, epochs=23)  0.796627  0.124342
0   HyperParams(lr=0.19839015020036918, epochs=27)  0.797619  0.124497
2  HyperParams(lr=0.009377725074904707, epochs=21)  0.799603  0.124806
2                 HyperParams(lr=0.5, epochs=21)  0.801587  0.125116
0               HyperParams(lr=0.001, epochs=30)  0.801587  0.125116
0               HyperParams(lr=0.001, epochs=29)  0.801587  0.125116
6    HyperParams(lr=0.3088212076749669, epochs=21)  0.803571  0.125426
6  HyperParams(lr=0.005850987972820287, epochs=26)  0.804563  0.125581
<ipython-input-89-04a472deed6c>:90: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-d
  self.df.cs = self.df.fitnes / self.df.fitnes.sum()
(HyperParams(lr=0.3088212076749669, epochs=21), 0.8035714285714286)
```

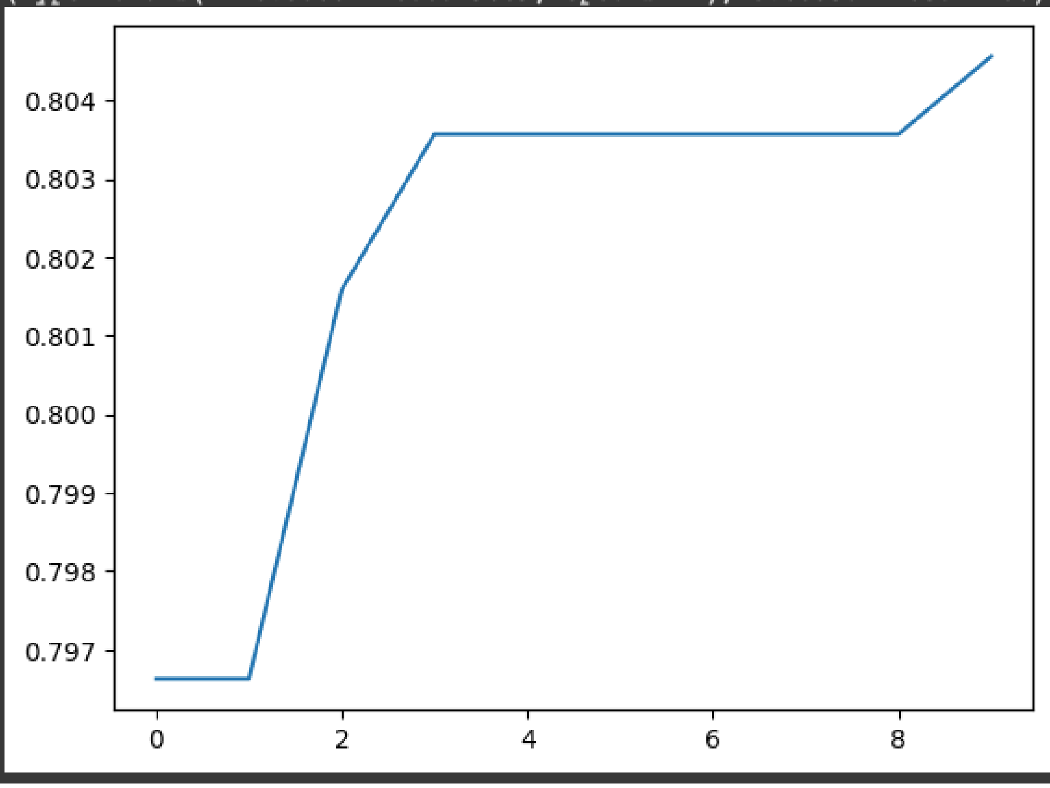


Рис. 1 — Результат работы генетичесокго алгоритма

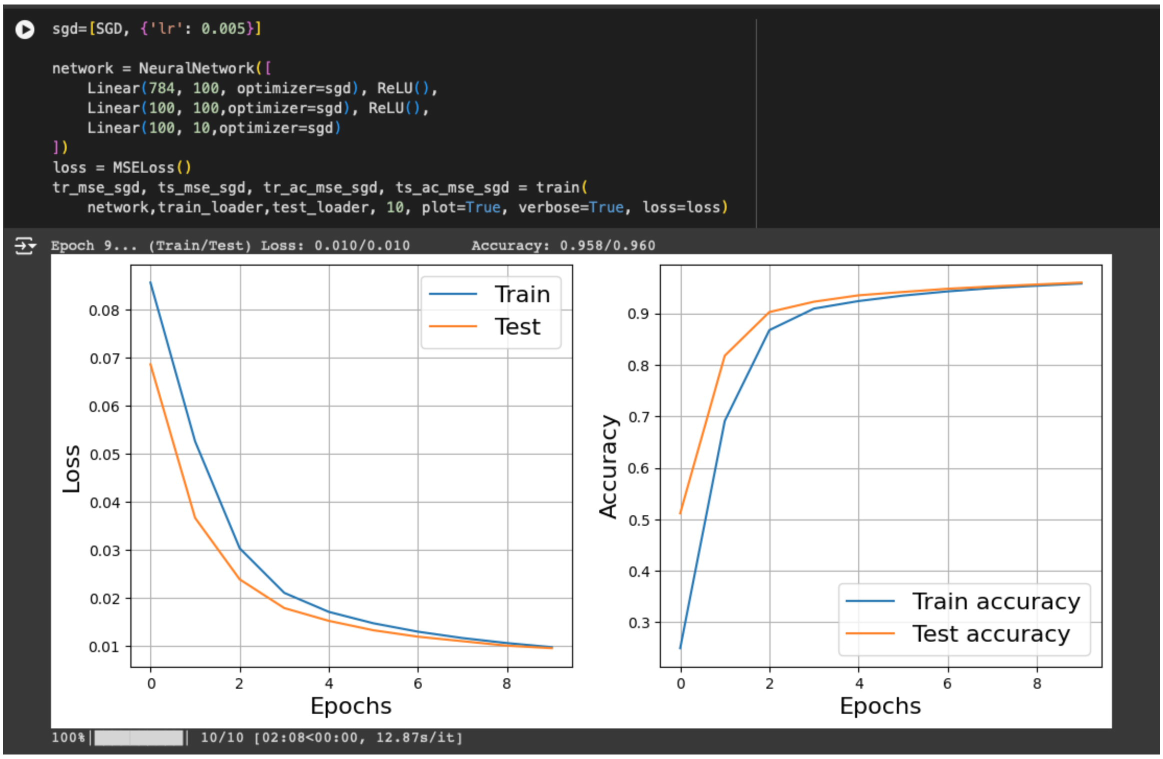


Рис. 2 — Стохастический градиентный спуск (SGD)

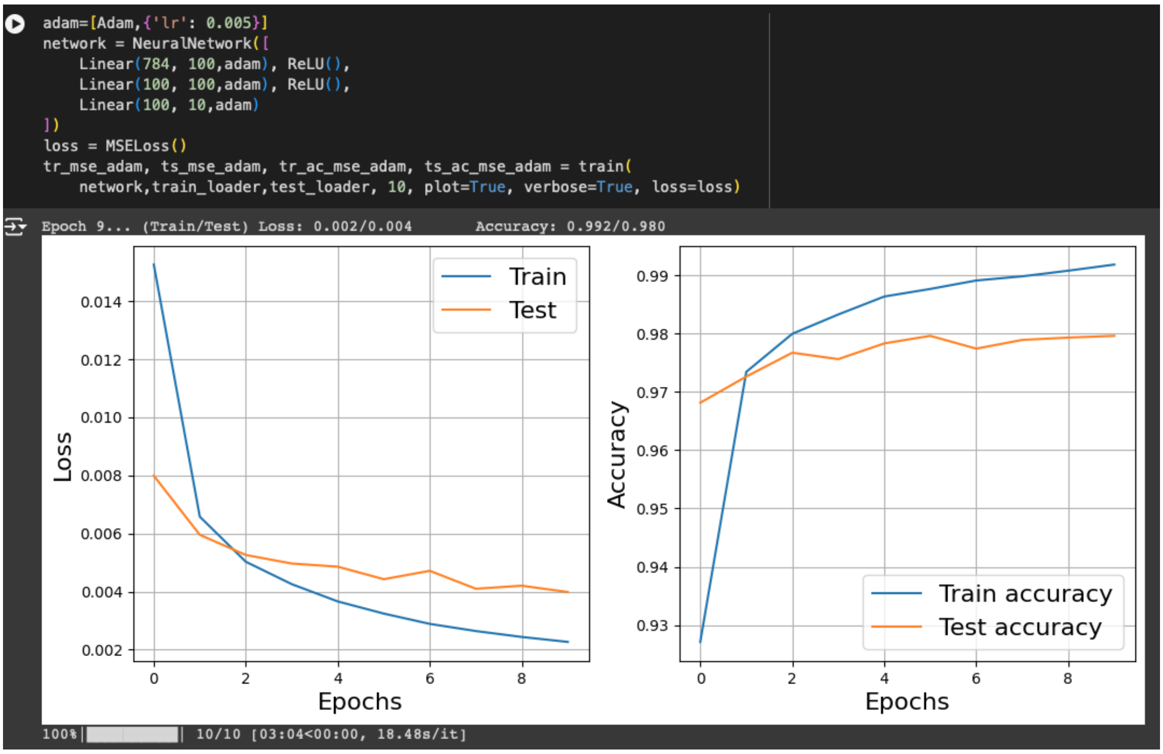
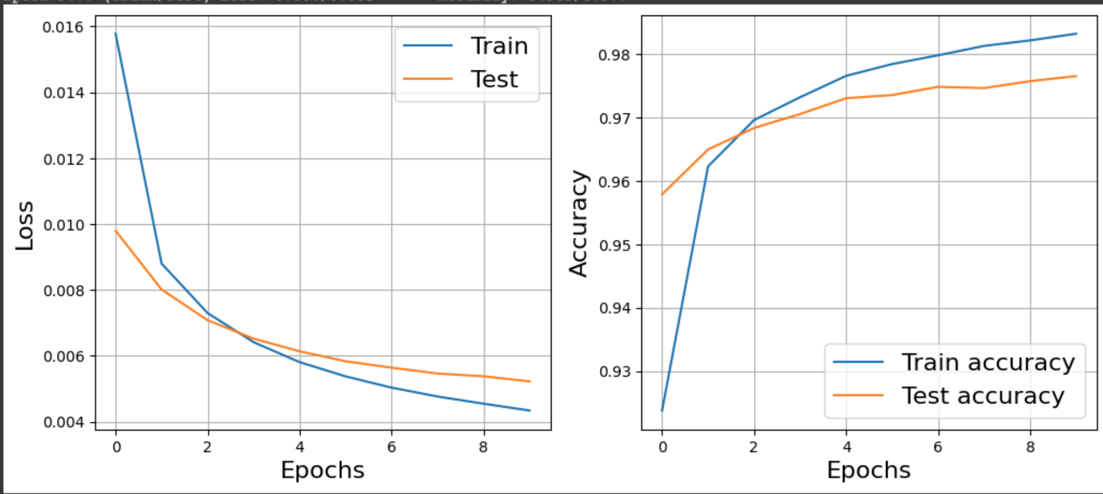


Рис. 3 — Adam

```
adagrad = [AdaGrad,{'lr': 0.005}]
network = NeuralNetwork([
    Linear(784, 100,adagrad), ReLU(),
    Linear(100, 100,adagrad), ReLU(),
    Linear(100, 10,adagrad)
])
loss = MSELoss()
tr_mse_adg, ts_mse_adg, tr_ac_mse_adg, ts_ac_mse_adg = train(
    network,train_loader,test_loader, 10, plot=True, verbose=True, loss=loss)
```

```
Epoch 9... (Train/Test) Loss: 0.004/0.005        Accuracy: 0.983/0.977
```

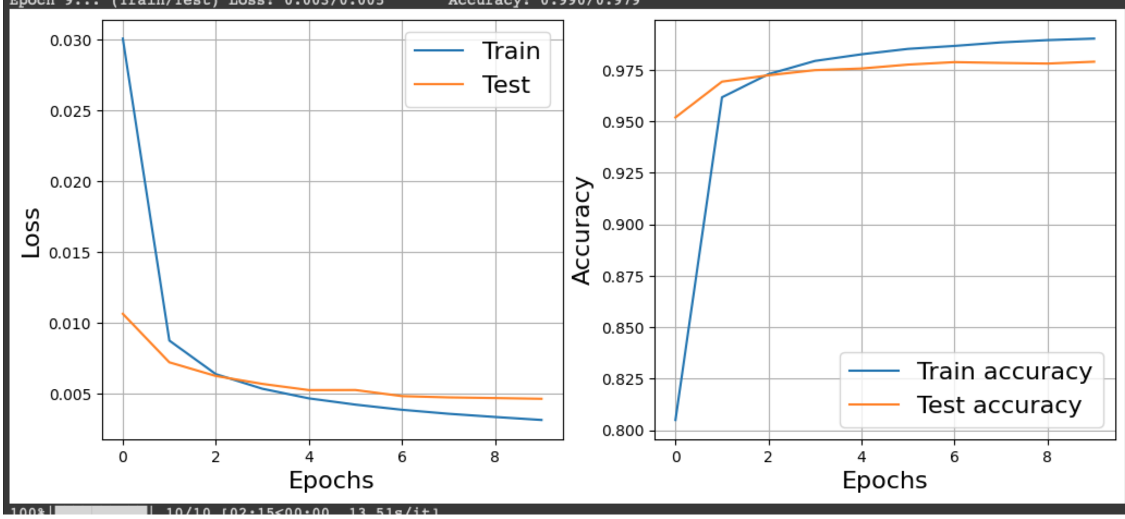



```
100%|██████████| 10/10 [02:22<00:00, 14.20s/it]
```

Рис. 4 — AdaGrad

```
nag = [NAG,{'lr': 0.005}]
network = NeuralNetwork([
    Linear(784, 100,nag), ReLU(),
    Linear(100, 100,nag), ReLU(),
    Linear(100, 10,nag)
])
loss = MSELoss()
tr_mse_mm, ts_mse_mm, tr_ac_mse_mm, ts_ac_mse_mm = train(
    network,train_loader,test_loader, 10, plot=True, verbose=True, loss=loss)
```

```
Epoch 9... (Train/Test) Loss: 0.003/0.005        Accuracy: 0.990/0.979
```




```
100%|██████████| 10/10 [02:15<00:00, 13.51s/it]
```

Рис. 5 — NAG

5 Выводы

В результе выполнения данной лабораторной работы был реализован генетический алгоритмы, для поиска оптимальных гиперпараметров, и засчёт этого удалось улучшить точность предсказаний нейронной сети из домшнего задания номер 2.

Помимо этого были реализованы различные алгоритмы оптимизации, тестирование которых показало, что Adam является более успешным по скорости сходимости из всех рассматриваемых методов.