# Лабораторная работа №8 по курсу "Нейроинформатика".

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## Цель работы.

Исследование свойств некоторых динамических нейронных сетей, алгоритмов обучения, а также применение сетей в задачах аппроксимации функций и распознавания динамических образов.

In [1]:

```
import numpy as np
import matplotlib.pyplot as plt
import torch
import torch.nn as nn
from collections import OrderedDict
from torchvision.datasets import MNIST, CIFAR10
from torch.utils.data import DataLoader
from torch.optim import Adam
import torchvision.transforms as transforms
import random
from tqdm import tqdm
from collections import deque
```

## TDL.

In [2]:

```
class TDL(nn.Module):
    def __init__(self, in_features, delays=1):
        super().__init__()
        self.in_features = in_features
        self.delays = delays
        self.line = deque()
        self.clear()

    def clear(self):
        self.line.clear()
        for i in range(self.delays):
            self.line.append(torch.zeros(self.in_features))

    def push(self, inputs):
        self.line.appendleft(inputs)

    def forward(self, inputs=0):
        return self.line.pop()
```

## NARX.

In [3]:

```
class NARX(nn.Module):
    def __init__(self, in_features, h_features, out_features, delay1, delay2):
        super().__init__()
        self.in_features = in_features
        self.h_features = h_features
        self.out_features = out_features

        self.line1 = TDL(in_features, delay1)
        self.line2 = TDL(out_features, delay2)

        self.w1 = torch.nn.Parameter(torch.randn(in_features, h_features))
        self.w2 = torch.nn.Parameter(torch.randn(h_features, out_features))
        self.w3 = torch.nn.Parameter(torch.randn(out_features, h_features))

        self.b1 = torch.nn.Parameter(torch.ones(h_features))
        self.b2 = torch.nn.Parameter(torch.ones(out_features))

    def clear(self):
        self.line1.clear()
        self.line2.clear()

    def forward(self, inputs):
        out1 = torch.tanh(self.line1() @ self.w1 + self.line2() @ self.w3 + self.b1)
        out2 = out1 @ self.w2 + self.b2

        self.line1.push(torch.tensor(inputs))
        self.line2.push(torch.tensor(out2))

        return out2
```

## Обучение.

In [4]:

```
lr = 0.001
wd = 0.00001

model = NARX(5, 10, 5, 3, 3)
optimizer = Adam(model.parameters(), lr=lr, weight_decay=wd)

epochs = 100
n, w  = 600, 5

t = np.linspace(0, 5, n)
uk, yk = np.cos(t**2 + 10*t + 3), [0]

for i in range(n-1):
    yk += [yk[-1] / (1 + yk[-1]**2) + uk[i]]

train_data = [(np.array(uk[i:i+w], dtype=np.float32),
                np.array(yk[i:i+w], dtype=np.float32)) for i in range(n - 5)]

train_loader = torch.utils.data.DataLoader(train_data, batch_size=1, shuffle=False)
```

In [5]:

```
model.train()

train_loss = []
crit = nn.MSELoss()

for i in range(epochs):
    pbar = tqdm(enumerate(train_loader))

    model.clear()

    epoch_loss = []

    for _, (inputs, outputs_gt) in pbar:
        outputs = model(inputs)

        loss = torch.sqrt(crit(outputs_gt, outputs))
        epoch_loss += [loss.item()]

        optimizer.zero_grad()
        loss.backward()
        optimizer.step()

    train_loss += [np.mean(epoch_loss)]
    pbar.write(f'{i+1} loss: {train_loss[-1]:.4f}')
```

```
0it [00:00, ?it/s]<ipython-input-3-ddc148b1b73b>:26: UserWarning: To copy
construct from a tensor, it is recommended to use sourceTensor.clone().det
ach() or sourceTensor.clone().detach().requires_grad_(True), rather than t
orch.tensor(sourceTensor).
  self.line1.push(torch.tensor(inputs))
<ipython-input-3-ddc148b1b73b>:27: UserWarning: To copy construct from a t
ensor, it is recommended to use sourceTensor.clone().detach() or sourceTen
sor.clone().detach().requires_grad_(True), rather than torch.tensor(source
Tensor).
  self.line2.push(torch.tensor(out2))
/usr/local/lib/python3.8/dist-packages/torch/nn/modules/loss.py:536: UserW
arning: Using a target size (torch.Size([5])) that is different to the inp
ut size (torch.Size([1, 5])). This will likely lead to incorrect results d
ue to broadcasting. Please ensure they have the same size.
  return F.mse_loss(input, target, reduction=self.reduction)
595it [00:01, 508.39it/s]

1 loss: 2.5522

595it [00:00, 1231.66it/s]

2 loss: 1.5893

595it [00:00, 1128.55it/s]

3 loss: 0.9785

595it [00:00, 954.70it/s]

4 loss: 0.5610

595it [00:00, 679.11it/s]

5 loss: 0.5015

595it [00:01, 497.78it/s]

6 loss: 0.4273

595it [00:01, 558.35it/s]

7 loss: 0.3518

595it [00:01, 547.69it/s]

8 loss: 0.2901

595it [00:01, 532.06it/s]

9 loss: 0.2073

595it [00:00, 711.50it/s]

10 loss: 0.1739

595it [00:01, 498.22it/s]

11 loss: 0.1491

595it [00:00, 964.98it/s]

12 loss: 0.1351

595it [00:00, 1245.95it/s]

13 loss: 0.1242
```

```
595it [00:00, 1259.83it/s]

14 loss: 0.1129

595it [00:00, 1214.80it/s]

15 loss: 0.1052

595it [00:00, 1275.87it/s]

16 loss: 0.1007

595it [00:00, 1234.35it/s]

17 loss: 0.0960

595it [00:00, 1211.51it/s]

18 loss: 0.0914

595it [00:00, 1226.71it/s]

19 loss: 0.0861

595it [00:00, 1254.13it/s]

20 loss: 0.0851

595it [00:00, 1236.42it/s]

21 loss: 0.0849

595it [00:00, 1199.31it/s]

22 loss: 0.0830

595it [00:00, 1221.39it/s]

23 loss: 0.0801

595it [00:00, 1230.93it/s]

24 loss: 0.0807

595it [00:00, 1150.02it/s]

25 loss: 0.0773

595it [00:00, 1215.94it/s]

26 loss: 0.0764

595it [00:00, 1217.20it/s]

27 loss: 0.0745

595it [00:00, 1226.08it/s]

28 loss: 0.0815

595it [00:00, 1232.08it/s]

29 loss: 0.0783

595it [00:00, 1262.93it/s]

30 loss: 0.0798
```

```
595it [00:00, 1214.57it/s]

31 loss: 0.0751

595it [00:00, 1254.61it/s]

32 loss: 0.0788

595it [00:00, 1239.78it/s]

33 loss: 0.0732

595it [00:00, 1241.72it/s]

34 loss: 0.0784

595it [00:00, 1226.30it/s]

35 loss: 0.0712

595it [00:00, 1258.49it/s]

36 loss: 0.0772

595it [00:00, 1230.41it/s]

37 loss: 0.0666

595it [00:00, 1238.46it/s]

38 loss: 0.0752

595it [00:00, 1175.05it/s]

39 loss: 0.0661

595it [00:00, 1261.60it/s]

40 loss: 0.0695

595it [00:00, 1276.18it/s]

41 loss: 0.0647

595it [00:00, 1236.98it/s]

42 loss: 0.0738

595it [00:00, 1232.44it/s]

43 loss: 0.0650

595it [00:00, 1147.19it/s]

44 loss: 0.0735

595it [00:00, 1225.88it/s]

45 loss: 0.0647

595it [00:00, 1252.93it/s]

46 loss: 0.0665

595it [00:00, 1198.42it/s]

47 loss: 0.0635
```

```
595it [00:00, 1213.10it/s]
48 loss: 0.0666
595it [00:00, 1237.93it/s]
49 loss: 0.0621
595it [00:00, 1235.13it/s]
50 loss: 0.0662
595it [00:00, 1253.62it/s]
51 loss: 0.0621
595it [00:00, 1215.16it/s]
52 loss: 0.0657
595it [00:00, 1229.16it/s]
53 loss: 0.0623
595it [00:00, 1225.70it/s]
54 loss: 0.0652
595it [00:00, 1255.49it/s]
55 loss: 0.0620
595it [00:00, 1223.77it/s]
56 loss: 0.0646
595it [00:00, 1248.86it/s]
57 loss: 0.0615
595it [00:00, 1228.66it/s]

58 loss: 0.0638
595it [00:00, 1233.47it/s]
59 loss: 0.0618
595it [00:00, 1238.02it/s]
60 loss: 0.0627
595it [00:00, 1257.71it/s]
61 loss: 0.0620
595it [00:00, 1262.08it/s]
62 loss: 0.0614
595it [00:00, 1268.05it/s]
63 loss: 0.0613
595it [00:00, 1280.93it/s]
64 loss: 0.0608
```

```
595it [00:00, 1265.56it/s]

65 loss: 0.0603

595it [00:00, 1247.14it/s]

66 loss: 0.0601

595it [00:00, 1253.09it/s]

67 loss: 0.0597

595it [00:00, 1277.12it/s]

68 loss: 0.0593

595it [00:00, 1234.51it/s]

69 loss: 0.0590

595it [00:00, 1249.48it/s]

70 loss: 0.0586

595it [00:00, 1264.00it/s]

71 loss: 0.0583

595it [00:00, 1237.57it/s]

72 loss: 0.0579

595it [00:00, 1256.64it/s]

73 loss: 0.0576

595it [00:00, 1222.91it/s]

74 loss: 0.0572

595it [00:00, 1255.45it/s]

75 loss: 0.0569

595it [00:00, 1230.24it/s]

76 loss: 0.0565

595it [00:00, 1244.07it/s]

77 loss: 0.0565

595it [00:00, 1265.22it/s]

78 loss: 0.0560

595it [00:00, 1231.38it/s]

79 loss: 0.0562

595it [00:00, 1253.27it/s]

80 loss: 0.0562

595it [00:00, 1263.73it/s]

81 loss: 0.0554
```

```
595it [00:00, 1263.89it/s]

82 loss: 0.0567

595it [00:00, 1245.61it/s]

83 loss: 0.0559

595it [00:00, 1253.72it/s]

84 loss: 0.0554

595it [00:00, 1250.32it/s]

85 loss: 0.0556

595it [00:00, 1280.77it/s]

86 loss: 0.0528

595it [00:00, 1218.93it/s]

87 loss: 0.0565

595it [00:00, 1193.97it/s]

88 loss: 0.0526

595it [00:00, 1275.47it/s]

89 loss: 0.0560

595it [00:00, 1213.48it/s]

90 loss: 0.0528

595it [00:00, 1270.43it/s]

91 loss: 0.0556

595it [00:00, 1202.61it/s]

92 loss: 0.0528

595it [00:00, 1237.24it/s]

93 loss: 0.0552

595it [00:00, 1215.97it/s]

94 loss: 0.0520

595it [00:00, 1258.79it/s]

95 loss: 0.0550

595it [00:00, 1230.27it/s]

96 loss: 0.0510

595it [00:00, 1276.81it/s]

97 loss: 0.0546

595it [00:00, 1245.77it/s]

98 loss: 0.0512
```

```
595it [00:00, 1250.63it/s]

99 loss: 0.0539

595it [00:00, 1224.31it/s]

100 loss: 0.0503
```

# Графики

In [6]:

```
model.eval()
model.clear()
```

In [7]:

```
predict = []

for x, _ in train_data:
    predict += [model(x).detach().numpy().item(-1)]
```

```
<ipython-input-3-ddc148b1b73b>:27: UserWarning: To copy construct from a t
ensor, it is recommended to use sourceTensor.clone().detach() or sourceTen
sor.clone().detach().requires_grad_(True), rather than torch.tensor(source
Tensor).
  self.line2.push(torch.tensor(out2))
```

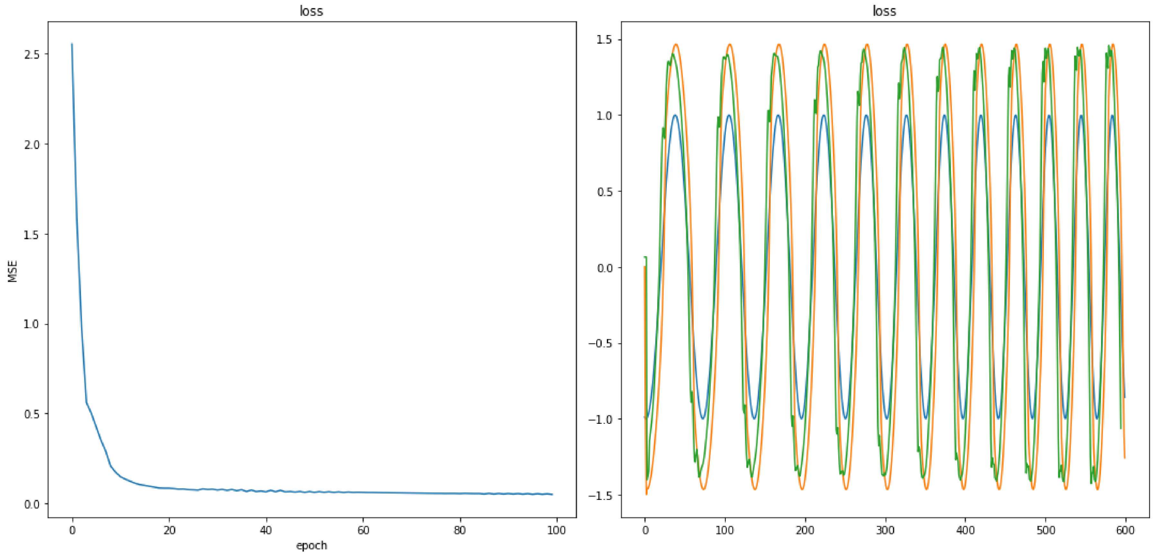
In [8]:

```
fig, axes = plt.subplots(1, 2, figsize=(15,7))
fig.tight_layout()

axes[0].set_title('loss')
axes[0].set_xlabel('epoch')
axes[0].set_ylabel('MSE')
axes[0].plot(train_loss)

axes[1].set_title('loss')
axes[1].plot(uk)
axes[1].plot(yk)
axes[1].plot(predict, '-')

plt.show()
```



# Выводы.

В данной лабораторной работе мы научились работать с сетью NARX.

In [8]: