Лабораторная работа № **8** по Нейроинформатике

Динамические сети

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Вариант № **16**

In [188]:

```
import numpy as np
import torch
import torch.nn as nn
from torch import optim
import matplotlib.pyplot as plt
from timeit import default_timer as timer
from tqdm import tqdm
from collections import deque
```

Создадим класс слоя с временной задержкой

In [189]:

```
class TDL(nn.Module):
    def __init__(self, in_features, delays=1):
        super(TDL, self).__init__()
        self.in_features = in_features
        self.delays = delays
        self.deque = deque()
        self.clear()
    def clear(self):
        self.deque.clear()
        for i in range(self.delays):
            self.deque.append(torch.zeros(self.in_features))
    def push(self, inputs):
        self.deque.appendleft(inputs)
    def forward(self, inputs=0):
        return self.deque.pop()
```

Создадим класс для **NARX (**нелинейная авторегрессионная сеть с внешними входами**)**

In [190]:

```
class NARX(nn.Module):
    def __init__(self, in_features, hidden_features, out_features, delay1, delay2):
        super(NARX, self).__init__()
        self.in_features = in_features
        self.hidden_features = hidden_features
        self.out_features = out_features
        self.deque1 = TDL(in_features, delay1)
        self.deque2 = TDL(out_features, delay2)
        self.w1 = torch.nn.Parameter(torch.randn(in_features, hidden_features))
        self.w2 = torch.nn.Parameter(torch.randn(hidden_features, out_features))
        self.w3 = torch.nn.Parameter(torch.randn(out_features, hidden_features))
        self.b1 = torch.nn.Parameter(torch.ones(hidden_features))
        self.b2 = torch.nn.Parameter(torch.ones(out_features))
    def forward(self, inputs):
        out1 = torch.tanh(self.deque1() @ self.w1 + self.deque2() @ self.w3 + self.b1)
        out2 = out1 @ self.w2 + self.b2
        self.deque1.push(torch.tensor(inputs))
        self.deque2.push(torch.tensor(out2))
        return out2
    def clear(self):
        self.deque1.clear()
        self.deque2.clear()
```

Параметры модели

In [191]:

```
epochs = 200
n = 600
w = 5
```

Зададим управляющий и идеальный сигналы

In [192]:

```
t = np.linspace(0, 5, n)
ut = np.cos(t ** 2 - 15 * t + 3) - np.cos(t)
```

In [193]:

```
yt = [0]
for i in range(n - 1):
    yt += [yt[-1] / (1 + yt[-1] ** 2) + ut[i] ** 3]
```

In [194]:

```
train_data = [(np.array(ut[i:i + w], dtype=np.float32),
               np.array(yt[i:i + w], dtype=np.float32)) for i in range(n - w)]
train_loader = torch.utils.data.DataLoader(dataset=train_data, batch_size=1, shuffle=Fal
se)
```

Создаём модель

In [195]:

```
model = NARX(5, 10, 5, 3, 3)
optimizer = optim.Adam(model.parameters(), lr=1e-3)
```

Обучаем

In [196]:

```
model.train()
```

Out[196]:

```
NARX(
  (deque1): TDL()
  (deque2): TDL()
)
```

In [197]:

```
train_loss = []
start_time = timer()
for i in range(epochs):
    pbar = tqdm(enumerate(train_loader))
    #model.clear()
    loss_per_epoch = []
    for _, (inputs, given_outputs) in pbar:
        outputs = model(inputs)
        crit = nn.MSELoss()
        loss = crit(given_outputs, outputs)
        loss_per_epoch += [loss.item()]
        optimizer.zero_grad()
        loss.backward()
        optimizer.step()
    train_loss += [np.mean(loss_per_epoch)]
    pbar.write('%d. loss = %f ' % (i + 1, train_loss[-1]))
end_time = timer()
```

```
0it [00:00, ?it/s]C:\Users\volch\AppData\Local\Temp\ipykernel_5012\2841970211.py:17: User
```

```
Warning: To copy construct from a tensor, it is recommended to use sourceTensor.clone().d
etach() or sourceTensor.clone().detach().requires_grad_(True), rather than torch.tensor(s
ourceTensor).
  self.deque1.push(torch.tensor(inputs))
C:\Users\volch\AppData\Local\Temp\ipykernel_5012\2841970211.py:18: UserWarning: To copy c
onstruct from a tensor, it is recommended to use sourceTensor.clone().detach() or sourceT
ensor.clone().detach().requires_grad_(True), rather than torch.tensor(sourceTensor).
  self.deque2.push(torch.tensor(out2))
595it [00:00, 1375.54it/s]
1. loss = 10.126014
595it [00:00, 1431.42it/s]
2. loss = 6.405377
595it [00:00, 1426.75it/s]
3. loss = 4.247128
595it [00:00, 1433.32it/s]
4. loss = 3.154549
595it [00:00, 1427.56it/s]
5. loss = 2.760195
595it [00:00, 1431.74it/s]
6. loss = 2.479308
595it [00:00, 1437.42it/s]
7. loss = 2.161671
595it [00:00, 1439.00it/s]
8. loss = 2.174271
595it [00:00, 1442.35it/s]
9. loss = 1.786616
595it [00:00, 1432.92it/s]
10. loss = 1.668497
595it [00:00, 1421.34it/s]
11. loss = 1.709817
595it [00:00, 1396.91it/s]
12. loss = 1.535436
595it [00:00, 1437.26it/s]
13. loss = 1.630287
595it [00:00, 1421.65it/s]
14. loss = 1.743165
595it [00:00, 1427.22it/s]
15. loss = 1.729573
595it [00:00, 1432.27it/s]
16. loss = 1.600381
595it [00:00, 1425.43it/s]
17. loss = 1.774336
595it [00:00, 1446.71it/s]
18. loss = 1.370347
```

```
595it [00:00, 1432.95it/s]
19. loss = 1.279798
595it [00:00, 1432.10it/s]
20. loss = 1.292278
595it [00:00, 1439.48it/s]
21. loss = 1.182380
595it [00:00, 1430.45it/s]
22. loss = 1.108096
595it [00:00, 1429.82it/s]
23. loss = 1.118440
595it [00:00, 1453.52it/s]
24. loss = 0.936224
595it [00:00, 1433.87it/s]
25. loss = 1.023491
595it [00:00, 1440.76it/s]
26. loss = 1.047860
595it [00:00, 1426.42it/s]
27. loss = 0.940208
595it [00:00, 1441.05it/s]
28. loss = 0.977149
595it [00:00, 1433.11it/s]
29. loss = 0.986639
595it [00:00, 1444.73it/s]
30. loss = 1.053385
595it [00:00, 1440.12it/s]
31. loss = 1.051814
595it [00:00, 1442.83it/s]
32. loss = 1.030685
595it [00:00, 1452.76it/s]
33. loss = 1.013026
595it [00:00, 1442.76it/s]
34. loss = 0.940240
595it [00:00, 1445.78it/s]
35. loss = 0.882799
595it [00:00, 1426.08it/s]
36. loss = 0.899881
595it [00:00, 1444.94it/s]
37. loss = 0.832506
595it [00:00, 1435.48it/s]
38. loss = 0.818019
```

```
595it [00:00, 1444.26it/s]
39. loss = 0.792344
595it [00:00, 1462.64it/s]
40. loss = 0.742686
595it [00:00, 1433.33it/s]
41. loss = 0.753732
595it [00:00, 1445.21it/s]
42. loss = 0.710376
595it [00:00, 1449.80it/s]
43. loss = 0.693317
595it [00:00, 1436.41it/s]
44. loss = 0.678962
595it [00:00, 1448.08it/s]
45. loss = 0.717800
595it [00:00, 1445.45it/s]
46. loss = 0.601143
595it [00:00, 1453.57it/s]
47. loss = 0.620551
595it [00:00, 1456.32it/s]
48. loss = 0.643751
595it [00:00, 1435.48it/s]
49. loss = 0.598219
595it [00:00, 1446.93it/s]
50. loss = 0.587942
595it [00:00, 1438.79it/s]
51. loss = 0.578667
595it [00:00, 1447.45it/s]
52. loss = 0.578387
595it [00:00, 1446.74it/s]
53. loss = 0.550301
595it [00:00, 1455.22it/s]
54. loss = 0.565554
595it [00:00, 1444.62it/s]
55. loss = 0.543771
595it [00:00, 1444.37it/s]
56. loss = 0.523524
595it [00:00, 1445.11it/s]
57. loss = 0.518379
595it [00:00, 1443.76it/s]
58. loss = 0.513059
```

595it [00:00, 1421.64it/s]

59. loss = 0.502928

595it [00:00, 1418.87it/s]

60. loss = 0.491748

595it [00:00, 1439.60it/s]

61. loss = 0.467623

595it [00:00, 1448.35it/s]

62. loss = 0.468435

595it [00:00, 1445.42it/s]

63. loss = 0.464246

595it [00:00, 1454.25it/s]

64. loss = 0.463490

595it [00:00, 1430.42it/s]

65. loss = 0.457314

595it [00:00, 1443.28it/s]

66. loss = 0.452185

595it [00:00, 1447.23it/s]

67. loss = 0.443755

595it [00:00, 1445.28it/s]

68. loss = 0.435647

595it [00:00, 1443.48it/s]

69. loss = 0.428068

595it [00:00, 1439.03it/s]

70. loss = 0.420788

595it [00:00, 1445.48it/s]

71. loss = 0.413721

595it [00:00, 1460.20it/s]

72. loss = 0.406513

595it [00:00, 1442.77it/s]

73. loss = 0.399040

595it [00:00, 1444.97it/s]

74. loss = 0.391951

595it [00:00, 1456.72it/s]

75. loss = 0.385554

595it [00:00, 1435.00it/s]

76. loss = 0.379742

595it [00:00, 1443.46it/s]

77. loss = 0.374996

595it [00:00, 1442.53it/s]

78. loss = 0.370609

```
595it [00:00, 1447.55it/s]
79. loss = 0.365966
595it [00:00, 1453.33it/s]
80. loss = 0.360876
595it [00:00, 1452.74it/s]
81. loss = 0.355497
595it [00:00, 1449.91it/s]
82. loss = 0.350227
595it [00:00, 1443.28it/s]
83. loss = 0.345443
595it [00:00, 1444.66it/s]
84. loss = 0.341321
595it [00:00, 1446.64it/s]
85. loss = 0.337837
595it [00:00, 1438.12it/s]
86. loss = 0.334837
595it [00:00, 1449.28it/s]
87. loss = 0.332063
595it [00:00, 1439.30it/s]
88. loss = 0.329220
595it [00:00, 1436.29it/s]
89. loss = 0.326131
595it [00:00, 1444.49it/s]
90. loss = 0.322838
595it [00:00, 1434.00it/s]
91. loss = 0.319631
595it [00:00, 1442.76it/s]
92. loss = 0.316743
595it [00:00, 1460.20it/s]
93. loss = 0.314088
595it [00:00, 1436.77it/s]
94. loss = 0.311299
595it [00:00, 1445.40it/s]
95. loss = 0.308181
595it [00:00, 1450.96it/s]
96. loss = 0.305032
595it [00:00, 1435.49it/s]
97. loss = 0.302472
595it [00:00, 1443.16it/s]
98. loss = 0.300764
```

```
595it [00:00, 1435.95it/s]
99. loss = 0.299122
595it [00:00, 1452.89it/s]
100. loss = 0.296436
595it [00:00, 1444.63it/s]
101. loss = 0.292136
595it [00:00, 1457.32it/s]
102. loss = 0.286436
595it [00:00, 1429.67it/s]
103. loss = 0.280150
595it [00:00, 1466.51it/s]
104. loss = 0.274600
595it [00:00, 1440.94it/s]
105. loss = 0.271094
595it [00:00, 1449.17it/s]
106. loss = 0.270220
595it [00:00, 1418.54it/s]
107. loss = 0.270262
595it [00:00, 1421.41it/s]
108. loss = 0.272679
595it [00:00, 1448.58it/s]
109. loss = 0.288829
595it [00:00, 1443.60it/s]
110. loss = 0.329095
595it [00:00, 1458.83it/s]
111. loss = 0.344066
595it [00:00, 1443.43it/s]
112. loss = 0.314018
595it [00:00, 1445.94it/s]
113. loss = 0.276153
595it [00:00, 1450.25it/s]
114. loss = 0.266861
595it [00:00, 1429.88it/s]
115. loss = 0.264573
595it [00:00, 1444.16it/s]
116. loss = 0.268092
595it [00:00, 1444.08it/s]
117. loss = 0.270422
595it [00:00, 1452.56it/s]
118. loss = 0.273680
```

595it [00:00, 1459.77it/s]

119. loss = 0.274282

595it [00:00, 1460.22it/s]

120. loss = 0.274388

595it [00:00, 1442.16it/s]

121. loss = 0.268124

595it [00:00, 1422.87it/s]

122. loss = 0.269410

595it [00:00, 1447.09it/s]

123. loss = 0.266370

595it [00:00, 1431.41it/s]

124. loss = 0.271464

595it [00:00, 1447.04it/s]

125. loss = 0.258507

595it [00:00, 1440.38it/s]

126. loss = 0.268037

595it [00:00, 1453.06it/s]

127. loss = 0.246643

595it [00:00, 1439.86it/s]

128. loss = 0.257732

595it [00:00, 1455.71it/s]

129. loss = 0.232777

595it [00:00, 1440.06it/s]

130. loss = 0.243915

595it [00:00, 1452.50it/s]

131. loss = 0.217265

595it [00:00, 1442.16it/s]

132. loss = 0.235778

595it [00:00, 1444.10it/s]

133. loss = 0.209310

595it [00:00, 1442.49it/s]

134. loss = 0.243735

595it [00:00, 1439.87it/s]

135. loss = 0.207337

595it [00:00, 1445.69it/s]

136. loss = 0.238532

595it [00:00, 1447.73it/s]

137. loss = 0.209820

595it [00:00, 1451.35it/s]

138. loss = 0.237038

595it [00:00, 1448.28it/s]

139. loss = 0.205297

595it [00:00, 1430.05it/s]

140. loss = 0.228404

595it [00:00, 1441.02it/s]

141. loss = 0.211902

595it [00:00, 1438.17it/s]

142. loss = 0.228456

595it [00:00, 1449.70it/s]

143. loss = 0.204086

595it [00:00, 1452.28it/s]

144. loss = 0.215419

595it [00:00, 1442.89it/s]

145. loss = 0.219498

595it [00:00, 1447.61it/s]

146. loss = 0.214190

595it [00:00, 1443.13it/s]

147. loss = 0.206538

595it [00:00, 1447.95it/s]

148. loss = 0.208043

595it [00:00, 1444.48it/s]

149. loss = 0.207606

595it [00:00, 1431.88it/s]

150. loss = 0.208671

595it [00:00, 1455.74it/s]

151. loss = 0.205331

595it [00:00, 1449.14it/s]

152. loss = 0.206893

595it [00:00, 1430.21it/s]

153. loss = 0.202990

595it [00:00, 1433.32it/s]

154. loss = 0.207107

595it [00:00, 1436.53it/s]

155. loss = 0.196437

595it [00:00, 1422.53it/s]

156. loss = 0.211698

595it [00:00, 1421.73it/s]

157. loss = 0.191082

595it [00:00, 1436.48it/s]

158. loss = 0.214614

595it [00:00, 1447.19it/s]

159. loss = 0.193516

595it [00:00, 1436.62it/s]

160. loss = 0.218641

595it [00:00, 1445.67it/s]

161. loss = 0.191112

595it [00:00, 1447.23it/s]

162. loss = 0.211363

595it [00:00, 1442.54it/s]

163. loss = 0.203206

595it [00:00, 1452.69it/s]

164. loss = 0.197787

595it [00:00, 1437.03it/s]

165. loss = 0.198272

595it [00:00, 1448.67it/s]

166. loss = 0.192917

595it [00:00, 1445.48it/s]

167. loss = 0.205881

595it [00:00, 1450.68it/s]

168. loss = 0.187253

595it [00:00, 1437.48it/s]

169. loss = 0.213052

595it [00:00, 1448.56it/s]

170. loss = 0.188132

595it [00:00, 1444.57it/s]

171. loss = 0.213710

595it [00:00, 1450.59it/s]

172. loss = 0.188331

595it [00:00, 1454.68it/s]

173. loss = 0.209259

595it [00:00, 1458.37it/s]

174. loss = 0.188208

595it [00:00, 1441.17it/s]

175. loss = 0.211784

595it [00:00, 1448.82it/s]

176. loss = 0.188130

595it [00:00, 1447.74it/s]

177. loss = 0.206827

595it [00:00, 1440.70it/s]

178. loss = 0.188124

595it [00:00, 1446.90it/s]

179. loss = 0.210105

595it [00:00, 1444.24it/s]

180. loss = 0.187953

595it [00:00, 1444.25it/s]

181. loss = 0.206255

595it [00:00, 1441.75it/s]

182. loss = 0.187681

595it [00:00, 1425.55it/s]

183. loss = 0.207856

595it [00:00, 1434.13it/s]

184. loss = 0.187910

595it [00:00, 1439.17it/s]

185. loss = 0.204547

595it [00:00, 1462.28it/s]

186. loss = 0.187847

595it [00:00, 1444.49it/s]

187. loss = 0.205093

595it [00:00, 1446.26it/s]

188. loss = 0.187989

595it [00:00, 1441.97it/s]

189. loss = 0.202763

595it [00:00, 1434.11it/s]

190. loss = 0.188210

595it [00:00, 1444.51it/s]

191. loss = 0.201781

595it [00:00, 1455.26it/s]

192. loss = 0.188466

595it [00:00, 1446.32it/s]

193. loss = 0.199997

595it [00:00, 1439.86it/s]

194. loss = 0.188809

595it [00:00, 1456.55it/s]

195. loss = 0.197154

595it [00:00, 1453.03it/s]

196. loss = 0.189057

595it [00:00, 1435.48it/s]

197. loss = 0.193807

595it [00:00, 1451.50it/s]

198. loss = 0.189796

```
595it [00:00, 1451.71it/s]
199. loss = 0.192564
595it [00:00, 1391.33it/s]
200. loss = 0.192022
```

In [198]:

```
model.eval()
```

Out[198]:

```
NARX(
  (deque1): TDL()
  (deque2): TDL()
)
```

In [199]:

```
#model.clear()
```

In [200]:

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

```
C:\Users\volch\AppData\Local\Temp\ipykernel_5012\2841970211.py:18: UserWarning: To copy c
onstruct from a tensor, it is recommended to use sourceTensor.clone().detach() or sourceT
ensor.clone().detach().requires_grad_(True), rather than torch.tensor(sourceTensor).
  self.deque2.push(torch.tensor(out2))
```

Выводим результаты

In [201]:

```
print('Время обучения = {0} секунд'.format(int(end_time - start_time)))
print('Количество эпох = {0}'.format(epochs))
```

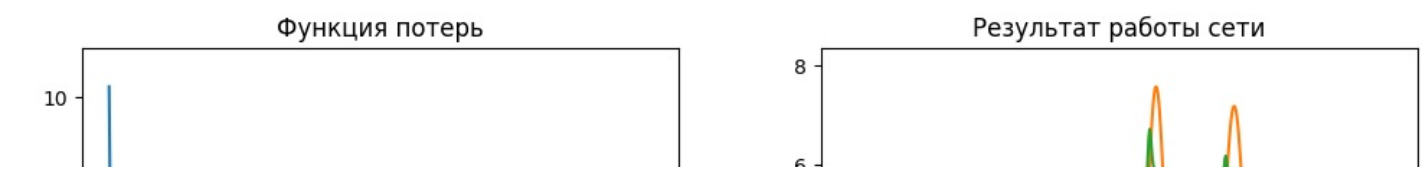
```
Время обучения = 82 секунд
Количество эпох = 200
```

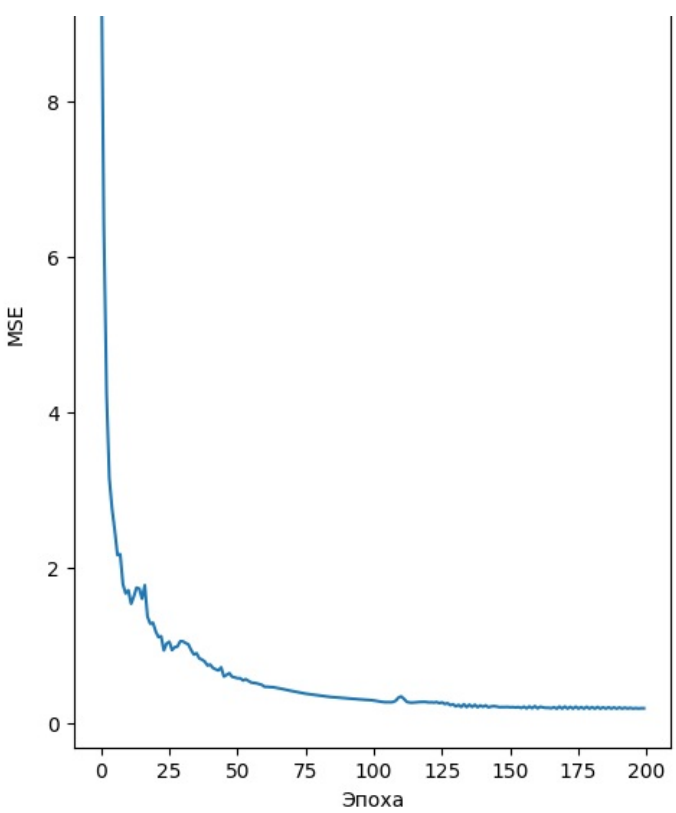
In [202]:

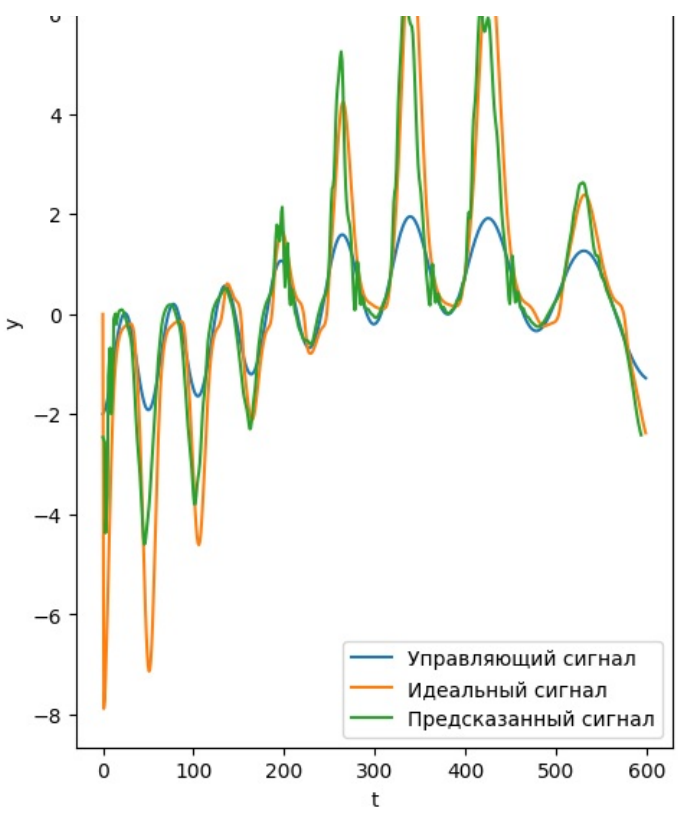
```
fig, axes = plt.subplots(1, 2, figsize=(10, 6.5))
fig.tight_layout(h_pad = 4, w_pad = 4)

axes[0].set_title('Функция потерь')
axes[0].set_xlabel('Эпоха')
axes[0].set_ylabel('MSE')
axes[0].plot(train_loss)

axes[1].set_title('Результат работы сети')
axes[1].set_xlabel('t')
axes[1].set_ylabel('y')
axes[1].plot(ut, label = 'Управляющий сигнал')
axes[1].plot(yt, label = 'Идеальный сигнал')
axes[1].plot(predicted, label = 'Предсказанный сигнал')
axes[1].legend()
```

Out[202]:

```
<matplotlib.legend.Legend at 0x1c4d52ae7d0>
```




MSE
Эпоха
0
2
4
6
8
0
25
50
75
100
125
150
175
200


y
t
Управляющий сигнал
Идеальный сигнал
Предсказанный сигнал
−8
−6
−4
−2
0
2
4
0
100
200
300
400
500
600