

Реалізація

Обчислення, наведені в теоретичних відомостях, було реалізовано мовою С. Також було створено допоміжний скрипт мовою Python для генерації навчальних прикладів.

Посилання на репозиторій (код програм, датасети): <https://github.com/Bohdan628318ylypchenko/MLDL-Lab1.git>

```
PS J:\repos\MLDL\Lab1\x64\Release> .\Neuron.exe
x0 = 0.200000, x1 = 0.700000, x_shift = 1.000000
Iteration 0 | w0 = 0.900000, w1 = 0.100000, w_shift = 0.400000 | ya = 0.657010
Iteration 1 | w0 = 0.908085, w1 = 0.128296, w_shift = 0.440423 | ya = 0.670809
Iteration 2 | w0 = 0.916169, w1 = 0.156592, w_shift = 0.480845 | ya = 0.684319
Iteration 3 | w0 = 0.924254, w1 = 0.184887, w_shift = 0.521268 | ya = 0.697525
Iteration 4 | w0 = 0.932338, w1 = 0.213183, w_shift = 0.561690 | ya = 0.710412
Iteration 5 | w0 = 0.940423, w1 = 0.241479, w_shift = 0.602113 | ya = 0.722968
Iteration 6 | w0 = 0.948507, w1 = 0.269775, w_shift = 0.642536 | ya = 0.735183
Iteration 7 | w0 = 0.956592, w1 = 0.298071, w_shift = 0.682958 | ya = 0.747047
Iteration 8 | w0 = 0.964676, w1 = 0.326367, w_shift = 0.723381 | ya = 0.758555
Iteration 9 | w0 = 0.972761, w1 = 0.354662, w_shift = 0.763803 | ya = 0.769700
Iteration 10 | w0 = 0.980845, w1 = 0.382958, w_shift = 0.804226 | ya = 0.780480
Iteration 11 | w0 = 0.988930, w1 = 0.411254, w_shift = 0.844649 | ya = 0.790892
Iteration 12 | w0 = 0.997014, w1 = 0.439550, w_shift = 0.885071 | ya = 0.800937
Iteration 13 | w0 = 1.005099, w1 = 0.467846, w_shift = 0.925494 | ya = 0.810614
Iteration 14 | w0 = 1.013183, w1 = 0.496142, w_shift = 0.965916 | ya = 0.819927
Iteration 15 | w0 = 1.021268, w1 = 0.524437, w_shift = 1.006339 | ya = 0.828878
Iteration 16 | w0 = 1.029352, w1 = 0.552733, w_shift = 1.046762 | ya = 0.837473
Iteration 17 | w0 = 1.037437, w1 = 0.581029, w_shift = 1.087184 | ya = 0.845716
Iteration 18 | w0 = 1.045521, w1 = 0.609325, w_shift = 1.127607 | ya = 0.853615
Iteration 19 | w0 = 1.053606, w1 = 0.637621, w_shift = 1.168029 | ya = 0.861175
Iteration 20 | w0 = 1.061690, w1 = 0.665916, w_shift = 1.208452 | ya = 0.868405
Iteration 21 | w0 = 1.069775, w1 = 0.694212, w_shift = 1.248875 | ya = 0.875313
Iteration 22 | w0 = 1.077859, w1 = 0.722508, w_shift = 1.289297 | ya = 0.881908
Iteration 23 | w0 = 1.085944, w1 = 0.750804, w_shift = 1.329720 | ya = 0.888199
Iteration 24 | w0 = 1.094029, w1 = 0.779100, w_shift = 1.370143 | ya = 0.894194
Iteration 25 | w0 = 1.102113, w1 = 0.807396, w_shift = 1.410565 | ya = 0.899905
PS J:\repos\MLDL\Lab1\x64\Release>
```

Навчання мережі-нейрону на єдиному прикладі (x0=0.2, x1=0.7)
Мережа досягла похибки 0.001 за 25 ітерації з параметрами lambda = 1, alpha = 0.05
Остаточні вагові коефіцієнти:
W0 = 1.10213 | W1 = 0.807396 | W_Shift = 1.410565
Початкові вагові коефіцієнти:
W0 = 0.9 | W1 = 0.1 | W_Shift = 0.4

```
PS J:\repos\MLDL\Lab1\x64\Release> .\NN231.exe
Usage:
[n]ew;
[t]rain a l example-path epoch-count;
[v]alidate example-path;
[s]ave path;
[l]oad path;
[p]rint;
[r]un x1 x2;
[u]sage;
[e]xit;
Command: n
Command: p
l = 1.0000; a = 0.1000;
w12:
| 0.1000 | 0.1000 | 0.1000 |
| 0.1000 | 0.1000 | 0.1000 |
| 0.1000 | 0.1000 | 0.1000 |
w23:
| 0.1000 | 0.1000 | 0.1000 | 0.1000 |
Command: v examples2.txt
oa = 0.564342; ot = 0.174900
oa = 0.565400; ot = 0.751900
error = 0.186447
Command: t 1 4 examples2.txt 100
Command: p
l = 4.0000; a = 1.0000;
w12:
| -0.8983 | -0.8983 | -0.8983 |
| -0.1581 | -0.1581 | -0.1581 |
| 0.0460 | 0.0460 | 0.0460 |
w23:
| -0.7563 | -0.7563 | -0.7563 | 0.5185 |
Command: v examples2.txt
oa = 0.174901; ot = 0.174900
oa = 0.751900; ot = 0.751900
error = 0.000000
Command: s examples2-learned.nn
Command: e
PS J:\repos\MLDL\Lab1\x64\Release>
```

Навчання мережі 2-3-1 на датасеті examples2.txt (2 приклади).

```
PS J:\repos\MLDL\Lab1\x64\Release> .\NN231.exe
Usage:
[n]ew;
[t]rain a l example-path epoch-count;
[v]alidate example-path;
[s]ave path;
[l]oad path;
[p]rint;
[r]un x1 x2;
[u]sage;
[e]xit;
Command: l examples100-trained.nn
Command: p
l = 2.0000; a = 2.0000;
w12:
| 1.1734 | 1.1734 | 1.1734 |
| 1.1288 | 1.1288 | 1.1288 |
| -1.2425 | -1.2425 | -1.2425 |
w23:
| 2.0146 | 2.0146 | 2.0146 | -1.2944 |
Command: v examples100.txt
```

```
oa = 0.785319; ot = 0.747400
oa = 0.239995; ot = 0.209300
oa = 0.898389; ot = 0.888300
oa = 0.768722; ot = 0.728700
oa = 0.847976; ot = 0.818000
oa = 0.625345; ot = 0.619600
oa = 0.890756; ot = 0.868000
error = 0.709704
average_error = 0.000710
```

$$coverage\ error = \left(\sum_{i=1}^{example_count} (o_i - o_i^*)^2 \right) / example_count$$

```
PS J:\repos\MLDL\Lab1\x64\Release> .\NN231.exe
Usage:
[n]ew;
[t]rain a l example-path epoch-count;
[v]alidate example-path;
[s]ave path;
[l]oad path;
[p]rint;
[r]un x1 x2;
[u]sage;
[e]xit;
Command: n
Command: p
l = 1.0000; a = 0.1000;
w12:
| 0.1000 | 0.1000 | 0.1000 |
| 0.1000 | 0.1000 | 0.1000 |
| 0.1000 | 0.1000 | 0.1000 |
w23:
| 0.1000 | 0.1000 | 0.1000 | 0.1000 |
Command: t 2 2 examples100.txt 5000
Command: v examples2.txt
oa = 0.224212; ot = 0.174900
oa = 0.721838; ot = 0.751900
error = 0.004027
Command: v examples100.txt
oa = 0.255825; ot = 0.241600
oa = 0.698727; ot = 0.681800
oa = 0.937071; ot = 0.966300
oa = 0.825084; ot = 0.785100
oa = 0.339915; ot = 0.358300
oa = 0.895158; ot = 0.905100
oa = 0.428279; ot = 0.450500
oa = 0.852852; ot = 0.826800
oa = 0.573037; ot = 0.565800
oa = 0.933016; ot = 0.959400
oa = 0.364517; ot = 0.385500
oa = 0.417787; ot = 0.432100
oa = 0.276596; ot = 0.266600
oa = 0.840169; ot = 0.805900
oa = 0.920098; ot = 0.938500
oa = 0.751951; ot = 0.710900
oa = 0.833323; ot = 0.801000
oa = 0.808864; ot = 0.789700
oa = 0.940257; ot = 0.972200
oa = 0.629626; ot = 0.631900
oa = 0.564007; ot = 0.560400
oa = 0.838031; ot = 0.796000
oa = 0.701951; ot = 0.671500
oa = 0.923312; ot = 0.933200
oa = 0.746713; ot = 0.715800
oa = 0.542394; ot = 0.547700
oa = 0.924862; ot = 0.941000
oa = 0.884941; ot = 0.884200
oa = 0.838833; ot = 0.812600
oa = 0.893520; ot = 0.870500
oa = 0.930405; ot = 0.949200
oa = 0.645329; ot = 0.636800
oa = 0.812338; ot = 0.785900
oa = 0.820195; ot = 0.777900
oa = 0.255152; ot = 0.235200
oa = 0.853108; ot = 0.844200
oa = 0.369517; ot = 0.385300
oa = 0.453891; ot = 0.473700
oa = 0.558886; ot = 0.571100
oa = 0.288356; ot = 0.290300
oa = 0.605635; ot = 0.611700
oa = 0.646359; ot = 0.624300
oa = 0.489536; ot = 0.513500
oa = 0.408918; ot = 0.424500
oa = 0.941663; ot = 0.970200
oa = 0.866503; ot = 0.845700
oa = 0.790077; ot = 0.761200
oa = 0.726966; ot = 0.705800
oa = 0.255762; ot = 0.239000
oa = 0.351962; ot = 0.370900
oa = 0.823048; ot = 0.808400
oa = 0.837929; ot = 0.813700
oa = 0.484255; ot = 0.509100
oa = 0.478233; ot = 0.503000
oa = 0.554537; ot = 0.553600
oa = 0.909155; ot = 0.922700
oa = 0.422471; ot = 0.441700
oa = 0.489384; ot = 0.507600
oa = 0.585302; ot = 0.583900
oa = 0.416572; ot = 0.436200
oa = 0.943739; ot = 0.997600
oa = 0.658655; ot = 0.650000
oa = 0.818678; ot = 0.778000
oa = 0.805133; ot = 0.767600
oa = 0.917606; ot = 0.911000
oa = 0.944328; ot = 0.983400
oa = 0.196579; ot = 0.114700
oa = 0.777249; ot = 0.737100
oa = 0.470080; ot = 0.492100
oa = 0.609126; ot = 0.604500
oa = 0.902361; ot = 0.902400
oa = 0.478039; ot = 0.489500
oa = 0.885459; ot = 0.880100
oa = 0.678544; ot = 0.662000
oa = 0.476832; ot = 0.488600
oa = 0.720659; ot = 0.694400
oa = 0.278224; ot = 0.278900
oa = 0.796841; ot = 0.773200
oa = 0.396525; ot = 0.412200
oa = 0.400869; ot = 0.431600
oa = 0.662659; ot = 0.645800
oa = 0.868025; ot = 0.859200
oa = 0.937996; ot = 0.978400
oa = 0.816928; ot = 0.780000
oa = 0.253956; ot = 0.236400
oa = 0.164920; ot = 0.018200
oa = 0.670622; ot = 0.650900
oa = 0.479737; ot = 0.497900
oa = 0.923031; ot = 0.945800
oa = 0.824475; ot = 0.808300
oa = 0.827163; ot = 0.796600
oa = 0.644453; ot = 0.623600
oa = 0.916554; ot = 0.919900
oa = 0.559305; ot = 0.568500
oa = 0.300073; ot = 0.305600
oa = 0.557101; ot = 0.553000
oa = 0.935792; ot = 0.981100
oa = 0.914030; ot = 0.924300
oa = 0.757533; ot = 0.740500
oa = 0.948061; ot = 0.996600
error = 0.081400
Command: p
l = 2.0000; a = 2.0000;
w12:
| 1.1734 | 1.1734 | 1.1734 |
| 1.1288 | 1.1288 | 1.1288 |
| -1.2425 | -1.2425 | -1.2425 |
w23:
| 2.0146 | 2.0146 | 2.0146 | -1.2944 |
Command: s examples100-trained.nn
Command: e
PS J:\repos\MLDL\Lab1\x64\Release>
```

Валідація мережі на examples2.txt (не вносить в навчальну вибірку)

Валідація мережі
Похибка суттєва

Навчаємо мережу

Мережа після навчання

Похибка майже 0, мережа перенавчилась

Валідація на навчальній вибірці

Навчана мережа

Навчання мережі 2-3-1 на датасеті examples100.txt (100 прикладів)