Title: Design and implementation of a system for classifying two-dimensional, nonlinearly separable data with the use of artificial neural network.

Goal: The aim of the project is to construct a classifier of two-dimensional, nonlinearly separable data, using an artificial neural network (the so-called multilayer perceptron) and to conduct tests of the system's operating.

Project:

Ad. 1. Creation of two primary datasets: training and test datasets.

Table 1. The primary learning dataset (158 data samples):

	x1, x2	Class
0	[-2.0, -0.0377358490566042]	0.0
1	[-2.98461538461539, 2.0]	0.0
2	[-1.93846153846154, 3.9622641509434]	0.0
3	[0.0307692307692289, 5.09433962264151]	0.0
4	[2.0, 5.92452830188679]	0.0
5	[4.09230769230769, 5.09433962264151]	0.0
6	[6.06153846153846, 4.11320754716981]	0.0
7	[7.16923076923077, 2.07547169811321]	0.0
8	[7.96923076923077, 0.0377358490566042]	0.0
9	[8.27692307692307, -2.0]	0.0
10	[7.78461538461538, -3.88679245283019]	0.0
11	[6.86153846153846, -6.0]	0.0
12	[5.87692307692308, -7.81132075471698]	0.0
13	[4.15384615384615, -9.16981132075472]	0.0
14	[2.06153846153846, -10.0754716981132]	0.0
15	[-0.0307692307692324, 1.74254182983268]	1.0
16	[2.0, 3.1061587753649]	1.0
17	[4.21538461538461, 1.8940548237807]	1.0
18	[5.38461538461538, 0.151655393378427]	1.0
19	[5.87692307692308, -1.8937700249199]	1.0
20	[5.38461538461538, -4.3937344250623]	1.0
21	[4.03076923076923, -5.90886436454254]	1.0
22	[2.18461538461538, -6.81794232823069]	1.0
23	[0.0307692307692289, -7.87853328586686]	1.0
24	[-2.12307692307692, -8.03004627981488]	1.0
25	[-4.03076923076923, -7.4997508009968]	1.0
26	[-6.06153846153846, -7.04521181915272]	1.0
27	[-7.78461538461539, -5.83310786756853]	1.0
28	[-9.01538461538462, -4.01495194019224]	1.0
29	[-9.87692307692308, -2.19679601281595]	1.0
30	[1.93846153846154, -0.0756140975436104]	2.0
31	[3.04615384615384, -1.96952652189391]	2.0
32	[1.93846153846154, -4.09070843716625]	2.0
33	[-0.0307692307692324, -5.37856888572446]	2.0
34	[-1.87692307692308, -5.90886436454254]	2.0
35	[-4.03076923076923, -5.30281238875045]	2.0
36	[-6.0, -3.86343894624422]	2.0
37	[-7.23076923076923, -1.96952652189391]	2.0
38	[-8.09230769230769, 0.000142399430401952]	2.0
39	[-8.33846153846154, 2.12132431470274]	2.0

	x1, x2	Class
40	[-7.72307692307692, 4.31826272694909]	2.0
41	[-6.92307692307692, 6.59095763616946]	2.0
42	[-5.93846153846154, 8.1060875756497]	2.0
43	[-4.03076923076923, 9.16667853328587]	2.0
44	[-2.06153846153846, 9.77273050907796]	2.0
45	[0.0307692307692289, -2.04528301886793]	3.0
46	[-2.0, -3.18163047347811]	3.0
47	[-3.90769230769231, -1.96952652189391]	3.0
48	[-5.32307692307692, -0.0756140975436104]	3.0
49	[-6.0, 1.81829832680669]	3.0
50	[-5.50769230769231, 3.93948024207903]	3.0
51	[-4.15384615384616, 5.90914916340335]	3.0
52	[-2.0, 7.57579209683161]	3.0
53	[0.0307692307692289, 7.95457458170167]	3.0
54	[2.12307692307692, 8.40911356354574]	3.0
55	[4.15384615384615, 7.95457458170167]	3.0
56	[6.0, 7.27276610893556]	3.0
57	[7.84615384615384, 6.21217515129939]	3.0
58	[9.2, 4.01523673905304]	3.0
59	[10.0, 1.74254182983268]	3.0

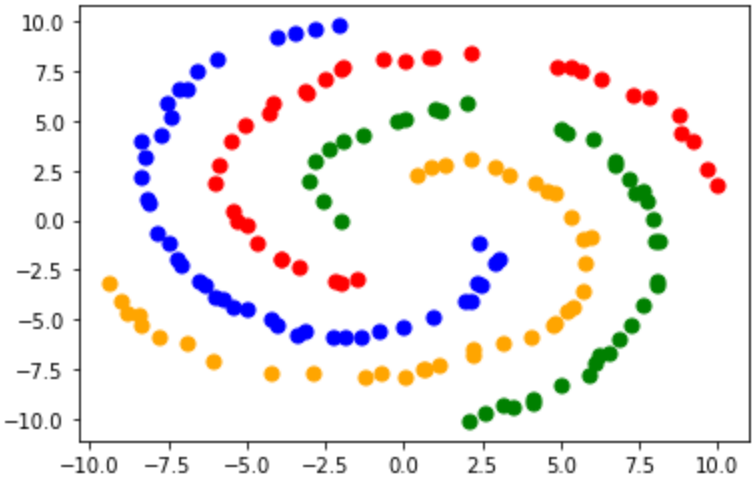


Fig. 1. Graphical representation of the primary learning dataset of Table 1

Table 2. The primary test dataset (78 data samples):

	x1, x2	Class
0	[6.12307692307692, 3.1061587753649]	0.0
1	[7.23076923076923, -4.9997864008544]	0.0
2	[-2.67692307692308, 2.65161979352083]	0.0
3	[8.27692307692307, -2.0]	0.0
4	[5.2, -8.33307226771093]	0.0
5	[7.78461538461538, -3.88679245283019]	0.0
6	[3.10769230769231, -9.46941972232111]	0.0
7	[3.04615384615384, 5.83339266642933]	0.0
8	[4.58461538461538, -8.56034175863297]	0.0
9	[2.3076923076923, 5.75763616945532]	0.0
10	[-2.61538461538462, 0.757707369170523]	0.0
11	[5.69230769230769, -7.80277678889284]	0.0
12	[-1.2, 4.3940192239231]	0.0
13	[7.78461538461538, 0.378924884300462]	0.0
14	[3.35384615384615, 5.37885368458526]	0.0
15	[4.64615384615384, 4.69704521181915]	0.0
16	[8.09230769230769, -2.12103951584194]	0.0
17	[6.86153846153846, -5.90886436454254]	0.0
18	[4.09230769230769, 5.09433962264151]	0.0
19	[-3.10769230769231, -7.87853328586686]	1.0
20	[2.73846153846154, 2.80313278746885]	1.0
21	[-0.0307692307692324, 1.74254182983268]	1.0

22	[5.87692307692308, -1.8937700249199]	1.0
23	[-6.18461538461539, -6.81794232823069]	1.0
24	[-2.12307692307692, -8.03004627981488]	1.0
25	[4.03076923076923, 1.96981132075472]	1.0
26	[-5.2, -7.04521181915272]	1.0
27	[-4.03076923076923, -7.4997508009968]	1.0
28	[5.38461538461538, 0.151655393378427]	1.0
29	[2.0, 3.1061587753649]	1.0
30	[2.92307692307692, -6.36340334638661]	1.0
31	[-9.38461538461539, -3.40889996440014]	1.0
32	[-2.12307692307692, -7.87853328586686]	1.0
33	[5.07692307692307, 0.757707369170523]	1.0
34	[5.69230769230769, -3.03011747953008]	1.0
35	[3.96923076923077, -5.75735137059452]	1.0
36	[-5.2, -7.19672481310075]	1.0
37	[-7.10769230769231, -6.51491634033464]	1.0
38	[-9.87692307692308, -2.19679601281595]	1.0
39	[-7.35384615384615, -5.75735137059452]	1.0
40	[-0.0923076923076938, -5.60583837664649]	2.0
41	[1.93846153846154, -0.0756140975436104]	2.0
42	[-2.67692307692308, 9.69697401210395]	2.0
43	[-4.21538461538462, 9.09092203631185]	2.0
44	[-8.27692307692308, 3.1061587753649]	2.0
45	[1.2, -4.92402990388038]	2.0
46	[-0.76923076923077, -5.83310786756853]	2.0
47	[1.69230769230769, -4.46949092203631]	2.0
48	[-5.50769230769231, 8.18184407262371]	2.0
49	[-7.6, -0.984692061231755]	2.0
50	[-5.07692307692308, 8.78789604841581]	2.0
51	[-8.09230769230769, 0.000142399430401952]	2.0
52	[-6.43076923076923, 7.27276610893556]	2.0
53	[0.646153846153844, -5.07554289782841]	2.0
54	[2.49230769230769, -0.757422570309719]	2.0
55	[-7.90769230769231, 4.92431470274119]	2.0
56	[-0.830769230769233, 7.57579209683161]	3.0
57	[-0.584615384615386, -2.80284798860805]	3.0
58	[-5.81538461538462, 2.87888928444286]	3.0
59	[4.15384615384615, 7.95457458170167]	3.0
60	[-0.707692307692309, -2.65133499466002]	3.0
61	[-4.89230769230769, 4.54553221787113]	3.0
62	[-5.75384615384615, 0.833463866144536]	3.0
63	[-4.33846153846154, -1.2877180491278]	3.0
64	[0.0307692307692289, -2.04528301886793]	3.0
65	[1.56923076923077, 8.18184407262371]	3.0
66	[-3.72307692307692, 6.06066215735137]	3.0
67	[8.15384615384615, 5.53036667853329]	3.0
68	[-5.44615384615385, 4.31826272694909]	3.0
69	[-5.75384615384615, 3.56069775720897]	3.0
70	[3.35384615384615, 7.95457458170167]	3.0
71	[-5.87692307692308, 1.59102883588466]	3.0
72	[7.10769230769231, 6.81822712709149]	3.0
73	[3.78461538461538, 7.87881808472766]	3.0
74	[2.73846153846154, 8.18184407262371]	3.0
75	[-3.04615384615385, -2.80284798860805]	3.0
76	[6.0, 7.27276610893556]	3.0
77	[-3.04615384615385, -2.95436098255607]	3.0

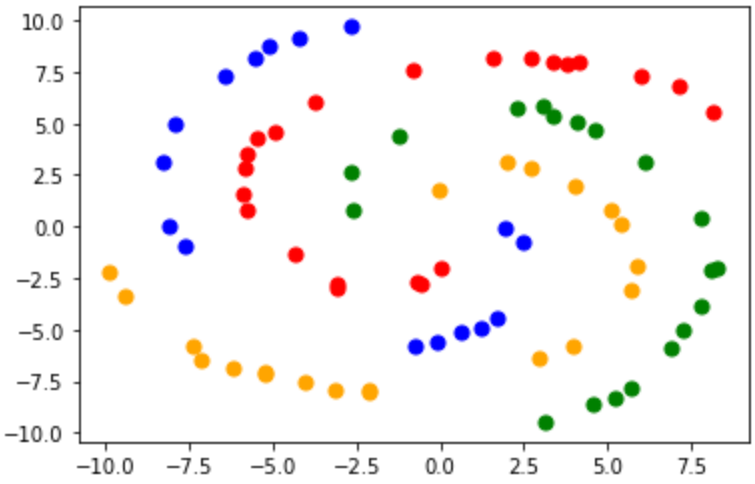


Fig. 2. Graphical representation of the primary test dataset of Table 2

Ad. 2. Process of data preprocessing of primary datasets into numerical datasets.

Table 3. The primary and numerical learning datasets - a variant without data scaling:

	x1	x2	Class	y1	y2	y3	y4
0	1.200000	5.454610	0.0	1	0	0	0
27	7.600000	-4.242221	0.0	1	0	0	0
117	8.092308	-3.030117	0.0	1	0	0	0
61	5.200000	4.394019	0.0	1	0	0	0
110	-1.261538	4.242506	0.0	1	0	0	0
34	4.153846	-9.014881	0.0	1	0	0	0
105	7.353846	1.363759	0.0	1	0	0	0
99	4.153846	-9.169811	0.0	1	0	0	0
98	7.969231	0.037736	0.0	1	0	0	0
40	-2.800000	2.954646	0.0	1	0	0	0
97	7.784615	0.984977	0.0	1	0	0	0
26	-1.938462	3.962264	0.0	1	0	0	0
94	5.015385	-8.257316	0.0	1	0	0	0
46	6.861538	-6.000000	0.0	1	0	0	0
89	6.553846	-6.666429	0.0	1	0	0	0
48	1.015385	5.606123	0.0	1	0	0	0
49	6.061538	4.113208	0.0	1	0	0	0
85	-2.553846	0.984977	0.0	1	0	0	0
52	2.000000	5.924528	0.0	1	0	0	0
80	0.030769	5.094340	0.0	1	0	0	0
56	-2.369231	3.560698	0.0	1	0	0	0
71	6.123077	-7.196725	0.0	1	0	0	0
69	3.169231	-9.317907	0.0	1	0	0	0
91	7.169231	2.075472	0.0	1	0	0	0
25	-2.000000	-0.037736	0.0	1	0	0	0
63	-0.215385	5.000071	0.0	1	0	0	0
123	3.476923	-9.393663	0.0	1	0	0	0
151	8.153846	-1.060449	0.0	1	0	0	0
5	5.876923	-7.811321	0.0	1	0	0	0
13	5.015385	4.621289	0.0	1	0	0	0
14	6.738462	2.954646	0.0	1	0	0	0
15	8.092308	-3.257387	0.0	1	0	0	0
152	6.738462	2.803133	0.0	1	0	0	0
143	2.615385	-9.696689	0.0	1	0	0	0
135	-2.984615	2.000000	0.0	1	0	0	0
145	8.030769	-1.060449	0.0	1	0	0	0
19	7.230769	-5.302812	0.0	1	0	0	0
129	7.600000	1.439516	0.0	1	0	0	0
154	2.061538	-10.075472	0.0	1	0	0	0
130	6.246154	-6.742186	0.0	1	0	0	0

153	2.184615	-6.514916	1.0	0	1	0	0
79	-6.923077	-6.136134	1.0	0	1	0	0
73	4.830769	1.363759	1.0	0	1	0	0
155	2.123077	3.106159	1.0	0	1	0	0
81	3.169231	-6.136134	1.0	0	1	0	0
68	0.030769	-7.878533	1.0	0	1	0	0
150	5.384615	-4.393734	1.0	0	1	0	0
75	3.353846	2.272837	1.0	0	1	0	0
92	-4.215385	-7.651264	1.0	0	1	0	0
142	-8.830769	-4.621004	1.0	0	1	0	0
119	-9.384615	-3.105874	1.0	0	1	0	0
93	1.323077	2.727376	1.0	0	1	0	0
141	5.692308	-0.984692	1.0	0	1	0	0
140	4.830769	-5.151299	1.0	0	1	0	0
101	1.138462	-7.272481	1.0	0	1	0	0
103	4.215385	1.894055	1.0	0	1	0	0
106	-8.400000	-4.772517	1.0	0	1	0	0
114	0.892308	2.651620	1.0	0	1	0	0
116	2.923077	2.651620	1.0	0	1	0	0
126	-2.861538	-7.651264	1.0	0	1	0	0
124	4.030769	-5.908864	1.0	0	1	0	0
144	-1.200000	-7.878533	1.0	0	1	0	0
112	-0.707692	-7.651264	1.0	0	1	0	0
157	5.200000	-4.545247	1.0	0	1	0	0
37	5.323077	0.151655	1.0	0	1	0	0
41	2.184615	-6.817942	1.0	0	1	0	0
2	4.769231	-5.302812	1.0	0	1	0	0
33	0.400000	2.272837	1.0	0	1	0	0
42	0.707692	-7.423994	1.0	0	1	0	0
7	-9.015385	-4.014952	1.0	0	1	0	0
17	5.692308	-3.560413	1.0	0	1	0	0
21	-6.061538	-7.045212	1.0	0	1	0	0
50	-7.784615	-5.833108	1.0	0	1	0	0
30	-8.338462	-5.227056	1.0	0	1	0	0
9	4.584615	1.439516	1.0	0	1	0	0
10	0.646154	-7.423994	1.0	0	1	0	0
29	5.753846	-2.196796	1.0	0	1	0	0
24	5.938462	-0.833179	1.0	0	1	0	0
20	-7.846154	-0.681666	2.0	0	0	1	0
31	-8.338462	3.939480	2.0	0	0	1	0
108	2.430769	-1.136205	2.0	0	0	1	0
107	-5.753846	-3.939195	2.0	0	0	1	0
109	-8.153846	1.060733	2.0	0	0	1	0
18	-7.538462	5.833393	2.0	0	0	1	0
64	-2.061538	9.772731	2.0	0	0	1	0
132	-7.230769	-1.969527	2.0	0	0	1	0
102	-3.415385	-5.757351	2.0	0	0	1	0
137	-3.476923	9.393948	2.0	0	0	1	0
138	-2.246154	-5.908864	2.0	0	0	1	0
16	-6.923077	6.590958	2.0	0	0	1	0
8	-5.938462	8.106088	2.0	0	0	1	0
146	-6.492308	-3.030117	2.0	0	0	1	0
147	0.953846	-4.848273	2.0	0	0	1	0
148	2.923077	-2.196796	2.0	0	0	1	0
6	-4.030769	-5.302812	2.0	0	0	1	0
4	3.046154	-1.969527	2.0	0	0	1	0
3	-8.092308	0.833464	2.0	0	0	1	0
1	-7.107692	-2.272553	2.0	0	0	1	0
131	-1.384615	-5.833108	2.0	0	0	1	0
134	-2.800000	9.621218	2.0	0	0	1	0
78	-6.553846	7.500036	2.0	0	0	1	0
38	-6.000000	-3.863439	2.0	0	0	1	0
65	-8.215385	3.181915	2.0	0	0	1	0
66	-7.723077	4.318263	2.0	0	0	1	0
67	2.123077	-4.014952	2.0	0	0	1	0
59	-3.169231	-5.605838	2.0	0	0	1	0

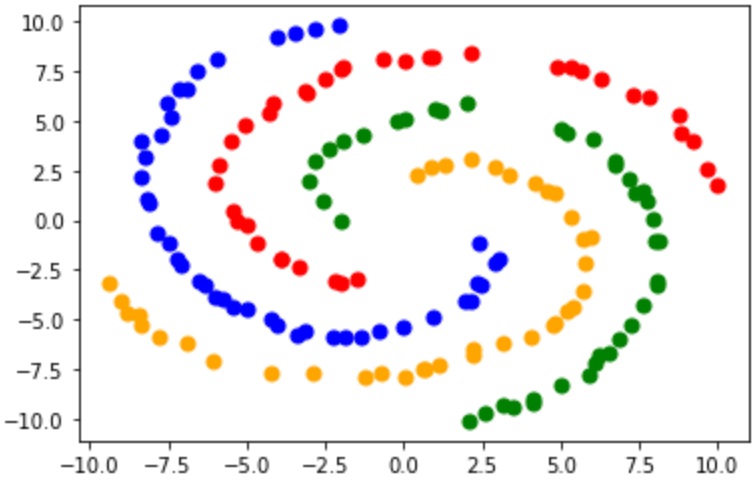
58	-0.769231	-5.605838	2.0	0	0	1	0
72	-8.338462	2.121324	2.0	0	0	1	0
57	-6.307692	-3.257387	2.0	0	0	1	0
77	-4.030769	9.166679	2.0	0	0	1	0
54	1.938462	-4.090708	2.0	0	0	1	0
53	2.369231	-3.105874	2.0	0	0	1	0
51	-7.169231	6.590958	2.0	0	0	1	0
83	-5.446154	-4.393734	2.0	0	0	1	0
84	-5.015385	-4.469491	2.0	0	0	1	0
86	-7.415385	5.227341	2.0	0	0	1	0
39	-7.476923	-1.136205	2.0	0	0	1	0
45	-0.030769	-5.378569	2.0	0	0	1	0
44	-4.215385	-4.999786	2.0	0	0	1	0
90	-1.876923	-5.908864	2.0	0	0	1	0
95	2.492308	-3.257387	2.0	0	0	1	0
47	0.953846	8.181844	3.0	0	0	0	1
12	-4.153846	5.909149	3.0	0	0	0	1
11	-5.446154	0.454681	3.0	0	0	0	1
76	7.292308	6.287932	3.0	0	0	0	1
55	-2.492308	7.121253	3.0	0	0	0	1
74	-3.907692	-1.969527	3.0	0	0	0	1
43	-2.184615	-3.030117	3.0	0	0	0	1
96	-4.646154	-1.136205	3.0	0	0	0	1
149	9.692308	2.575863	3.0	0	0	0	1
70	0.830769	8.181844	3.0	0	0	0	1
35	-4.276923	5.378854	3.0	0	0	0	1
60	6.307692	7.121253	3.0	0	0	0	1
104	-3.169231	6.515201	3.0	0	0	0	1
36	-3.907692	-1.969527	3.0	0	0	0	1
139	-1.507692	-2.954361	3.0	0	0	0	1
156	8.830769	4.394019	3.0	0	0	0	1
136	-2.000000	7.575792	3.0	0	0	0	1
115	4.892308	7.727305	3.0	0	0	0	1
28	-2.000000	-3.181630	3.0	0	0	0	1
118	5.323077	7.651549	3.0	0	0	0	1
88	-5.076923	4.772802	3.0	0	0	0	1
120	-0.646154	8.106088	3.0	0	0	0	1
121	9.200000	4.015237	3.0	0	0	0	1
122	-5.323077	-0.075614	3.0	0	0	0	1
23	5.630769	7.500036	3.0	0	0	0	1
22	-3.353846	-2.348309	3.0	0	0	0	1
125	7.846154	6.212175	3.0	0	0	0	1
87	-6.000000	1.818298	3.0	0	0	0	1
127	-5.876923	2.727376	3.0	0	0	0	1
128	-3.046154	6.363688	3.0	0	0	0	1
100	10.000000	1.742542	3.0	0	0	0	1
113	-5.507692	3.939480	3.0	0	0	0	1
82	0.030769	7.954575	3.0	0	0	0	1
133	-4.953846	-0.227127	3.0	0	0	0	1
111	2.123077	8.409114	3.0	0	0	0	1
62	8.769231	5.303097	3.0	0	0	0	1
32	-1.938462	7.651549	3.0	0	0	0	1

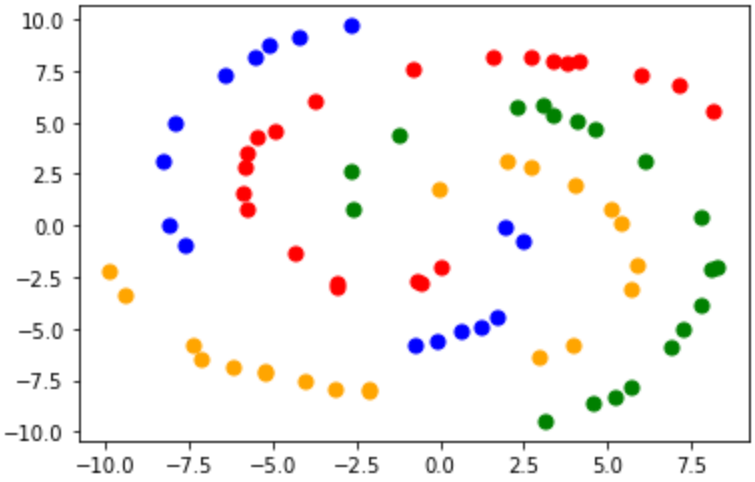
Table 4. The primary and numerical test datasets - a variant without data scaling:

	x1	x2	Class	y1	y2	y3	y4
0	6.123077	3.106159	0.0	1	0	0	0
43	-2.615385	0.757707	0.0	1	0	0	0
52	-1.200000	4.394019	0.0	1	0	0	0
57	7.784615	0.378925	0.0	1	0	0	0
31	2.307692	5.757636	0.0	1	0	0	0
28	4.584615	-8.560342	0.0	1	0	0	0
27	3.046154	5.833393	0.0	1	0	0	0
26	3.107692	-9.469420	0.0	1	0	0	0
21	7.784615	-3.886792	0.0	1	0	0	0

67	4.646154	4.697045	0.0	1	0	0	0
68	8.092308	-2.121040	0.0	1	0	0	0
12	5.200000	-8.333072	0.0	1	0	0	0
64	3.353846	5.378854	0.0	1	0	0	0
46	5.692308	-7.802777	0.0	1	0	0	0
1	7.230769	-4.999786	0.0	1	0	0	0
2	-2.676923	2.651620	0.0	1	0	0	0
72	6.861538	-5.908864	0.0	1	0	0	0
3	8.276923	-2.000000	0.0	1	0	0	0
73	4.092308	5.094340	0.0	1	0	0	0
44	2.923077	-6.363403	1.0	0	1	0	0
54	-2.123077	-7.878533	1.0	0	1	0	0
37	2.000000	3.106159	1.0	0	1	0	0
55	5.076923	0.757707	1.0	0	1	0	0
56	5.692308	-3.030117	1.0	0	1	0	0
59	3.969231	-5.757351	1.0	0	1	0	0
62	-5.200000	-7.196725	1.0	0	1	0	0
70	-7.353846	-5.757351	1.0	0	1	0	0
5	-3.107692	-7.878533	1.0	0	1	0	0
69	-9.876923	-2.196796	1.0	0	1	0	0
25	-4.030769	-7.499751	1.0	0	1	0	0
9	-0.030769	1.742542	1.0	0	1	0	0
16	5.876923	-1.893770	1.0	0	1	0	0
17	-6.184615	-6.817942	1.0	0	1	0	0
7	2.738462	2.803133	1.0	0	1	0	0
19	-2.123077	-8.030046	1.0	0	1	0	0
66	-7.107692	-6.514916	1.0	0	1	0	0
22	4.030769	1.969811	1.0	0	1	0	0
47	-9.384615	-3.408900	1.0	0	1	0	0
24	-5.200000	-7.045212	1.0	0	1	0	0
29	5.384615	0.151655	1.0	0	1	0	0
58	-8.092308	0.000142	2.0	0	0	1	0
53	-5.076923	8.787896	2.0	0	0	1	0
75	2.492308	-0.757423	2.0	0	0	1	0
49	-7.600000	-0.984692	2.0	0	0	1	0
48	-5.507692	8.181844	2.0	0	0	1	0
71	0.646154	-5.075543	2.0	0	0	1	0
65	-6.430769	7.272766	2.0	0	0	1	0
38	-0.769231	-5.833108	2.0	0	0	1	0
42	1.692308	-4.469491	2.0	0	0	1	0
4	-0.092308	-5.605838	2.0	0	0	1	0
13	1.938462	-0.075614	2.0	0	0	1	0
15	-2.676923	9.696974	2.0	0	0	1	0
33	-8.276923	3.106159	2.0	0	0	1	0
34	1.200000	-4.924030	2.0	0	0	1	0
30	-4.215385	9.090922	2.0	0	0	1	0
76	-7.907692	4.924315	2.0	0	0	1	0
36	-3.723077	6.060662	3.0	0	0	0	1
41	-5.753846	3.560698	3.0	0	0	0	1
74	6.000000	7.272766	3.0	0	0	0	1
6	-0.830769	7.575792	3.0	0	0	0	1
8	-0.584615	-2.802848	3.0	0	0	0	1
10	-5.815385	2.878889	3.0	0	0	0	1
11	4.153846	7.954575	3.0	0	0	0	1
50	-5.876923	1.591029	3.0	0	0	0	1
14	-0.707692	-2.651335	3.0	0	0	0	1
51	7.107692	6.818227	3.0	0	0	0	1
18	-4.892308	4.545532	3.0	0	0	0	1
23	-4.338462	-1.287718	3.0	0	0	0	1
63	-3.046154	-2.802848	3.0	0	0	0	1
45	3.353846	7.954575	3.0	0	0	0	1
61	2.738462	8.181844	3.0	0	0	0	1
60	3.784615	7.878818	3.0	0	0	0	1
32	0.030769	-2.045283	3.0	0	0	0	1
40	-5.446154	4.318263	3.0	0	0	0	1
39	8.153846	5.530367	3.0	0	0	0	1

```
35  1.569231   8.181844     3.0    0    0    0    1
20 -5.753846   0.833464     3.0    0    0    0    1
77 -3.046154  -2.954361     3.0    0    0    0    1
```





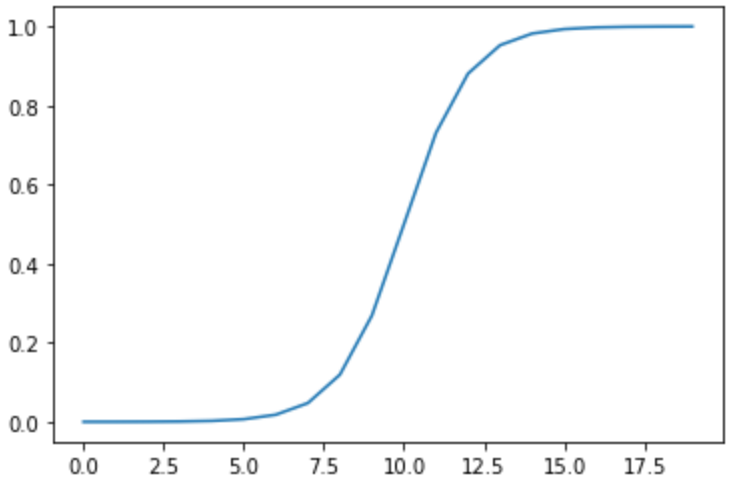
Ad. 3. Designing the structure of a neural network.

The four structures of the neural network will be considered later in the report:

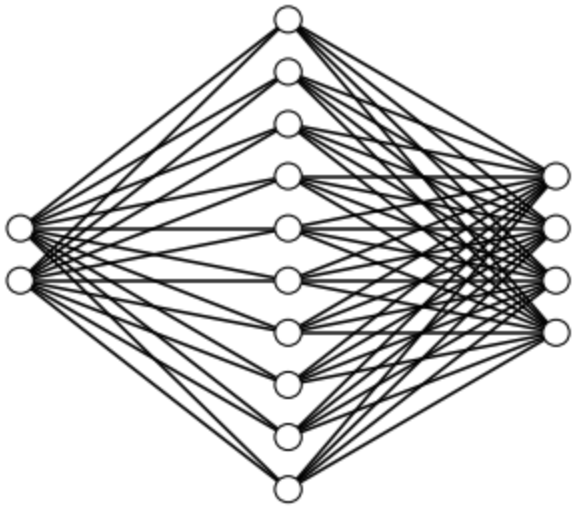
a) 2L-SIG - single-layer neural network with the sigmoid activation function; number of neurons in the hidden layer: 50 (Fig. 4),

b) 3L-SIG - double-layer neural network with the sigmoid activation function; number of neurons in the hidden layer No. 1 / 2: 30 / 10 (Fig. 5).

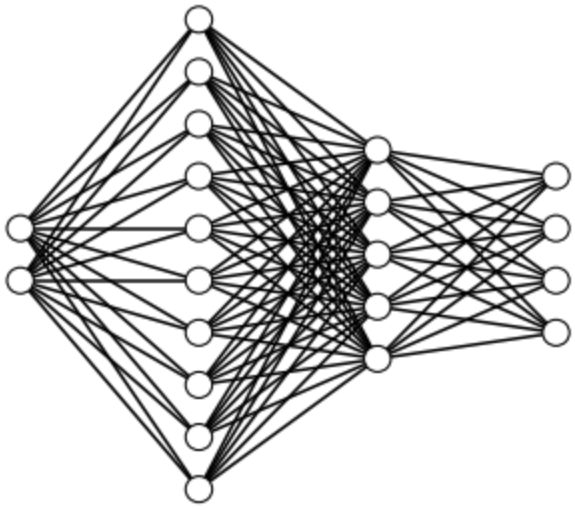
Following is a graph of how a sigmoid activation function might look like:



Following is an example graph of a neural network with 1 hidden layer, in our use case we will hav
e 50 neurons in the hidden layer:



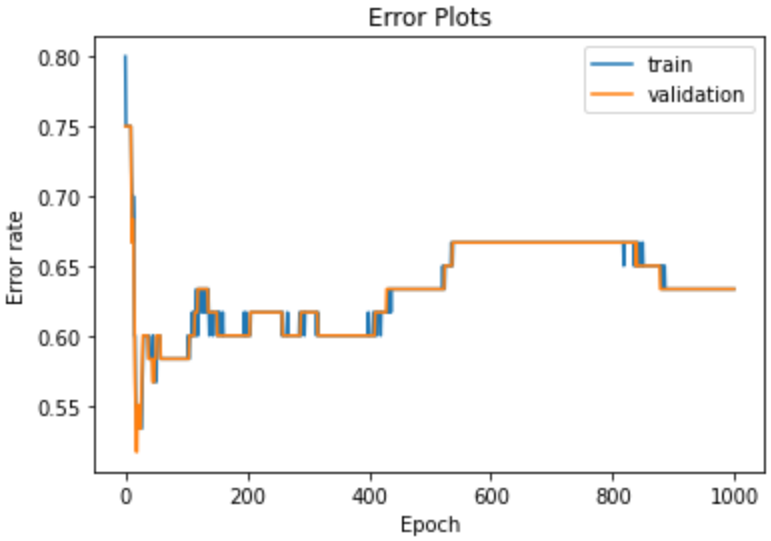
Following is an example graph of a neural network with 2 hidden layers, in our use case we will ha
ve 30 neurons in the first hidden layer, and 10 neurons in the second hidden layer:



From left to right, the first layer is the input layer (x1, x2), the middle layers are hidden laye
rs, and the last layer is the output layer (y1, y2, y3, y4)

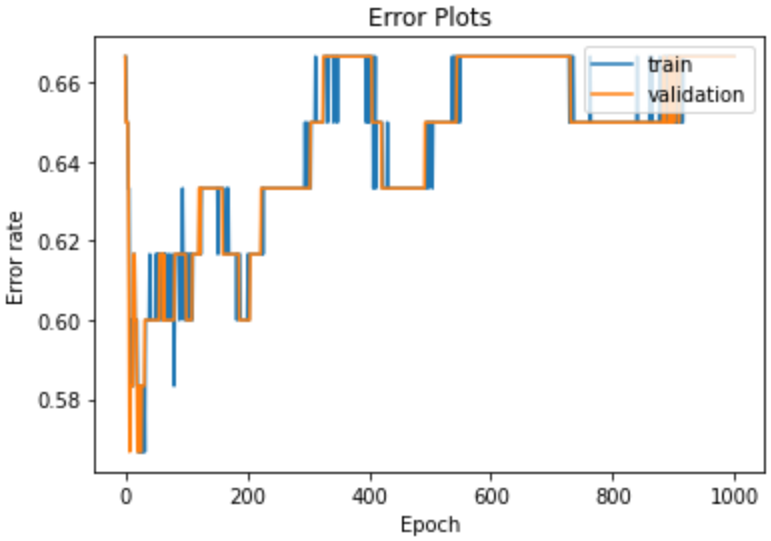
Ad. 4. A. Learning processes of a double-layer neural network with continuous outputs (neurons with the sigmoid activation function) (2L-SIG)

Training for Learning Rate= 0.1 for 5000 Epochs, using the 2L-SIG Neural Net



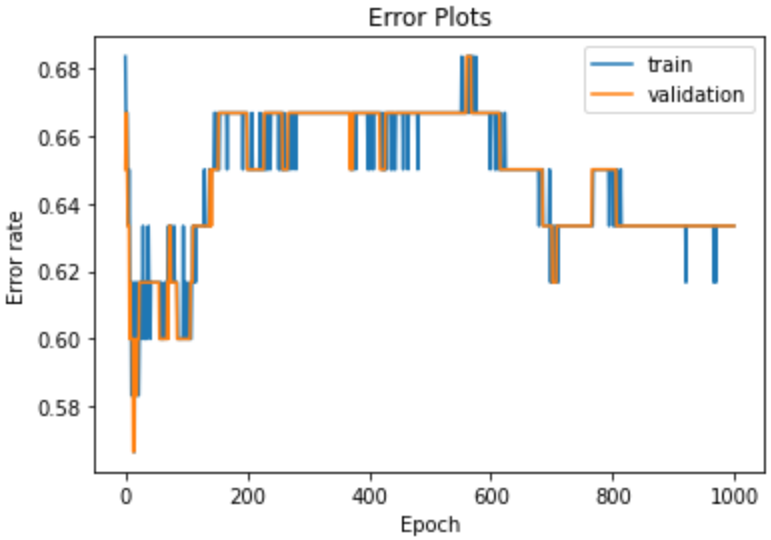
Finally, the learning error rate is: 0.6333333253860474
The test error rate is: 0.6333333253860474
The number of learning samples within 0.1 tolerance is: 0 out of 158
The number of test samples within 0.3 tolerance is: 0 out of 78

Training for Learning Rate= 0.2 for 5000 Epochs, using the 2L-SIG Neural Net

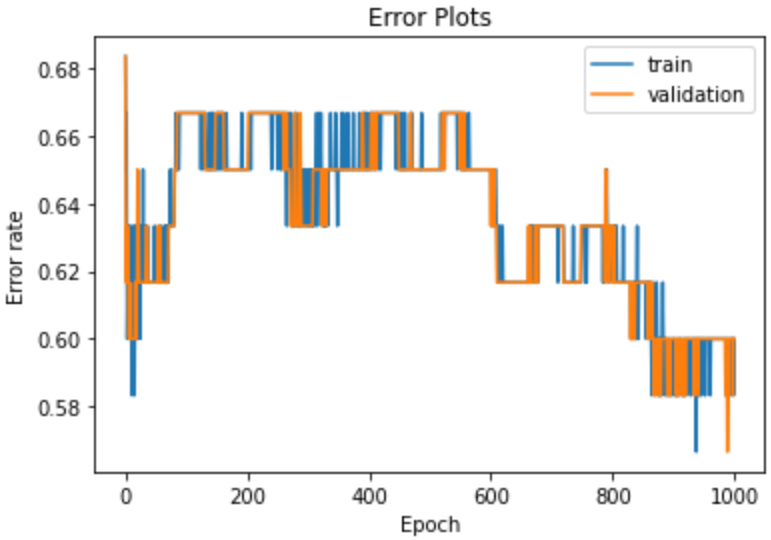


Finally, the learning error rate is: 0.6666666567325592
The test error rate is: 0.6666666567325592
The number of learning samples within 0.1 tolerance is: 0 out of 158
The number of test samples within 0.3 tolerance is: 0 out of 78

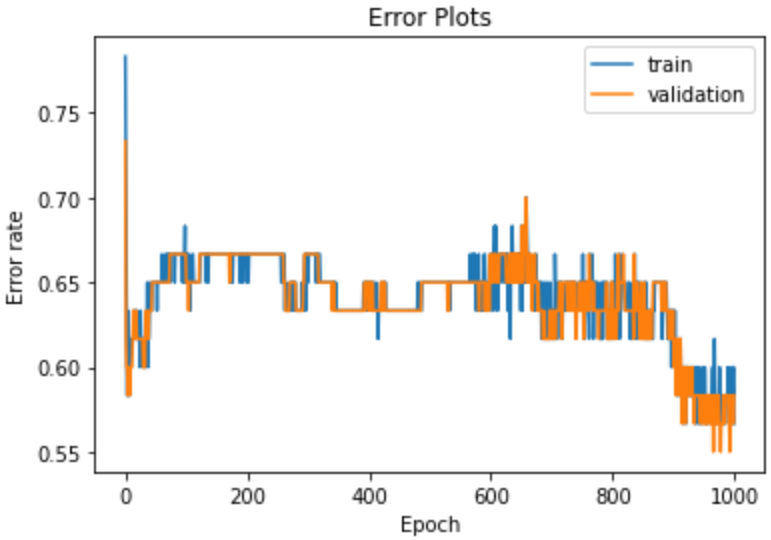
Training for Learning Rate= 0.4 for 5000 Epochs, using the 2L-SIG Neural Net




```
Finally, the learning error rate is: 0.6333333253860474
The test error rate is: 0.6333333253860474
The number of learning samples within 0.1 tolerance is: 0 out of 158
The number of test samples within 0.3 tolerance is: 0 out of 78
------------------------------------------------------------
Training for Learning Rate= 0.6 for 5000 Epochs, using the 2L-SIG Neural Net
```

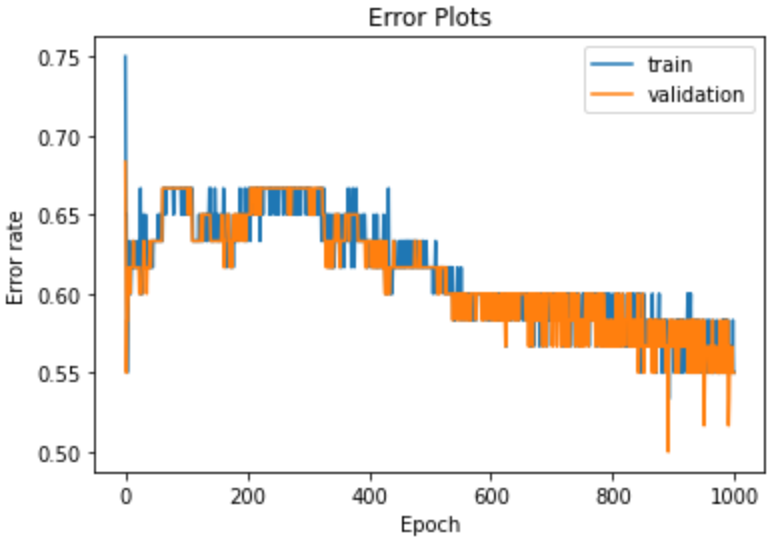



```
Finally, the learning error rate is: 0.5999999940395355
The test error rate is: 0.5999999940395355
The number of learning samples within 0.1 tolerance is: 0 out of 158
The number of test samples within 0.3 tolerance is: 0 out of 78
------------------------------------------------------------
Training for Learning Rate= 0.8 for 5000 Epochs, using the 2L-SIG Neural Net
```

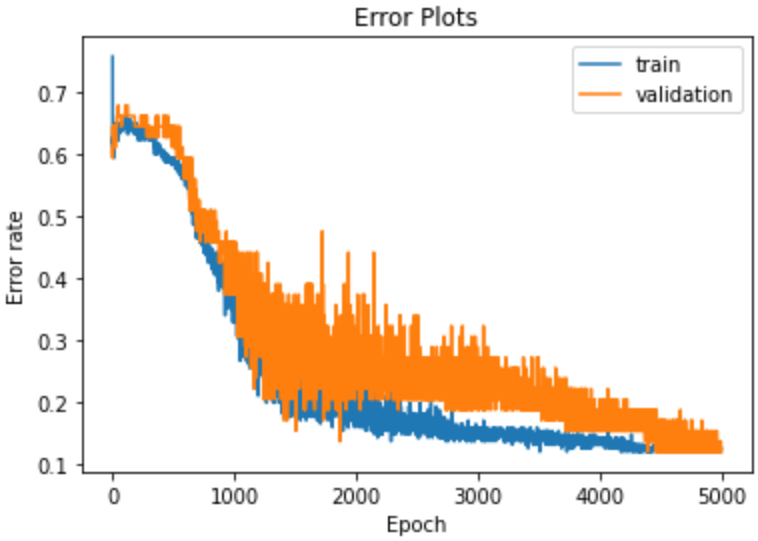



```
Finally, the learning error rate is: 0.5666666626930237
```

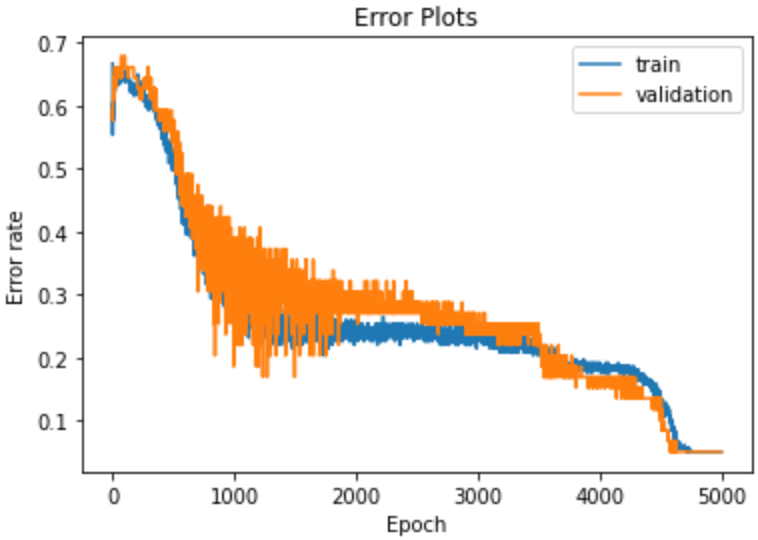
```
The test error rate is: 0.5833333432674408
The number of learning samples within 0.1 tolerance is: 0 out of 158
The number of test samples within 0.3 tolerance is: 0 out of 78
------------------------------------------------------------
Training for Learning Rate= 0.9 for 5000 Epochs, using the 2L-SIG Neural Net
```



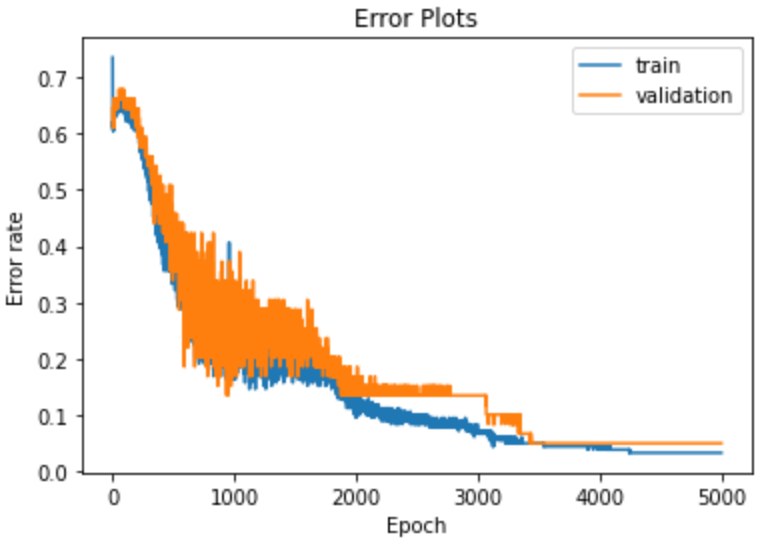

```
Finally, the learning error rate is: 0.550000011920929
The test error rate is: 0.550000011920929
The number of learning samples within 0.1 tolerance is: 0 out of 158
The number of test samples within 0.3 tolerance is: 0 out of 78

------------------------------------------------------------
Training for Momentum Factor= 0.2 for 5000 Epochs, using the 2L-SIG Neural Net
```



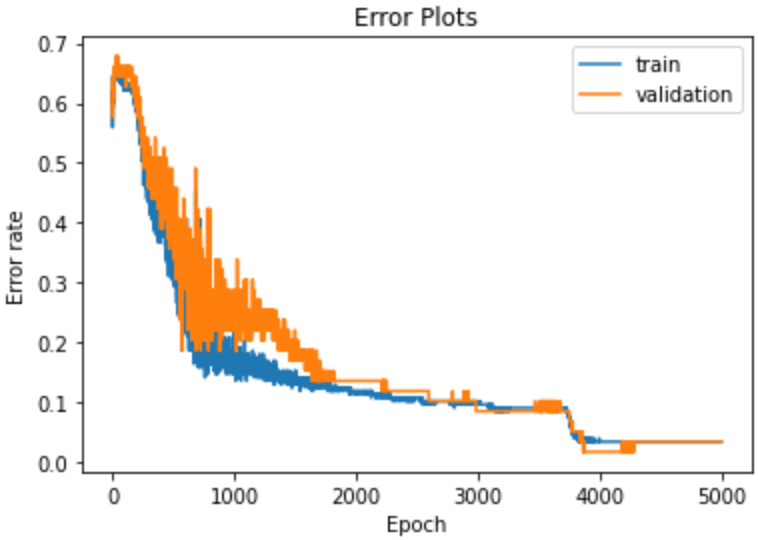

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.12429380416870117
The test error rate is: 0.11864405870437622
The number of learning samples within 0.1 tolerance is: 115 out of 158
The number of test samples within 0.3 tolerance is: 60 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.4 for 5000 Epochs, using the 2L-SIG Neural Net
```



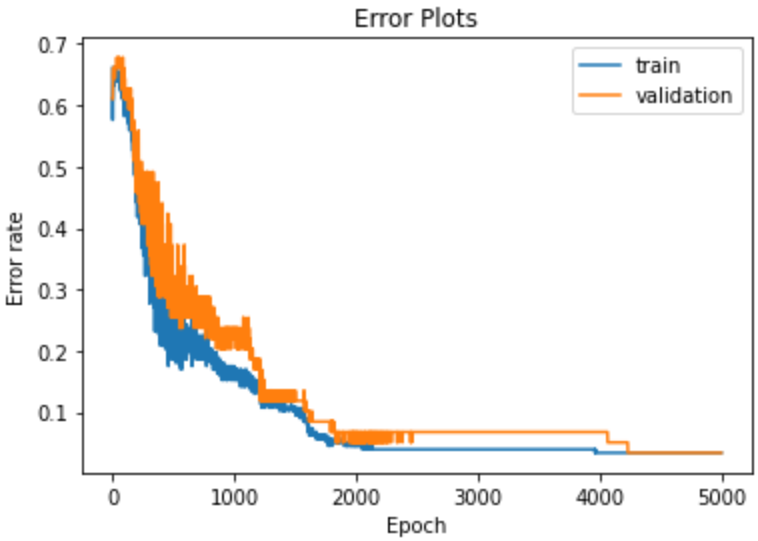

```
5/5 [==============================] - 0s 2ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.05084747076034546
The test error rate is: 0.05084747076034546
The number of learning samples within 0.1 tolerance is: 116 out of 158
The number of test samples within 0.3 tolerance is: 69 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.6 for 5000 Epochs, using the 2L-SIG Neural Net
```



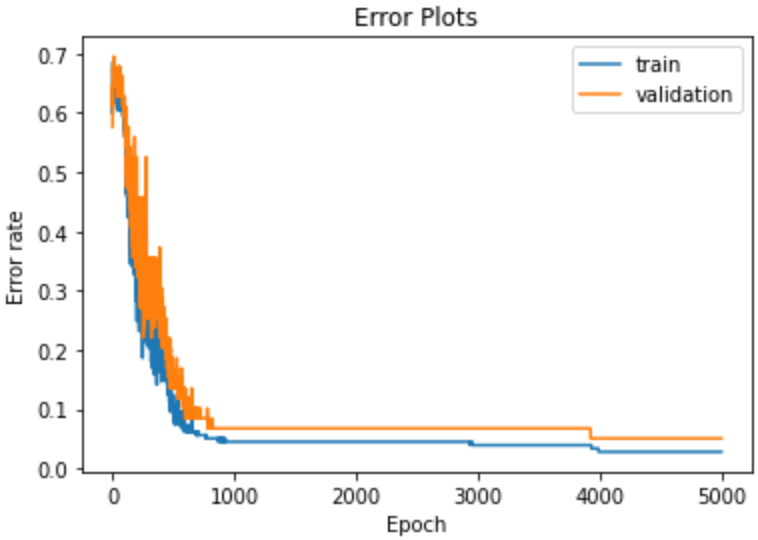

```
5/5 [==============================] - 0s 2ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.03389829397201538
The test error rate is: 0.05084747076034546
The number of learning samples within 0.1 tolerance is: 148 out of 158
The number of test samples within 0.3 tolerance is: 73 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.7 for 5000 Epochs, using the 2L-SIG Neural Net
```



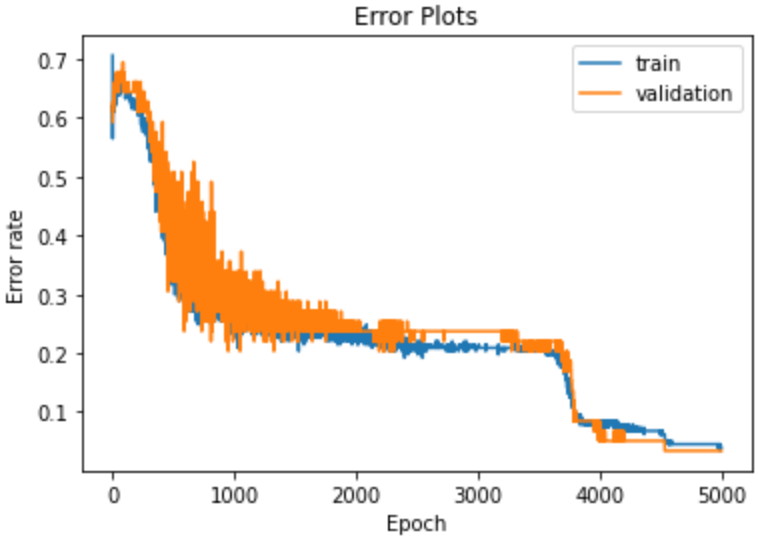

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.03389829397201538
The test error rate is: 0.03389829397201538
The number of learning samples within 0.1 tolerance is: 150 out of 158
The number of test samples within 0.3 tolerance is: 74 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.8 for 5000 Epochs, using the 2L-SIG Neural Net
```



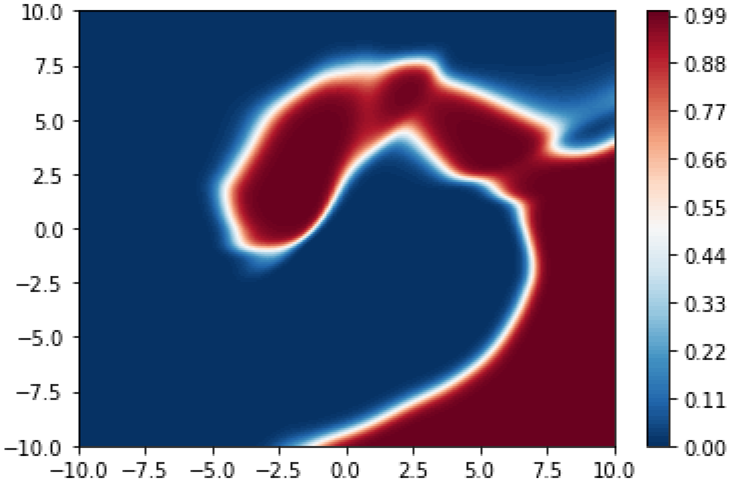

```
5/5 [==============================] - 0s 2ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.03389829397201538
The test error rate is: 0.03389829397201538
The number of learning samples within 0.1 tolerance is: 150 out of 158
The number of test samples within 0.3 tolerance is: 74 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.9 for 5000 Epochs, using the 2L-SIG Neural Net
```

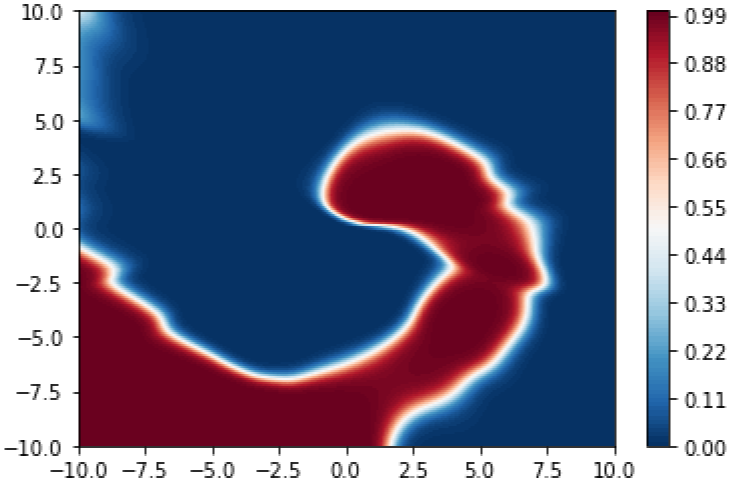


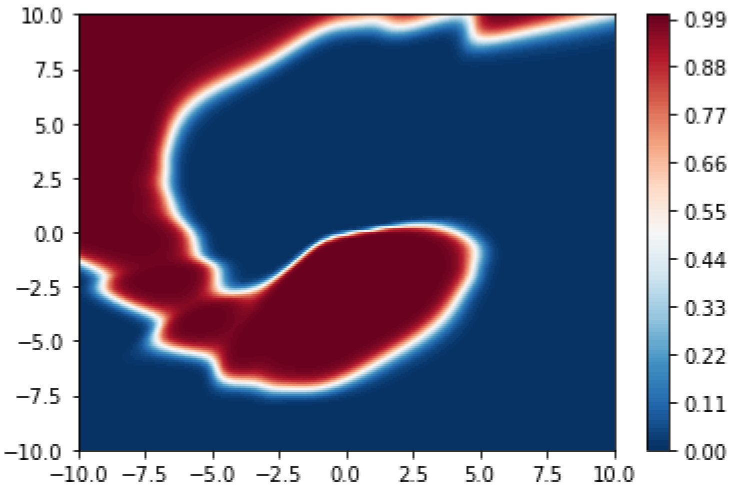

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 1ms/step
Finally, the learning error rate is: 0.028248608112335205
The test error rate is: 0.05084747076034546
The number of learning samples within 0.1 tolerance is: 149 out of 158
The number of test samples within 0.3 tolerance is: 74 out of 78

------------------------------------------------------------
Shuffle True
```

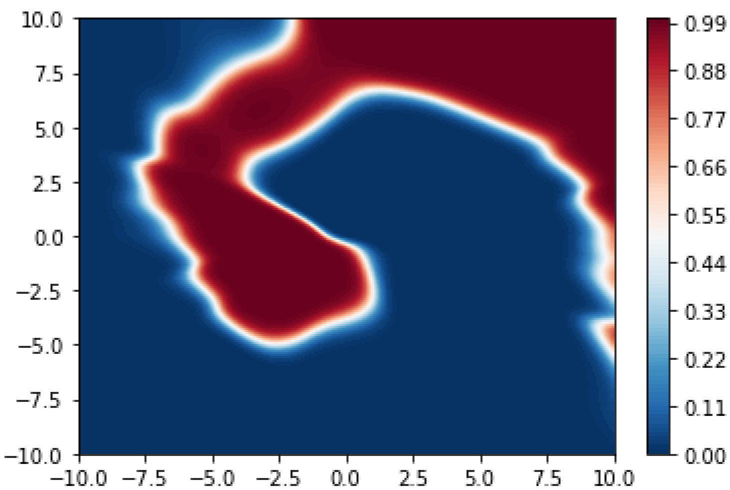



```
5/5 [==============================] - 0s 2ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.03954803943634033
The test error rate is: 0.03389829397201538
The number of learning samples within 0.1 tolerance is: 147 out of 158
The number of test samples within 0.3 tolerance is: 72 out of 78
```

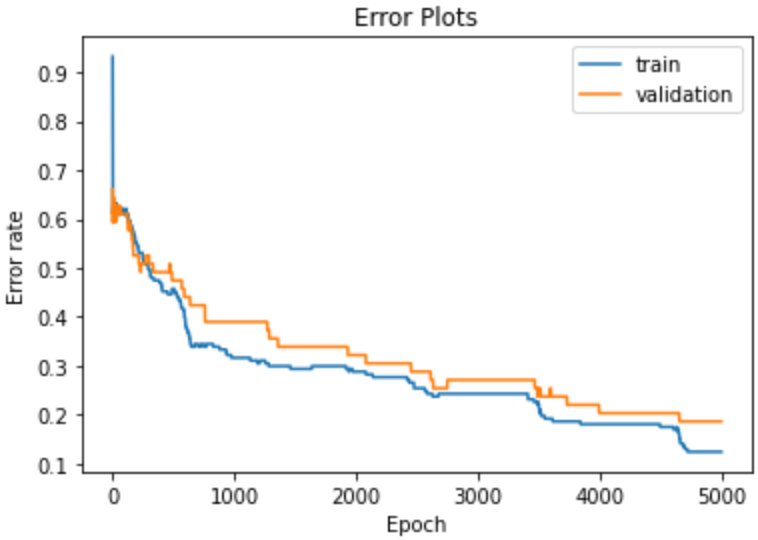




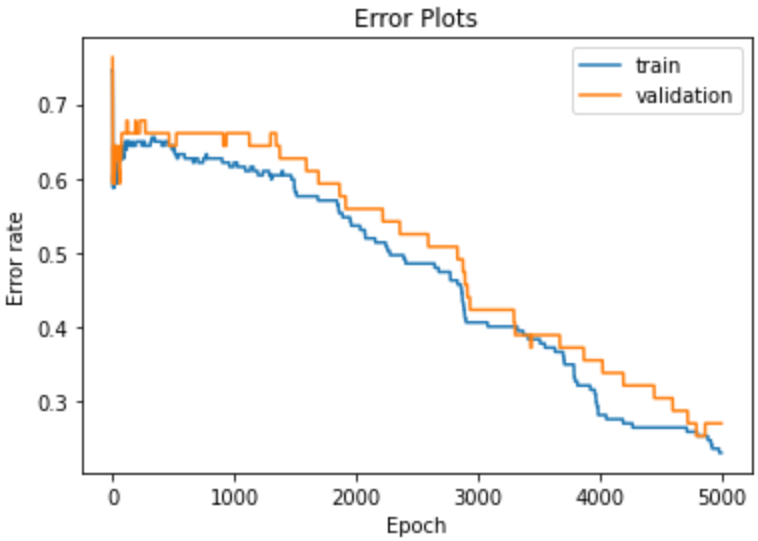




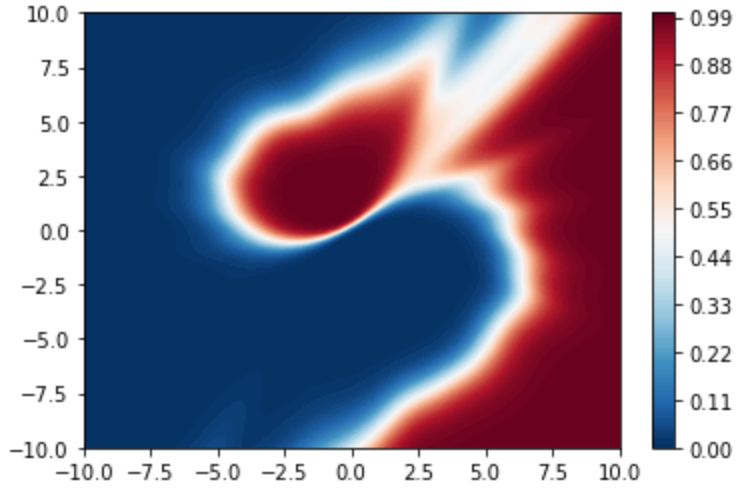

```
------------------------------------------------------------
Shuffle False
```

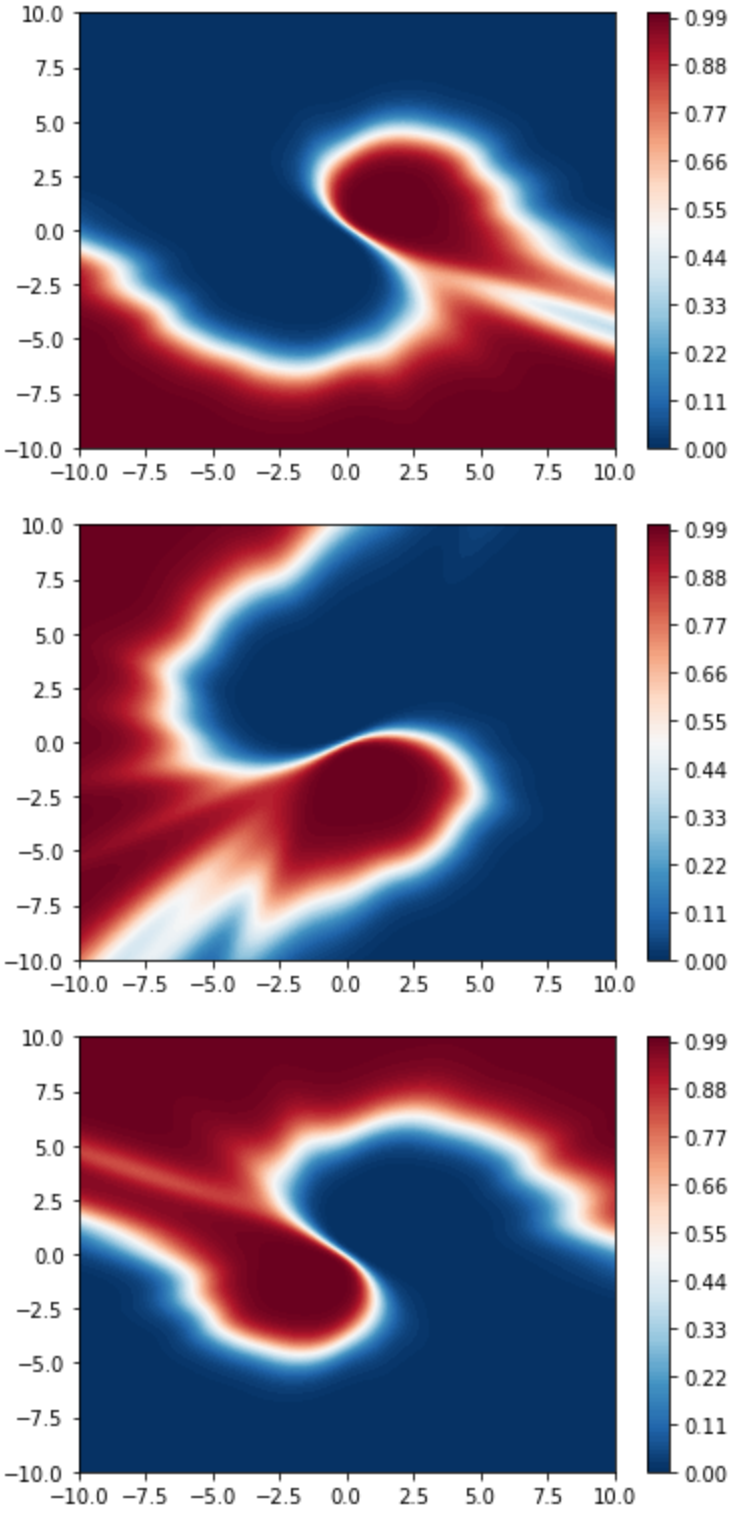



```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.12429380416870117
The test error rate is: 0.18644070625305176
The number of learning samples within 0.1 tolerance is: 138 out of 158
The number of test samples within 0.3 tolerance is: 70 out of 78
------------------------------------------------------------
Shuffle True, batch size = training dataset size
```



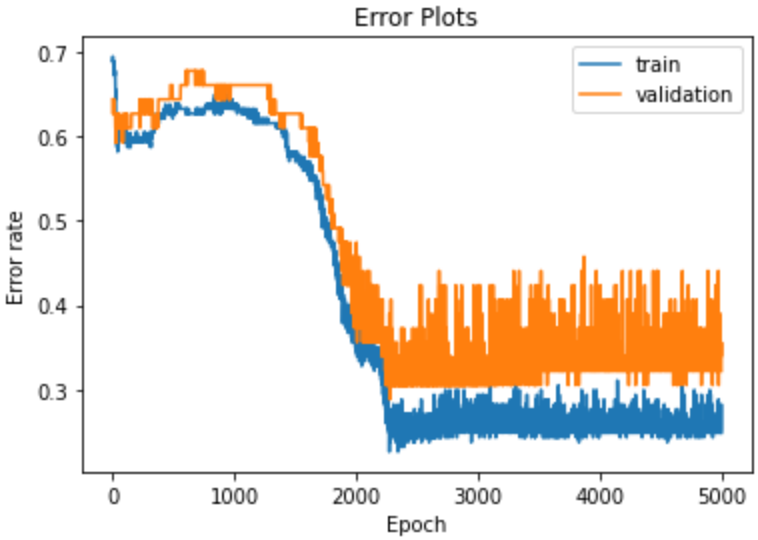

```
5/5 [==============================] - 0s 2ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.23163843154907227
The test error rate is: 0.2711864113807678
The number of learning samples within 0.1 tolerance is: 2 out of 158
The number of test samples within 0.3 tolerance is: 29 out of 78
```



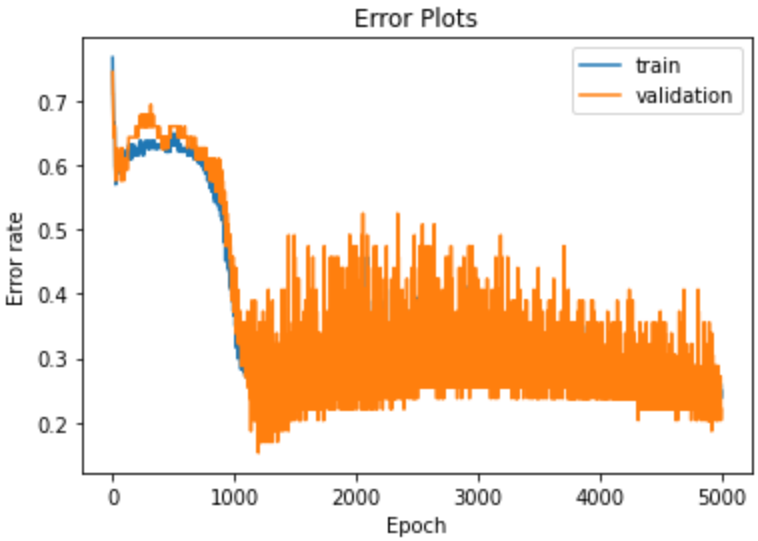


Ad. 4. B. Learning processes of a three-layer neural network with continuous outputs (neurons with the signum activation function) (3L-SIG)

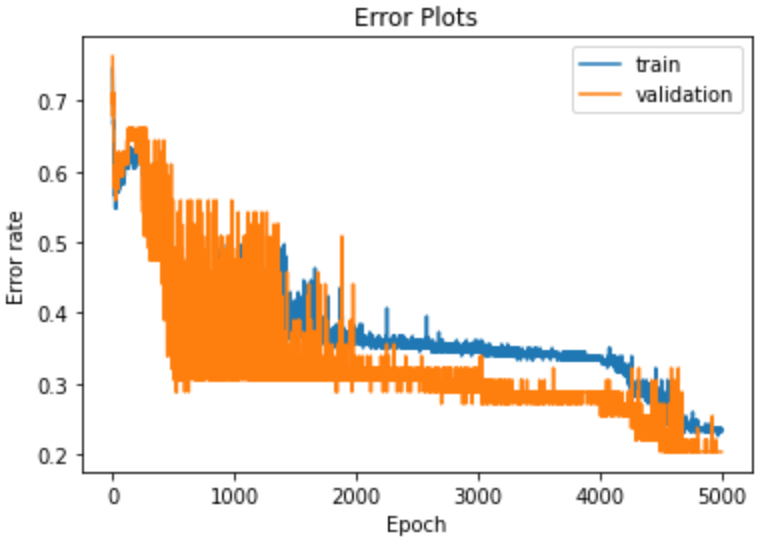
```
------------------------------------------------------------
Training for Learning Rate= 0.1 for 5000 Epochs, using the 2L-SIG Neural Net
```



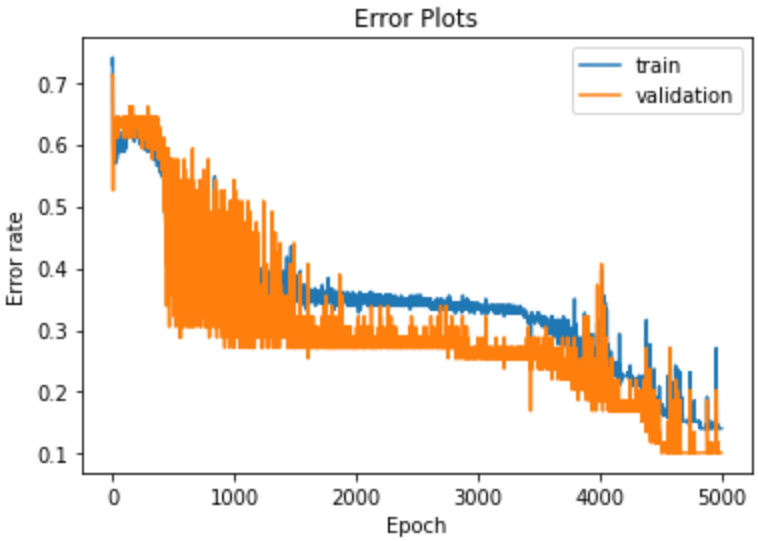

```
5/5 [==============================] - 0s 2ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.24858754873275757
The test error rate is: 0.3220338821411133
The number of learning samples within 0.1 tolerance is: 82 out of 158
The number of test samples within 0.3 tolerance is: 47 out of 78
------------------------------------------------------------
Training for Learning Rate= 0.2 for 5000 Epochs, using the 2L-SIG Neural Net
```



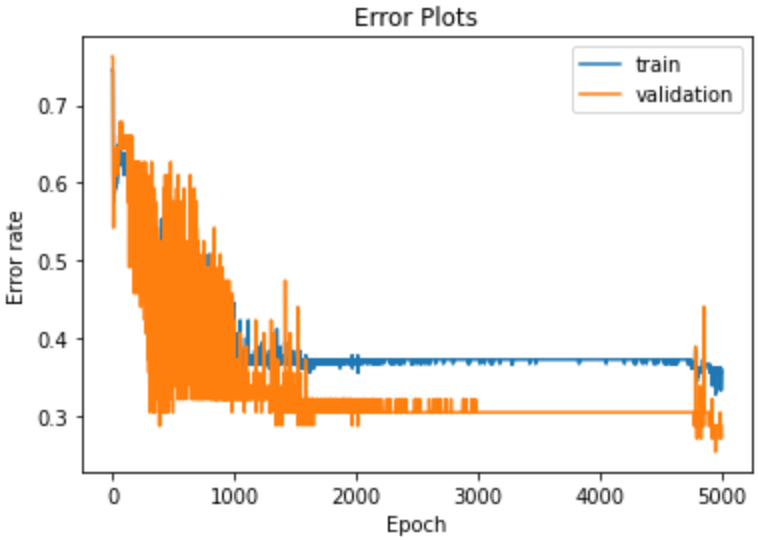

```
5/5 [==============================] - 0s 999us/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.24858754873275757
The test error rate is: 0.22033900022506714
The number of learning samples within 0.1 tolerance is: 98 out of 158
The number of test samples within 0.3 tolerance is: 51 out of 78
------------------------------------------------------------
Training for Learning Rate= 0.4 for 5000 Epochs, using the 2L-SIG Neural Net
```



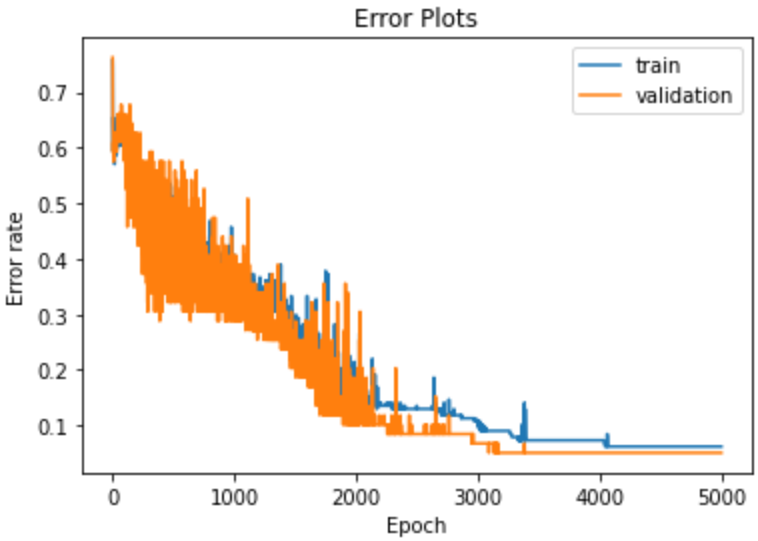

```
5/5 [==============================] - 0s 2ms/step
3/3 [==============================] - 0s 1ms/step
Finally, the learning error rate is: 0.23163843154907227
The test error rate is: 0.20338982343673706
The number of learning samples within 0.1 tolerance is: 120 out of 158
The number of test samples within 0.3 tolerance is: 57 out of 78
------------------------------------------------------------
Training for Learning Rate= 0.6 for 5000 Epochs, using the 2L-SIG Neural Net
```



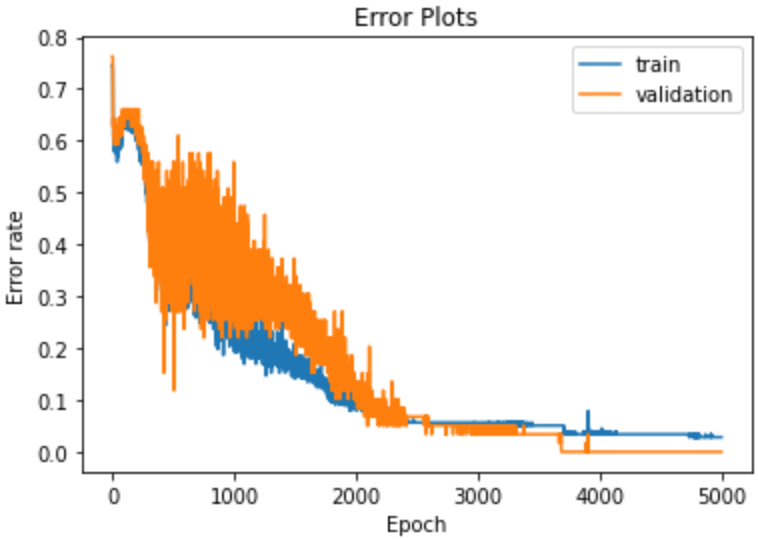

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.14124292135238647
The test error rate is: 0.10169494152069092
The number of learning samples within 0.1 tolerance is: 137 out of 158
The number of test samples within 0.3 tolerance is: 66 out of 78
------------------------------------------------------------
Training for Learning Rate= 0.8 for 5000 Epochs, using the 2L-SIG Neural Net
```



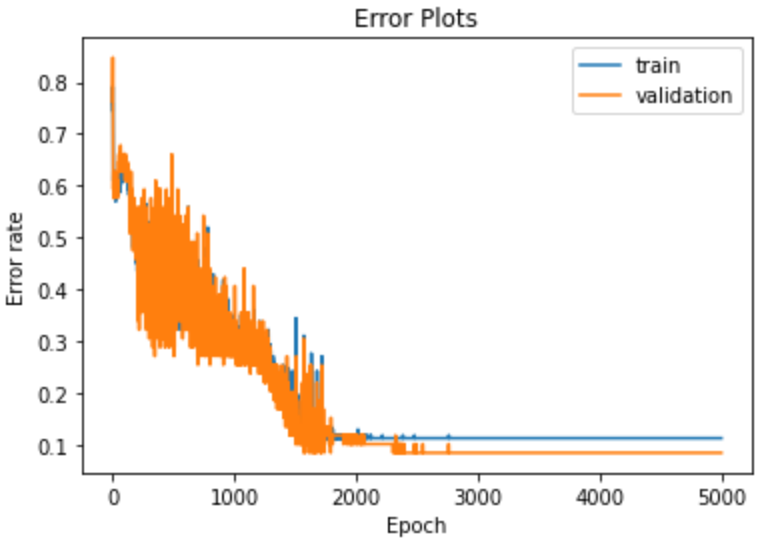

```
5/5 [==============================] - 0s 2ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.35593217611312866
The test error rate is: 0.2881355881690979
The number of learning samples within 0.1 tolerance is: 102 out of 158
The number of test samples within 0.3 tolerance is: 46 out of 78
------------------------------------------------------------
Training for Learning Rate= 0.9 for 5000 Epochs, using the 2L-SIG Neural Net
```



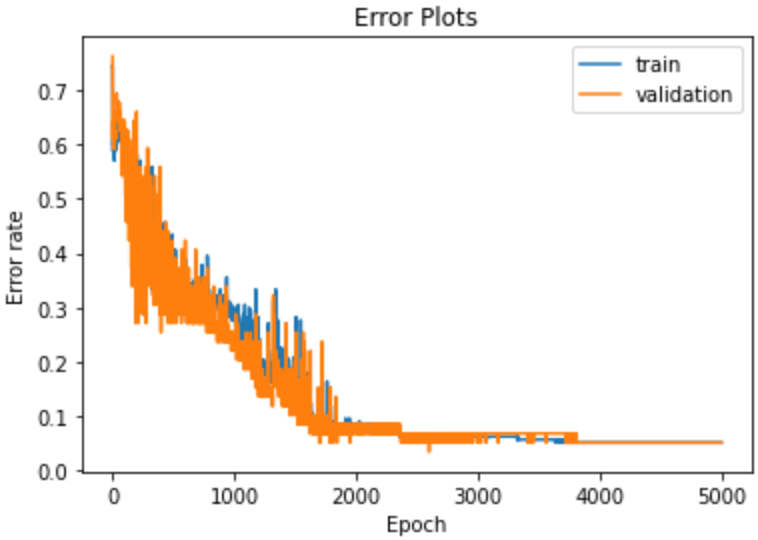

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.062146902084350586
The test error rate is: 0.05084747076034546
The number of learning samples within 0.1 tolerance is: 151 out of 158
The number of test samples within 0.3 tolerance is: 72 out of 78


------------------------------------------------------------
Training for Momentum Factor= 0.2 for 5000 Epochs, using the 3L-SIG Neural Net
```



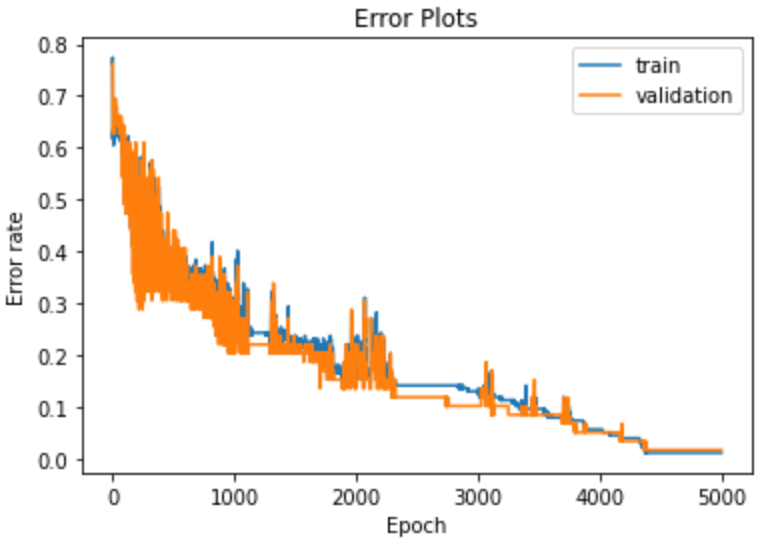

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.028248608112335205
The test error rate is: 0.0
The number of learning samples within 0.1 tolerance is: 153 out of 158
The number of test samples within 0.3 tolerance is: 71 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.4 for 5000 Epochs, using the 3L-SIG Neural Net
```



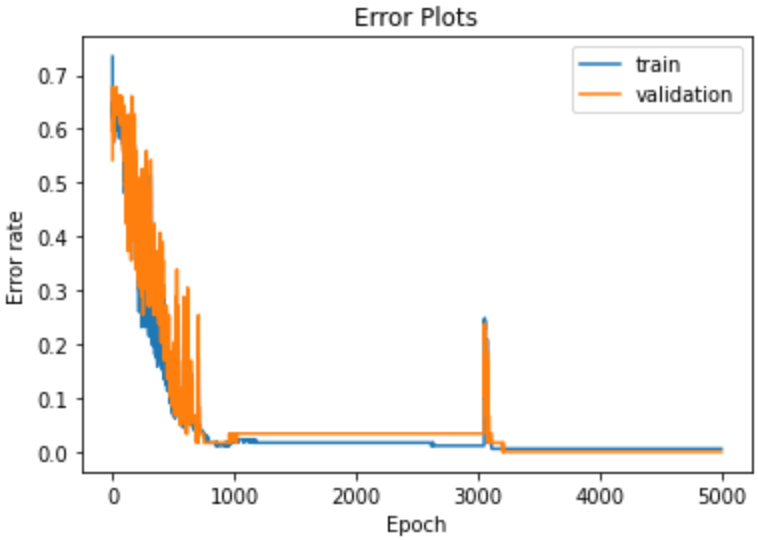

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 1ms/step
Finally, the learning error rate is: 0.11299437284469604
The test error rate is: 0.08474576473236084
The number of learning samples within 0.1 tolerance is: 141 out of 158
The number of test samples within 0.3 tolerance is: 68 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.6 for 5000 Epochs, using the 3L-SIG Neural Net
```



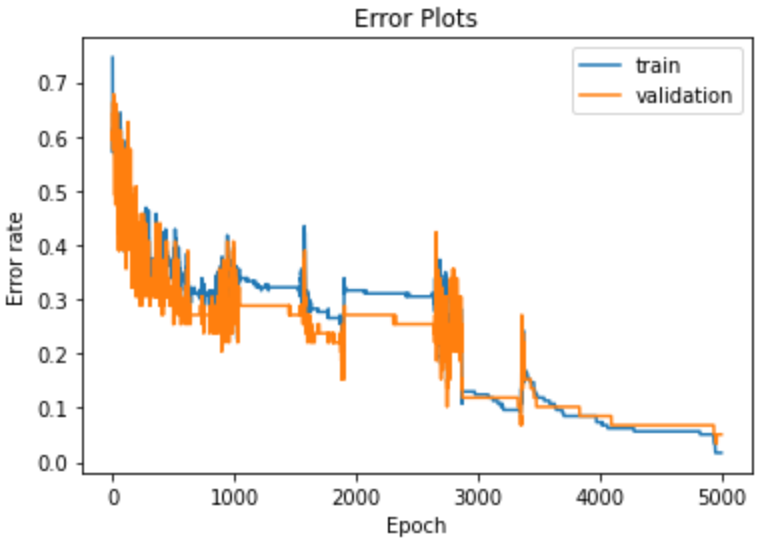

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.05084747076034546
The test error rate is: 0.05084747076034546
The number of learning samples within 0.1 tolerance is: 148 out of 158
The number of test samples within 0.3 tolerance is: 74 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.7 for 5000 Epochs, using the 3L-SIG Neural Net
```



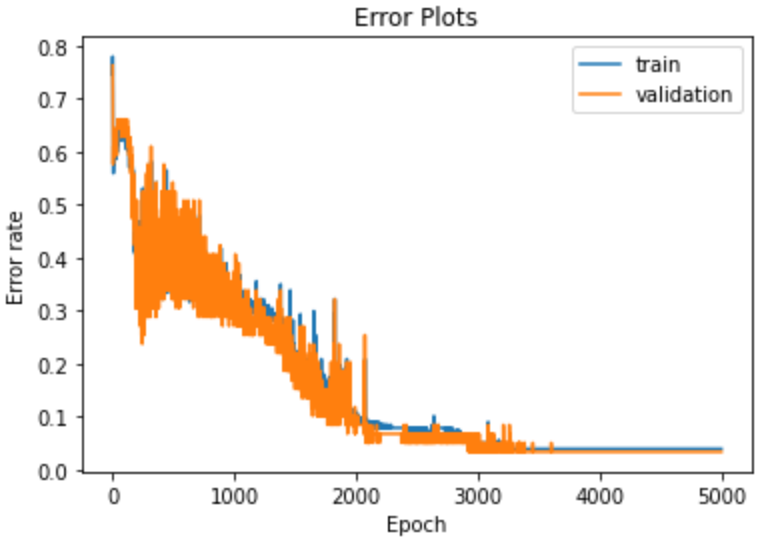

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.011299431324005127
The test error rate is: 0.016949176788330078
The number of learning samples within 0.1 tolerance is: 156 out of 158
The number of test samples within 0.3 tolerance is: 77 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.8 for 5000 Epochs, using the 3L-SIG Neural Net
```



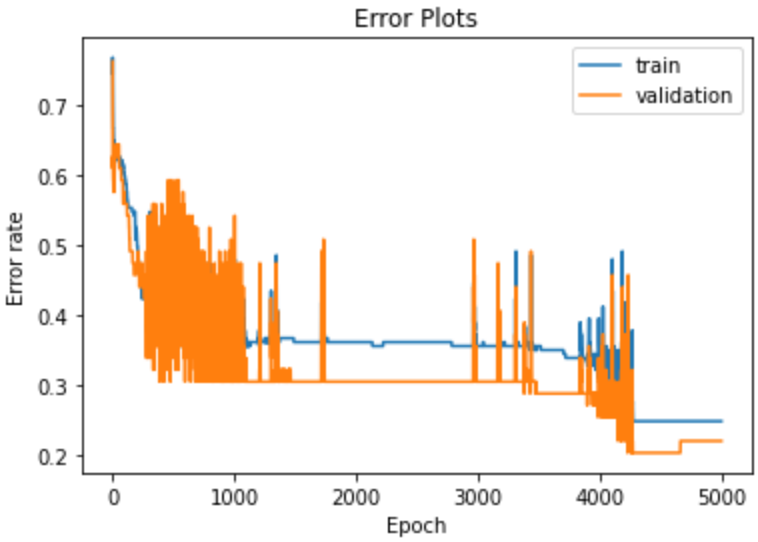

```
5/5 [==============================] - 0s 2ms/step
3/3 [==============================] - 0s 1ms/step
Finally, the learning error rate is: 0.005649745464324951
The test error rate is: 0.0
The number of learning samples within 0.1 tolerance is: 156 out of 158
The number of test samples within 0.3 tolerance is: 78 out of 78
------------------------------------------------------------
Training for Momentum Factor= 0.9 for 5000 Epochs, using the 3L-SIG Neural Net
```



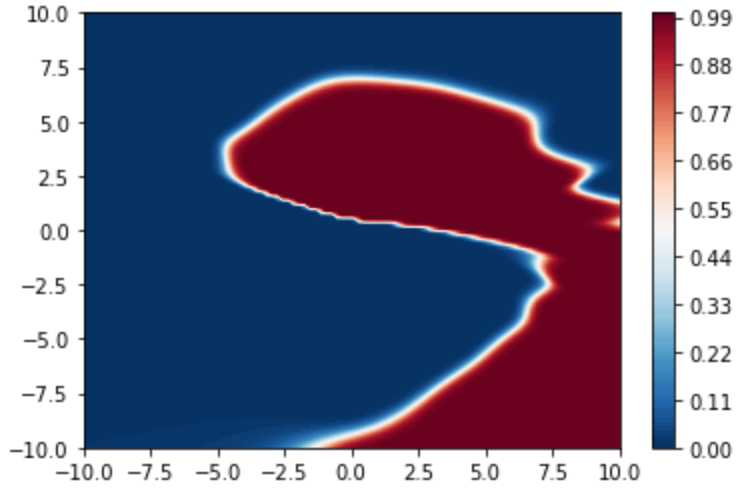

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 1ms/step
Finally, the learning error rate is: 0.016949176788330078
The test error rate is: 0.05084747076034546
The number of learning samples within 0.1 tolerance is: 146 out of 158
The number of test samples within 0.3 tolerance is: 72 out of 78

------------------------------------------------------------
Shuffle True
```

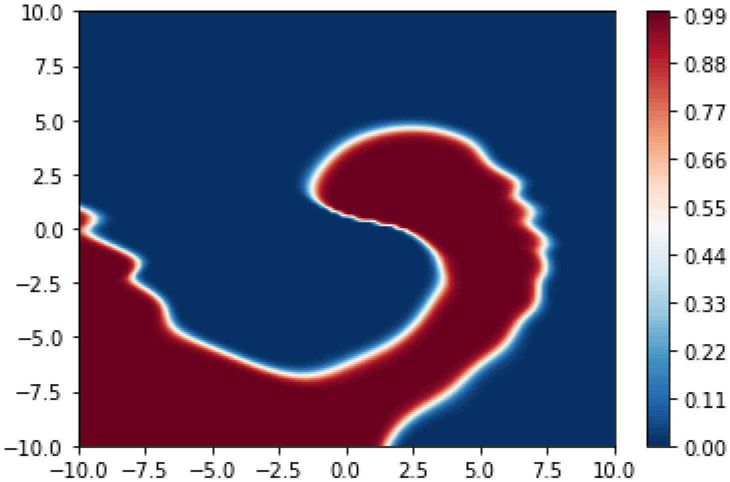


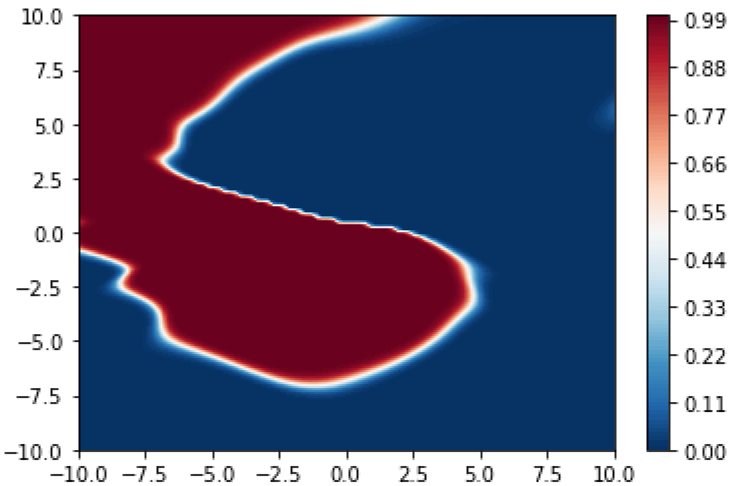

```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.03954803943634033
The test error rate is: 0.03389829397201538
The number of learning samples within 0.1 tolerance is: 150 out of 158
The number of test samples within 0.3 tolerance is: 72 out of 78
------------------------------------------------------------
Shuffle False
```

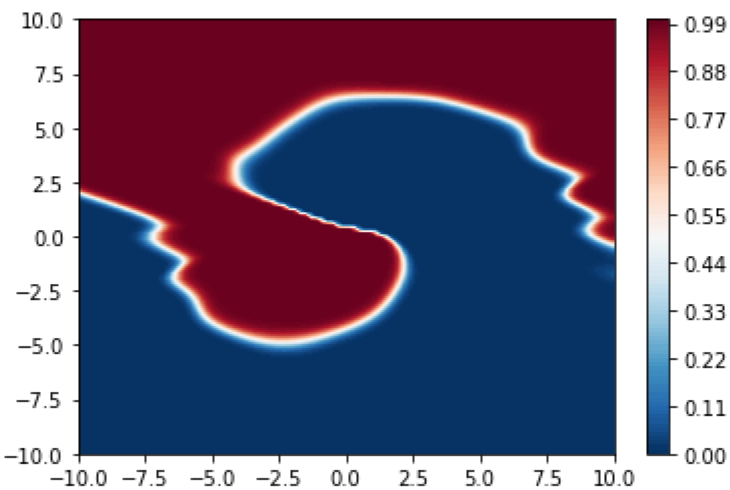



```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 1ms/step
Finally, the learning error rate is: 0.24858754873275757
The test error rate is: 0.22033900022506714
The number of learning samples within 0.1 tolerance is: 121 out of 158
The number of test samples within 0.3 tolerance is: 56 out of 78
```

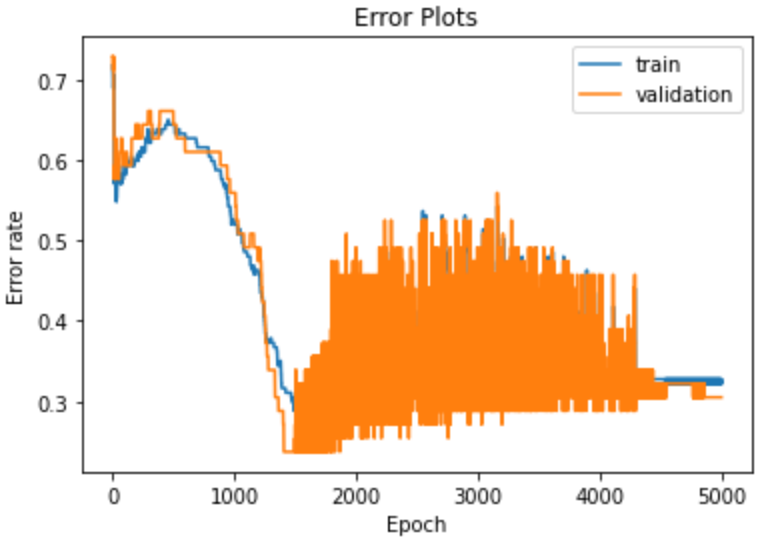




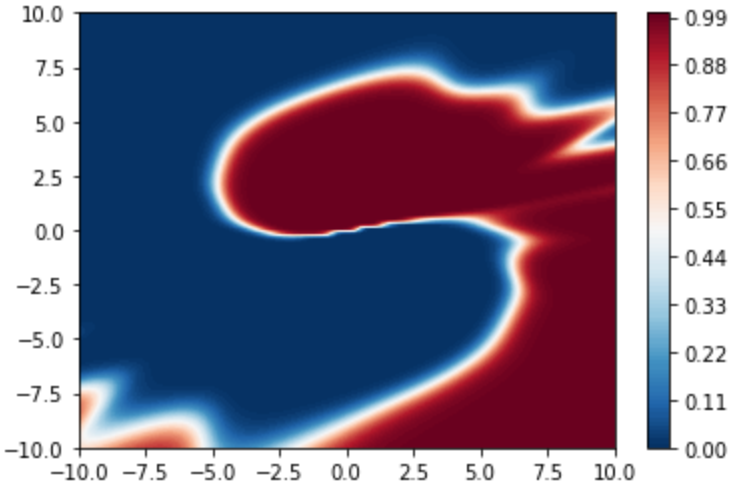


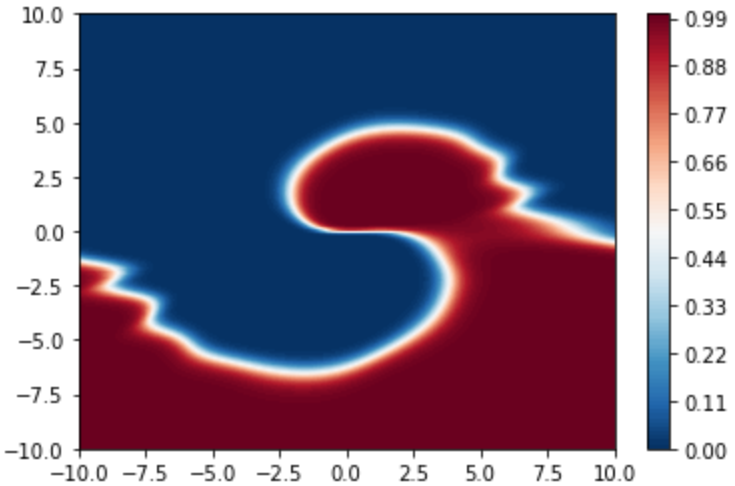


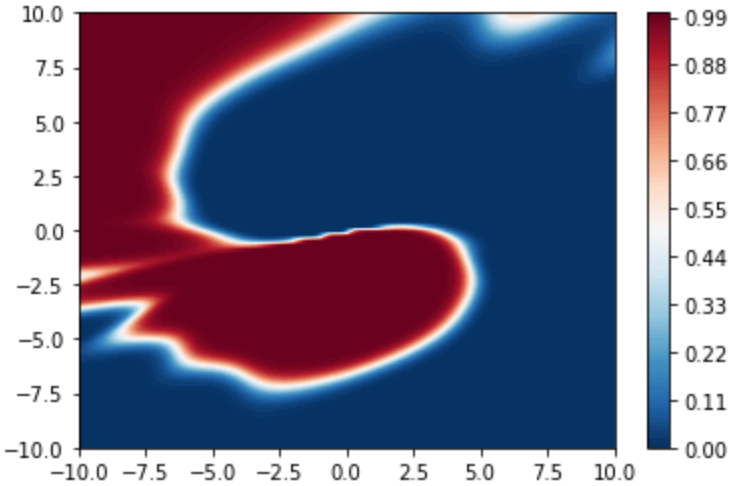

```
--------------------------------------------------------------
Shuffle True, batch size = training dataset size
```

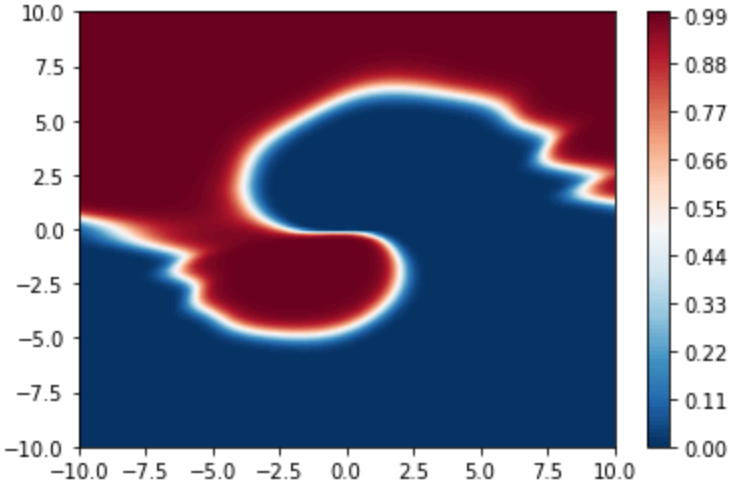



```
5/5 [==============================] - 0s 1ms/step
3/3 [==============================] - 0s 2ms/step
Finally, the learning error rate is: 0.3220338821411133
The test error rate is: 0.305084764957428
The number of learning samples within 0.1 tolerance is: 83 out of 158
The number of test samples within 0.3 tolerance is: 44 out of 78
```






10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−10.0 −7.5 −5.0 −2.5 0.0 2.5 5.0 7.5 10.0
0.99
0.88
0.77
0.66
0.55
0.44
0.33
0.22
0.11
0.00


10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
−10.0 −7.5 −5.0 −2.5 0.0 2.5 5.0 7.5 10.0
0.99
0.88
0.77
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0.55
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0.22
0.11
0.00