In [4]:
```
import sys
import pandas as pd
import matplotlib as mtp
import statistics as sts
import math
import matplotlib.image as mpimg
import matplotlib.pyplot as pplt
import numpy as np
from PIL import Image as pimg
from itertools import chain
from sklearn import preprocessing
from sklearn.preprocessing import MinMaxScaler
from copy import deepcopy
from numpy import array
```

In [5]:
```
labels_data_frame = pd.read_csv("labels.csv")
labels_data_frame
```

Out[5]:

	id	label
0	8	horse
1	10	cat
2	12	horse
3	13	horse
4	18	cat
...	...	...
9995	49979	horse
9996	49980	cat
9997	49983	cat
9998	49984	cat
9999	49987	horse

10000 rows × 2 columns

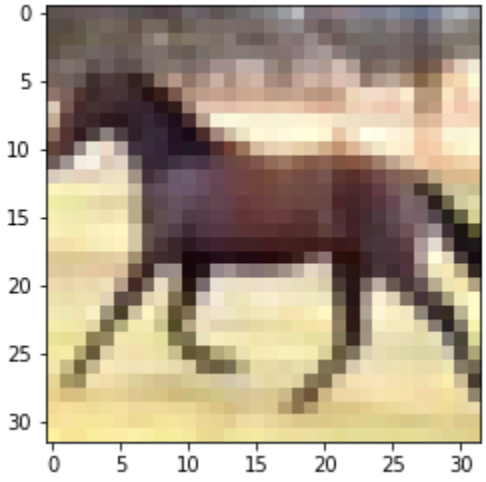
In [6]:
```
image_name_list = labels_data_frame["id"].values
images_list = []

for img_name in image_name_list:
    img_dir = str("data/"+str(img_name)+".png")
    current_image = pimg.open(img_dir)
    image_matrix = array(current_image)
    images_list.append(image_matrix)
```

In [7]:
```
def img_invert(rgb):
    return np.dot(rgb[...,:3], [0.2989, 0.5870, 0.1140])

inverted_images_list = []

for image in images_list:
    inverted_images_list.append(img_invert(image))
```

In [8]:

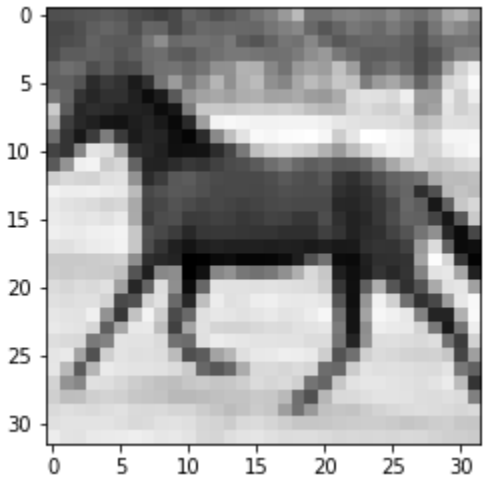
```
pplt.imshow(images_list[1405])
```

Out[8]:
```
<matplotlib.image.AxesImage at 0x7fd79fa6a580>
```



In [9]:
```
pplt.imshow(inverted_images_list[1405], cmap="gray")
```

Out[9]:
```
<matplotlib.image.AxesImage at 0x7fd79f88bee0>
```



In [10]:
```
print(images_list[1405][0])
```

```
[[ 91  85  80]
 [ 95  84  83]
 [104  87  89]
 [103  88  92]
 [108  93  99]
 [101  90  93]
 [ 88  82  81]
 [ 86  76  78]
 [ 82  67  73]
 [ 89  77  81]
 [110 103 106]
 [103  95 101]
 [ 93  85  84]
 [ 99  96  93]
 [111 106 106]
 [123 119 118]
 [132 132 132]
 [154 157 160]
 [187 186 192]
 [123 115 122]
 [129 114 121]
```

```
[143 126 133]
[140 130 143]
[127 126 142]
[123 126 142]
[132 139 156]
[114 124 142]
[108 116 139]
[126 133 155]
[163 169 178]
[175 179 188]
[153 153 160]]
```

In [11]:

```
print(inverted_images_list[1405][0])
```

```
[ 86.2149  87.1655  92.3006  92.9307  98.1582  93.6209  83.6712  79.2094
  72.1608  81.0351 105.424   98.0657  87.2687  96.5451 107.4839 120.0697
 131.9868 156.4296 186.9643 118.1777 119.2701 131.8667 134.458  128.1103
 126.9147 138.8318 123.0506 116.2192 133.4024 168.2157 178.8125 153.7827]
```

In [12]:

```
flat_images = [list(chain.from_iterable(image)) for image in inverted_images_list]
flat_data_frame = pd.DataFrame(flat_images)
```

In [13]:

```
flat_data_frame
```

Out[13]:

	0	1	2	3	4	5	6	7	8	9	...	
0	33.3602	33.9410	41.0497	75.4608	76.3467	43.2729	41.9571	56.1298	69.7325	77.1833	...	11
1	123.9615	102.5400	92.7798	99.3384	100.7404	136.3239	171.0215	170.3205	142.5082	92.8014	...	10
2	147.2348	171.4128	168.7784	172.6595	200.7384	212.2795	196.1052	135.0880	119.2252	133.2669	...	15
3	203.0406	200.2258	200.2258	201.2257	200.9268	201.3397	202.2256	202.2256	201.9375	201.9375	...	15
4	104.9850	135.1408	144.5159	129.9887	81.9487	55.4675	48.1092	51.9239	52.0379	53.1518	...	7
...	...	...	...	...	...	...	...	...	...	...	...	
9995	161.8006	82.6146	104.2211	107.4704	104.2966	103.8406	108.3949	118.5896	126.0619	130.2464	...	23
9996	3.9996	3.9996	4.9995	0.0000	65.4360	174.2267	166.7759	153.7556	153.0716	150.1859	...	5
9997	40.9959	38.7681	38.6541	39.8389	41.7247	41.8387	43.8385	45.8383	46.9522	48.3650	...	5
9998	31.6719	31.5687	29.9387	31.0095	33.2759	36.9335	37.6884	41.3722	87.6880	146.9377	...	18
9999	140.5443	141.4302	142.3161	142.3161	142.7290	143.1419	143.7289	144.3159	144.3159	144.4299	...	19

10000 rows × 1024 columns

In [14]:

```
# number of train images: 8500
# number of test images: 1500

test_data_frame = flat_data_frame[:1500]
train_data_frame = flat_data_frame[1500:]

test_images_list = inverted_images_list[:1500]
train_images_list = inverted_images_list[1500:]

test_labels = labels_data_frame[:1500]
train_labels = labels_data_frame[1500:]

print(len(test_labels)," ",len(test_images_list)," ",len(test_data_frame))
```

```
1500   1500   1500
```

In [15]:
```
train_data_frame
```

Out[15]:

	0	1	2	3	4	5	6	7	8	9	...	
1500	54.1674	73.9678	73.7615	78.7116	82.1736	78.1267	76.5225	82.4661	66.4264	73.8645	...	4
1501	140.4699	152.7676	151.7677	137.7691	142.5298	152.4040	158.0444	162.7558	150.5999	137.5581	...	20
1502	67.6205	68.4355	79.8274	62.3159	58.4411	72.3489	77.1096	71.7511	67.1106	65.9797	...	11
1503	2.8148	2.9288	2.9288	3.0428	3.1568	4.2707	4.2707	3.2708	5.2706	12.7537	...	1
1504	34.0442	34.0442	34.0442	34.0550	34.7668	33.7669	34.7668	35.7667	35.8807	37.8805	...	15
...	...	...	...	...	...	...	...	...	...	...	...	
9995	161.8006	82.6146	104.2211	107.4704	104.2966	103.8406	108.3949	118.5896	126.0619	130.2464	...	23
9996	3.9996	3.9996	4.9995	0.0000	65.4360	174.2267	166.7759	153.7556	153.0716	150.1859	...	5
9997	40.9959	38.7681	38.6541	39.8389	41.7247	41.8387	43.8385	45.8383	46.9522	48.3650	...	5
9998	31.6719	31.5687	29.9387	31.0095	33.2759	36.9335	37.6884	41.3722	87.6880	146.9377	...	18
9999	140.5443	141.4302	142.3161	142.3161	142.7290	143.1419	143.7289	144.3159	144.3159	144.4299	...	19

8500 rows × 1024 columns

In [16]:
```
train_images_list
```

Out[16]:
```
[array([[54.1674, 73.9678, 73.7615, ..., 65.3062, 63.7795, 62.0076],
        [53.0857, 71.5164, 71.3487, ..., 67.9039, 68.893 , 63.3494],
        [61.6442, 70.1961, 72.0282, ..., 70.5553, 70.5768, 66.7018],
        ...,
        [41.093 , 42.6154, 44.6582, ..., 29.3778, 36.203 , 33.8612],
        [42.2068, 40.8543, 40.9081, ..., 34.3064, 37.3169, 38.6157],
        [34.5666, 35.2246, 36.2783, ..., 41.5768, 37.5341, 39.5447]]),
 array([[140.4699, 152.7676, 151.7677, ..., 137.0188, 139.5455, 145.246 ],
        [141.7687, 154.7674, 153.7675, ..., 139.3175, 141.5453, 146.2459],
        [141.7687, 153.7675, 153.7675, ..., 138.9046, 140.5454, 145.246 ],
        ...,
        [188.9624, 190.7342, 191.6201, ..., 198.9569, 195.5443, 191.3706],
        [189.9623, 191.7341, 192.62  , ..., 207.0377, 206.0378, 205.4508],
        [185.9627, 186.7346, 188.6204, ..., 202.049 , 201.0491, 199.8643]]),
 array([[ 67.6205,  68.4355,  79.8274, ..., 166.0417, 167.4545, 169.0522],
        [ 82.4358,  79.3051,  78.4084, ..., 167.4761, 169.4759, 170.7747],
        [ 87.1642,  87.403 ,  62.6318, ..., 173.1273, 173.1273, 174.7142],
        ...,
        [118.7544, 119.6403, 107.5428, ..., 112.2882, 112.1742, 117.0597],
        [ 70.8097,  58.8047,  52.7945, ..., 113.8859, 102.3431,  99.1307],
        [107.5212, 102.5972, 104.842 , ..., 115.0168,  98.2834, 105.8975]]),
 array([[  2.8148,   2.9288,   2.9288, ...,  35.1168,  30.0572,  21.5742],
        [  1.9289,   2.9288,   3.9287, ...,  30.1173,  25.3458,  17.9767],
        [  3.8147,   3.8147,   4.8146, ...,  23.118 ,  17.2326,  12.4503],
        ...,
        [  8.3582,  10.8418,  22.9223, ...,  15.0757,  14.8908,  12.5212],
        [ 48.1109,  47.7088,  44.4318, ...,  14.7768,  13.4071,  10.7386],
        [130.6098, 112.3666,  84.4556, ...,  13.347 ,   8.9668,   4.2985]]),
 array([[ 34.0442,  34.0442,  34.0442, ...,  50.5372,  50.1243,  50.2383],
        [ 34.1582,  35.0441,  35.0441, ...,  54.0099,  52.0101,  52.1241],
        [ 36.044 ,  36.044 ,  35.0441, ...,  54.8958,  52.896 ,  52.896 ],
        ...,
        [ 98.2954,  96.8396,  59.1037, ..., 160.098 , 164.0976, 168.7982],
        [126.5098, 129.8901, 111.8641, ..., 161.9838, 166.9833, 172.9827],
        [134.623 , 142.7039, 136.5627, ..., 158.9841, 164.9835, 169.983 ]]),
 array([[ 31.61  ,  14.3128,  45.9138, ...,  93.6613,  74.5815, 119.7035],
```

```
       [ 33.3325,  15.9105,  33.4312, ..., 119.6542,  89.9498, 103.0795],
       [ 45.4022,  21.6218,  49.5652, ..., 116.8609, 102.0904, 104.0902],
       ...,
       [168.5398, 188.6688, 217.6874, ...,  59.9573,  42.2795,  56.235 ],
       [180.7343, 199.9235, 217.1991, ...,  66.7394,  41.0238,  61.3916],
       [201.1837, 199.4998, 213.6725, ...,  72.7496,  62.4301,  83.2   ]]),
array([[ 58.0606,  58.1746,  60.1744, ...,  47.3822,  29.498 ,  31.4978],
       [ 58.0606,  58.1746,  60.1744, ...,  10.3796,   6.8961,   5.8962],
       [ 59.1745,  60.1744,  62.1742, ...,   2.5267,   2.0429,   1.3419],
       ...,
       [ 56.3041,  62.3035,  68.3029, ..., 109.6623,  91.6579,  66.2583],
       [ 63.3034,  70.3027,  71.8896, ..., 108.0045,  88.8862,  64.0305],
       [ 68.3029,  70.3027,  71.3026, ..., 104.6458,  85.2995,  60.5039]]),
array([[105.9724, 103.9726, 103.9726, ...,  77.6655,  79.3664,  80.6652],
       [104.9725, 105.9724, 104.9725, ...,  75.6657,  78.6654,  80.6652],
       [104.9725, 107.9722, 108.9721, ...,  77.6655,  79.6653,  82.665 ],
       ...,
       [ 19.2431,  19.656 ,  23.5416, ..., 157.866 , 154.8663, 152.3935],
       [ 16.4714,  17.1724,  18.6992, ..., 152.7355, 154.5073, 154.0944],
       [ 91.3356,  84.9772,  96.3181, ..., 159.0769, 158.7349, 153.0945]]),
array([[124.3439, 118.936 , 105.0497, ..., 242.2827, 239.169 , 238.582 ],
       [138.8846, 138.6934, 127.9225, ..., 242.4245, 240.2506, 238.7346],
       [196.5206, 199.155 , 190.8694, ..., 240.8098, 240.7389, 231.5935],
       ...,
       [119.435 ,  38.8282,  44.2298, ..., 139.1477, 138.5607, 134.974 ],
       [132.9651, 106.527 , 151.1096, ..., 136.963 , 133.5612, 131.8603],
       [175.4061, 186.1061, 209.4458, ..., 136.604 , 132.2023, 130.6755]]),
array([[239.3118, 242.3115, 242.3115, ..., 248.4527, 248.9257, 237.6988],
       [237.198 , 240.3117, 240.4257, ..., 248.4527, 248.9257, 238.4707],
       [234.3123, 237.312 , 237.312 , ..., 246.4529, 247.6269, 236.8129],
       ...,
       [ 66.9933,  70.3628,  68.5479, ..., 106.0064, 108.0493, 122.4608],
       [ 64.7655,  67.7221,  61.3206, ...,  99.2028, 117.0592, 130.688 ],
       [ 63.1355,  63.5053,  59.6906, ...,  91.2036, 121.3469, 134.0467]]),
array([[199.7994, 217.9394, 162.2268, ..., 146.4115, 143.2269, 164.8612],
       [201.0982, 201.5712, 145.4888, ..., 143.4935, 138.8252, 138.7498],
       [204.2119, 183.6161, 137.8639, ..., 159.9003, 138.38  , 134.8965],
       ...,
       [133.9523, 138.2077, 142.6911, ..., 136.2276, 150.7163, 187.7898],
       [132.3546, 151.1355, 168.5036, ..., 139.896 , 166.0846, 193.6043],
       [136.9843, 146.6521, 169.8347, ..., 147.2328, 184.7515, 181.9367]]),
array([[199.7036, 174.9313, 150.0723, ..., 155.5819, 146.2945, 117.5409],
       [201.9575, 166.0508, 152.5174, ..., 148.4425, 134.4916,  98.1179],
       [180.4759, 146.6121, 147.1143, ..., 150.0694, 144.791 , 120.6549],
       ...,
       [119.2199, 106.1068, 104.9324, ...,  85.1229,  91.3503,  86.2198],
       [ 93.3024,  99.0813, 117.6156, ...,  72.6341,  69.9764,  61.2053],
       [ 98.7426, 111.8553, 130.4082, ...,  80.9322,  69.5034,  63.031 ]]),
array([[160.897 , 170.1734, 167.9456, ...,   0.    ,   0.    ,   0.    ],
       [176.6611, 175.4672, 162.8491, ...,   0.    ,   0.    ,   0.    ],
       [183.4063, 171.7404, 154.5788, ...,   0.    ,   0.    ,   0.    ],
       ...,
       [ 81.7289,  93.3073,  94.3457, ..., 126.2431, 124.6993, 121.6287],
       [ 78.3549,  84.4591,  78.0082, ..., 126.542 , 124.5853, 121.1126],
       [ 76.3381,  80.3177,  64.4424, ..., 126.4711, 125.5143, 119.3408]]),
array([[ 62.2234,  15.8906,   5.3693, ...,   6.739 ,  13.8307,  35.9578],
       [ 43.8123,  17.6516,   9.657 , ...,   4.1522,   5.7714,  26.7415],
       [ 25.8141,  26.3518,  11.2331, ...,   5.1521,   4.0705,  15.2265],
       ...,
       [103.8308,  14.7966,   1.6947, ...,  50.5309,  48.83  ,  45.9721],
       [134.501 ,  83.7727,  60.547 , ...,  57.5733,  54.3564,  55.1283],
       [125.1321, 102.1838, 106.3575, ...,  82.5385,  82.1364,  65.91  ]]),
array([[223.9776, 228.9771, 226.9773, ..., 229.977 , 231.9768, 230.9769],
       [227.9772, 229.977 , 230.9769, ..., 229.977 , 229.977 , 229.977 ],
       [228.9771, 230.9769, 231.9768, ..., 229.977 , 228.9771, 227.9772],
       ...,
```

```
       [237.9762, 239.976 , 239.976 , ..., 248.9751, 249.975 , 246.9753],
       [237.9762, 240.9759, 240.9759, ..., 247.9752, 249.975 , 248.9751],
       [239.976 , 240.9759, 241.9758, ..., 248.9751, 249.975 , 247.9752]]),
array([[215.1392, 208.314 , 209.488 , ..., 117.6525, 108.4963, 107.1975],
       [221.6224, 212.9114, 212.9006, ..., 111.6962, 101.839 , 101.611 ],
       [215.7971, 206.439 , 205.1294, ..., 108.2127,  98.3555,  96.8395],
       ...,
       [ 77.1979,  77.013 ,  77.0839, ...,  75.9269,  77.4106,  75.9269],
       [ 81.8662,  76.899 ,  75.9099, ...,  82.0834,  80.1545,  87.5774],
       [ 76.654 ,  73.2414,  75.611 , ...,  89.8699,  87.6421,  90.3922]]),
array([[164.3261, 167.7897, 178.4358, ..., 180.198 , 220.8054, 200.1818],
       [185.4023, 156.5997, 163.3925, ..., 180.0301, 191.1413, 196.7539],
       [161.0536, 151.2548, 162.2599, ..., 164.2319, 175.7038, 197.5706],
       ...,
       [129.5838, 136.8712, 138.0191, ..., 147.8655, 153.2779, 164.3029],
       [142.5564, 154.7293, 148.089 , ..., 141.0726, 144.1432, 159.0986],
       [154.5614, 151.4585, 156.4302, ..., 130.2184, 128.0399, 146.046 ]]),
array([[ 5.2105,  5.2105,  5.2105, ...,  8.2102,  8.2102,  8.2102],
       [ 4.2106,  4.2106,  4.2106, ...,  7.2103,  7.2103,  8.2102],
       [ 3.7977,  5.2105,  3.2107, ...,  5.2105,  5.2105,  6.2104],
       ...,
       [26.6446, 34.2479, 27.9666, ..., 20.243 , 20.0905, 22.6557],
       [30.1173, 29.1344, 29.2654, ..., 17.8627, 18.5637, 23.5632],
       [34.6608, 31.1342, 42.905 , ..., 22.5634, 17.097 , 27.2532]]),
array([[224.9712, 231.4992, 248.5701, ..., 227.215 , 226.8838, 231.8232],
       [217.559 , 222.799 , 241.5708, ..., 170.0654, 176.1465, 183.7759],
       [217.673 , 218.9134, 239.571 , ..., 162.1865, 169.6696, 175.2283],
       ...,
       [145.049 , 110.7796,  18.841 , ..., 155.4592, 158.9444, 166.2596],
       [149.0486, 121.5505,  27.4981, ..., 147.9608, 150.1302, 147.6143],
       [136.5229, 123.3223,  43.0405, ..., 137.5767, 138.5012, 123.3286]]),
array([[150.2162, 122.7243, 118.5506, ..., 131.6111, 123.0418, 137.9864],
       [152.4009, 127.5605, 118.0345, ..., 125.792 , 124.1619, 114.6251],
       [151.1452, 119.3055, 124.9907, ..., 121.76  , 115.5325, 105.9571],
       ...,
       [217.6459, 160.7782, 139.8557, ..., 144.1219, 155.0068, 158.4795],
       [237.1476, 179.2925, 164.2617, ..., 150.0181, 154.3767, 167.0549],
       [254.6325, 233.5008, 207.1955, ..., 152.8822, 145.3129, 168.3151]]),
array([[246.2204, 242.21  , 242.8078, ..., 237.0364, 233.8626, 239.6062],
       [248.7901, 244.0787, 246.7903, ..., 235.2798, 234.6928, 238.7355],
       [251.5295, 246.4052, 249.0028, ..., 236.8021, 234.9163, 236.4862],
       ...,
       [188.2235, 182.6154, 187.2128, ..., 191.6253, 195.2012, 186.3269],
       [185.2238, 177.6159, 187.3268, ..., 188.3267, 190.6038, 180.2027],
       [184.8325, 179.3384, 183.2348, ..., 171.9262, 175.6161, 175.6269]]),
array([[48.0186, 46.2037, 49.3174, ..., 45.5135, 46.0512, 43.5784],
       [47.8014, 47.2745, 48.6873, ..., 45.1715, 43.8234, 43.2364],
       [47.1004, 46.9864, 47.1004, ..., 45.5844, 43.8234, 43.2364],
       ...,
       [65.3003, 65.1863, 65.1863, ..., 40.2138, 52.8518, 60.8986],
       [69.001 , 68.4633, 68.8654, ..., 44.0177, 58.1547, 59.7569],
       [67.9302, 66.1045, 67.3925, ..., 47.2376, 49.6486, 48.3436]]),
array([[211.1359, 207.8373, 209.2501, ..., 218.0138, 177.6866, 137.3809],
       [208.1362, 204.1366, 204.1366, ..., 205.3911, 169.3284, 132.9191],
       [204.8376, 201.1369, 202.1368, ..., 198.4009, 157.4158, 135.908 ],
       ...,
       [106.8645, 112.1629, 111.163 , ...,  91.008 ,  81.4497,  74.0591],
       [115.5755, 111.277 , 114.2767, ...,  59.0175,  54.833 ,  55.1427],
       [ 96.4634,  90.0511, 102.1639, ...,  46.333 ,  44.931 ,  47.9307]]),
array([[239.5073, 231.79  , 207.0483, ...,  69.9639,  48.949 ,  54.4754],
       [220.1564, 221.449 , 148.327 , ...,  50.6607,  25.2872,  45.2852],
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...]
```

In [17]:

```
train_labels
```

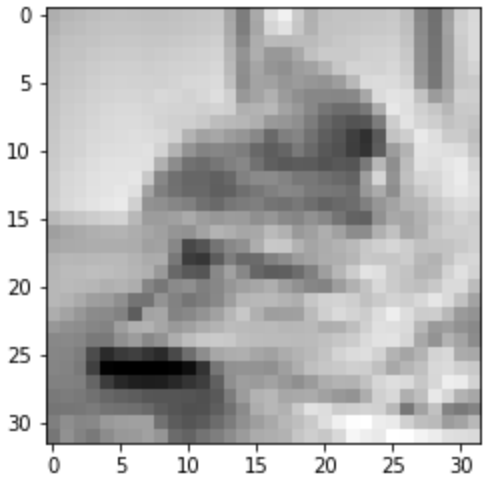
Out[17]:

	id	label
1500	7486	cat
1501	7488	cat
1502	7489	horse
1503	7490	cat
1504	7493	cat
...	...	...
9995	49979	horse
9996	49980	cat
9997	49983	cat
9998	49984	cat
9999	49987	horse

8500 rows × 2 columns

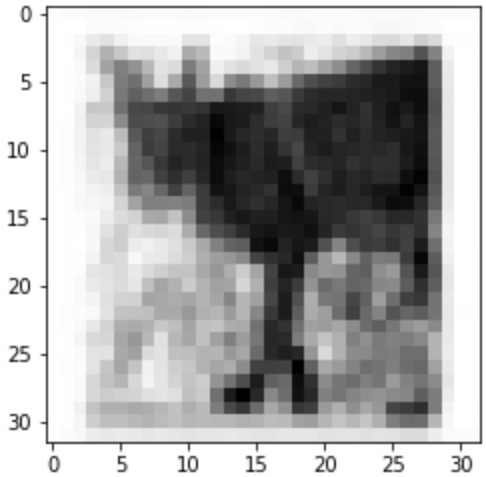
In [18]:
```
# show a random train data information and content
rand_index = 512

print("Image type is: ", train_labels["label"].values[rand_index])

pplt.imshow(train_images_list[rand_index], cmap="gray")

print("Minimum and maximum pixel numbers: **{}, {}**".format(min(train_data_frame.iloc[ran
```

```
Image type is:  cat
Minimum and maximum pixel numbers: **0.0, 254.27349999999998**
```



In [19]:
```
# show a random test data information and content
rand_index = 497

print("Image type is: ", test_labels["label"].values[rand_index])

pplt.imshow(test_images_list[rand_index], cmap="gray")

print("Minimum and maximum pixel numbers: **{}, {}**".format(min(test_data_frame.iloc[rand
```

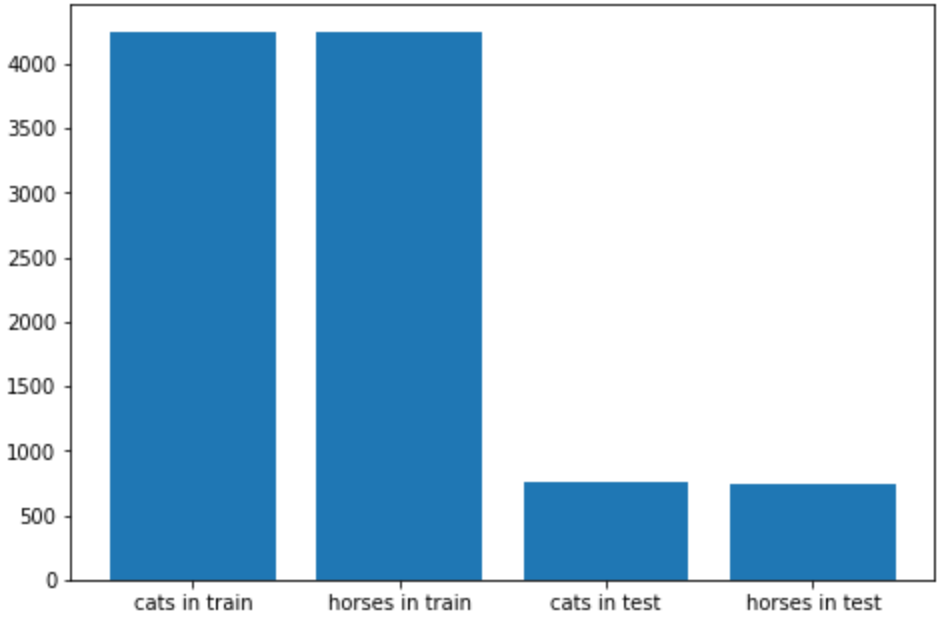
```
Image type is:  cat
Minimum and maximum pixel numbers: **19.4172, 254.97449999999998**
```



In [20]:
```
figure = pplt.figure()
axis = figure.add_axes([0,0,1,1])
names = ['cats in train','horses in train','cats in test','horses in test']

numbers = [train_labels['label'].value_counts()['cat'], train_labels['label'].value_counts
```

```
print("difference between train = {}".format(train_labels['label'].value_counts()['cat']-t
print("difference between test = {}".format(test_labels['label'].value_counts()['cat']-tes

axis.bar(names, numbers)
pplt.show()
```

```
difference between train = -4
difference between test = 4
```



In [21]:

```
# normalize train data
print(train_data_frame)

temp_data_frame = train_data_frame.copy()
temp_column = temp_data_frame.columns

for column in temp_column:
    temp_data_frame[column] = (train_data_frame[column]-min(train_data_frame[column])) / (

train_data_frame = temp_data_frame

print(train_data_frame)
```

```
          0         1         2         3         4         5         6     \
1500   54.1674   73.9678   73.7615   78.7116   82.1736   78.1267   76.5225
1501  140.4699  152.7676  151.7677  137.7691  142.5298  152.4040  158.0444
1502   67.6205   68.4355   79.8274   62.3159   58.4411   72.3489   77.1096
1503    2.8148    2.9288    2.9288    3.0428    3.1568    4.2707    4.2707
1504   34.0442   34.0442   34.0442   34.0550   34.7668   33.7669   34.7668
...        ...       ...       ...       ...       ...       ...       ...
9995  161.8006   82.6146  104.2211  107.4704  104.2966  103.8406  108.3949
9996    3.9996    3.9996    4.9995    0.0000   65.4360  174.2267  166.7759
9997   40.9959   38.7681   38.6541   39.8389   41.7247   41.8387   43.8385
9998   31.6719   31.5687   29.9387   31.0095   33.2759   36.9335   37.6884
9999  140.5443  141.4302  142.3161  142.3161  142.7290  143.1419  143.7289

          7         8         9     ...      1014      1015      1016  \
1500   82.4661   66.4264   73.8645  ...   42.9961   40.9575   39.3491
1501  162.7558  150.5999  137.5581  ...  205.1519  205.1519  205.1519
1502   71.7511   67.1106   65.9797  ...  114.2664  113.4514  115.4620
1503    3.2708    5.2706   12.7537  ...   17.9614   17.9614   17.9614
1504   35.7667   35.8807   37.8805  ...  151.5073  150.0236  148.6539
...        ...       ...       ...  ...       ...       ...       ...
9995  118.5896  126.0619  130.2464  ...  238.7157  238.7157  238.7157
```

```
9996  153.7556  153.0716  150.1859  ...   51.9966   64.8382   84.7284
9997   45.8383   46.9522   48.3650  ...   58.8434   58.6154   59.0283
9998   41.3722   87.6880  146.9377  ...  184.1393  121.9069  147.0075
9999  144.3159  144.3159  144.4299  ...  193.9501  191.5374  186.2390

          1017      1018      1019      1020      1021      1022      1023
1500   41.8542   41.7510   45.1207   47.0603   41.5768   37.5341   39.5447
1501  204.1520  202.1630  201.1631  202.1630  202.0490  201.0491  199.8643
1502  111.7721  103.8869  104.1149  113.9999  115.0168   98.2834  105.8975
1503   17.2496   16.6626   15.7767   15.4177   13.3470    8.9668    4.2985
1504  147.0562  146.0563  148.0561  153.0556  158.9841  164.9835  169.9830
...        ...       ...       ...       ...       ...       ...       ...
9995  238.7157  238.7157  238.7157  238.7157  236.0041  226.7277  253.9746
9996   74.8973   49.1432   22.7374    7.2443   12.4718   10.9989    2.9997
9997   60.8001   61.0281   61.9140   62.7999   61.8000   62.3978   65.1695
9998  178.1289  217.7674  224.1967  215.7461  225.0872  232.7058  217.7998
9999  187.6518  184.0543  184.9402  183.4565  189.8365  182.2394  181.3535

[8500 rows x 1024 columns]
          0         1         2         3         4         5         6     \
1500  0.212442  0.290099  0.289290  0.308704  0.322282  0.306410  0.300118
1501  0.550917  0.599149  0.595227  0.540325  0.558996  0.597723  0.619844
1502  0.265205  0.268401  0.313080  0.244401  0.229204  0.283750  0.302421
1503  0.011040  0.011487  0.011487  0.011934  0.012381  0.016750  0.016750
1504  0.133520  0.133520  0.133520  0.133562  0.136354  0.132432  0.136354
...        ...       ...       ...       ...       ...       ...       ...
9995  0.634576  0.324011  0.408751  0.421495  0.409047  0.407259  0.425121
9996  0.015686  0.015686  0.019608  0.000000  0.256637  0.683310  0.654089
9997  0.160784  0.152047  0.151600  0.156247  0.163643  0.164090  0.171933
9998  0.124216  0.123811  0.117418  0.121618  0.130507  0.144852  0.147812
9999  0.551209  0.554684  0.558158  0.558158  0.559778  0.561397  0.563699

          7         8         9     ...      1014      1015      1016  \
1500  0.323429  0.260522  0.289694  ...  0.168629  0.160634  0.154326
1501  0.638322  0.590647  0.539497  ...  0.804598  0.804598  0.804598
1502  0.281405  0.263205  0.258770  ...  0.448148  0.444952  0.452837
1503  0.012828  0.020671  0.050020  ...  0.070444  0.070444  0.070444
1504  0.140276  0.140723  0.148566  ...  0.594206  0.588387  0.583015
...        ...       ...       ...  ...       ...       ...       ...
9995  0.465104  0.494410  0.510821  ...  0.936234  0.936234  0.936234
9996  0.603023  0.600341  0.589023  ...  0.203929  0.254293  0.332301
9997  0.179776  0.184145  0.189686  ...  0.230782  0.229887  0.231507
9998  0.162260  0.343909  0.576284  ...  0.722187  0.478114  0.576558
9999  0.566001  0.566001  0.566448  ...  0.760665  0.751202  0.730422

          1017      1018      1019      1020      1021      1022      1023
1500  0.164151  0.163746  0.176962  0.184569  0.163063  0.147207  0.155093
1501  0.800676  0.792875  0.788954  0.792875  0.792428  0.788507  0.783860
1502  0.438366  0.407440  0.408335  0.447103  0.451091  0.385464  0.415326
1503  0.067652  0.065350  0.061876  0.060468  0.052346  0.035167  0.016859
1504  0.576749  0.572827  0.580670  0.600278  0.623529  0.647059  0.666667
...        ...       ...       ...       ...       ...       ...       ...
9995  0.936234  0.936234  0.936234  0.936234  0.925599  0.889217  0.996078
9996  0.293744  0.192738  0.089175  0.028412  0.048914  0.043137  0.011765
9997  0.238456  0.239350  0.242824  0.246299  0.242377  0.244722  0.255592
9998  0.698615  0.854075  0.879291  0.846148  0.882783  0.912663  0.854202
9999  0.735963  0.721854  0.725328  0.719509  0.744531  0.714736  0.711261

[8500 rows x 1024 columns]
```

In [22]:

```
# normalize test data
print(test_data_frame)

temp_data_frame = test_data_frame.copy()
temp_column = temp_data_frame.columns
```

```
for column in temp_column:
    temp_data_frame[column] = (test_data_frame[column]-min(test_data_frame[column])) / (ma

test_data_frame = temp_data_frame

print(train_data_frame)
```

```
          0         1         2         3         4         5         6     \
0      33.3602   33.9410   41.0497   75.4608   76.3467   43.2729   41.9571
1     123.9615  102.5400   92.7798   99.3384  100.7404  136.3239  171.0215
2     147.2348  171.4128  168.7784  172.6595  200.7384  212.2795  196.1052
3     203.0406  200.2258  200.2258  201.2257  200.9268  201.3397  202.2256
4     104.9850  135.1408  144.5159  129.9887   81.9487   55.4675   48.1092
...        ...       ...       ...       ...       ...       ...       ...
1495  198.4531  200.0292  190.5571  187.6606  184.9490  173.4170  180.4639
1496  156.0354  155.4098  150.3717  155.4035  157.2184  155.1046  150.4363
1497  105.8108   71.0423   75.2268   37.0134   55.2396   67.8793   44.1097
1498  186.7353  176.5083  195.9794  200.8649  203.5226  201.4088  197.5771
1499  150.1025  147.8038  146.1029  151.1024  153.5860  150.8852  151.8851

          7         8         9     ...      1014      1015      1016  \
0      56.1298   69.7325   77.1833  ...  119.9004  113.3032  136.6922
1     170.3205  142.5082   92.8014  ...  107.3428  108.1578  109.9018
2     135.0880  119.2252  133.2669  ...  155.4702  151.6232  124.9849
3     202.2256  201.9375  201.9375  ...  152.5182  148.1057  145.2200
4      51.9239   52.0379   53.1518  ...   70.0452   69.8711   64.9856
...        ...       ...       ...  ...       ...       ...       ...
1495  163.4099  141.2254  133.1167  ...  197.9253  198.9144  197.3598
1496  143.7682  138.8827  142.2953  ...  148.4940  143.7826  143.0708
1497   47.9953   63.6517   47.2018  ...  122.4385  110.6057   83.6389
1498  196.5602  196.2335  194.4617  ...  157.5578  155.6289  155.7106
1499  155.8847  155.8847  155.3578  ...  107.1930  155.6334  168.7847

          1017      1018      1019      1020      1021      1022      1023
0     140.8659  131.4108  149.7680  152.5828  127.6114  125.7256  123.3129
1     112.0156  113.7704  115.9982  117.9980  120.7697  120.4107  120.9376
2      75.6244   69.5864  122.7446  134.2875  131.9842  132.6852  134.7497
3     145.9210  145.5081  144.7362  138.6058  138.5996  139.6596  137.6660
4      62.0999   63.9426   58.0033   54.8788   48.4665   47.8903   50.4879
...        ...       ...       ...       ...       ...       ...       ...
1495  197.7018  198.0007  197.0008  198.0007  193.1152  188.6426  182.9852
1496  139.7722  145.4727  143.8750  137.3810  126.9691  117.7420  103.2273
1497   64.9244  120.1981  128.5887  121.2689  154.6489  242.1993  253.1165
1498  155.8955  152.7818  152.4829  152.8958  151.5970  151.5970  153.5968
1499  166.4429  170.8015  183.4582  186.3439  185.9849  187.0988  189.0986

[1500 rows x 1024 columns]
          0         1         2         3         4         5         6     \
1500  0.212442  0.290099  0.289290  0.308704  0.322282  0.306410  0.300118
1501  0.550917  0.599149  0.595227  0.540325  0.558996  0.597723  0.619844
1502  0.265205  0.268401  0.313080  0.244401  0.229204  0.283750  0.302421
1503  0.011040  0.011487  0.011487  0.011934  0.012381  0.016750  0.016750
1504  0.133520  0.133520  0.133520  0.133562  0.136354  0.132432  0.136354
...        ...       ...       ...       ...       ...       ...       ...
9995  0.634576  0.324011  0.408751  0.421495  0.409047  0.407259  0.425121
9996  0.015686  0.015686  0.019608  0.000000  0.256637  0.683310  0.654089
9997  0.160784  0.152047  0.151600  0.156247  0.163643  0.164090  0.171933
9998  0.124216  0.123811  0.117418  0.121618  0.130507  0.144852  0.147812
9999  0.551209  0.554684  0.558158  0.558158  0.559778  0.561397  0.563699

          7         8         9     ...      1014      1015      1016  \
1500  0.323429  0.260522  0.289694  ...  0.168629  0.160634  0.154326
1501  0.638322  0.590647  0.539497  ...  0.804598  0.804598  0.804598
1502  0.281405  0.263205  0.258770  ...  0.448148  0.444952  0.452837
```

```
1503  0.012828  0.020671  0.050020  ...  0.070444  0.070444  0.070444
1504  0.140276  0.140723  0.148566  ...  0.594206  0.588387  0.583015
...        ...       ...       ...  ...       ...       ...       ...
9995  0.465104  0.494410  0.510821  ...  0.936234  0.936234  0.936234
9996  0.603023  0.600341  0.589023  ...  0.203929  0.254293  0.332301
9997  0.179776  0.184145  0.189686  ...  0.230782  0.229887  0.231507
9998  0.162260  0.343909  0.576284  ...  0.722187  0.478114  0.576558
9999  0.566001  0.566001  0.566448  ...  0.760665  0.751202  0.730422

          1017      1018      1019      1020      1021      1022      1023
1500  0.164151  0.163746  0.176962  0.184569  0.163063  0.147207  0.155093
1501  0.800676  0.792875  0.788954  0.792875  0.792428  0.788507  0.783860
1502  0.438366  0.407440  0.408335  0.447103  0.451091  0.385464  0.415326
1503  0.067652  0.065350  0.061876  0.060468  0.052346  0.035167  0.016859
1504  0.576749  0.572827  0.580670  0.600278  0.623529  0.647059  0.666667
...        ...       ...       ...       ...       ...       ...       ...
9995  0.936234  0.936234  0.936234  0.936234  0.925599  0.889217  0.996078
9996  0.293744  0.192738  0.089175  0.028412  0.048914  0.043137  0.011765
9997  0.238456  0.239350  0.242824  0.246299  0.242377  0.244722  0.255592
9998  0.698615  0.854075  0.879291  0.846148  0.882783  0.912663  0.854202
9999  0.735963  0.721854  0.725328  0.719509  0.744531  0.714736  0.711261

[8500 rows x 1024 columns]
```

Dataloader

In [23]:

```
class Dataloader:
    '''
    This class prepares the dataset for the neural network.
    '''

    def __init__(self, data, labels, n_classes, batch_size=None, shuffle=False):
        '''
        This is the constructor. It gets dataset information and initializes the
        Dataloader class fields.
            Parameters:
                data: features your dataset in pandas.Dataframe format.
                labels: labels of your dataset in pandas.Dataframe format.
                n_classes: number of classes you have in your dataset.
                batch_size: the number of samples that will be propagated through the netw
                shuffle: boolean value indicating whether or not the dataset should be shu
        '''

        assert len(data)==len(labels)
        self.__n_classes = n_classes
        self.__batch_size = batch_size
        self.__shuffle = shuffle
        self.__data = data
        self.__onehot_labels = self.__onehot(labels, self.__n_classes)

    def __onehot(self, labels, n_classes):
        '''
        This private method gets labels and provides one_hot vectors of labels.
        For categorical variables where no such ordinal relationship exists,
        the integer encoding is not enough.
        In this case, a one-hot encoding can be applied to the integer representation.
        This is where the integer encoded variable is removed, and a new binary variable i
        added for each unique integer value.
        example:
            red,    green,    blue
            1,      0,        0
            0,      1,        0
            0,      0,        1
```

```
                Parameters:
                        label: lables of your dataset in pandas.Dataframe format.
                        n_classes: number of classes you have in your dataset.

                Returns:
                    onehot_vectors: onehot vectors of the labels
        '''
        # TODO: Implement
        onehot_vectors = []
        for label in labels:
            row = [0] * n_classes
            if label == "horse":
                row[1] = 1
            else:
                row[0] = 1
            onehot_vectors.append(row)
        return onehot_vectors

    def __shuffle_dataset(self):
        '''
        This private method shuffles your dataset.
        It uses data and onehot_labels to shuffle them
        symmetrical.
        '''
        # TODO: Implement

    def __iter__(self):
        '''
        The __iter__() function returns an iterator for the
        given object (array, set, tuple, etc., or custom objects).
        This will return your dataset in the batch_size given. This should
        be used to provide data for the neural network.
        '''

        if self.__shuffle:
            self.__shuffle_dataset()

        if self.__batch_size==None:
            yield (np.matrix(self.__data), np.matrix(self.__onehot_labels))
            return

        for idx in range(0, len(self.__data), self.__batch_size):
            yield (np.matrix(self.__data[idx:idx+self.__batch_size]),
                   np.matrix(self.__onehot_labels[idx:idx+self.__batch_size]))
```

Activation Functions

In [24]:

```
from copy import deepcopy

class Identical:
    '''
    This is the Identical activation function. This activation function just
    return the value it gets.
    '''

    def __init__(self):
        pass
        '''
        This is the constructor. It does not have any fields
        as a result, there is no need to do anything in the constructor.
        '''
```

```
    def __val(self, matrix):
        '''
        This private method gets a matrix and uses the activity function on that.
        As this is an identical activity function, it just
        returns np.matrix of the input.

            Parameters:
                matrix: np.matrix of values
            Returns:
                identical_value: np.matrix of input with float datatypes
        '''
        identical_value = np.matrix(matrix, dtype=float)
        return identical_value

    def derivative(self, matrix):
        '''
        This method returns the derivation of the input.
        As the derivation of x is one, this method returns
        a matrix of one with the shape of the input matrix.

            Parameters:
                matrix: np.matrix of values
            Returns:
                identical_derivative: np.matrix of ones with matrix shape
        '''
        temp = np.matrix(matrix, dtype=float)
        identical_derivative = np.matrix(np.full(np.shape(temp), 1.))
        return identical_derivative

    def __call__(self, matrix):
        '''
        __call__ is a special function in Python that, when implemented inside a class,
        gives its instances (objects) the ability to behave like a function.
        Here we return the _value method output.

            Parameters:
                matrix: np.matrix of values
            Returns:
                __val(matrix): __val return value for the input matrix
        '''
        return self.__val(matrix)


class Relu:
    '''
    This is the Relu activation function.
    The rectified linear activation function or ReLU for short
    is a piecewise linear function that will output the input directly
    if it is positive, otherwise, it will output zero.
    '''

    def __init__(self):
        pass
        '''
        This is the constructor. It does not have any fields
        as a result, there is no need to do anything in the constructor.
        '''

    def __val(self, matrix):
        '''
        This private method gets a matrix and uses the activity function on that.
        It will set 0 in the matrix if the value is less than 0 else, it returns the value

            Parameters:
                matrix: np.matrix of values
            Returns:
```

```
            relu_value: np.matrix of relu activation function result
        '''
        relu_value = np.array(matrix, dtype=float)
        relu_value[relu_value < 0] = 0
        return relu_value

    def derivative(self, matrix):
        '''
        Returns the derivation value of relu function on input matrix.

            Parameters:
                matrix: np.matrix of values
            Returns:
                relu_derivative: np.matrix of relu activation function derivation result
        '''
        relu_derivative = np.array([np.array(x, copy=True) for x in matrix])
        relu_derivative[relu_derivative < 0] = 0
        relu_derivative[relu_derivative > 0] = 1
        return relu_derivative

    def __call__(self, matrix):
        '''
        __call__ is a special function in Python that, when implemented inside a class,
        gives its instances (objects) the ability to behave like a function.
        Here we return the _relu method output.

            Parameters:
                matrix: np.matrix of values
            Returns:
                __relu(matrix): __relu return value for the input matrix
        '''
        return self.__val(matrix)


class LeakyRelu:
    '''
    This is the Leaky Relu activation function.
    Leaky Rectified Linear Unit, or Leaky ReLU,
    is a type of activation function based on a ReLU,
    but it has a small slope for negative values instead
    of a flat slope.
    '''

    def __init__(self, negative_slope=0.01):
        '''
        This is the constructor.
        It sets negative_slope field.
            Parameters:
                negative_slope: slope for negative input values
        '''
        self.negative_slope = 0.01

    def __val(self, matrix):
        '''
        This private method gets a matrix and uses the activity function on that.
        It will set negative_slope*value in the matrix if the value is less than 0, else i
        returns the value itself.

            Parameters:
                matrix: np.matrix of values
            Returns:
                relu_value: np.matrix of relu activation function result
        '''
        leacky_relu_value = np.array([np.array(x, copy=True) for x in matrix])
        return np.where(leacky_relu_value > 0, leacky_relu_value, leacky_relu_value * 0.01
```

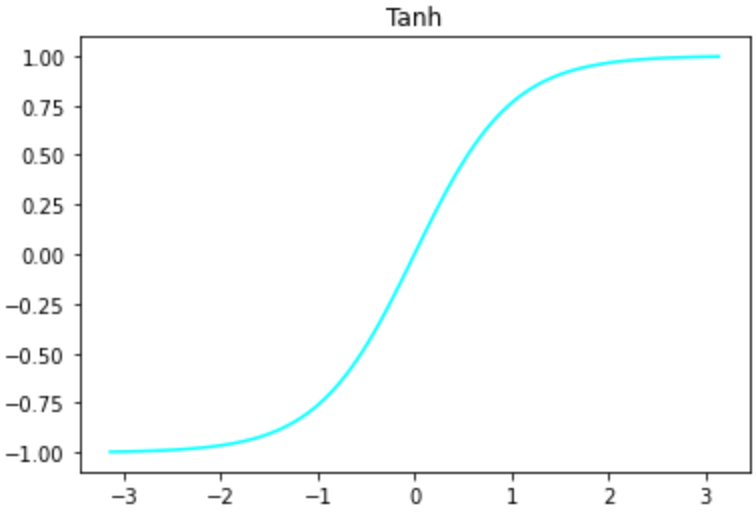
```
    def derivative(self, matrix):
        '''
        Returns the derivation value of leaky relu function on input matrix.

            Parameters:
                matrix: np.matrix of values
            Returns:
                leacky_relu_derivative: np.matrix of leaky relu activation function deriva
        '''
        leacky_relu_derivative = np.array(matrix, dtype=float)
        leacky_relu_derivative[leacky_relu_derivative > 0] = 1
        leacky_relu_derivative[leacky_relu_derivative < 0] = 0.01
        return leacky_relu_derivative

    def __call__(self, matrix):
        '''
        __call__ is a special function in Python that, when implemented inside a class,
        gives its instances (objects) the ability to behave like a function.
        Here we return the _val method output.

            Parameters:
                matrix: np.matrix of values
            Returns:
                __val(matrix): __val return value for the input matrix
        '''
        return self.__val(matrix)


class Sigmoid:
    '''
    A sigmoid function is a mathematical function having a
    characteristic "S"-shaped curve or sigmoid curve.
    It return S(x)=1/(1+e^-x)
    '''

    def __init__(self):
        pass

    def __val(self, matrix):
        '''
        Returns 1/(1+e^-x) of values

            Parameters:
                matrix: np.matrix of values
            Returns:
                sigmoid_value: np.matrix of relu activation function result
        '''
        return 1.0 / (1.0 + np.exp(-matrix))

    def derivative(self, matrix):
        '''
        Returns the derivation value of sigmoid function on input matrix.

            Parameters:
                matrix: np.matrix of values
            Returns:
                sigmoid_derivative: np.matrix of sigmoid activation function derivation re
        '''
        return np.multiply(self.__val(matrix), 1-self.__val(matrix))

    def __call__(self, matrix):
        '''
        __call__ is a special function in Python that, when implemented inside a class,
        gives its instances (objects) the ability to behave like a function.
        Here we return the _val method output.
```

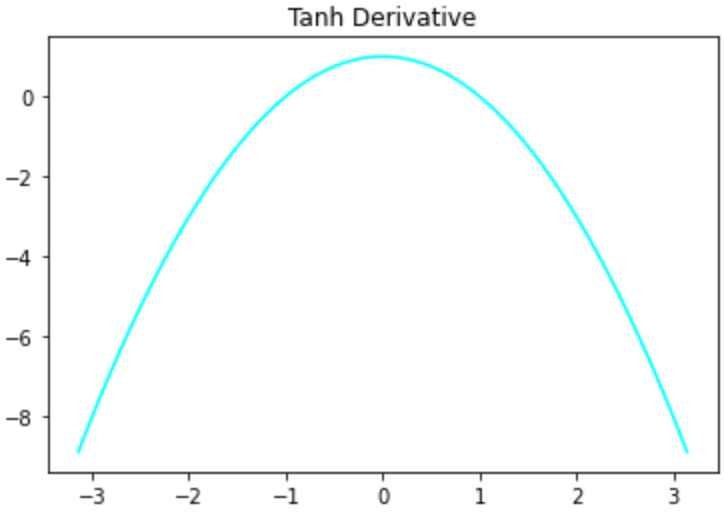
```
            Parameters:
                matrix: np.matrix of values
            Returns:
                __val(matrix): __val return value for the input matrix
        '''
        return self.__val(matrix)


class Softmax:
    '''
    The softmax function, also known as softargmax or normalized
    exponential function is a generalization of the logistic
    function to multiple dimensions. It is used in multinomial logistic
    regression and is often used as the last activation function of a neural
    network to normalize the output of a network to a probability distribution
    over predicted output classes, based on Luce's choice axiom.
    Softmax return (e^x_i / (Σe^x_j for j = 1, ..., J))
    '''

    def __init__(self):
        pass
        '''
        This is the constructor. It does not have any fields
        as a result, there is no need to do anything in the constructor.
        '''

    def __val(self, matrix):
        '''
        This private method gets a matrix and uses the softmax on that.
        Softmax return (e^x_i / (Σe^x_j for j = 1, ..., J))

            Parameters:
                matrix: np.matrix of values
            Returns:
                relu_value: np.matrix of relu activation function result
        '''
        value = np.zeros(matrix.shape)
        for i in range(len(matrix)):
            value[i] = np.exp(matrix[i] - np.max(matrix[i]))
            value[i] = value[i] / np.sum(value[i])
        return value

    def __call__(self, matrix):
        '''
        __call__ is a special function in Python that, when implemented inside a class,
        gives its instances (objects) the ability to behave like a function.
        Here we return the _val method output.

            Parameters:
                matrix: np.matrix of values
            Returns:
                __val(matrix): __val return value for the input matrix
        '''
        return self.__val(matrix)

class Tanh:

    def __init__(self):
        pass


    def __val(self, matrix):
        '''
        This private method gets a matrix and uses the activity function on that.
        It performs Tanh on the values.
```

```
            Parameters:
                matrix: np.matrix of values
            Returns:
                tanh_value: np.matrix of Tanh activation function result
        '''
        return np.tanh(matrix)

    def derivative(self, matrix):
        '''
        Returns the derivation value of Tanh function on input matrix.

            Parameters:
                matrix: np.matrix of values
            Returns:
                sigmoid_derivative: np.matrix of Tanh activation function derivation resul
        '''
        return 1 - np.multiply(matrix, matrix)

    def __call__(self, matrix):
        '''
        __call__ is a special function in Python that, when implemented inside a class,
        gives its instances (objects) the ability to behave like a function.
        Here we return the _val method output.

            Parameters:
                matrix: np.matrix of values
            Returns:
                __val(matrix): __val return value for the input matrix
        '''
        return self.__val(matrix)
```

In [25]:

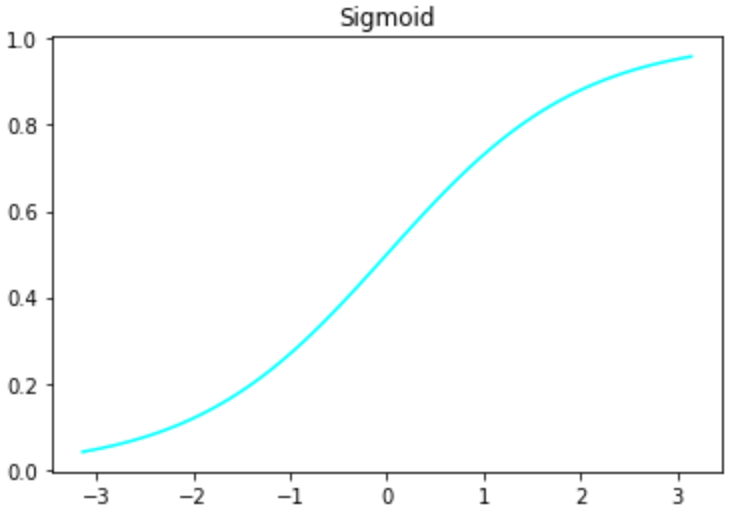
```
# check Tanh activation and its derivative
test_span = np.linspace(-np.pi, np.pi, 100)
function = Tanh()
diagram = function(test_span)

pplt.plot(test_span, diagram, color = 'cyan')
pplt.title("Tanh")
pplt.show()


diagram = function.derivative(test_span)

pplt.plot(test_span, diagram, color = 'cyan')
pplt.title("Tanh Derivative")
pplt.show()
```

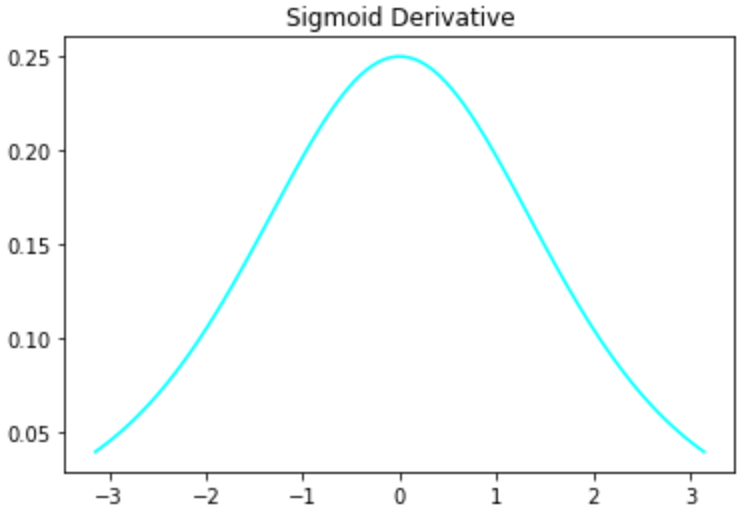




In [26]:

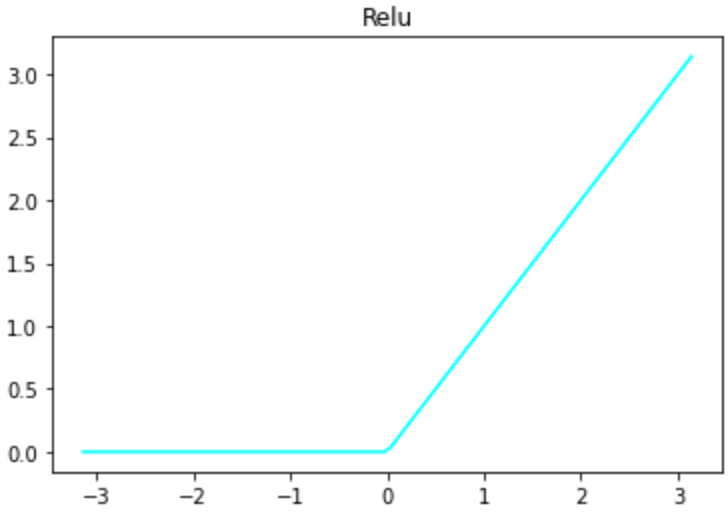
```
# check Sigmoid activation and its derivative
test_span = np.linspace(-np.pi, np.pi, 100)
function = Sigmoid()
diagram = function(test_span)

pplt.plot(test_span, diagram, color = 'cyan')
pplt.title("Sigmoid")
pplt.show()


diagram = function.derivative(test_span)

pplt.plot(test_span, diagram, color = 'cyan')
pplt.title("Sigmoid Derivative")
pplt.show()
```

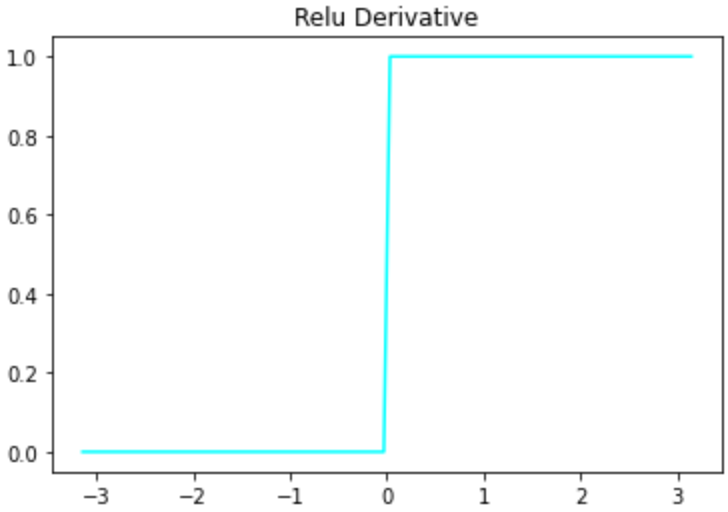




In [27]:

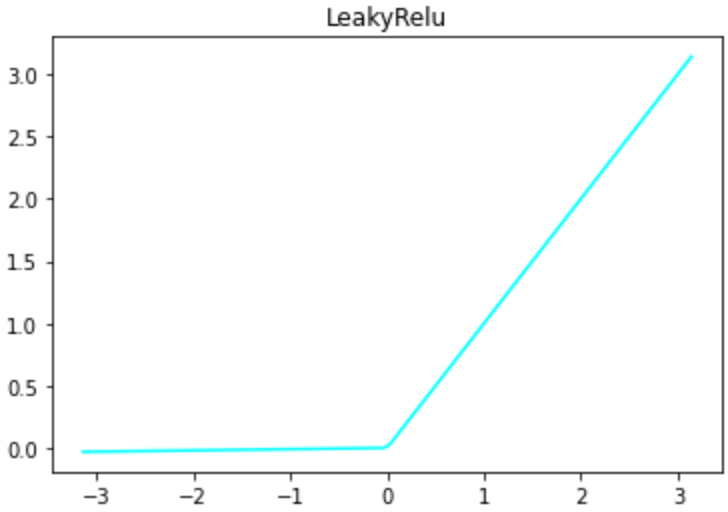
```
# check Relu activation and its derivative
test_span = np.linspace(-np.pi, np.pi, 100)
function = Relu()
diagram = function(test_span)

pplt.plot(test_span, diagram, color = 'cyan')
pplt.title("Relu")
pplt.show()


diagram = function.derivative(test_span)

pplt.plot(test_span, diagram, color = 'cyan')
pplt.title("Relu Derivative")
pplt.show()
```

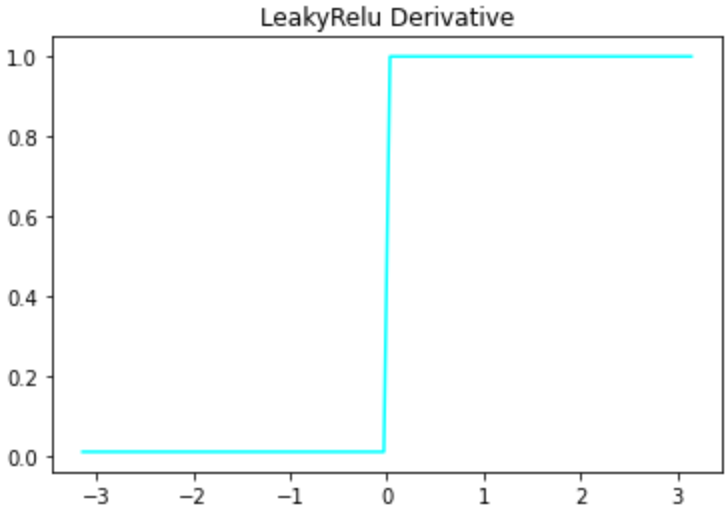


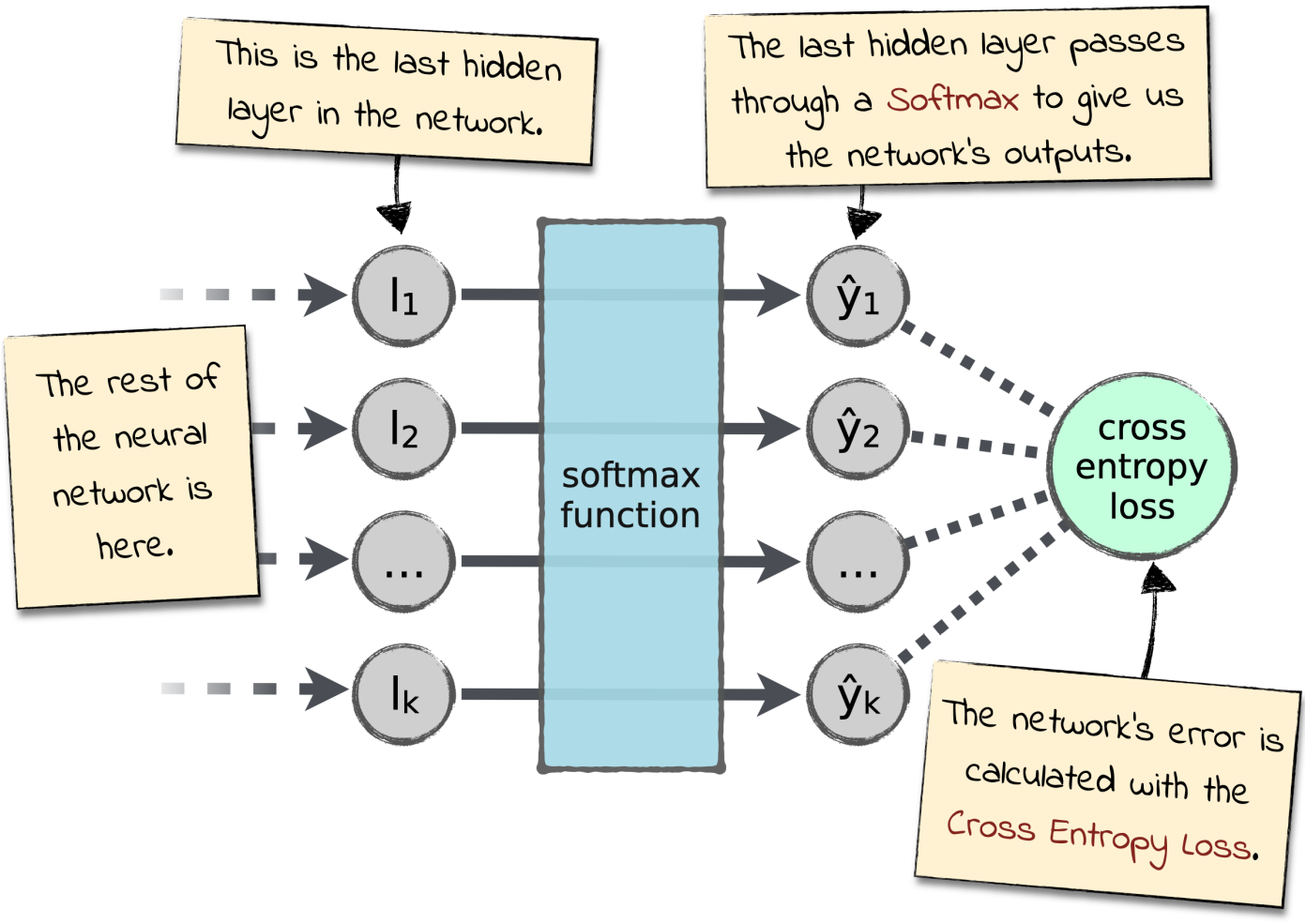


In [28]:

```
# check LeakyRelu activation and its derivative
test_span = np.linspace(-np.pi, np.pi, 100)
function = LeakyRelu()
diagram = function(test_span)

pplt.plot(test_span, diagram, color = 'cyan')
pplt.title("LeakyRelu")
pplt.show()


diagram = function.derivative(test_span)

pplt.plot(test_span, diagram, color = 'cyan')
pplt.title("LeakyRelu Derivative")
pplt.show()
```


LeakyRelu
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−3
−2
−1
0
1
2
3


LeakyRelu Derivative
1.0
0.8
0.6
0.4
0.2
0.0
−3
−2
−1
0
1
2
3


This is the last hidden layer in the network.
The last hidden layer passes through a Softmax to give us the network's outputs.
The rest of the neural network is here.
l_1
l_2
...
l_k
softmax function
$\hat{y}_1$
$\hat{y}_2$
...
$\hat{y}_k$
cross entropy loss
The network's error is calculated with the Cross Entropy Loss.

Loss Function

In [29]:

```
class CrossEntropy: #(with softmax)
    '''
    Cross-entropy is a measure of the difference between two probability
    distributions for a given random variable or set of events. You might
    recall that information quantifies the number of bits required to encode
    and transmit an event.
    The above image can help you.
    '''
    EPSILON = 1e-45

    def __init__(self):
        pass
        '''
        This is the constructor. It does not have any fields
        as a result, there is no need to do anything in the constructor.
        '''

    def __val(self, true_val, expected_val):
        '''
        L(y^, y) = - Σ (y^(k)log (y^)^(k)) for k in K
        Parameters:
            true_val: calculated values (generated by neural network)
            expected_val: real values in dataset
        Returns:
            cross_entropy_value: cross entropy of inputs
        '''
        assert np.shape(true_val)==np.shape(expected_val)
        function = Softmax()

        softmax_log_value = np.log(np.clip(function(true_val), self.EPSILON, 1 - self.EPSI
        cross_entropy_value = np.multiply(-expected_val, softmax_log_value).sum(axis = 1)

        return cross_entropy_value

    def derivative(self, true_val, expected_val):
        '''
        Returns derivation of cross entropy.
            Parameters:
                true_val: calculated values (generated by neural network)
                expected_val: real values in dataset
            Returns:
                cross_entropy_derivative: cross entropy derivation of inputs
        '''
        assert np.shape(true_val)==np.shape(expected_val)
        function = Softmax()

        cross_entropy_derivative = function(true_val + self.EPSILON) - expected_val
        return cross_entropy_derivative

    def __call__(self, true_val, expected_val):
        '''
        __call__ is a special function in Python that, when implemented inside a class,
        gives its instances (objects) the ability to behave like a function.
        Here we return the _val method output.

            Parameters:
                true_val: calculated values (generated by neural network)
                expected_val: real values in dataset
            Returns:
                __val(matrix): __val return value for the input matrix
        '''
        return self.__val(true_val, expected_val)
```

Layer

In [95]:

```
sys.setrecursionlimit(500000)

class Layer:
    '''
    The layer class is used to define neural network layers.
    It stores all needed information for each layer, such as neurons count,
    weight matrix, bias, the output after applying the activation function, etc.
    '''

    DEFAULT_LOW, DEFAULT_HIGH, DEFAULT_MEAN, DEFAULT_VAR = 0, 0.05, 0., 1.

    def __init__(self, input_size, output_size, activation=Identical(), initial_weight='ur
                 **initializing_parameters):
        '''
        Parameters:
            input_size: the size of the input of this layer.
            output_size: the size of the output after this layer.
            activation: the activation function. It can be initialized to either of the pr
                                default is an Identical activation function.
            initial_weight: either normal or uniform. It defines the method for weight ini
        '''

        assert type(initial_weight)==str, 'Undefined activation function!'

        self.__weight_initializer_dict = {'uniform':self.__uniform_weight, 'normal':self._

        assert initial_weight in self.__weight_initializer_dict, 'Undefined weight initial


        self.__n_neurons = output_size
        weight_initializer = self.__weight_initializer_dict[initial_weight]
        self.__weight = weight_initializer(input_size, self.__n_neurons, **initializing_pa
        self.__bias = weight_initializer(1, self.__n_neurons, **initializing_parameters)
        self.__activation = activation

        self.__last_input = None
        self.__last_activation_input = None
        self.__last_activation_output = None
        self.__last_activation_derivative = None

    def forward(self, layer_input):
        '''
        It calculates the output of this layer for the layer_input argument.
        This method also stores __last_input, __last_activation_input, and __last_activati
        for future use in backpropagation.
        Parameters:
            layer_input: 2d np.matrix representing the input matrix of this layer.
        Returns:
            Final output of this layer after applying the activation function.
        '''

        # TODO: Implement

        assert np.ndim(layer_input)==2
        assert np.size(self.__weight,0) == np.size(layer_input,1)

        self.__last_input = layer_input
        self.__last_activation_input =  layer_input @ self.weight + self.bias
        self.__last_activation_output = self.activation(self.__last_activation_input)
        self.__last_activation_derivative = np.squeeze(self.activation.derivative(self.__l
```

```
        return self.__last_activation_output

    def update_weights(self, backprop_tensor, lr):
        '''
        It updates Layer weights according to the backpropagation matrix and learning rate
        This method updates bias values as well.
        Parameters:
            backprop_tensor: 2d np.matrix passed from the next layer containing gradient v
            lr: learning rate
        Returns:
            backprop_tensor to be used by the previous layer.
        '''
        assert np.ndim(backprop_tensor)==2
        assert np.size(backprop_tensor,0) == np.size(self.__last_activation_derivative,0)
        assert np.size(backprop_tensor,1) == self.__n_neurons

        transpose_input_matrix = self.__last_input.transpose()

        backprop_mult = np.multiply(backprop_tensor, self.__last_activation_derivative)
        backprop_matrix = np.matrix(np.tile(1, (1, backprop_mult.shape[0])))

        weight_product = np.matmul(transpose_input_matrix, backprop_mult)
        backprop_product = np.matmul(backprop_matrix, backprop_mult)

        backprop_tensor = np.matmul(backprop_mult, self.__weight.transpose())

        self.__weight -= weight_product * lr
        self.__bias -= backprop_product * lr

        return backprop_tensor

    def __uniform_weight(self, dim1, dim2, **initializing_parameters):
        '''
        Initializes weights as a uniform distribution between low and high values.
        It uses default low and high values unless low or high are passed in initializing_
        Parameters:
            dim1: the size of the first dimension of weights.
            dim2: the size of the second dimension of weights.
            initializing_parameters: other initializing parameters; it can include custom
        Returns:
            np.matrix with size (dim1, dim2) initialized using uniformly distributed value
        '''
        low, high = self.DEFAULT_LOW, self.DEFAULT_HIGH
        if 'low' in initializing_parameters.keys(): low = initializing_parameters['low']
        if 'high' in initializing_parameters.keys(): high = initializing_parameters['high'


        return np.random.uniform(low = low, high = high, size = (dim1, dim2))

    def __normal_weight(self, dim1, dim2, **initializing_parameters):
        '''
        Initializes weights as a normal distribution with mean and var values.
        It uses default mean and variance values unless mean or var are passed in initiali
        Parameters:
            dim1: the size of the first dimension of weights.
            dim2: the size of the second dimension of weights.
            initializing_parameters: other initializing parameters; it can include custom
        Returns:
            np.matrix with size (dim1, dim2) initialized using normaly distributed values.
        '''
        mean, var = self.DEFAULT_MEAN, self.DEFAULT_VAR
        if 'mean' in initializing_parameters.keys(): mean = initializing_parameters['mean'
        if 'var' in initializing_parameters.keys(): var = initializing_parameters['var']
```

```
        return np.random.normal(loc = mean, scale = math.sqrt(var), size=(dim1, dim2))

    @property
    def n_neurons(self): return self.__n_neurons

    @property
    def weight(self): return self.__weight

    @property
    def bias(self): return self.__bias

    @property
    def activation(self): return self.__activation
```

Feed Forward Neural Network

In [31]:

```
class FeedForwardNN:
    '''
    This class is used in order to implement custom feed-forward neural networks.
    The FeedForwardNN class stores a list of layers that determines all network layers.
    It also consists of the learning rate and loss function.
    '''
    def __init__(self, input_shape):
        '''
        Parameters:
            input_shape: the size of the first input to our neural network.
        '''

        self.__input_shape = input_shape
        self.__output_shape = None

        self.__layers_list = []

        self.__lr = None
        self.__loss = None


    def add_layer(self, n_neurons, activation=Relu(), initial_weight='uniform', **initiali
        '''
         This method adds a new custom layer to the layers_list.
         Parameters:
             n_neurons: number of neurons in this layer
             activation: the activation function of this layer, default is Relu
             initial_weight: either a uniform or normal, default is uniform
             initializing_parameters: other initializing parameters such as low, high, mea
        '''

        assert type(n_neurons)==int, "Invalid number of neurons for the layer!"
        assert n_neurons>0, "Invalid number of neurons for the layer!"

        n_prev_neurons = self.__input_shape if len(self.__layers_list)==0 else self.__laye
        new_layer = Layer(n_prev_neurons, n_neurons, activation, initial_weight, **initial
        self.__layers_list.append(new_layer)
        self.__output_shape = self.__layers_list[-1].n_neurons


    def set_training_param(self, loss=CrossEntropy(), lr=1e-3):
        '''
        This method is used to set training parameters.
        Parameters:
            loss: loss function, default is CrossEntropy
            lr: learning rate, default is 1e-3
```

```
        '''
        assert self.__layers_list, "Uncomplete model!"
        self.__loss = loss
        self.__lr = lr


    def forward(self, network_input):
        '''
        This method calculates the output of the complete neural network for a passed inpu
        Parameters:
            network_input: input of the neural network
        Returns:
            network_output: output of the neural network after forwarding the network_inpu
        '''
        assert type(self.__output_shape) != None, "Model is not compiled!"

        output = deepcopy(network_input)

        for layer in self.__layers_list:
            output = layer.forward(output)
            output = np.squeeze(output)

        return output


    def fit(self, epochs, trainloader, testloader=None, print_results=True):
        '''
        This method trains the neural network using specified parameters.
        It runs the __train private method epoch times and fills the log dictionary.
        Parameters:
            epochs: number of epochs to run
            trainloader: DataLoader for train data
            testloader: DataLoader for test data
            print_results: whether or not to print the results
        Returns:
            log: complete log of the training process as a dictionary consisting of
            train_accuracy, train_loss, test_accuracy, test_loss
        '''

        assert type(self.__output_shape) != None, "Model is not compiled!"
        assert type(self.__lr) != None and type(self.__loss) != None, "Training paramente

        log = {"train_accuracy":[], "train_loss":[], "test_accuracy":[], "test_loss":[]}

        for epoch in range(1, epochs+1):

            if print_results:
                print('Epoch {}:'.format(epoch))

            average_accuracy, average_loss = self.__train(trainloader)
            log['train_accuracy'].append(average_accuracy)
            log['train_loss'].append(average_loss)
            if print_results:
                print('\tTrain: Average Accuracy: {}\tAverage Loss: {}'.format(average_acc

            if type(testloader) != type(None):
                average_accuracy, average_loss = self.__test(testloader)
                log['test_accuracy'].append(average_accuracy)
                log['test_loss'].append(average_loss)
                if print_results:
                    print('\tTest: Average Accuracy: {}\tAverage Loss: {}'.format(average_

        return log


    def __train(self, trainloader):
```

```
        '''
        Trains the neural network for one epoch.
        Parameters:
            trainloader: A DataLoader consisting of train data
        Returns:
            batch_accuracy, batch_loss: mean of all batch_accuracies, batch_losses
        '''
        bach_accuracies, batch_losses = [], []
        for x_train, y_train in trainloader:
            batch_accuracy, batch_loss = self.__train_on_batch(x_train, y_train)
            bach_accuracies.append(batch_accuracy)
            batch_losses.append(batch_loss)
        return np.mean(bach_accuracies), np.mean(batch_losses)


    def __test(self, testloader):
        '''
        Test the neural network using a testloader.
        Parameters:
            testloader: A DataLoader of test data
        Returns:
            batch_accuracy, batch_loss: mean of all batch_accuracies, batch_losses
        '''
        bach_accuracies, batch_losses = [], []
        for x_test, y_test in testloader:
            batch_accuracy, batch_loss = self.__test_on_batch(x_test, y_test)
            bach_accuracies.append(batch_accuracy)
            batch_losses.append(batch_loss)
        return np.mean(bach_accuracies), np.mean(batch_losses)


    def __train_on_batch(self, x_batch, y_batch):
        '''
        Trains the neural network for one batch of train data.
        Parameters:
            x_batch: one batch data
            y_batch: labels for one batch
        Returns:
            (batch_accuracy, batch_average_loss)
        '''
        out_batch = self.forward(x_batch)

        batch_accuracy = self.__compute_accuracy(out_batch, y_batch)

        batch_average_loss = self.__update_weights(out_batch, y_batch)


        return (batch_accuracy, batch_average_loss)


    def __test_on_batch(self, x_batch, y_batch):
        '''
        Tests the neural network for one batch of test data.
        Parameters:
            x_batch: one batch data
            y_batch: labels for one batch
        Returns:
            (batch_accuracy, batch_average_loss)
        '''
        out_batch = self.forward(x_batch)

        cross_entropy = CrossEntropy()

        batch_average_loss = np.sum(cross_entropy(out_batch, y_batch)) / len(out_batch)

        batch_accuracy = self.__compute_accuracy(out_batch, y_batch)
```

```
        return (batch_accuracy, batch_average_loss)


    def __get_labels(self, outputs):
        '''
        Parameters:
            outputs: output of the neural network
        Returns:
            labels: labels generated from the outputs of the neural network
        '''
        labels = np.argmax(outputs, axis = 1)

        return labels


    def __compute_accuracy(self, output, expected_output):
        '''
        Computes accuracy by comparing output and expected_output.
        Parameters:
            output: actual output of the neural network
            expected_output: expected output
        Returns:
            accuracy
        '''
        labels = self.__get_labels(output)

        correct_count = 0
        n = len(output)

        for i in range(n):
            if (expected_output[i, labels[i]] == 1):
                correct_count += 1

        accuracy = correct_count/n
        return accuracy


    def __update_weights(self, output, y_train):
        '''
        Updates weights of all layers according to neural network output and labels.
        Parameters:
            output: output of the neural network
            y_train: y labels for one batch of train data
        Returns:
            None
        '''
        crossEntropy = CrossEntropy()

        derivative = crossEntropy.derivative(output, y_train)
        n = len(output)

        for layer in reversed(self.__layers_list):
             derivative = layer.update_weights(derivative, self.__lr)

        return np.sum(crossEntropy(output, y_train)) / n
```

Training Sample Code

In [86]:

```
TRAINLOADER = Dataloader(data = train_data_frame.values.tolist(), labels = train_labels['
                         n_classes = 2, batch_size = BATCH_SIZE, shuffle = False)
```

```
TESTLOADER = Dataloader(data = test_data_frame.values.tolist(), labels = test_labels['labe
                        n_classes = 2, batch_size = BATCH_SIZE, shuffle = False)
```

In [83]:

```
# Sample code for building and training a model

INPUT_SHAPE = 1024
LEARNING_RATE = 0.001
EPOCHS = 30
BATCH_SIZE = 32

network = FeedForwardNN(INPUT_SHAPE)
network.add_layer(n_neurons = 4, activation = Relu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 4, activation = Relu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 2, activation = Identical(), weight_initializer = 'uniform')
network.set_training_param(loss = CrossEntropy(), lr = LEARNING_RATE)

log = network.fit(EPOCHS, TRAINLOADER, TESTLOADER)
```

```
Epoch 1:
        Train: Average Accuracy: 0.503125       Average Loss: 0.6936219326596251
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6931807747766351
Epoch 2:
        Train: Average Accuracy: 0.5082941729323309     Average Loss: 0.69326494056308
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6930918720391889
Epoch 3:
        Train: Average Accuracy: 0.5093515037593985     Average Loss: 0.6932429947992685
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6929760406563952
Epoch 4:
        Train: Average Accuracy: 0.5113486842105264     Average Loss: 0.6932180797521781
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6928302583026352
Epoch 5:
        Train: Average Accuracy: 0.512406015037594      Average Loss: 0.693180539373886
        Test: Average Accuracy: 0.5009498480243161      Average Loss: 0.6926530468365671
Epoch 6:
        Train: Average Accuracy: 0.5139332706766918     Average Loss: 0.6931201905067854
        Test: Average Accuracy: 0.5002849544072948      Average Loss: 0.6924312703644862
Epoch 7:
        Train: Average Accuracy: 0.5158599624060151     Average Loss: 0.6930202936530518
        Test: Average Accuracy: 0.4962955927051672      Average Loss: 0.6921331561378135
Epoch 8:
        Train: Average Accuracy: 0.5183270676691729     Average Loss: 0.6928484671496141
        Test: Average Accuracy: 0.4903115501519757      Average Loss: 0.6916851976890498
Epoch 9:
        Train: Average Accuracy: 0.5237312030075187     Average Loss: 0.6925379762599104
        Test: Average Accuracy: 0.4869870820668693      Average Loss: 0.6909203098352886
Epoch 10:
        Train: Average Accuracy: 0.5318843984962406     Average Loss: 0.6918916890341654
        Test: Average Accuracy: 0.49287613981762923     Average Loss: 0.6893175811104888
Epoch 11:
        Train: Average Accuracy: 0.5407424812030075     Average Loss: 0.6902486999520389
        Test: Average Accuracy: 0.529540273556231       Average Loss: 0.6848375636684076
Epoch 12:
        Train: Average Accuracy: 0.5577302631578946     Average Loss: 0.6861849326657393
        Test: Average Accuracy: 0.5857712765957447      Average Loss: 0.6756004106734452
Epoch 13:
        Train: Average Accuracy: 0.5756578947368421     Average Loss: 0.6798822360065859
        Test: Average Accuracy: 0.6151215805471124      Average Loss: 0.6657120075617122
Epoch 14:
        Train: Average Accuracy: 0.5910479323308271     Average Loss: 0.6730828106888531
        Test: Average Accuracy: 0.6276595744680851      Average Loss: 0.6563823567615051
Epoch 15:
        Train: Average Accuracy: 0.6011043233082707     Average Loss: 0.6659321923832673
        Test: Average Accuracy: 0.6423822188449848      Average Loss: 0.6455855709386591
Epoch 16:
```

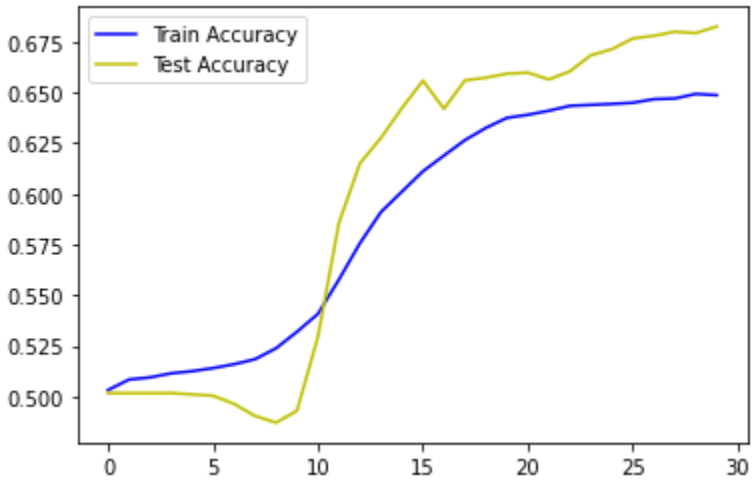
```
        Train: Average Accuracy: 0.6111607142857143     Average Loss: 0.6588384825700565
        Test: Average Accuracy: 0.6559650455927052      Average Loss: 0.6325664018952879
Epoch 17:
        Train: Average Accuracy: 0.6189144736842105     Average Loss: 0.6522034532679537
        Test: Average Accuracy: 0.6420022796352584      Average Loss: 0.6358668039613359
Epoch 18:
        Train: Average Accuracy: 0.6265507518796992     Average Loss: 0.6473750299317307
        Test: Average Accuracy: 0.6560600303951367      Average Loss: 0.6207619491192357
Epoch 19:
        Train: Average Accuracy: 0.6326127819548872     Average Loss: 0.6437171913420751
        Test: Average Accuracy: 0.6573898176291793      Average Loss: 0.6180501453884654
Epoch 20:
        Train: Average Accuracy: 0.6375469924812031     Average Loss: 0.640201712697974
        Test: Average Accuracy: 0.6593844984802432      Average Loss: 0.6147209243760726
Epoch 21:
        Train: Average Accuracy: 0.6390742481203008     Average Loss: 0.6382730501949744
        Test: Average Accuracy: 0.6598594224924013      Average Loss: 0.6111248996158709
Epoch 22:
        Train: Average Accuracy: 0.6410714285714286     Average Loss: 0.635304414775031
        Test: Average Accuracy: 0.6565349544072948      Average Loss: 0.6101577419443769
Epoch 23:
        Train: Average Accuracy: 0.6434915413533834     Average Loss: 0.6333540891497078
        Test: Average Accuracy: 0.6605243161094225      Average Loss: 0.60900497876819
Epoch 24:
        Train: Average Accuracy: 0.6439614661654135     Average Loss: 0.6321910861604038
        Test: Average Accuracy: 0.6685030395136778      Average Loss: 0.6083610115534918
Epoch 25:
        Train: Average Accuracy: 0.6444313909774436     Average Loss: 0.6311490943094753
        Test: Average Accuracy: 0.6714475683890577      Average Loss: 0.6102116373970483
Epoch 26:
        Train: Average Accuracy: 0.6450187969924812     Average Loss: 0.6300742275931062
        Test: Average Accuracy: 0.676766717325228       Average Loss: 0.6099132125789235
Epoch 27:
        Train: Average Accuracy: 0.6467810150375939     Average Loss: 0.6288809671205137
        Test: Average Accuracy: 0.6780965045592705      Average Loss: 0.6095110313994095
Epoch 28:
        Train: Average Accuracy: 0.6471334586466165     Average Loss: 0.6278728564911964
        Test: Average Accuracy: 0.6800911854103344      Average Loss: 0.6090942124126707
Epoch 29:
        Train: Average Accuracy: 0.6493656015037593     Average Loss: 0.6271142380231616
        Test: Average Accuracy: 0.679426291793313       Average Loss: 0.6088773647949245
Epoch 30:
        Train: Average Accuracy: 0.6487781954887217     Average Loss: 0.6263386795361428
        Test: Average Accuracy: 0.6826557750759878      Average Loss: 0.6086779409477509
```

In [84]:

```
train_acc, = pplt.plot(log['train_accuracy'], label="Train Accuracy", color='b')
test_acc, = pplt.plot(log['test_accuracy'], label="Test Accuracy", color='y')
pplt.legend(handles = [train_acc, test_acc])
```

Out[84]:

```
<matplotlib.legend.Legend at 0x7fd764cc8ca0>
```

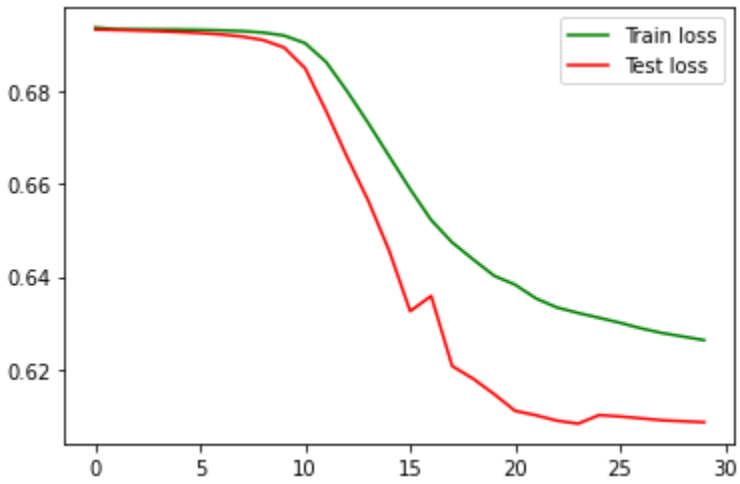


In [85]:

```
train_loss, = pplt.plot(log['train_loss'], label="Train loss", color='g')
test_loss, = pplt.plot(log['test_loss'], label="Test loss", color='r')
pplt.legend(handles = [train_loss, test_loss])
```

Out[85]:

```
<matplotlib.legend.Legend at 0x7fd764c35610>
```



In [55]:

```
learn_rate_range = np.linspace(0, 1, 20)
print("this is the learning rate: {}".format(learn_rate_range))
learn_rate_holder = [learn_rate_range[0], 0.50]

print("learn rate before test: {}".format(learn_rate_holder))

EPOCHS = 5

for rate in learn_rate_range:
    network.set_training_param(loss = CrossEntropy(), lr = rate)
    log = network.fit(EPOCHS, TRAINLOADER, TESTLOADER, print_results = False)
    print("learn rate is: {}".format(learn_rate_holder))
    if max(log['test_accuracy']) > learn_rate_holder[1]:
        learn_rate_holder = [rate, max(log['test_accuracy'])]

print("this is the best learning rate so far: {}".format(learn_rate_holder))
```

```
this is the learning rate: [0.         0.05263158 0.10526316 0.15789474 0.21052632 0.26315
789
 0.31578947 0.36842105 0.42105263 0.47368421 0.52631579 0.57894737
 0.63157895 0.68421053 0.73684211 0.78947368 0.84210526 0.89473684
 0.94736842 1.        ]
learn rate before test: [0.0, 0.5]
learn rate is: [0.0, 0.5]
learn rate is: [0.0, 0.6681231003039514]
```

```
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
learn rate is: [0.0, 0.6681231003039514]
this is the best learning rate so far: [0.0, 0.6681231003039514]
```

In [70]:

```
# Sample code for building and training a model
# learning rate is 10 times less than first try


INPUT_SHAPE = 1024
LEARNING_RATE = 0.0001
EPOCHS = 30
BATCH_SIZE = 32

network = FeedForwardNN(INPUT_SHAPE)
network.add_layer(n_neurons = 4, activation = Relu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 4, activation = Relu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 2, activation = Identical(), weight_initializer = 'uniform')
network.set_training_param(loss = CrossEntropy(), lr = LEARNING_RATE)

log = network.fit(EPOCHS, TRAINLOADER, TESTLOADER)
```

```
Epoch 1:
        Train: Average Accuracy: 0.4984727443609023     Average Loss: 0.6932416024708485
        Test: Average Accuracy: 0.5396086626139818      Average Loss: 0.6931054362514183
Epoch 2:
        Train: Average Accuracy: 0.5004229323308271     Average Loss: 0.6931410996319651
        Test: Average Accuracy: 0.5583206686930091      Average Loss: 0.6929968928906965
Epoch 3:
        Train: Average Accuracy: 0.5074483082706767     Average Loss: 0.693060395848438
        Test: Average Accuracy: 0.5592705167173252      Average Loss: 0.692895270163938
Epoch 4:
        Train: Average Accuracy: 0.5143327067669173     Average Loss: 0.6929838589392946
        Test: Average Accuracy: 0.5550911854103344      Average Loss: 0.6927981094344853
Epoch 5:
        Train: Average Accuracy: 0.5236137218045113     Average Loss: 0.6929108665669528
        Test: Average Accuracy: 0.5530965045592705      Average Loss: 0.6927050364908727
Epoch 6:
        Train: Average Accuracy: 0.5273731203007519     Average Loss: 0.6928411658660704
        Test: Average Accuracy: 0.5570858662613982      Average Loss: 0.6926157576602721
Epoch 7:
        Train: Average Accuracy: 0.5311325187969925     Average Loss: 0.692774527575526
        Test: Average Accuracy: 0.5570858662613982      Average Loss: 0.6925300006651851
Epoch 8:
        Train: Average Accuracy: 0.5360667293233082     Average Loss: 0.692710735864864
        Test: Average Accuracy: 0.5543313069908814      Average Loss: 0.6924475126639591
Epoch 9:
        Train: Average Accuracy: 0.5401080827067669     Average Loss: 0.6926495882002986
        Test: Average Accuracy: 0.5543313069908814      Average Loss: 0.6923680597446504
Epoch 10:
```

```
        Train: Average Accuracy: 0.5430451127819549     Average Loss: 0.6925908953688773
        Test: Average Accuracy: 0.5557560790273557      Average Loss: 0.6922914261606812
Epoch 11:
        Train: Average Accuracy: 0.5456296992481202     Average Loss: 0.6925344813154235
        Test: Average Accuracy: 0.551766717325228       Average Loss: 0.6922174133111599
Epoch 12:
        Train: Average Accuracy: 0.5459821428571429     Average Loss: 0.6924801827781695
        Test: Average Accuracy: 0.5530965045592705      Average Loss: 0.6921458385364435
Epoch 13:
        Train: Average Accuracy: 0.5477443609022556     Average Loss: 0.6924278487421262
        Test: Average Accuracy: 0.5492021276595744      Average Loss: 0.6920765338038115
Epoch 14:
        Train: Average Accuracy: 0.5479793233082706     Average Loss: 0.6923773397450586
        Test: Average Accuracy: 0.5465425531914894      Average Loss: 0.69200934435231
Epoch 15:
        Train: Average Accuracy: 0.5466400375939849     Average Loss: 0.6923285270784881
        Test: Average Accuracy: 0.543218085106383       Average Loss: 0.6919441273543305
Epoch 16:
        Train: Average Accuracy: 0.5472274436090225     Average Loss: 0.6922812919268797
        Test: Average Accuracy: 0.5445478723404256      Average Loss: 0.6918807506373374
Epoch 17:
        Train: Average Accuracy: 0.5462875939849624     Average Loss: 0.6922355244840762
        Test: Average Accuracy: 0.5418882978723404      Average Loss: 0.6918190914947949
Epoch 18:
        Train: Average Accuracy: 0.5457001879699248     Average Loss: 0.6921911230791199
        Test: Average Accuracy: 0.5372340425531915      Average Loss: 0.6917590356025527
Epoch 19:
        Train: Average Accuracy: 0.5452302631578947     Average Loss: 0.692147993335665
        Test: Average Accuracy: 0.5352393617021277      Average Loss: 0.691700476046581
Epoch 20:
        Train: Average Accuracy: 0.5454652255639098     Average Loss: 0.6921060473814253
        Test: Average Accuracy: 0.5365691489361702      Average Loss: 0.6916433124603071
Epoch 21:
        Train: Average Accuracy: 0.5446428571428571     Average Loss: 0.6920652031173311
        Test: Average Accuracy: 0.5372340425531915      Average Loss: 0.6915874502646789
Epoch 22:
        Train: Average Accuracy: 0.543703007518797      Average Loss: 0.6920253835505965
        Test: Average Accuracy: 0.5412234042553191      Average Loss: 0.6915328000010729
Epoch 23:
        Train: Average Accuracy: 0.5447133458646617     Average Loss: 0.6919865161917792
        Test: Average Accuracy: 0.5378989361702128      Average Loss: 0.6914792767457472
Epoch 24:
        Train: Average Accuracy: 0.5462406015037594     Average Loss: 0.6919485325130349
        Test: Average Accuracy: 0.5365691489361702      Average Loss: 0.6914267995942777
Epoch 25:
        Train: Average Accuracy: 0.5454182330827068     Average Loss: 0.6919113674629142
        Test: Average Accuracy: 0.5353343465045592      Average Loss: 0.6913752912048668
Epoch 26:
        Train: Average Accuracy: 0.5458881578947369     Average Loss: 0.6918749590319908
        Test: Average Accuracy: 0.5333396656534954      Average Loss: 0.691324677390298
Epoch 27:
        Train: Average Accuracy: 0.5454182330827068     Average Loss: 0.6918392478631482
        Test: Average Accuracy: 0.5326747720364742      Average Loss: 0.6912748867493782
Epoch 28:
        Train: Average Accuracy: 0.546358082706767      Average Loss: 0.6918041769002766
        Test: Average Accuracy: 0.5313449848024316      Average Loss: 0.691225850329823
Epoch 29:
        Train: Average Accuracy: 0.5458881578947369     Average Loss: 0.6917696910693368
        Test: Average Accuracy: 0.5340995440729484      Average Loss: 0.6911775013155927
Epoch 30:
        Train: Average Accuracy: 0.5460056390977444     Average Loss: 0.6917357369860798
        Test: Average Accuracy: 0.5327697568389058      Average Loss: 0.6911297747326272
```

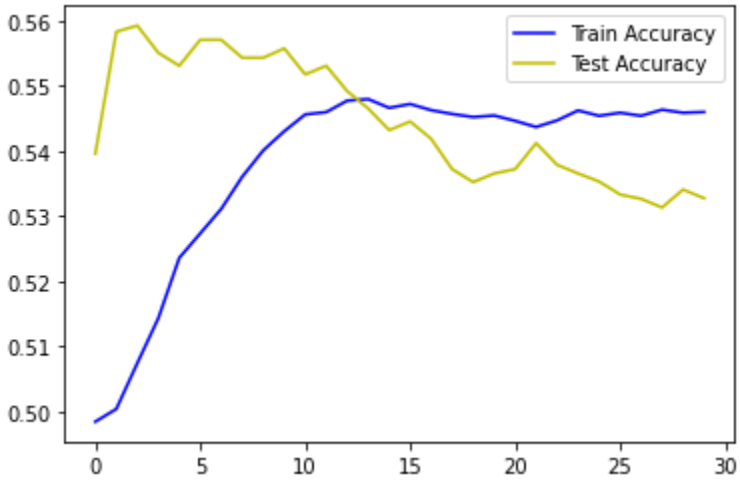
In [71]:

```
train_acc, = pplt.plot(log['train_accuracy'], label="Train Accuracy", color='b')
test_acc, = pplt.plot(log['test_accuracy'], label="Test Accuracy", color='y')
```

```
pplt.legend(handles = [train_acc, test_acc])
```

Out[71]:

```
<matplotlib.legend.Legend at 0x7fd77eeca8e0>
```

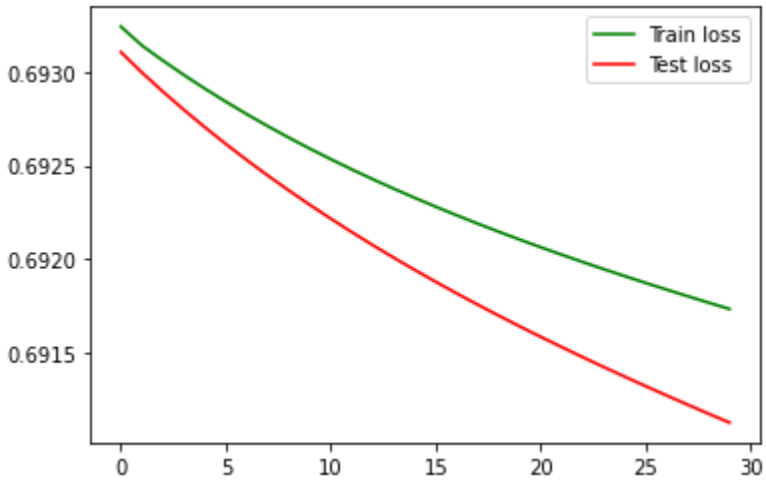


In [72]:

```
train_loss, = pplt.plot(log['train_loss'], label="Train loss", color='g')
test_loss, = pplt.plot(log['test_loss'], label="Test loss", color='r')
pplt.legend(handles = [train_loss, test_loss])
```

Out[72]:

```
<matplotlib.legend.Legend at 0x7fd77efc5670>
```



In [87]:

```
# Sample code for building and training a model
# learning rate is 10 times larger than first try

# Sample code for building and training a model

INPUT_SHAPE = 1024
LEARNING_RATE = 0.01
EPOCHS = 30
BATCH_SIZE = 32

network = FeedForwardNN(INPUT_SHAPE)
network.add_layer(n_neurons = 4, activation = Relu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 4, activation = Relu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 2, activation = Identical(), weight_initializer = 'uniform')
network.set_training_param(loss = CrossEntropy(), lr = LEARNING_RATE)

log = network.fit(EPOCHS, TRAINLOADER, TESTLOADER)
```

```
Epoch 1:
        Train: Average Accuracy: 0.4930216165413534     Average Loss: 0.6952251274701153
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
```

```
Epoch 2:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 3:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 4:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 5:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 6:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 7:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 8:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 9:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 10:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 11:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 12:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 13:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 14:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 15:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 16:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 17:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 18:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 19:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 20:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 21:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 22:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 23:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
```

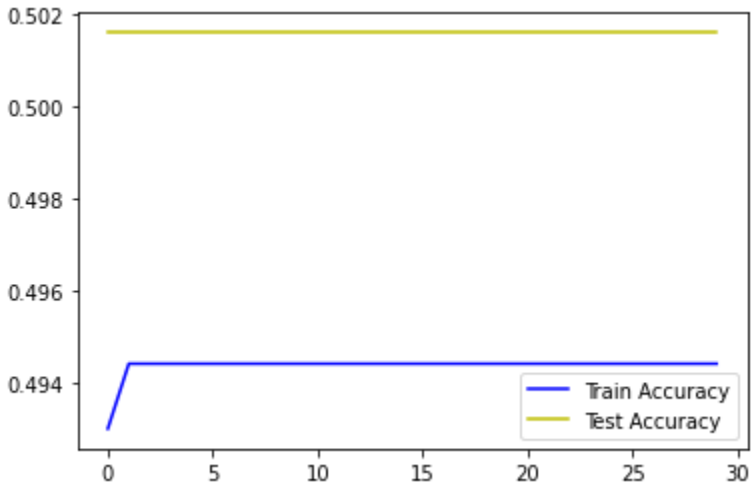
```
Epoch 24:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 25:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 26:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 27:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 28:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 29:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
Epoch 30:
        Train: Average Accuracy: 0.49443139097744365    Average Loss: 0.6950199065801795
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6936881682169781
```

In [88]:

```
train_acc, = pplt.plot(log['train_accuracy'], label="Train Accuracy", color='b')
test_acc, = pplt.plot(log['test_accuracy'], label="Test Accuracy", color='y')
pplt.legend(handles = [train_acc, test_acc])
```

Out[88]:

```
<matplotlib.legend.Legend at 0x7fd764cf5310>
```

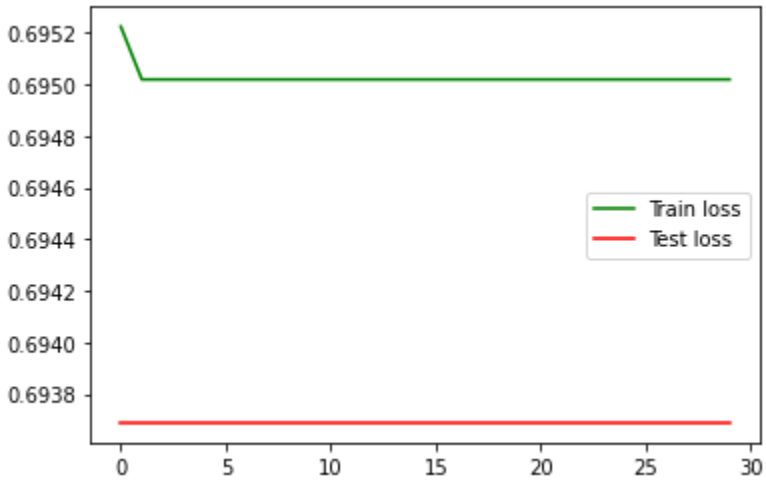


In [89]:

```
train_loss, = pplt.plot(log['train_loss'], label="Train loss", color='g')
test_loss, = pplt.plot(log['test_loss'], label="Test loss", color='r')
pplt.legend(handles = [train_loss, test_loss])
```

Out[89]:

```
<matplotlib.legend.Legend at 0x7fd775f8a880>
```

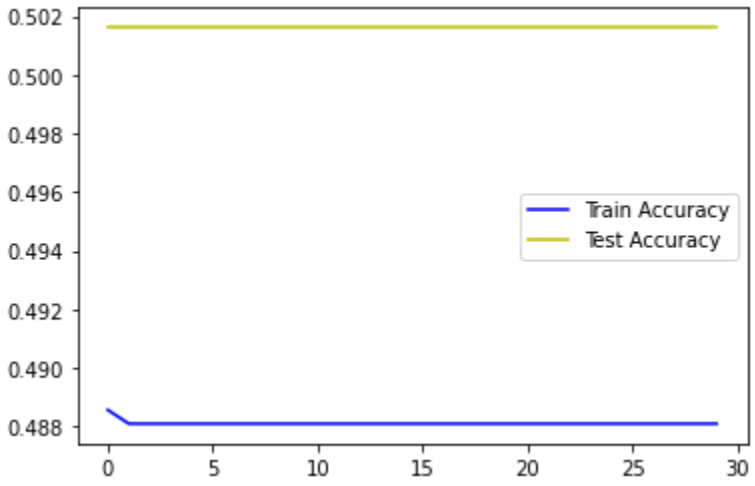


In [90]:
```
# test different activation functions

INPUT_SHAPE = 1024
LEARNING_RATE = 0.001
EPOCHS = 30
BATCH_SIZE = 32

TRAINLOADER = Dataloader(data = train_data_frame.values.tolist(), labels = train_labels['
                         n_classes = 2, batch_size = BATCH_SIZE, shuffle = False)
TESTLOADER = Dataloader(data = test_data_frame.values.tolist(), labels = test_labels['labe
                        n_classes = 2, batch_size = BATCH_SIZE, shuffle = False)
```

In [91]:
```
# sigmoid


network = FeedForwardNN(INPUT_SHAPE)
network.add_layer(n_neurons = 4, activation = Sigmoid(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 4, activation = Sigmoid(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 2, activation = Identical(), weight_initializer = 'uniform')
network.set_training_param(loss = CrossEntropy(), lr = LEARNING_RATE)

log = network.fit(EPOCHS, TRAINLOADER, TESTLOADER, print_results = False)
```

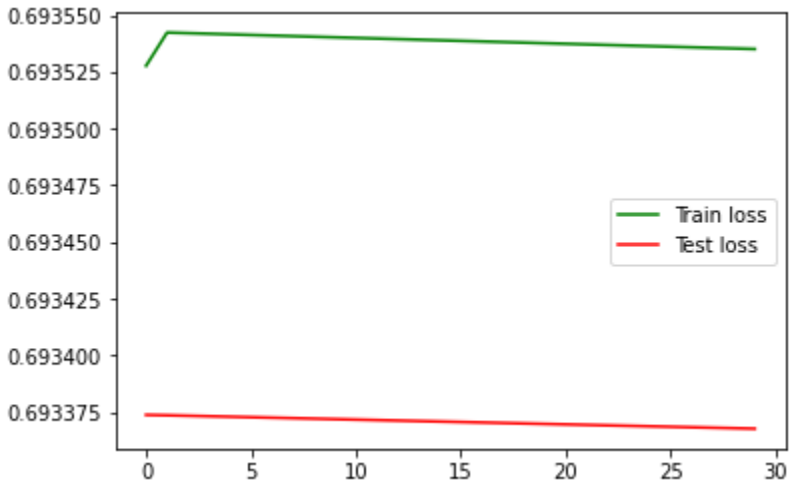
In [92]:
```
train_acc, = pplt.plot(log['train_accuracy'], label="Train Accuracy", color='b')
test_acc, = pplt.plot(log['test_accuracy'], label="Test Accuracy", color='y')
pplt.legend(handles = [train_acc, test_acc])
```

Out[92]:
```
<matplotlib.legend.Legend at 0x7fd7650b1b20>
```



In [93]:
```
train_loss, = pplt.plot(log['train_loss'], label="Train loss", color='g')
test_loss, = pplt.plot(log['test_loss'], label="Test loss", color='r')
pplt.legend(handles = [train_loss, test_loss])
```

Out[93]:
```
<matplotlib.legend.Legend at 0x7fd75396b970>
```



In [94]:
```
max_values = [max(log['train_accuracy']), max(log['train_loss']), max(log['test_accuracy']

print("Maximum values in each diagram are: \n train_acc: {} \n train_loss: {} \n test_acc
```

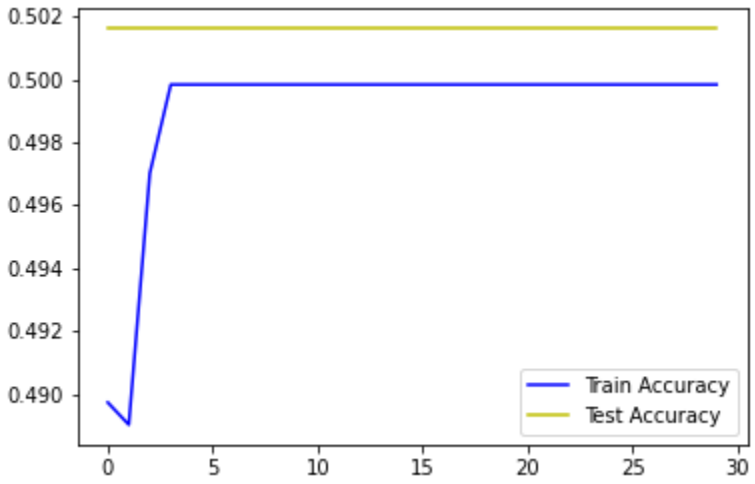
```
Maximum values in each diagram are:
 train_acc: 0.4885573308270677
 train_loss: 0.6935423055214439
 test_acc: 0.5016147416413373
 train_loss: 0.6933737603051517
```

In [96]:
```
# Tanh


network = FeedForwardNN(INPUT_SHAPE)
network.add_layer(n_neurons = 4, activation = Tanh(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 4, activation = Tanh(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 2, activation = Identical(), weight_initializer = 'uniform')
network.set_training_param(loss = CrossEntropy(), lr = LEARNING_RATE)

log = network.fit(EPOCHS, TRAINLOADER, TESTLOADER, print_results = False)
```

```
/tmp/ipykernel_122701/285069891.py:86: RuntimeWarning: overflow encountered in matmul
  backprop_tensor = np.matmul(backprop_mult, self.__weight.transpose())
/tmp/ipykernel_122701/3305472401.py:297: RuntimeWarning: overflow encountered in multiply
  return 1 - np.multiply(matrix, matrix)
/tmp/ipykernel_122701/285069891.py:83: RuntimeWarning: invalid value encountered in matmul
  weight_product = np.matmul(transpose_input_matrix, backprop_mult)
/tmp/ipykernel_122701/285069891.py:84: RuntimeWarning: invalid value encountered in matmul
  backprop_product = np.matmul(backprop_matrix, backprop_mult)
```

In [100…
```
train_acc, = pplt.plot(log['train_accuracy'], label="Train Accuracy", color='b')
test_acc, = pplt.plot(log['test_accuracy'], label="Test Accuracy", color='y')
pplt.legend(handles = [train_acc, test_acc])
```

Out[100…
```
<matplotlib.legend.Legend at 0x7fd761b4a400>
```

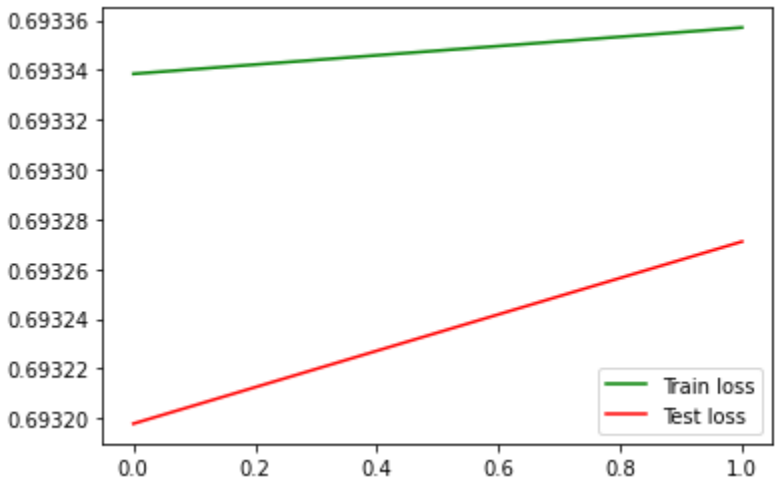


In [101…

```
train_loss, = pplt.plot(log['train_loss'], label="Train loss", color='g')
test_loss, = pplt.plot(log['test_loss'], label="Test loss", color='r')
pplt.legend(handles = [train_loss, test_loss])
```

Out[101…

```
<matplotlib.legend.Legend at 0x7fd77d065fd0>
```



In [102…

```
max_values = [max(log['train_accuracy']), max(log['train_loss']), max(log['test_accuracy']

print("Maximum values in each diagram are: \n train_acc: {} \n train_loss: {} \n test_acc:
```

```
Maximum values in each diagram are:
 train_acc: 0.49983552631578954
 train_loss: 0.6933570698140448
 test_acc: 0.5016147416413373
 train_loss: 0.6932710588589622
```

In [103…

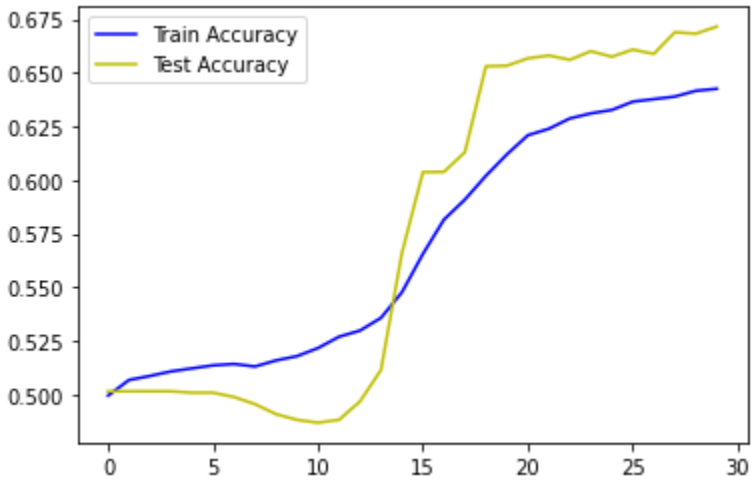
```
# Leaky ReLU

network = FeedForwardNN(INPUT_SHAPE)
network.add_layer(n_neurons = 4, activation = LeakyRelu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 4, activation = LeakyRelu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 2, activation = Identical(), weight_initializer = 'uniform')
network.set_training_param(loss = CrossEntropy(), lr = LEARNING_RATE)

log = network.fit(EPOCHS, TRAINLOADER, TESTLOADER, print_results = False)
```

In [104…

```
train_acc, = pplt.plot(log['train_accuracy'], label="Train Accuracy", color='b')
test_acc, = pplt.plot(log['test_accuracy'], label="Test Accuracy", color='y')
pplt.legend(handles = [train_acc, test_acc])
```

Out[104…

```
<matplotlib.legend.Legend at 0x7fd77cfdd8b0>
```

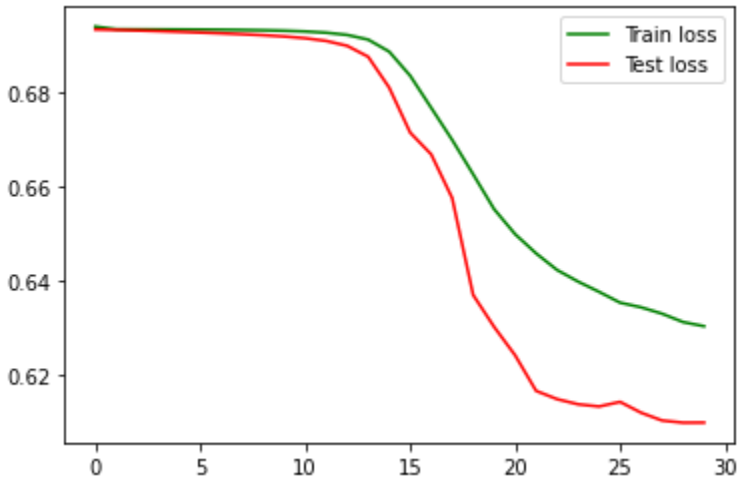


In [105…

```
train_loss, = pplt.plot(log['train_loss'], label="Train loss", color='g')
test_loss, = pplt.plot(log['test_loss'], label="Test loss", color='r')
pplt.legend(handles = [train_loss, test_loss])
```

Out[105…

```
<matplotlib.legend.Legend at 0x7fd77cf5be50>
```



In [106…

```
max_values = [max(log['train_accuracy']), max(log['train_loss']), max(log['test_accuracy']

print("Maximum values in each diagram are: \n train_acc: {} \n train_loss: {} \n test_acc
```

```
Maximum values in each diagram are:
 train_acc: 0.6425516917293232
 train_loss: 0.6938160016626426
 test_acc: 0.6715425531914894
 train_loss: 0.6931931356157522
```

In [ ]:

```
# checking batch size impact
```

In [ ]:

```
TRAINLOADER = Dataloader(data = train_data_frame.values.tolist(), labels = train_labels['
                         n_classes = 2, batch_size = BATCH_SIZE, shuffle = False)
TESTLOADER = Dataloader(data = test_data_frame.values.tolist(), labels = test_labels['labe
                        n_classes = 2, batch_size = BATCH_SIZE, shuffle = False)
```

In [107…

```
# batch size = 16
```

```
INPUT_SHAPE = 1024
LEARNING_RATE = 0.001
EPOCHS = 30
BATCH_SIZE = 16

network = FeedForwardNN(INPUT_SHAPE)
network.add_layer(n_neurons = 4, activation = LeakyRelu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 4, activation = LeakyRelu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 2, activation = Identical(), weight_initializer = 'uniform')
network.set_training_param(loss = CrossEntropy(), lr = LEARNING_RATE)

log = network.fit(EPOCHS, TRAINLOADER, TESTLOADER)
```

```
Epoch 1:
        Train: Average Accuracy: 0.4984257518796993     Average Loss: 0.6934856276749097
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6932022249811475
Epoch 2:
        Train: Average Accuracy: 0.5023026315789474     Average Loss: 0.6932701402556646
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6931519607771521
Epoch 3:
        Train: Average Accuracy: 0.508999060150376      Average Loss: 0.6932427480024351
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6930559892780499
Epoch 4:
        Train: Average Accuracy: 0.5104088345864662     Average Loss: 0.6932226610798196
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6929242953729287
Epoch 5:
        Train: Average Accuracy: 0.5122885338345865     Average Loss: 0.6932032162370562
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6927725446509235
Epoch 6:
        Train: Average Accuracy: 0.5133458646616542     Average Loss: 0.6931786665190435
        Test: Average Accuracy: 0.5002849544072948      Average Loss: 0.6926048369574913
Epoch 7:
        Train: Average Accuracy: 0.5128054511278195     Average Loss: 0.6931426782262298
        Test: Average Accuracy: 0.4989551671732523      Average Loss: 0.6924229398754107
Epoch 8:
        Train: Average Accuracy: 0.5144501879699248     Average Loss: 0.6930903385856211
        Test: Average Accuracy: 0.4949658054711246      Average Loss: 0.6922182575312988
Epoch 9:
        Train: Average Accuracy: 0.5151550751879699     Average Loss: 0.6930105086459474
        Test: Average Accuracy: 0.49164133738601823     Average Loss: 0.6919712494238172
Epoch 10:
        Train: Average Accuracy: 0.5183270676691729     Average Loss: 0.692886305412411
        Test: Average Accuracy: 0.48898176291793316     Average Loss: 0.6916457019846179
Epoch 11:
        Train: Average Accuracy: 0.5216165413533834     Average Loss: 0.6926810771610065
        Test: Average Accuracy: 0.48765197568389057     Average Loss: 0.6911651431103745
Epoch 12:
        Train: Average Accuracy: 0.5284304511278195     Average Loss: 0.6923142797382392
        Test: Average Accuracy: 0.4902165653495441      Average Loss: 0.6903468175922253
Epoch 13:
        Train: Average Accuracy: 0.5339285714285714     Average Loss: 0.6915740707994048
        Test: Average Accuracy: 0.5001899696048633      Average Loss: 0.6886397928323749
Epoch 14:
        Train: Average Accuracy: 0.5436325187969925     Average Loss: 0.6897696830366996
        Test: Average Accuracy: 0.5421732522796353      Average Loss: 0.6839455133250348
Epoch 15:
        Train: Average Accuracy: 0.5591400375939849     Average Loss: 0.6852850456688027
        Test: Average Accuracy: 0.5917553191489362      Average Loss: 0.6748030462951681
Epoch 16:
        Train: Average Accuracy: 0.5773026315789473     Average Loss: 0.6789096177482563
        Test: Average Accuracy: 0.6084726443768996      Average Loss: 0.6683355881378669
Epoch 17:
        Train: Average Accuracy: 0.5895206766917294     Average Loss: 0.6720283553366889
        Test: Average Accuracy: 0.6136968085106383      Average Loss: 0.6603943869537904
Epoch 18:
```

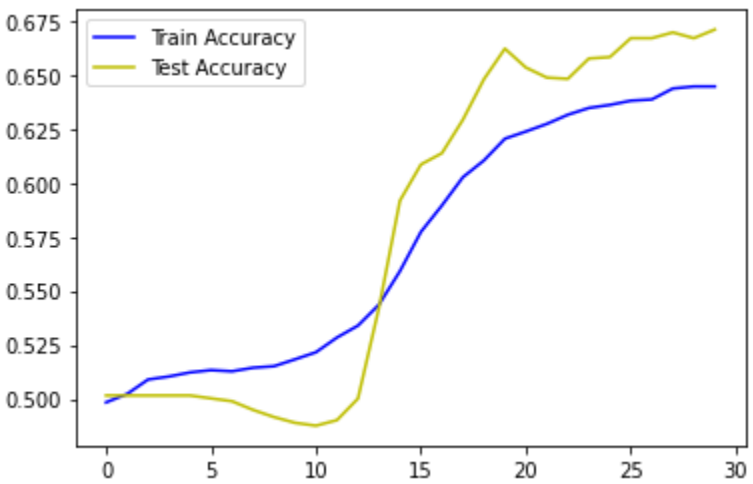
```
        Train: Average Accuracy: 0.6025845864661654     Average Loss: 0.6653593948349091
        Test: Average Accuracy: 0.6291793313069909      Average Loss: 0.6491495947692822
Epoch 19:
        Train: Average Accuracy: 0.6103383458646616     Average Loss: 0.6577182997667567
        Test: Average Accuracy: 0.6478913373860182      Average Loss: 0.6340683059914438
Epoch 20:
        Train: Average Accuracy: 0.6203947368421053     Average Loss: 0.6512892045671674
        Test: Average Accuracy: 0.6620440729483282      Average Loss: 0.6236350139162588
Epoch 21:
        Train: Average Accuracy: 0.6237312030075188     Average Loss: 0.64696568299883
        Test: Average Accuracy: 0.65330547112462        Average Loss: 0.6211854945922546
Epoch 22:
        Train: Average Accuracy: 0.6272556390977443     Average Loss: 0.6435608723827742
        Test: Average Accuracy: 0.6486512158054711      Average Loss: 0.6179503901192035
Epoch 23:
        Train: Average Accuracy: 0.631484962406015      Average Loss: 0.6408534697201359
        Test: Average Accuracy: 0.6480813069908814      Average Loss: 0.6164079313769081
Epoch 24:
        Train: Average Accuracy: 0.6346099624060151     Average Loss: 0.638538498104739
        Test: Average Accuracy: 0.657484802431611       Average Loss: 0.6148230279470905
Epoch 25:
        Train: Average Accuracy: 0.6360197368421053     Average Loss: 0.6366944660360112
        Test: Average Accuracy: 0.6581496960486323      Average Loss: 0.6148566251986135
Epoch 26:
        Train: Average Accuracy: 0.6379699248120301     Average Loss: 0.6348535791260592
        Test: Average Accuracy: 0.6668882978723404      Average Loss: 0.6112872539682829
Epoch 27:
        Train: Average Accuracy: 0.6385573308270677     Average Loss: 0.6330676025643055
        Test: Average Accuracy: 0.6668882978723404      Average Loss: 0.6104981052152149
Epoch 28:
        Train: Average Accuracy: 0.643609022556391      Average Loss: 0.6319463158325889
        Test: Average Accuracy: 0.6695478723404256      Average Loss: 0.6100142371735405
Epoch 29:
        Train: Average Accuracy: 0.6445488721804511     Average Loss: 0.6305561159946358
        Test: Average Accuracy: 0.6668882978723404      Average Loss: 0.6094117524772528
Epoch 30:
        Train: Average Accuracy: 0.6445488721804511     Average Loss: 0.6297288874081927
        Test: Average Accuracy: 0.6708776595744681      Average Loss: 0.6092663568014578
```

In [108…

```
train_acc, = pplt.plot(log['train_accuracy'], label="Train Accuracy", color='b')
test_acc, = pplt.plot(log['test_accuracy'], label="Test Accuracy", color='y')
pplt.legend(handles = [train_acc, test_acc])
```

Out[108…

```
<matplotlib.legend.Legend at 0x7fd77cecd0d0>
```

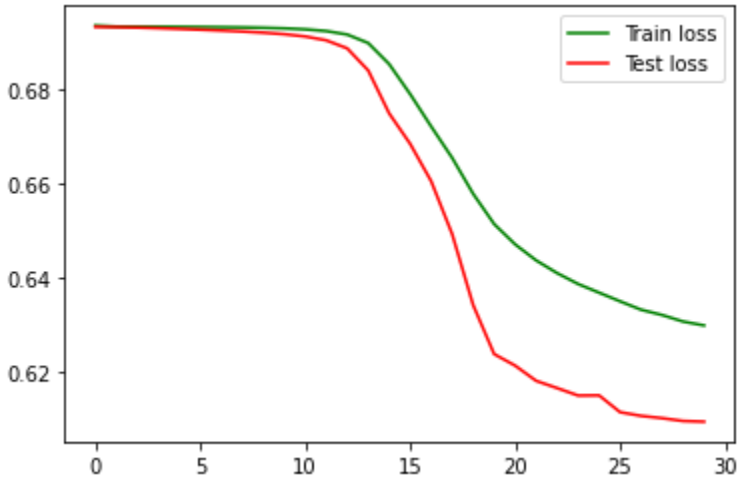


In [109…

```
train_loss, = pplt.plot(log['train_loss'], label="Train loss", color='g')
test_loss, = pplt.plot(log['test_loss'], label="Test loss", color='r')
pplt.legend(handles = [train_loss, test_loss])
```

Out[109…

```
<matplotlib.legend.Legend at 0x7fd77ceba6a0>
```



In [111…

```
max_values = [max(log['train_accuracy']), max(log['train_loss']), max(log['test_accuracy']

print("Maximum values in each diagram are: \n train_acc: {} \n train_loss: {} \n test_acc:
```

```
Maximum values in each diagram are:
 train_acc: 0.6459586466165413
 train_loss: 0.6935174052223896
 test_acc: 0.6761968085106383
 train_loss: 0.6931322626650259
```

In [110…

```
# batch size = 16

INPUT_SHAPE = 1024
LEARNING_RATE = 0.001
EPOCHS = 30
BATCH_SIZE = 256

network = FeedForwardNN(INPUT_SHAPE)
network.add_layer(n_neurons = 4, activation = LeakyRelu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 4, activation = LeakyRelu(), weight_initializer = 'uniform')
network.add_layer(n_neurons = 2, activation = Identical(), weight_initializer = 'uniform')
network.set_training_param(loss = CrossEntropy(), lr = LEARNING_RATE)

log = network.fit(EPOCHS, TRAINLOADER, TESTLOADER)
```

```
Epoch 1:
        Train: Average Accuracy: 0.5026550751879699     Average Loss: 0.6935174052223896
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6931322626650259
Epoch 2:
        Train: Average Accuracy: 0.5088815789473685     Average Loss: 0.6932092258106791
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6930089348188843
Epoch 3:
        Train: Average Accuracy: 0.5125234962406016     Average Loss: 0.693177085294213
        Test: Average Accuracy: 0.5016147416413373      Average Loss: 0.6928467375864438
Epoch 4:
        Train: Average Accuracy: 0.5136983082706768     Average Loss: 0.6931434802315823
        Test: Average Accuracy: 0.5002849544072948      Average Loss: 0.6926540137704921
Epoch 5:
        Train: Average Accuracy: 0.5139802631578947     Average Loss: 0.6930968102369485
        Test: Average Accuracy: 0.5009498480243161      Average Loss: 0.6924324331456098
Epoch 6:
        Train: Average Accuracy: 0.5151550751879699     Average Loss: 0.6930243488262067
        Test: Average Accuracy: 0.4956306990881459      Average Loss: 0.6921669316152269
Epoch 7:
        Train: Average Accuracy: 0.5175046992481203     Average Loss: 0.6929058950053374
```

```
        Test: Average Accuracy: 0.49097644376899696     Average Loss: 0.6918193489332355
Epoch 8:
        Train: Average Accuracy: 0.521499060150376      Average Loss: 0.6927027140473583
        Test: Average Accuracy: 0.48765197568389057     Average Loss: 0.6913055457281474
Epoch 9:
        Train: Average Accuracy: 0.5269031954887218     Average Loss: 0.6923284899455056
        Test: Average Accuracy: 0.48822188449848025     Average Loss: 0.6904194981965538
Epoch 10:
        Train: Average Accuracy: 0.5332941729323308     Average Loss: 0.6915542863377324
        Test: Average Accuracy: 0.5041793313069909      Average Loss: 0.6885470120122886
Epoch 11:
        Train: Average Accuracy: 0.543984962406015      Average Loss: 0.6896139019323588
        Test: Average Accuracy: 0.5514817629179332      Average Loss: 0.6834078319104123
Epoch 12:
        Train: Average Accuracy: 0.5619125939849624     Average Loss: 0.6852714612268358
        Test: Average Accuracy: 0.5863411854103344      Average Loss: 0.6753769262604948
Epoch 13:
        Train: Average Accuracy: 0.5753524436090225     Average Loss: 0.6790271690009618
        Test: Average Accuracy: 0.5712386018237082      Average Loss: 0.6754313562173182
Epoch 14:
        Train: Average Accuracy: 0.5894031954887218     Average Loss: 0.6726012911612232
        Test: Average Accuracy: 0.6031534954407295      Average Loss: 0.6639938082397584
Epoch 15:
        Train: Average Accuracy: 0.6008928571428571     Average Loss: 0.6655776583115885
        Test: Average Accuracy: 0.6318389057750761      Average Loss: 0.6498134863089252
Epoch 16:
        Train: Average Accuracy: 0.6079887218045112     Average Loss: 0.6583419531672482
        Test: Average Accuracy: 0.6439019756838906      Average Loss: 0.6360690451904291
Epoch 17:
        Train: Average Accuracy: 0.6175046992481202     Average Loss: 0.6527125855534825
        Test: Average Accuracy: 0.6539703647416413      Average Loss: 0.6279273927068406
Epoch 18:
        Train: Average Accuracy: 0.6225563909774436     Average Loss: 0.6480305861837494
        Test: Average Accuracy: 0.6540653495440729      Average Loss: 0.6213786898634823
Epoch 19:
        Train: Average Accuracy: 0.6271381578947368     Average Loss: 0.644553989100522
        Test: Average Accuracy: 0.6572948328267477      Average Loss: 0.6181762641550808
Epoch 20:
        Train: Average Accuracy: 0.6294407894736842     Average Loss: 0.6412316130128708
        Test: Average Accuracy: 0.6599544072948328      Average Loss: 0.6141706938967736
Epoch 21:
        Train: Average Accuracy: 0.6317434210526315     Average Loss: 0.6389607300421539
        Test: Average Accuracy: 0.6587196048632219      Average Loss: 0.6144646879447215
Epoch 22:
        Train: Average Accuracy: 0.6354323308270677     Average Loss: 0.6365787163717883
        Test: Average Accuracy: 0.6628039513677811      Average Loss: 0.6130328342512384
Epoch 23:
        Train: Average Accuracy: 0.6378524436090225     Average Loss: 0.6347631650560328
        Test: Average Accuracy: 0.6647036474164133      Average Loss: 0.6105237000995531
Epoch 24:
        Train: Average Accuracy: 0.6392622180451127     Average Loss: 0.6333972727259237
        Test: Average Accuracy: 0.6667933130699089      Average Loss: 0.610479377945763
Epoch 25:
        Train: Average Accuracy: 0.6416118421052631     Average Loss: 0.6318416425740397
        Test: Average Accuracy: 0.6661284194528876      Average Loss: 0.6096004190937877
Epoch 26:
        Train: Average Accuracy: 0.6444313909774436     Average Loss: 0.6304847479773587
        Test: Average Accuracy: 0.6654635258358663      Average Loss: 0.6094198508376715
Epoch 27:
        Train: Average Accuracy: 0.6446663533834586     Average Loss: 0.629209988062819
        Test: Average Accuracy: 0.6688829787234043      Average Loss: 0.6094949249934116
Epoch 28:
        Train: Average Accuracy: 0.6445488721804511     Average Loss: 0.6284099773923669
        Test: Average Accuracy: 0.6735372340425532      Average Loss: 0.609603681729817
Epoch 29:
        Train: Average Accuracy: 0.6459586466165413     Average Loss: 0.6278615909439037
```

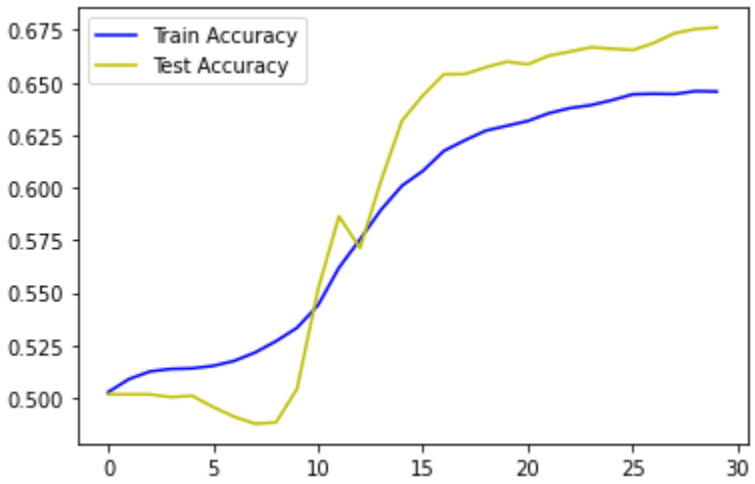
```
        Test: Average Accuracy: 0.675531914893617       Average Loss: 0.6092514468126317
Epoch 30:
        Train: Average Accuracy: 0.6457236842105263     Average Loss: 0.6269186526929997
        Test: Average Accuracy: 0.6761968085106383      Average Loss: 0.6096828085465489
```

In [112…

```
train_acc, = pplt.plot(log['train_accuracy'], label="Train Accuracy", color='b')
test_acc, = pplt.plot(log['test_accuracy'], label="Test Accuracy", color='y')
pplt.legend(handles = [train_acc, test_acc])
```

Out[112…

```
<matplotlib.legend.Legend at 0x7fd77ce2b8b0>
```

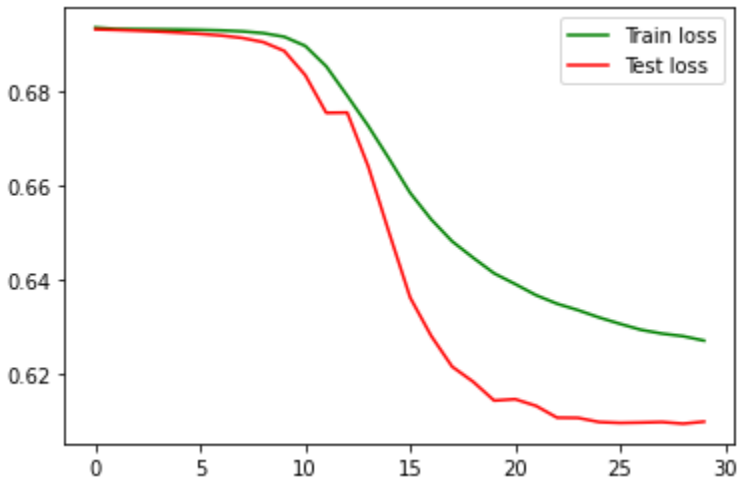


In [113…

```
train_loss, = pplt.plot(log['train_loss'], label="Train loss", color='g')
test_loss, = pplt.plot(log['test_loss'], label="Test loss", color='r')
pplt.legend(handles = [train_loss, test_loss])
```

Out[113…

```
<matplotlib.legend.Legend at 0x7fd77cda7c70>
```



In [114…

```
max_values = [max(log['train_accuracy']), max(log['train_loss']), max(log['test_accuracy']

print("Maximum values in each diagram are: \n train_acc: {} \n train_loss: {} \n test_acc
```

```
Maximum values in each diagram are:
 train_acc: 0.6459586466165413
 train_loss: 0.6935174052223896
 test_acc: 0.6761968085106383
 train_loss: 0.6931322626650259
```

In [ ]: