

# Q1

Given  $x = 2$ ,  $y = 1$

Feedforward propagation:

First layer:

$$z^{(1)} = \begin{pmatrix} 1 \\ 2 \end{pmatrix}^T * W^{(1)} = \begin{pmatrix} 0.7 \\ 1 \end{pmatrix}^T$$

$$a^{(1)} = \tanh(z^{(1)}) = \begin{pmatrix} \tanh(0.7) \\ \tanh(1) \end{pmatrix}^T \approx \begin{pmatrix} 0.604368 \\ 0.761594 \end{pmatrix}^T$$

Hidden layer:

$$z^{(2)} = \begin{pmatrix} 1 \\ a^{(1)} \end{pmatrix}^T * W^{(2)}$$

$$a^{(2)} = \tanh(z^{(2)}) \approx -0.901546$$

Output layer:

$$z^{(3)} = \begin{pmatrix} 1 \\ a^{(2)} \end{pmatrix}^T * W^{(3)}$$

$$h(x) = \tanh(z^{(3)}) \approx -0.665761$$

Now start backpropagation:

since the activation functions are all tanh, we use squared error cost function.

Errors:

Output Layer:

$$\delta^{(3)} = \frac{\partial J(w)}{\partial z^{(3)}} = 2(h(x) - y)(1 - (h(x))^2) \approx -1.854864$$

Second Layer:

$$\delta^{(2)} = \delta^{(3)} * W_{2,1}^{(3)} * [1 - a^{(2)^2}] \approx -0.694518$$

First Layer:

$$\delta^{(1)} = \delta^{(2)} * W_{2:3,1}^{(2)} * [1 - a^{(1)^2}] \approx \begin{pmatrix} -0.440838 \\ 0.87504 \end{pmatrix}$$

Now we can compute the partial derivatives needed for the gradient

First Layer

$$\frac{\partial J(w)}{\partial W^{(1)}} = \delta^{(1)} * \left( \frac{1}{x} \right)^T = \begin{bmatrix} -0.440838 & -0.881677 \\ 0.875040 & 1.750080 \end{bmatrix}$$

Second Layer

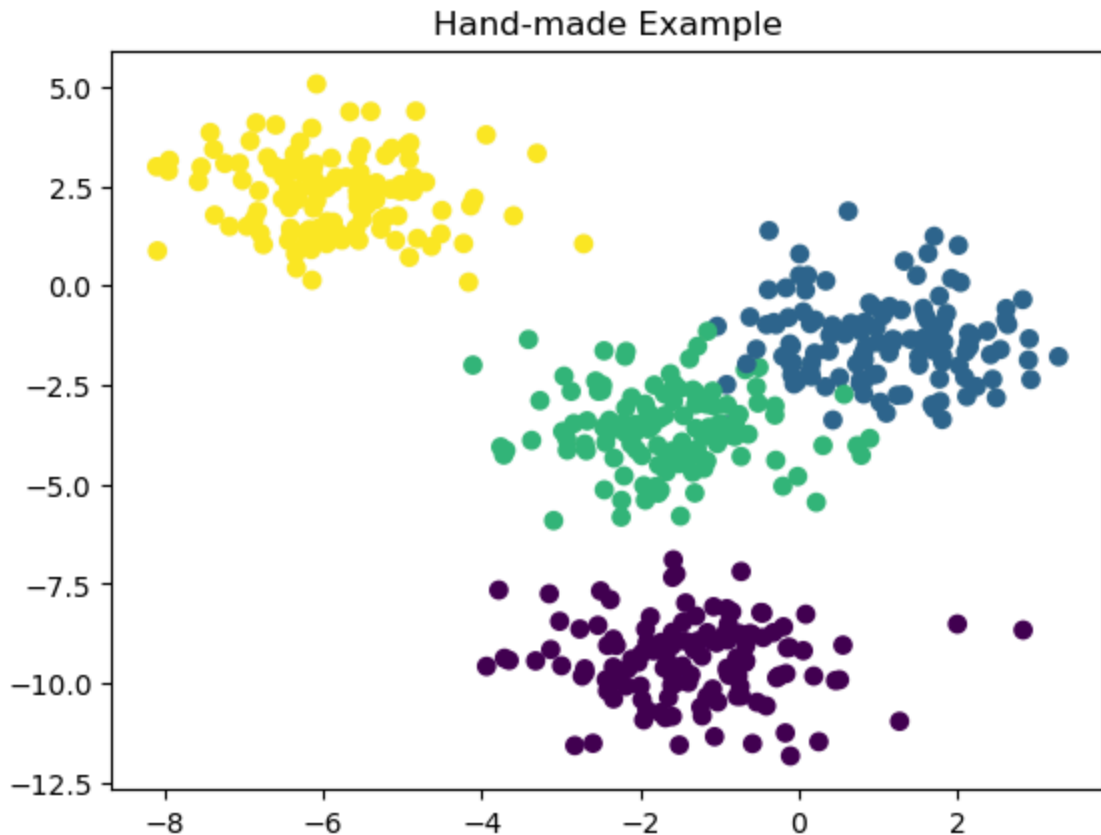
$$\frac{\partial J(w)}{\partial W^{(2)}} = \delta^{(2)} * \left( \frac{1}{a^{(2)}} \right)^T = \begin{pmatrix} -0.6945185 \\ -0.4197446 \\ -0.5289412 \end{pmatrix}$$

Third Layer:

$$\frac{\partial J(w)}{\partial W^{(3)}} = \delta^{(3)} * \left( \frac{1}{a^{(3)}} \right)^T = \begin{pmatrix} -1.8548644 \\ 1.6722449 \end{pmatrix}$$

## Q2

```
In [1]: import numpy as np
import matplotlib.pyplot as plt
from sklearn import datasets
X, y = datasets.make_blobs(centers=4, random_state=2, n_samples=500)
plt.scatter(X[:, 0], X[:, 1], c=y)
plt.title("Hand-made Example")
plt.show()
```



In [5]: `import torch`

In [3]: `from sklearn.model_selection import train_test_split  
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, random_state=42)  
  
# to pytorch tensor  
X_train = torch.tensor(X_train, dtype=torch.float32)  
X_test = torch.tensor(X_test, dtype=torch.float32)  
y_train = torch.tensor(y_train, dtype=torch.long)  
y_test = torch.tensor(y_test, dtype=torch.long)`

In [4]: `X.shape, y.shape`

Out[4]: `((500, 2), (500,))`

In [5]: `# define nn  
class MLP(torch.nn.Module):  
 def __init__(self, input_size, hidden_size, num_classes):  
 super(MLP, self).__init__()  
 self.layer1 = torch.nn.Linear(input_size, hidden_size)  
 self.layer2 = torch.nn.Linear(hidden_size, hidden_size)  
 self.output_layer = torch.nn.Linear(hidden_size, num_classes)  
  
 def forward(self, x):  
 x = self.layer1(x)  
 x = torch.tanh(self.layer2(x))  
 x = torch.softmax(self.output_layer(x), dim=-1)  
 return x`

```
In [6]: # Model parameters
input_size = 2
hidden_size = 128
num_classes = 4
num_epochs = 1024
learning_rate = 0.001

# Initialize the model
model = MLP(input_size, hidden_size, num_classes)

# This criterion computes the cross entropy loss between input logits and targets
loss_fn = torch.nn.CrossEntropyLoss()

# We will use Stochastic Gradient Descent
optimizer = torch.optim.SGD(model.parameters(), lr=learning_rate, momentum=0.9)
```

```
In [7]: # use summary writer to track the train and test loss for each epoch
from torch.utils.tensorboard import SummaryWriter
writer = SummaryWriter()

for epoch in range(num_epochs):
    # Forward pass
    y_pred = model(X_train)
    loss = loss_fn(y_pred, y_train)

    # Zero gradients for each batch
    optimizer.zero_grad()

    # Backward pass
    loss.backward()

    # Update gradients
    optimizer.step()

    # Test the model
    y_pred_test = model(X_test)
    loss_test = loss_fn(y_pred_test, y_test)

    # Log the loss
    writer.add_scalar('Loss/train', loss, epoch)
    writer.add_scalar('Loss/test', loss_test, epoch)

    # Print the loss for each epoch
    print(f"Epoch {epoch}: train loss: {loss.item()}, test loss: {loss_test.item()}")
```

Epoch 0: train loss: 1.431787133216858, test loss: 1.4364352226257324  
Epoch 1: train loss: 1.4304388761520386, test loss: 1.4338222742080688  
Epoch 2: train loss: 1.4278721809387207, test loss: 1.4300851821899414  
Epoch 3: train loss: 1.4242002964019775, test loss: 1.4253267049789429  
Epoch 4: train loss: 1.4195235967636108, test loss: 1.419641375541687  
Epoch 5: train loss: 1.413933515548706, test loss: 1.4131152629852295  
Epoch 6: train loss: 1.4075137376785278, test loss: 1.40583074092865  
Epoch 7: train loss: 1.4003444910049438, test loss: 1.3978681564331055  
Epoch 8: train loss: 1.3925038576126099, test loss: 1.3893072605133057  
Epoch 9: train loss: 1.384070634841919, test loss: 1.3802293539047241  
Epoch 10: train loss: 1.375124454498291, test loss: 1.3707187175750732  
Epoch 11: train loss: 1.365749478340149, test loss: 1.360862374305725  
Epoch 12: train loss: 1.3560329675674438, test loss: 1.3507510423660278  
Epoch 13: train loss: 1.3460654020309448, test loss: 1.3404769897460938  
Epoch 14: train loss: 1.3359402418136597, test loss: 1.3301326036453247  
Epoch 15: train loss: 1.325751543045044, test loss: 1.3198071718215942  
Epoch 16: train loss: 1.3155899047851562, test loss: 1.3095831871032715  
Epoch 17: train loss: 1.305539608001709, test loss: 1.2995332479476929  
Epoch 18: train loss: 1.2956756353378296, test loss: 1.2897169589996338  
Epoch 19: train loss: 1.2860597372055054, test loss: 1.2801786661148071  
Epoch 20: train loss: 1.276738166809082, test loss: 1.2709472179412842  
Epoch 21: train loss: 1.26774263381958, test loss: 1.2620348930358887  
Epoch 22: train loss: 1.2590885162353516, test loss: 1.2534409761428833  
Epoch 23: train loss: 1.2507768869400024, test loss: 1.245151400566101  
Epoch 24: train loss: 1.2427968978881836, test loss: 1.2371430397033691  
Epoch 25: train loss: 1.2351279258728027, test loss: 1.2293846607208252  
Epoch 26: train loss: 1.2277417182922363, test loss: 1.221840739250183  
Epoch 27: train loss: 1.220605731010437, test loss: 1.214472770690918  
Epoch 28: train loss: 1.2136834859848022, test loss: 1.2072408199310303  
Epoch 29: train loss: 1.2069374322891235, test loss: 1.2001066207885742  
Epoch 30: train loss: 1.200331449508667, test loss: 1.1930344104766846  
Epoch 31: train loss: 1.193830966949463, test loss: 1.1859924793243408  
Epoch 32: train loss: 1.187404751777649, test loss: 1.1789560317993164  
Epoch 33: train loss: 1.1810275316238403, test loss: 1.1719074249267578  
Epoch 34: train loss: 1.174680233001709, test loss: 1.1648386716842651  
Epoch 35: train loss: 1.1683518886566162, test loss: 1.1577527523040771  
Epoch 36: train loss: 1.1620410680770874, test loss: 1.1506645679473877  
Epoch 37: train loss: 1.155755877494812, test loss: 1.143599033355713  
Epoch 38: train loss: 1.1495144367218018, test loss: 1.1365916728973389  
Epoch 39: train loss: 1.143343448638916, test loss: 1.1296850442886353  
Epoch 40: train loss: 1.1372761726379395, test loss: 1.1229254007339478  
Epoch 41: train loss: 1.1313499212265015, test loss: 1.116359829902649  
Epoch 42: train loss: 1.1256024837493896, test loss: 1.110032081604004  
Epoch 43: train loss: 1.120069980621338, test loss: 1.103980302810669  
Epoch 44: train loss: 1.114783525466919, test loss: 1.0982334613800049  
Epoch 45: train loss: 1.1097666025161743, test loss: 1.0928106307983398  
Epoch 46: train loss: 1.1050351858139038, test loss: 1.087720513343811  
Epoch 47: train loss: 1.1005953550338745, test loss: 1.0829604864120483  
Epoch 48: train loss: 1.0964443683624268, test loss: 1.0785179138183594  
Epoch 49: train loss: 1.0925710201263428, test loss: 1.0743725299835205  
Epoch 50: train loss: 1.0889568328857422, test loss: 1.070497989654541  
Epoch 51: train loss: 1.085578441619873, test loss: 1.0668634176254272  
Epoch 52: train loss: 1.0824092626571655, test loss: 1.0634371042251587  
Epoch 53: train loss: 1.0794211626052856, test loss: 1.0601871013641357  
Epoch 54: train loss: 1.0765857696533203, test loss: 1.0570831298828125  
Epoch 55: train loss: 1.0738768577575684, test loss: 1.0540977716445923

Epoch 56: train loss: 1.0712696313858032, test loss: 1.0512064695358276  
Epoch 57: train loss: 1.0687427520751953, test loss: 1.048388123512268  
Epoch 58: train loss: 1.0662777423858643, test loss: 1.0456255674362183  
Epoch 59: train loss: 1.0638591051101685, test loss: 1.0429047346115112  
Epoch 60: train loss: 1.0614745616912842, test loss: 1.0402146577835083  
Epoch 61: train loss: 1.0591148138046265, test loss: 1.0375474691390991  
Epoch 62: train loss: 1.0567727088928223, test loss: 1.0348975658416748  
Epoch 63: train loss: 1.0544438362121582, test loss: 1.0322619676589966  
Epoch 64: train loss: 1.0521254539489746, test loss: 1.029639482498169  
Epoch 65: train loss: 1.0498168468475342, test loss: 1.0270298719406128  
Epoch 66: train loss: 1.0475186109542847, test loss: 1.0244351625442505  
Epoch 67: train loss: 1.0452322959899902, test loss: 1.0218578577041626  
Epoch 68: train loss: 1.0429604053497314, test loss: 1.0193008184432983  
Epoch 69: train loss: 1.0407061576843262, test loss: 1.0167675018310547  
Epoch 70: train loss: 1.0384726524353027, test loss: 1.0142618417739868  
Epoch 71: train loss: 1.0362639427185059, test loss: 1.0117875337600708  
Epoch 72: train loss: 1.0340828895568848, test loss: 1.009347677230835  
Epoch 73: train loss: 1.0319329500198364, test loss: 1.0069453716278076  
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Epoch 90: train loss: 1.0007102489471436, test loss: 0.9720785021781921  
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Epoch 194: train loss: 0.9029107689857483, test loss: 0.8698387742042542  
Epoch 195: train loss: 0.9023838639259338, test loss: 0.8693318367004395  
Epoch 196: train loss: 0.9018617272377014, test loss: 0.8688297867774963  
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Epoch 199: train loss: 0.9003225564956665, test loss: 0.8673529028892517  
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Epoch 201: train loss: 0.8993186950683594, test loss: 0.8663920760154724  
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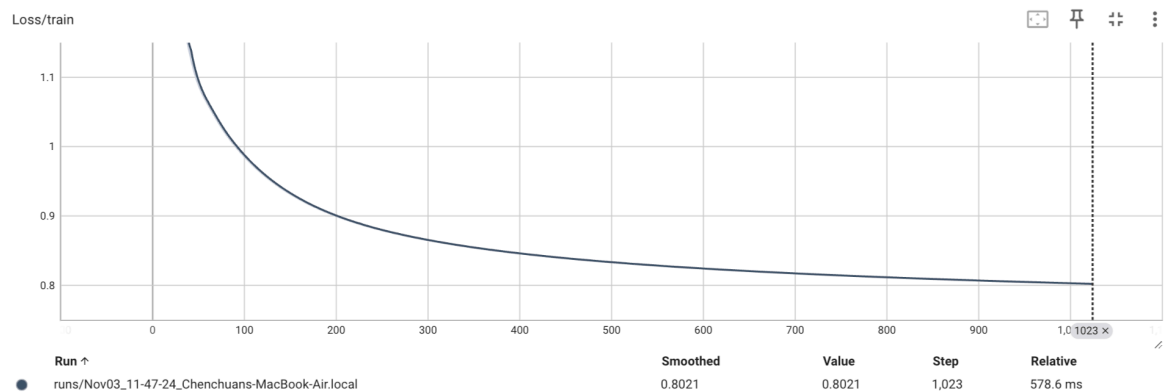
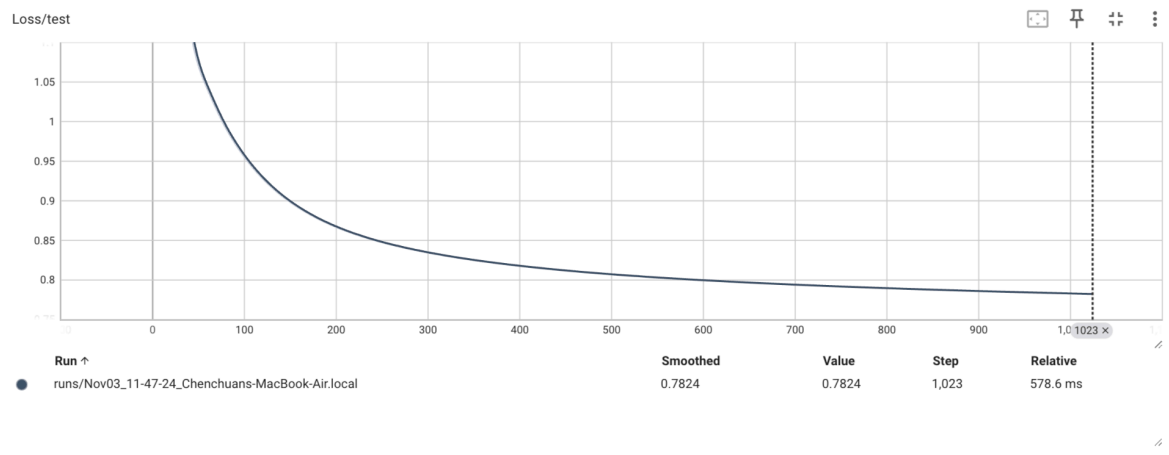
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Epoch 954: train loss: 0.804587185382843, test loss: 0.7843654751777649  
Epoch 955: train loss: 0.804548442363739, test loss: 0.7843353152275085  
Epoch 956: train loss: 0.8045098185539246, test loss: 0.7843053340911865  
Epoch 957: train loss: 0.8044712543487549, test loss: 0.7842752933502197  
Epoch 958: train loss: 0.8044326305389404, test loss: 0.7842453718185425  
Epoch 959: train loss: 0.8043941259384155, test loss: 0.7842154502868652  
Epoch 960: train loss: 0.804355800151825, test loss: 0.7841855883598328  
Epoch 961: train loss: 0.8043174147605896, test loss: 0.7841557860374451  
Epoch 962: train loss: 0.804279088973999, test loss: 0.7841261029243469  
Epoch 963: train loss: 0.8042409420013428, test loss: 0.7840963006019592  
Epoch 964: train loss: 0.8042027950286865, test loss: 0.7840666770935059  
Epoch 965: train loss: 0.8041646480560303, test loss: 0.7840371131896973  
Epoch 966: train loss: 0.804126501083374, test loss: 0.7840074896812439  
Epoch 967: train loss: 0.8040885925292969, test loss: 0.7839779853820801  
Epoch 968: train loss: 0.804050624370575, test loss: 0.7839484214782715  
Epoch 969: train loss: 0.804012656211853, test loss: 0.7839189767837524  
Epoch 970: train loss: 0.803974986076355, test loss: 0.7838895916938782  
Epoch 971: train loss: 0.8039371967315674, test loss: 0.7838602662086487  
Epoch 972: train loss: 0.8038994669914246, test loss: 0.783831000328064  
Epoch 973: train loss: 0.8038619160652161, test loss: 0.7838017344474792  
Epoch 974: train loss: 0.8038243055343628, test loss: 0.7837725877761841  
Epoch 975: train loss: 0.8037868738174438, test loss: 0.7837433815002441  
Epoch 976: train loss: 0.8037493824958801, test loss: 0.7837142944335938  
Epoch 977: train loss: 0.803712010383606, test loss: 0.7836852073669434  
Epoch 978: train loss: 0.8036746382713318, test loss: 0.7836562395095825  
Epoch 979: train loss: 0.8036374449729919, test loss: 0.7836273312568665  
Epoch 980: train loss: 0.8036001324653625, test loss: 0.7835984230041504  
Epoch 981: train loss: 0.8035629391670227, test loss: 0.7835693955421448  
Epoch 982: train loss: 0.8035259246826172, test loss: 0.7835405468940735  
Epoch 983: train loss: 0.8034889101982117, test loss: 0.7835118174552917  
Epoch 984: train loss: 0.8034518957138062, test loss: 0.7834829688072205  
Epoch 985: train loss: 0.8034150004386902, test loss: 0.7834543585777283  
Epoch 986: train loss: 0.8033780455589294, test loss: 0.7834256887435913  
Epoch 987: train loss: 0.803341269493103, test loss: 0.7833970785140991  
Epoch 988: train loss: 0.8033044934272766, test loss: 0.7833685874938965  
Epoch 989: train loss: 0.8032678365707397, test loss: 0.7833399176597595  
Epoch 990: train loss: 0.8032311201095581, test loss: 0.7833115458488464  
Epoch 991: train loss: 0.8031947612762451, test loss: 0.7832830548286438  
Epoch 992: train loss: 0.803158164024353, test loss: 0.7832546830177307  
Epoch 993: train loss: 0.8031217455863953, test loss: 0.7832263708114624  
Epoch 994: train loss: 0.8030853271484375, test loss: 0.7831981182098389  
Epoch 995: train loss: 0.8030489087104797, test loss: 0.7831698060035706  
Epoch 996: train loss: 0.8030126094818115, test loss: 0.783141553401947  
Epoch 997: train loss: 0.8029763102531433, test loss: 0.783113420009613  
Epoch 998: train loss: 0.8029401898384094, test loss: 0.7830852270126343  
Epoch 999: train loss: 0.8029041290283203, test loss: 0.7830572724342346  
Epoch 1000: train loss: 0.802868127822876, test loss: 0.7830290794372559  
Epoch 1001: train loss: 0.8028320074081421, test loss: 0.7830011248588562  
Epoch 1002: train loss: 0.8027960062026978, test loss: 0.7829731106758118  
Epoch 1003: train loss: 0.8027601838111877, test loss: 0.7829451560974121  
Epoch 1004: train loss: 0.8027243614196777, test loss: 0.7829173803329468  
Epoch 1005: train loss: 0.8026884198188782, test loss: 0.7828894853591919  
Epoch 1006: train loss: 0.8026527166366577, test loss: 0.7828617095947266  
Epoch 1007: train loss: 0.8026171922683716, test loss: 0.782833993434906

```
Epoch 1008: train loss: 0.8025814294815063, test loss: 0.7828063368797302
Epoch 1009: train loss: 0.8025459051132202, test loss: 0.7827785611152649
Epoch 1010: train loss: 0.8025104403495789, test loss: 0.7827509045600891
Epoch 1011: train loss: 0.8024749755859375, test loss: 0.7827233672142029
Epoch 1012: train loss: 0.8024395108222961, test loss: 0.7826959490776062
Epoch 1013: train loss: 0.8024042248725891, test loss: 0.7826683521270752
Epoch 1014: train loss: 0.8023689985275269, test loss: 0.7826409935951233
Epoch 1015: train loss: 0.802333652973175, test loss: 0.7826134562492371
Epoch 1016: train loss: 0.8022984862327576, test loss: 0.7825860381126404
Epoch 1017: train loss: 0.8022633194923401, test loss: 0.7825587391853333
Epoch 1018: train loss: 0.8022282123565674, test loss: 0.7825313806533813
Epoch 1019: train loss: 0.8021932244300842, test loss: 0.7825042009353638
Epoch 1020: train loss: 0.8021582961082458, test loss: 0.7824769616127014
Epoch 1021: train loss: 0.8021233081817627, test loss: 0.7824499011039734
Epoch 1022: train loss: 0.8020884990692139, test loss: 0.7824227213859558
Epoch 1023: train loss: 0.8020536303520203, test loss: 0.782395601272583
```

In [3]: `from IPython.display import Image`  
`Image(filename='/Users/chuan/Desktop/c815_course_hws/hw8/losses.png', width=`

Out[3]:



In [8]: `# Plot the decision boundary`

```
# set min and max values and give it some padding
x_min, x_max = -10, 10
y_min, y_max = -15, 10
xx, yy = np.meshgrid(np.arange(x_min, x_max, 0.01),
                      np.arange(y_min, y_max, 0.01))

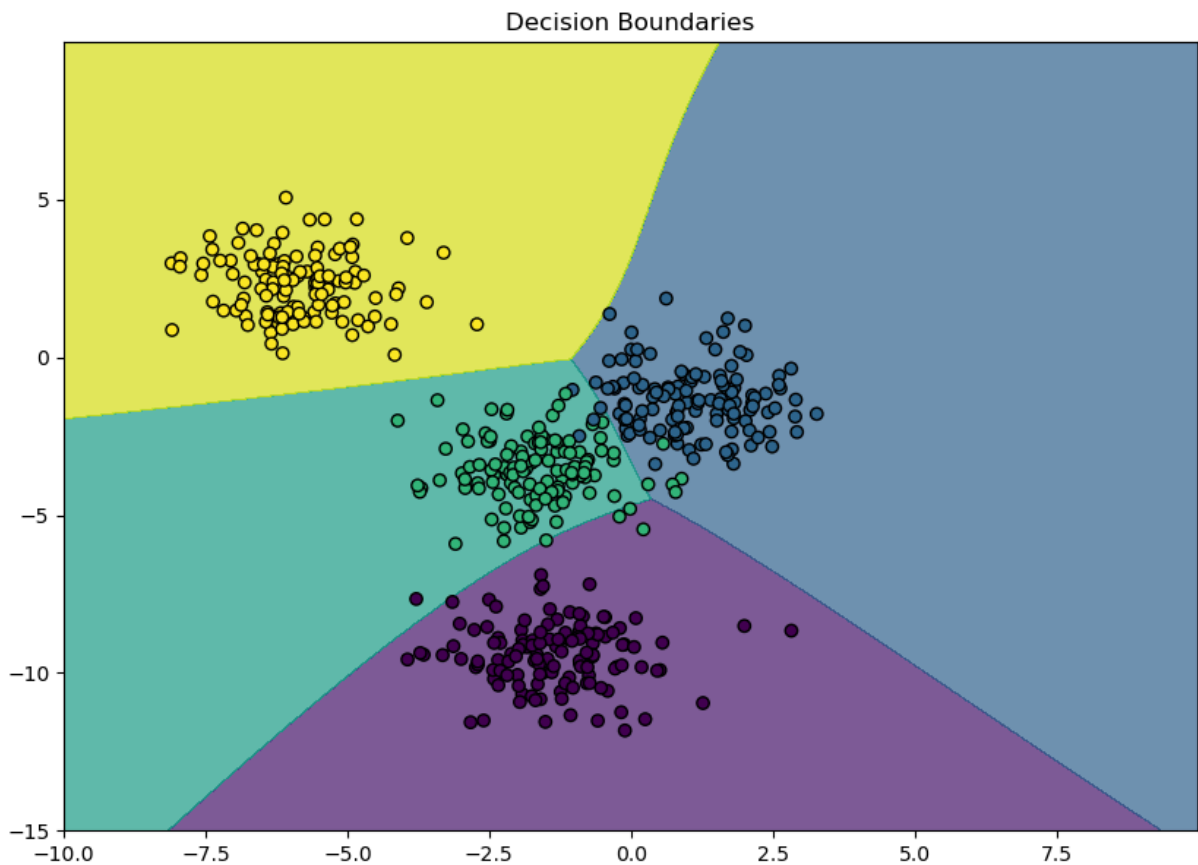
# convert the grid to a tensor and predict class labels for each point
```

```

grid = torch.Tensor(np.c_[xx.ravel(), yy.ravel()])
model.eval() # set model to evaluation mode
# disable gradient computation
with torch.no_grad():
    Z = model(grid).argmax(dim=1)
# convert the predictions back to numpy array
Z = Z.numpy().reshape(xx.shape)

plt.figure(figsize=(10, 7))
plt.contourf(xx, yy, Z, alpha=0.7)
plt.scatter(X[:, 0], X[:, 1], c=y, edgecolors='k')
plt.xlim(xx.min(), xx.max())
plt.ylim(yy.min(), yy.max())
plt.title('Decision Boundaries')
plt.show()

```



In [ ]: