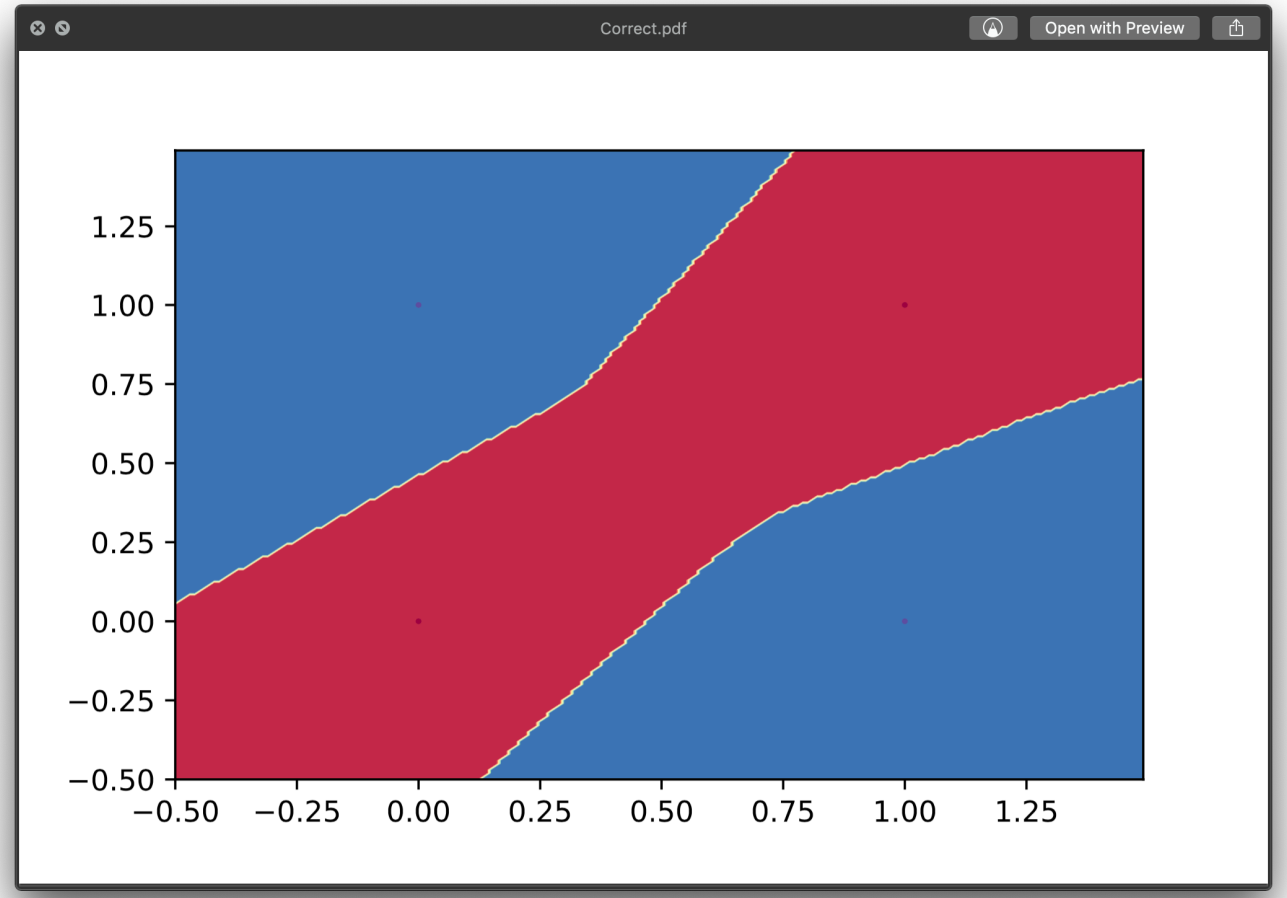
In [1]:
```
#Question 1
```

In [2]:
```
import torch
import torch.nn as nn
import torch.nn.functional as F
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
```

In [3]:
```
class Net(nn.Module):

    def __init__(self):
        super(Net, self).__init__()
        self.fc1 = nn.Linear(2, 20)
        self.fc2 = nn.Linear(20, 20)
        self.fc3 = nn.Linear(20, 20)
        self.fc4 = nn.Linear(20, 20)
        self.fc5 = nn.Linear(20, 20)
        self.fc6 = nn.Linear(20, 20)
        self.fc7 = nn.Linear(20, 2)

    def forward(self, x):
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = F.relu(self.fc3(x))
        x = F.relu(self.fc4(x))
        x = F.relu(self.fc5(x))
        x = F.relu(self.fc6(x))
        x = self.fc7(x)
        return F.log_softmax(x)
        #return F.softmax(x)
```


Correct.pdf
Open with Preview
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
1.25

In [1]:
```
#Question 1
```

In [2]:
```
import torch
import torch.nn as nn
import torch.nn.functional as F
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
```

In [3]:
```
class Net(nn.Module):

    def __init__(self):
        super(Net, self).__init__()
        self.fc1 = nn.Linear(2, 20)
        self.fc2 = nn.Linear(20, 20)
        self.fc3 = nn.Linear(20, 20)
        self.fc4 = nn.Linear(20, 20)
        self.fc5 = nn.Linear(20, 20)
        self.fc6 = nn.Linear(20, 20)
        self.fc7 = nn.Linear(20, 2)

    def forward(self, x):
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = F.relu(self.fc3(x))
        x = F.relu(self.fc4(x))
        x = F.relu(self.fc5(x))
        x = F.relu(self.fc6(x))
        x = self.fc7(x)
        return F.log_softmax(x)
        #return F.softmax(x)
```

In [4]:

```
#%% plot function

def plot_data(X, y, filename):
    plt.scatter(X[:, 0], X[:, 1], c=y, cmap=plt.cm.Spectral, s = 1)
    plt.savefig(filename)
    plt.close()

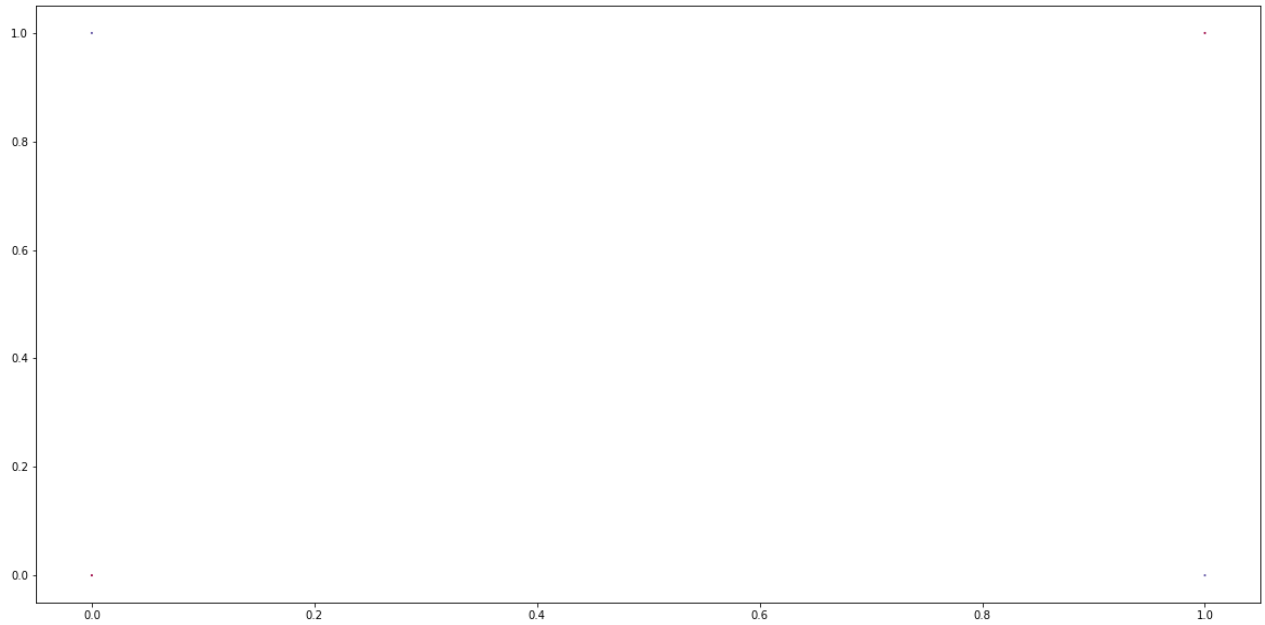
def plot_decision_boundary(clf, X, y, filename):
    # Set min and max values and give it some padding
    #x_min, x_max = X[:, 0].min() - .1, X[:, 0].max() + .1
    #y_min, y_max = X[:, 1].min() - .1, X[:, 1].max() + .1
    x_min, x_max = -0.5, 1.5
    y_min, y_max = -0.5, 1.5
    h = 0.01
    # Generate a grid of points with distance h between them
    xx, yy = np.meshgrid(np.arange(x_min, x_max, h), np.arange(y_min, y_ma
    # Predict the function value for the whole gid
    #Z = clf.predict(np.c_[xx.ravel(), yy.ravel()])
    X_out = net(torch.tensor(np.c_[xx.ravel(), yy.ravel()], dtype = torch.
    Z = X_out.data.max(1)[1]
    # Z.shape
    Z = Z.reshape(xx.shape)
    # Plot the contour and training examples
    plt.contourf(xx, yy, Z, cmap=plt.cm.Spectral)
    plt.scatter(X[:, 0], X[:, 1], c=y, cmap=plt.cm.Spectral, s = 1)
    plt.savefig(filename)
    plt.close()
```

In [5]:

```
#%% read data

data = pd.read_csv("XOR.csv")
X = data.values[:, 0:2]  # Take only the first two features.
X = torch.tensor(X, dtype = torch.float)
y = data.values[:, 2]
y = torch.tensor(y, dtype = torch.long)

plot_data(X,y,'data.pdf')
plt.figure(figsize=(20,10))
plt.scatter(X[:, 0], X[:, 1], c=y, cmap=plt.cm.Spectral, s = 1)
plt.show()
```



In [6]:
```
data
```

Out[6]:

	Input A	Input B	Output
0	0	0	0
1	0	1	1
2	1	0	1
3	1	1	0

In [7]:
```
#%% train
net = Net()

# create a stochastic gradient descent optimizer
learning_rate = .01
optimizer = torch.optim.SGD(net.parameters(), lr=learning_rate, momentum=0

# create a loss function
#criterion = nn.CrossEntropyLoss()
criterion = nn.NLLLoss()
```

In [8]:

```
# nepochs = 10000
nepochs = 3000 #10000
data, target = X, y
# run the main training loop
for epoch in range(nepochs):
#    adjust learning rate if desired
#    if epoch % 3000 == 0 and epoch <= 24000:
#        for g in optimizer.param_groups:
#            g['lr'] = g['lr']/2
    optimizer.zero_grad()
    # forward propagate
    net_out = net(data)
    # compute loss
    loss = criterion(net_out, target)

    # backpropagate
    loss.backward()
    # update parameters
    optimizer.step()
    # print out report

    if epoch % 10 == 0:
        print('Epoch ', epoch, 'Loss ', loss.item())
        net_out = net(data)
        pred = net_out.data.max(1)[1]  # get the index of the max log-prob
        correctidx = pred.eq(target.data)
        ncorrect = correctidx.sum()
        accuracy = ncorrect.item()/len(data)
        if accuracy== 1:
            break
        print('Training accuracy is ', accuracy)
```

```
<ipython-input-3-b68d425386b7>:21: UserWarning: Implicit dimension choice f
or log_softmax has been deprecated. Change the call to include dim=X as an
argument.
  return F.log_softmax(x)
Epoch  0 Loss  0.6941758394241333
Training accuracy is  0.5
Epoch  10 Loss  0.6936168670654297
Training accuracy is  0.5
Epoch  20 Loss  0.6931634545326233
Training accuracy is  0.5
Epoch  30 Loss  0.6930881142616272
Training accuracy is  0.5
Epoch  40 Loss  0.6930862665176392
Training accuracy is  0.5
Epoch  50 Loss  0.6930666565895081
Training accuracy is  0.5
Epoch  60 Loss  0.6930466890335083
Training accuracy is  0.5
Epoch  70 Loss  0.6930317282676697
Training accuracy is  0.75
Epoch  80 Loss  0.6930174827575684
Training accuracy is  0.5
Epoch  90 Loss  0.6930090188980103
Training accuracy is  0.5
Epoch  100 Loss  0.6930021047592163
```

```
Training accuracy is  0.75
Epoch  110 Loss  0.6929948925971985
Training accuracy is  0.75
Epoch  120 Loss  0.6929873824119568
Training accuracy is  0.75
Epoch  130 Loss  0.6929792761802673
Training accuracy is  0.75
Epoch  140 Loss  0.6929664015769958
Training accuracy is  0.75
Epoch  150 Loss  0.6929500102996826
Training accuracy is  0.75
Epoch  160 Loss  0.6929318904876709
Training accuracy is  0.75
Epoch  170 Loss  0.692912757396698
Training accuracy is  0.75
Epoch  180 Loss  0.6928925514221191
Training accuracy is  0.75
Epoch  190 Loss  0.6928713321685791
Training accuracy is  0.75
Epoch  200 Loss  0.6928490996360779
Training accuracy is  0.75
Epoch  210 Loss  0.692834734916687
Training accuracy is  0.75
Epoch  220 Loss  0.69282066822052
Training accuracy is  0.75
Epoch  230 Loss  0.692805826663971
Training accuracy is  0.75
Epoch  240 Loss  0.692790150642395
Training accuracy is  0.75
Epoch  250 Loss  0.6927738189697266
Training accuracy is  0.75
Epoch  260 Loss  0.6927566528320312
Training accuracy is  0.75
Epoch  270 Loss  0.6927385330200195
Training accuracy is  0.75
Epoch  280 Loss  0.6927194595336914
Training accuracy is  0.75
Epoch  290 Loss  0.6926991939544678
Training accuracy is  0.75
Epoch  300 Loss  0.6926789283752441
Training accuracy is  0.75
Epoch  310 Loss  0.6926573514938354
Training accuracy is  0.75
Epoch  320 Loss  0.6926344633102417
Training accuracy is  0.75
Epoch  330 Loss  0.6926104426383972
Training accuracy is  0.75
Epoch  340 Loss  0.6925852298736572
Training accuracy is  0.75
Epoch  350 Loss  0.6925604343414307
Training accuracy is  0.75
Epoch  360 Loss  0.692534327507019
Training accuracy is  0.75
Epoch  370 Loss  0.6925068497657776
Training accuracy is  0.75
Epoch  380 Loss  0.6924779415130615
Training accuracy is  0.75
Epoch  390 Loss  0.692447304725647
Training accuracy is  0.75
Epoch  400 Loss  0.6924149990081787
Training accuracy is  0.75
```

```
Epoch  410 Loss  0.6923807263374329
Training accuracy is  0.75
Epoch  420 Loss  0.6923444271087646
Training accuracy is  0.75
Epoch  430 Loss  0.6923058032989502
Training accuracy is  0.75
Epoch  440 Loss  0.6922647356987
Training accuracy is  0.75
Epoch  450 Loss  0.6922210454940796
Training accuracy is  0.75
Epoch  460 Loss  0.6921743154525757
Training accuracy is  0.75
Epoch  470 Loss  0.6921243667602539
Training accuracy is  0.75
Epoch  480 Loss  0.6920709609985352
Training accuracy is  0.75
Epoch  490 Loss  0.6920138001441956
Training accuracy is  0.75
Epoch  500 Loss  0.6919522881507874
Training accuracy is  0.75
Epoch  510 Loss  0.6918848752975464
Training accuracy is  0.75
Epoch  520 Loss  0.6918103098869324
Training accuracy is  0.75
Epoch  530 Loss  0.6917284727096558
Training accuracy is  0.75
Epoch  540 Loss  0.6916390657424927
Training accuracy is  0.75
Epoch  550 Loss  0.691541314125061
Training accuracy is  0.75
Epoch  560 Loss  0.6914339065551758
Training accuracy is  0.5
Epoch  570 Loss  0.691317081451416
Training accuracy is  0.5
Epoch  580 Loss  0.6911896467208862
Training accuracy is  0.5
Epoch  590 Loss  0.6910485029220581
Training accuracy is  0.5
Epoch  600 Loss  0.6908772587776184
Training accuracy is  0.5
Epoch  610 Loss  0.6906797289848328
Training accuracy is  0.5
Epoch  620 Loss  0.690450131893158
Training accuracy is  0.5
Epoch  630 Loss  0.6902066469192505
Training accuracy is  0.5
Epoch  640 Loss  0.6899532675743103
Training accuracy is  0.5
Epoch  650 Loss  0.6896663308143616
Training accuracy is  0.5
Epoch  660 Loss  0.6893412470817566
Training accuracy is  0.5
Epoch  670 Loss  0.6889669895172119
Training accuracy is  0.75
Epoch  680 Loss  0.6885308027267456
Training accuracy is  0.5
Epoch  690 Loss  0.6880131959915161
Training accuracy is  0.75
Epoch  700 Loss  0.6873992681503296
Training accuracy is  0.75
Epoch  710 Loss  0.6866694688796997
```

```
Training accuracy is  0.75
Epoch  720 Loss  0.6856508851051331
Training accuracy is  0.75
Epoch  730 Loss  0.6842676401138306
Training accuracy is  0.75
Epoch  740 Loss  0.6827037930488586
Training accuracy is  0.75
Epoch  750 Loss  0.6807572841644287
Training accuracy is  0.75
Epoch  760 Loss  0.6783814430236816
Training accuracy is  0.75
Epoch  770 Loss  0.6752572059631348
Training accuracy is  0.75
Epoch  780 Loss  0.6711351871490479
Training accuracy is  0.75
Epoch  790 Loss  0.6654714345932007
Training accuracy is  0.75
Epoch  800 Loss  0.6570992469787598
Training accuracy is  0.75
Epoch  810 Loss  0.6444829702377319
Training accuracy is  0.75
Epoch  820 Loss  0.6250220537185669
```

In [9]:

```
#%% compute accuracy on training data

net_out = net(data)
pred = net_out.data.max(1)[1]  # get the index of the max log-probability
correctidx = pred.eq(target.data)
ncorrect = correctidx.sum()
accuracy = ncorrect.item()/len(data)
print('Training accuracy is ', accuracy)
plt.scatter(X[:, 0], X[:, 1], c=pred, cmap=plt.cm.Spectral, s = 1)

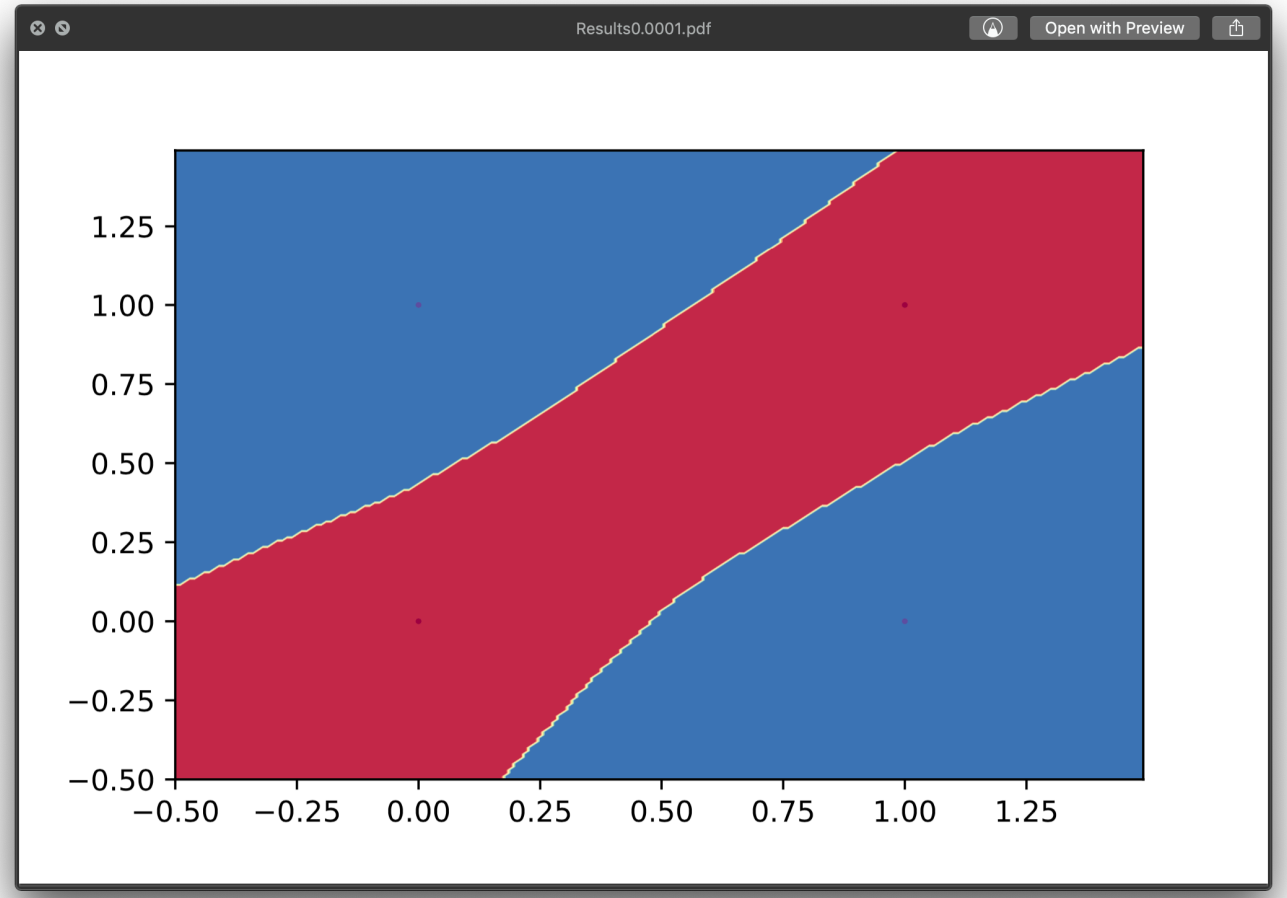
#%% if need to train further

# for epoch in range(nepochs):
#     # resize data from (batch_size, 1, 28, 28) to (batch_size, 28*28)
#     optimizer.zero_grad()
#     net_out = net(data)
#     loss = criterion(net_out, target)
#     loss.backward()
#     optimizer.step()
#     if epoch % 100 == 0:
#         print('Epoch ', epoch, 'Loss ', loss.item())


#%%  plot outputs
plot_decision_boundary(net, X, y, 'Results0.0001.pdf')
#plot_decision_boundary(net, X[correctidx,:], y[correctidx], 'Correct.pdf'
#plot_decision_boundary(net, X[~correctidx,:], y[~correctidx], 'Inorrect.p

#%% save model
```

```
Training accuracy is  1.0
<ipython-input-3-b68d425386b7>:21: UserWarning: Implicit dimension choice f
or log_softmax has been deprecated. Change the call to include dim=X as an
argument.
  return F.log_softmax(x)
```


Results0.0001.pdf
Open with Preview
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
1.25

In [10]:
```
#Question 2:
```

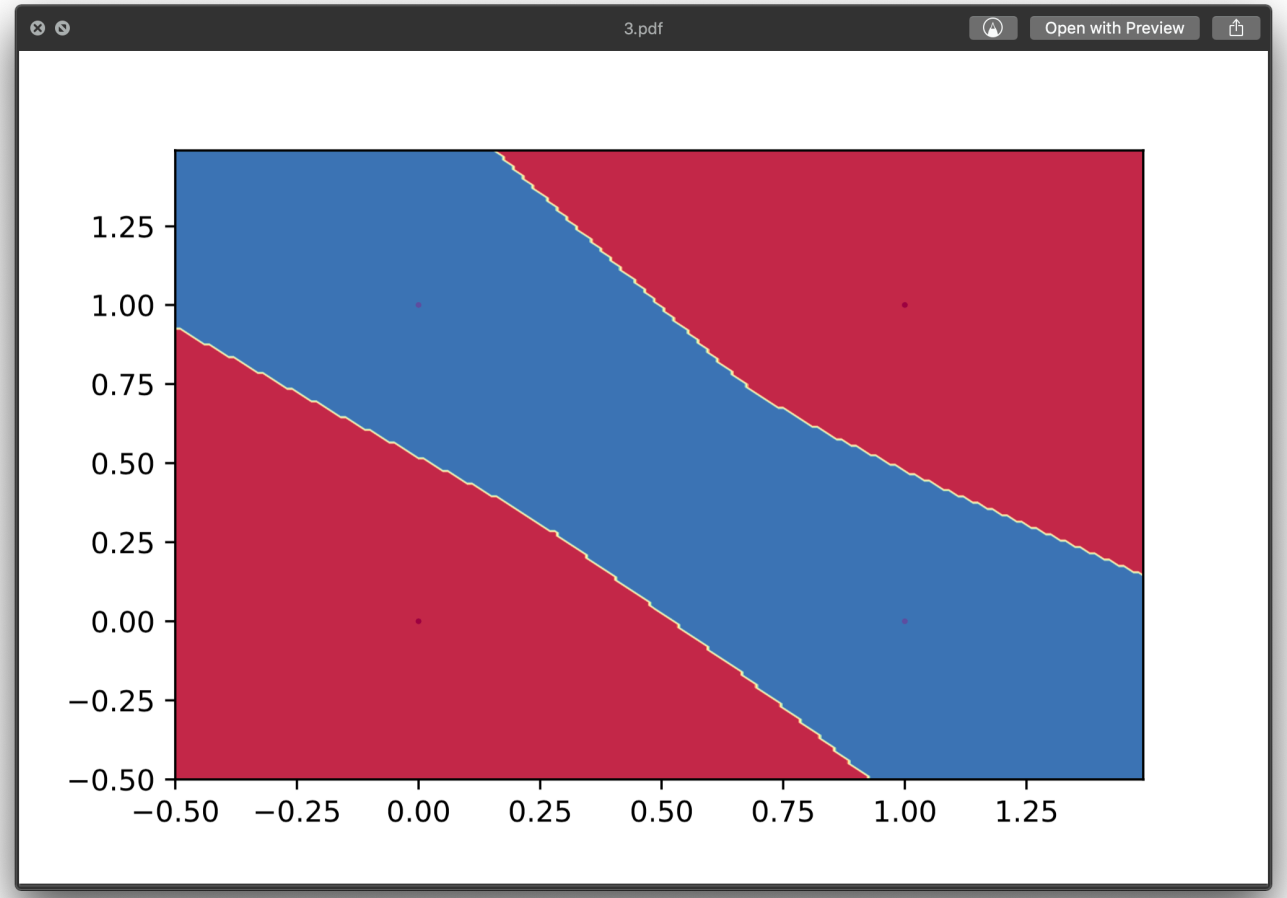
In [11]:
```
# nepochs = 10000
nepochs = 3000 #10000
data, target = X, y
# run the main training loop
for epoch in range(nepochs):
#    adjust learning rate if desired
#    if epoch % 3000 == 0 and epoch <= 24000:
#        for g in optimizer.param_groups:
#            g['lr'] = g['lr']/2
    optimizer.zero_grad()
    # forward propagate
    net_out = net(data)
    # compute loss
    loss = criterion(net_out, target)

    # backpropagate
    loss.backward()
    # update parameters
    optimizer.step()
    # print out report

    if epoch % 10 == 0:
        print('Epoch ', epoch, 'Loss ', loss.item())
        net_out = net(data)
        pred = net_out.data.max(1)[1]  # get the index of the max log-prob
        correctidx = pred.eq(target.data)
        ncorrect = correctidx.sum()
        accuracy = ncorrect.item()/len(data)
        if epoch< 0.001:
            break
        print('Training accuracy is ', accuracy)
```

```
Epoch  0 Loss  0.6225759387016296
<ipython-input-3-b68d425386b7>:21: UserWarning: Implicit dimension choice f
or log_softmax has been deprecated. Change the call to include dim=X as an
argument.
  return F.log_softmax(x)
```

In [12]:
```
#Question 3
```


3.pdf
Open with Preview
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00
1.25

In [13]:

```
class Net(nn.Module):

    def __init__(self):
        super(Net, self).__init__()
        self.fc1 = nn.Linear(2, 20)
        self.fc2 = nn.Linear(20, 20)
        self.fc3 = nn.Linear(20, 20)
        #self.fc4 = nn.Linear(20, 20)
        #self.fc5 = nn.Linear(20, 20)
        #self.fc6 = nn.Linear(20, 20)
        #self.fc7 = nn.Linear(20, 2)

    def forward(self, x):
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        #x = F.relu(self.fc3(x))
        #x = F.relu(self.fc4(x))
        #x = F.relu(self.fc5(x))
        #x = F.relu(self.fc6(x))
        x = self.fc3(x)
        return F.log_softmax(x)
        #return F.softmax(x)
```

In [14]:

```
# nepochs = 10000
nepochs = 3000 #10000
data, target = X, y
# run the main training loop
for epoch in range(nepochs):
#    adjust learning rate if desired
#    if epoch % 3000 == 0 and epoch <= 24000:
#        for g in optimizer.param_groups:
#            g['lr'] = g['lr']/2
    optimizer.zero_grad()
    # forward propagate
    net_out = net(data)
    # compute loss
    loss = criterion(net_out, target)

    # backpropagate
    loss.backward()
    # update parameters
    optimizer.step()
    # print out report

    if epoch % 10 == 0:
        print('Epoch ', epoch, 'Loss ', loss.item())
        net_out = net(data)
        pred = net_out.data.max(1)[1]  # get the index of the max log-prob
        correctidx = pred.eq(target.data)
        ncorrect = correctidx.sum()
        accuracy = ncorrect.item()/len(data)
        #if epochs< 0.001:
         #   break
        print('Training accuracy is ', accuracy)
```

```
<ipython-input-3-b68d425386b7>:21: UserWarning: Implicit dimension choice f
or log_softmax has been deprecated. Change the call to include dim=X as an
argument.
  return F.log_softmax(x)
Epoch  0 Loss  0.6200512647628784
Training accuracy is  1.0
Epoch  10 Loss  0.5861670970916748
Training accuracy is  1.0
Epoch  20 Loss  0.5298529863357544
Training accuracy is  1.0
Epoch  30 Loss  0.43002861738204956
Training accuracy is  1.0
Epoch  40 Loss  0.27282190322875977
Training accuracy is  1.0
Epoch  50 Loss  0.13154783844947815
Training accuracy is  1.0
Epoch  60 Loss  0.05327668413519859
Training accuracy is  1.0
Epoch  70 Loss  0.023709189146757126
Training accuracy is  1.0
Epoch  80 Loss  0.013243664987385273
Training accuracy is  1.0
Epoch  90 Loss  0.008865930140018463
Training accuracy is  1.0
Epoch  100 Loss  0.006658598780632019
```

```
Training accuracy is  1.0
Epoch  110 Loss  0.005379956215620041
Training accuracy is  1.0
Epoch  120 Loss  0.0045394496992230415
Training accuracy is  1.0
Epoch  130 Loss  0.003928876481950283
Training accuracy is  1.0
Epoch  140 Loss  0.00346049340441823
Training accuracy is  1.0
Epoch  150 Loss  0.0030872030183672905
Training accuracy is  1.0
Epoch  160 Loss  0.0027822465635836124
Training accuracy is  1.0
Epoch  170 Loss  0.0025281780399382114
Training accuracy is  1.0
Epoch  180 Loss  0.0023130846675485373
Training accuracy is  1.0
Epoch  190 Loss  0.0021286052651703358
Training accuracy is  1.0
Epoch  200 Loss  0.001969016157090664
Training accuracy is  1.0
Epoch  210 Loss  0.0018297492060810328
Training accuracy is  1.0
Epoch  220 Loss  0.001707063871435821
Training accuracy is  1.0
Epoch  230 Loss  0.0015983477933332324
Training accuracy is  1.0
Epoch  240 Loss  0.0015014930395409465
Training accuracy is  1.0
Epoch  250 Loss  0.0014145683962851763
Training accuracy is  1.0
Epoch  260 Loss  0.0013362973695620894
Training accuracy is  1.0
Epoch  270 Loss  0.0012653418816626072
Training accuracy is  1.0
Epoch  280 Loss  0.001200811006128788
Training accuracy is  1.0
Epoch  290 Loss  0.0011419614311307669
Training accuracy is  1.0
Epoch  300 Loss  0.001088079996407032
Training accuracy is  1.0
Epoch  310 Loss  0.0010385422501713037
Training accuracy is  1.0
Epoch  320 Loss  0.000992931891232729
Training accuracy is  1.0
Epoch  330 Loss  0.0009508328512310982
Training accuracy is  1.0
Epoch  340 Loss  0.0009117689915001392
Training accuracy is  1.0
Epoch  350 Loss  0.0008755025337450206
Training accuracy is  1.0
Epoch  360 Loss  0.0008417657809332013
Training accuracy is  1.0
Epoch  370 Loss  0.000810201745480299
Training accuracy is  1.0
Epoch  380 Loss  0.0007807806832715869
Training accuracy is  1.0
Epoch  390 Loss  0.0007531456649303436
Training accuracy is  1.0
Epoch  400 Loss  0.0007272965158335865
Training accuracy is  1.0
```

```
Epoch  410 Loss  0.0007029358530417085
Training accuracy is  1.0
Epoch  420 Loss  0.0006800339324399829
Training accuracy is  1.0
Epoch  430 Loss  0.0006584418006241322
Training accuracy is  1.0
Epoch  440 Loss  0.0006379810511134565
Training accuracy is  1.0
Epoch  450 Loss  0.0006187112303450704
Training accuracy is  1.0
Epoch  460 Loss  0.000600394036155194
Training accuracy is  1.0
Epoch  470 Loss  0.0005830595036968589
Training accuracy is  1.0
Epoch  480 Loss  0.0005665883654728532
Training accuracy is  1.0
Epoch  490 Loss  0.0005509211914613843
Training accuracy is  1.0
Epoch  500 Loss  0.0005360282375477254
Training accuracy is  1.0
Epoch  510 Loss  0.000521879643201828
Training accuracy is  1.0
Epoch  520 Loss  0.0005083564901724458
Training accuracy is  1.0
Epoch  530 Loss  0.0004953990573994815
Training accuracy is  1.0
Epoch  540 Loss  0.0004830968100577593
Training accuracy is  1.0
Epoch  550 Loss  0.000471300765639171
Training accuracy is  1.0
Epoch  560 Loss  0.00045998120913282037
Training accuracy is  1.0
Epoch  570 Loss  0.00044919774518348277
Training accuracy is  1.0
Epoch  580 Loss  0.0004388609668239951
Training accuracy is  1.0
Epoch  590 Loss  0.00042888158350251615
Training accuracy is  1.0
Epoch  600 Loss  0.00041931914165616035
Training accuracy is  1.0
Epoch  610 Loss  0.0004101736412849277
Training accuracy is  1.0
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