

## Task II: Quantum Generative Adversarial Network (QGAN) Part

You will explore how best to apply a quantum generative adversarial network (QGAN) to solve a High Energy Data analysis issue, more specifically, separating the signal events from the background events. You should use the Google Cirq and Tensorflow Quantum (TFQ) libraries for this task.

A set of input samples (simulated with Delphes) is provided in NumPy NPZ format [Download Input](#). In the input file, there are only 100 samples for training and 100 samples for testing so it won't take much computing resources to accomplish this task. The signal events are labeled with 1 while the background events are labeled with 0.

Be sure to show that you understand how to fine tune your machine learning model to improve the performance. The performance can be evaluated with classification accuracy or Area Under ROC Curve (AUC).

## Downloading the dataset

```
In [1]: !gdown --id 1r_MZB_crfpj6r3SxPDeU_3JD6t6AxAj -O events.npz

Downloading...
From: https://drive.google.com/uc?id=1r_MZB_crfpj6r3SxPDeU_3JD6t6AxAj
To: /content/events.npz
100% 9.14k/9.14k [00:00<00:00, 25.4MB/s]
```

## Setting up the required libraries

```
In [2]: !pip install -q tensorflow==2.3.1
!pip install -q tensorflow-quantum
import tensorflow as tf
import tensorflow_quantum as tfq

import cirq
import sympy
import numpy as np
import seaborn as sns
from sklearn.metrics import roc_curve, auc

%matplotlib inline
import matplotlib.pyplot as plt
from cirq.contrib.svg import SVGCircuit
```

	320.4MB 48kB/s
	20.1MB 1.4MB/s
	460kB 34.2MB/s

ERROR: datascience 0.10.6 has requirement folium==0.2.1, but you'll have folium 0.8.3 which is incompatible.

ERROR: alumentations 0.1.12 has requirement imgaug<0.2.7,>=0.2.5, but you'll have imgaug 0.2.9 which is incompatible.

	5.9MB 11.8MB/s
	5.6MB 48.2MB/s
	1.6MB 47.6MB/s

## Loading the data

```
In [3]: data = np.load('./events.npz', allow_pickle=True)
training_input = data['training_input']
test_input = data['test_input']
```

```
In [4]: training_input
```

```
Out[4]: array([[-0.43079088,  0.86834819, -0.92614721, -0.92662029, -0.56900862],
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```

```

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dtype=object)

```

```

In [5]: def prepare_data(training_input, test_input):
x_train_0 = training_input.item()['0']
x_train_1 = training_input.item()['1']
x_test_0 = test_input.item()['0']
x_test_1 = test_input.item()['1']
x_train = np.zeros((len(x_train_0) + len(x_train_1), x_train_0.shape[1]), dtype=np.float32)
x_test = np.zeros((len(x_test_0) + len(x_test_1), x_test_0.shape[1]), dtype=np.float32)
y_train = np.zeros((len(x_train_0) + len(x_train_1),), dtype=np.int32)
y_test = np.zeros((len(x_test_0) + len(x_test_1),), dtype=np.int32)
x_train[:len(x_train_0), :] = x_train_0
x_train[len(x_train_0):, :] = x_train_1
y_train[:len(x_train_0)] = 0
y_train[len(x_train_0):] = 1

x_test[:len(x_test_0), :] = x_test_0
x_test[len(x_test_0):, :] = x_test_1
y_test[:len(x_test_0)] = 0
y_test[len(x_test_0):] = 1

idx1 = np.random.permutation(len(x_train))
idx2 = np.random.permutation(len(x_test))
x_train, y_train = x_train[idx1], y_train[idx1]
x_test, y_test = x_test[idx2], y_test[idx2]

print('Shape of the training set:', x_train.shape)
print('Shape of the test set:', x_test.shape)

return x_train, y_train, x_test, y_test

x_train, y_train, x_test, y_test = prepare_data(training_input, test_input)

```

Shape of the training set: (100, 5)  
Shape of the test set: (100, 5)

## Approach

We will make use of a Quantum GAN in the following:

1. Train a GAN to produce samples that look like they came from quantum circuits.
2. Add a classification path to the discriminator and minimize both the minimax loss and classification loss.
3. We will use a random quantum circuit to generate random inputs for the generator. The intuition behind this is that the data that was provided are the results (measurements) taken from some quantum experiment. So if we succeed in training a GAN which generates outputs similar to the experimental data, this will help in identifying new or other possible outcomes of the same quantum experiment which have been missed in the dataset provided.
4. Simultaneously training the discriminator to classify signal events and background events will help in identifying the signal events generated from the fully trained generator.

## Data Generation

As provided in the dataset, each datapoint is 5-dimensional. Hence we will use 5 qubits and pass them through a random quantum circuit and then use these measurements as inputs to the GAN

```
In [6]: def generate_circuit(qubits):
        """Generate a random circuit on qubits."""
        random_circuit = cirq.generate_boixo_2018_supremacy_circuits_v2(qubits, cz_depth=2, seed=123242)
        return random_circuit

    def generate_data(circuit, n_samples):
        """Draw `n_samples` samples from circuit into a tf.Tensor."""
        return tf.squeeze(tfq.layers.Sample()(circuit, repetitions=n_samples).to_tensor())
```

```
In [7]: # sample data and circuit structure
qubits = cirq.GridQubit.rect(1, 5)
random_circuit_m = generate_circuit(qubits) + cirq.measure_each(*qubits)
SVGCircuit(random_circuit_m)
```

```
findfont: Font family ['Arial'] not found. Falling back to DejaVu Sans.
```

Out[7]:

Quantum circuit diagram showing 5 horizontal qubit lines labeled (0, 0), (0, 1), (0, 2), (0, 3), and (0, 4). Each line starts with an **H** box. Between the first and second **H** boxes, there are two CNOT gates: one with control on (0, 0) and target on (0, 1), and another with control on (0, 1) and target on (0, 2). Between the second and third **H** boxes, there is a **T** box on lines (0, 2) and (0, 3), and a  $Y^{0.5}$  box on line (0, 1). After the third **H** box, there are two more **H** boxes on each line, and finally an **M** box on each line.

```
In [8]: generate_data(random_circuit_m, 10)
```

```
Out[8]: <tf.Tensor: shape=(10, 5), dtype=int8, numpy=
array([[0, 0, 0, 0, 0],
       [0, 1, 0, 0, 0],
       [0, 1, 1, 0, 0],
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       [1, 0, 0, 0, 0],
       [1, 0, 1, 0, 0],
       [1, 0, 1, 0, 0]], dtype=int8)>
```

We will generate 200 random training data

```
In [9]: N_SAMPLES = 200
N_QUBITS = 5
QUBITS = cirq.GridQubit.rect(1, N_QUBITS)
REFERENCE_CIRCUIT = generate_circuit(QUBITS)
random_data = generate_data(REFERENCE_CIRCUIT, N_SAMPLES)
random_data
```

```
Out[9]: <tf.Tensor: shape=(200, 5), dtype=int8, numpy=
array([[0, 0, 0, 0, 0],
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       [0, 0, 0, 0, 1],
       [0, 0, 0, 0, 1],
```

[illegible]

[illegible]

## Building a Model

This GAN will be used to produce measurements corresponding to signal/background events.

```
In [10]: def make_generator():
        """Construct generator model."""
        model = tf.keras.Sequential()
        model.add(tf.keras.layers.Dense(256, use_bias=False, input_shape=(N_QUBITS, ), activation='elu'))
        model.add(tf.keras.layers.Dense(128, activation='relu'))
        model.add(tf.keras.layers.Dropout(0.3))
        model.add(tf.keras.layers.Dense(64, activation='relu'))
        model.add(tf.keras.layers.Dropout(0.3))
        model.add(tf.keras.layers.Dense(N_QUBITS, activation=tf.keras.activations.tanh))
        return model

def make_discriminator():
    """Construct discriminator model along with a classifier."""
    inp = tf.keras.Input(shape=(N_QUBITS, ), dtype=tf.float32)
    out = tf.keras.layers.Dense(256, use_bias=False, activation='elu')(inp)
    out = tf.keras.layers.Dense(128, activation='relu')(out)
    out = tf.keras.layers.Dropout(0.4)(out)
    out = tf.keras.layers.Dense(64, activation='relu')(out)
```



```

out = tf.keras.layers.Dropout(0.3)(out)
classification = tf.keras.layers.Dense(2, activation='softmax')(out)
discrimination = tf.keras.layers.Dense(1, activation='sigmoid')(out)
model = tf.keras.Model(inputs=[inp], outputs=[discrimination, classification])
return model

```

Let us instantiate our models, define the losses and define the `train_step` function which will be executed in each epoch

```

In [11]: generator = make_generator()
discriminator = make_discriminator()

```

```

In [12]: cross_entropy = tf.keras.losses.BinaryCrossentropy(from_logits=True)

def discriminator_loss(real_output, fake_output):
    """Computes the discriminator loss."""
    real_loss = cross_entropy(tf.ones_like(real_output), real_output)
    fake_loss = cross_entropy(tf.zeros_like(fake_output), fake_output)
    total_loss = real_loss + fake_loss
    return total_loss

def generator_loss(fake_output):
    """Compute the generator loss."""
    return cross_entropy(tf.ones_like(fake_output), fake_output)

generator_optimizer = tf.keras.optimizers.Adam(learning_rate=0.0002, beta_1=0.5)
discriminator_optimizer = tf.keras.optimizers.Adam(learning_rate=0.0002, beta_1=0.5)

```

```

In [13]: BATCH_SIZE = 16
bce = tf.keras.losses.BinaryCrossentropy(from_logits=False)
# auc = tf.keras.metrics.AUC()
@tf.function
def train_step(images, labels, noise):
    """Run train step on provided image batch."""
    with tf.GradientTape() as gen_tape, tf.GradientTape() as disc_tape:
        generated_data = generator(noise, training=True)

        real_output, real_preds = discriminator(images, training=True)
        fake_output, fake_preds = discriminator(generated_data, training=True)

        gen_loss = generator_loss(fake_output)
        disc_loss = discriminator_loss(real_output, fake_output)
        disc_loss = disc_loss + bce(tf.one_hot(tf.squeeze(labels), depth=2), real_preds)

    gradients_of_generator = gen_tape.gradient(gen_loss, generator.trainable_variables)
    gradients_of_discriminator = disc_tape.gradient(disc_loss, discriminator.trainable_variables)

    generator_optimizer.apply_gradients(zip(gradients_of_generator, generator.trainable_variables))
    discriminator_optimizer.apply_gradients(zip(gradients_of_discriminator, discriminator.trainable_variables))
    # auc.update_state(tf.one_hot(tf.squeeze(labels), depth=2), real_preds)

    return gen_loss, disc_loss

```

```

In [14]: def train(data, labels, noise, epochs):
    """Launch full training for the given number of epochs."""
    batched_data = tf.data.Dataset.from_tensor_slices(data).batch(BATCH_SIZE)
    batched_labels = tf.data.Dataset.from_tensor_slices(labels).batch(BATCH_SIZE)
    batched_noise = tf.data.Dataset.from_tensor_slices(noise).batch(BATCH_SIZE)
    AUC = tf.keras.metrics.AUC()
    g_losses = []
    d_losses = []
    # aucs = []
    for epoch in range(epochs):
        g_epoch_losses = []
        d_epoch_losses = []
        # aucs_epoch = []
        for i, (data_batch, labels_batch, noise_batch) in enumerate(zip(batched_data, batched_labels, batched_noise)):
            gl, dl = train_step(data_batch, labels_batch, noise_batch)
            g_epoch_losses.append(gl)
            d_epoch_losses.append(dl)
            # aucs_epoch.append(auc_roc)

        g_losses.append(tf.reduce_mean(g_epoch_losses))
        d_losses.append(tf.reduce_mean(d_epoch_losses))
        print('Epoch: {}, Generator Loss: {}, Discriminator Loss: {}'.format(epoch, tf.reduce_mean(g_epoch_losses), tf.reduce_mean(d_epoch_losses)))
        # aucs.append(tf.reduce_mean(aucs_epoch))
    return g_losses, d_losses

```

```

In [15]: gen_losses, disc_losses = train(x_train, y_train, random_data, 1000)

```

```

Epoch: 0, Generator Loss: 0.47245699167251587, Discriminator Loss: 2.1309597492218018
Epoch: 1, Generator Loss: 0.47354671359062195, Discriminator Loss: 2.0846550464630127
Epoch: 2, Generator Loss: 0.4747970402240753, Discriminator Loss: 2.075195550918579
Epoch: 3, Generator Loss: 0.47502169013023376, Discriminator Loss: 2.042206048965454
Epoch: 4, Generator Loss: 0.4750267565250397, Discriminator Loss: 2.0312952995300293
Epoch: 5, Generator Loss: 0.4736452102661133, Discriminator Loss: 2.017235040664673
Epoch: 6, Generator Loss: 0.4720909893512726, Discriminator Loss: 1.9946978092193604
Epoch: 7, Generator Loss: 0.46873971819877625, Discriminator Loss: 1.9959081411361694
Epoch: 8, Generator Loss: 0.46720847487449646, Discriminator Loss: 1.9918718338012695
Epoch: 9, Generator Loss: 0.46549269556999207, Discriminator Loss: 2.028303384780884
Epoch: 10, Generator Loss: 0.4661886096006714, Discriminator Loss: 1.9572858810424805
Epoch: 11, Generator Loss: 0.4672021269798279, Discriminator Loss: 1.956483244895935
Epoch: 12, Generator Loss: 0.4674927294254303, Discriminator Loss: 1.9482008218765259
Epoch: 13, Generator Loss: 0.4675862491130829, Discriminator Loss: 1.9636048078536987
Epoch: 14, Generator Loss: 0.4748061001300812, Discriminator Loss: 1.9643497467041016
Epoch: 15, Generator Loss: 0.4778321087360382, Discriminator Loss: 1.9405934810638428
Epoch: 16, Generator Loss: 0.47958749532699585, Discriminator Loss: 1.9556820392608643

```

Epoch: 17, Generator Loss: 0.4828241467475891, Discriminator Loss: 1.90898597240448  
Epoch: 18, Generator Loss: 0.4819352924823761, Discriminator Loss: 1.9337685108184814  
Epoch: 19, Generator Loss: 0.48568472266197205, Discriminator Loss: 1.9421571493148804  
Epoch: 20, Generator Loss: 0.49434393644332886, Discriminator Loss: 1.9321893453598022  
Epoch: 21, Generator Loss: 0.4991462528705597, Discriminator Loss: 1.930079460144043  
Epoch: 22, Generator Loss: 0.5063033699989319, Discriminator Loss: 1.8862199783325195  
Epoch: 23, Generator Loss: 0.505766749382019, Discriminator Loss: 1.917807936668396  
Epoch: 24, Generator Loss: 0.49457839131355286, Discriminator Loss: 1.9039415121078491  
Epoch: 25, Generator Loss: 0.48733657598495483, Discriminator Loss: 1.9469871520996094  
Epoch: 26, Generator Loss: 0.47996988892555237, Discriminator Loss: 1.9616447687149048  
Epoch: 27, Generator Loss: 0.4782406687736511, Discriminator Loss: 1.9432618618011475  
Epoch: 28, Generator Loss: 0.47633519768714905, Discriminator Loss: 1.9124267101287842  
Epoch: 29, Generator Loss: 0.4723445773124695, Discriminator Loss: 1.9401410818099976  
Epoch: 30, Generator Loss: 0.4662209451198578, Discriminator Loss: 1.899164080619812  
Epoch: 31, Generator Loss: 0.4601726233959198, Discriminator Loss: 1.965654969215393  
Epoch: 32, Generator Loss: 0.4676465094089508, Discriminator Loss: 1.9388188123703003  
Epoch: 33, Generator Loss: 0.47172150015830994, Discriminator Loss: 1.9266111850738525  
Epoch: 34, Generator Loss: 0.49127528071403503, Discriminator Loss: 1.8824323415756226  
Epoch: 35, Generator Loss: 0.4991036057472229, Discriminator Loss: 1.9555609226226807  
Epoch: 36, Generator Loss: 0.5034300088882446, Discriminator Loss: 1.8869209289550781  
Epoch: 37, Generator Loss: 0.5053252577781677, Discriminator Loss: 1.889276146888733  
Epoch: 38, Generator Loss: 0.4996817409992218, Discriminator Loss: 1.9249626398086548  
Epoch: 39, Generator Loss: 0.4961780905723572, Discriminator Loss: 1.906009316444397  
Epoch: 40, Generator Loss: 0.4840833842754364, Discriminator Loss: 1.929800033569336  
Epoch: 41, Generator Loss: 0.4854932129383087, Discriminator Loss: 1.9467328786849976  
Epoch: 42, Generator Loss: 0.495086133480072, Discriminator Loss: 1.9553041458129883  
Epoch: 43, Generator Loss: 0.5065574049949646, Discriminator Loss: 1.9479920864105225  
Epoch: 44, Generator Loss: 0.5183477401733398, Discriminator Loss: 1.9672572612762451  
Epoch: 45, Generator Loss: 0.5243074297904968, Discriminator Loss: 1.910927414894104  
Epoch: 46, Generator Loss: 0.5249665379524231, Discriminator Loss: 1.919148564338684  
Epoch: 47, Generator Loss: 0.529880166053772, Discriminator Loss: 1.923840880393982  
Epoch: 48, Generator Loss: 0.5328139662742615, Discriminator Loss: 1.9019012451171875  
Epoch: 49, Generator Loss: 0.5344147086143494, Discriminator Loss: 1.9173332452774048  
Epoch: 50, Generator Loss: 0.5417134165763855, Discriminator Loss: 1.9112889766693115  
Epoch: 51, Generator Loss: 0.54924076795578, Discriminator Loss: 1.8539237976074219  
Epoch: 52, Generator Loss: 0.5495539903640747, Discriminator Loss: 1.883928656578064  
Epoch: 53, Generator Loss: 0.5478733777999878, Discriminator Loss: 1.8430753946304321  
Epoch: 54, Generator Loss: 0.5377190113067627, Discriminator Loss: 1.8723548650741577  
Epoch: 55, Generator Loss: 0.5183801054954529, Discriminator Loss: 1.886048674583435  
Epoch: 56, Generator Loss: 0.4912142753601074, Discriminator Loss: 1.9496876001358032  
Epoch: 57, Generator Loss: 0.47742483019828796, Discriminator Loss: 1.9405990839004517  
Epoch: 58, Generator Loss: 0.4778480529785156, Discriminator Loss: 1.945410966873169  
Epoch: 59, Generator Loss: 0.48666617274284363, Discriminator Loss: 1.9604955911636353  
Epoch: 60, Generator Loss: 0.5039676427841187, Discriminator Loss: 1.8997727632522583  
Epoch: 61, Generator Loss: 0.528506338596344, Discriminator Loss: 1.8672453165054321  
Epoch: 62, Generator Loss: 0.5329515337944031, Discriminator Loss: 1.8696988821029663  
Epoch: 63, Generator Loss: 0.5410000681877136, Discriminator Loss: 1.8588272333145142  
Epoch: 64, Generator Loss: 0.5182962417602539, Discriminator Loss: 1.8751519918441772  
Epoch: 65, Generator Loss: 0.5201209783554077, Discriminator Loss: 1.892263412475586  
Epoch: 66, Generator Loss: 0.532818615436554, Discriminator Loss: 1.8661795854568481  
Epoch: 67, Generator Loss: 0.5395328402519226, Discriminator Loss: 1.8921520709991455  
Epoch: 68, Generator Loss: 0.5526874661445618, Discriminator Loss: 1.8613594770431519  
Epoch: 69, Generator Loss: 0.5561595559120178, Discriminator Loss: 1.8321349620819092  
Epoch: 70, Generator Loss: 0.5518271327018738, Discriminator Loss: 1.8868277072906494  
Epoch: 71, Generator Loss: 0.5390034914016724, Discriminator Loss: 1.887233018875122  
Epoch: 72, Generator Loss: 0.521506130695343, Discriminator Loss: 1.9402351379394531  
Epoch: 73, Generator Loss: 0.5270923376083374, Discriminator Loss: 1.8839147090911865  
Epoch: 74, Generator Loss: 0.5378847122192383, Discriminator Loss: 1.9119096994400024  
Epoch: 75, Generator Loss: 0.5516775250434875, Discriminator Loss: 1.899363398551941  
Epoch: 76, Generator Loss: 0.5606463551521301, Discriminator Loss: 1.8420372009277344  
Epoch: 77, Generator Loss: 0.5662694573402405, Discriminator Loss: 1.8485041856765747  
Epoch: 78, Generator Loss: 0.5752094984054565, Discriminator Loss: 1.845253586769104  
Epoch: 79, Generator Loss: 0.5783962607383728, Discriminator Loss: 1.8394582271575928  
Epoch: 80, Generator Loss: 0.5798035264015198, Discriminator Loss: 1.8407738208770752  
Epoch: 81, Generator Loss: 0.5705142617225647, Discriminator Loss: 1.8317338228225708  
Epoch: 82, Generator Loss: 0.5464543700218201, Discriminator Loss: 1.8880252838134766  
Epoch: 83, Generator Loss: 0.5176686644554138, Discriminator Loss: 1.9064760208129883  
Epoch: 84, Generator Loss: 0.5069132447242737, Discriminator Loss: 1.9146770238876343  
Epoch: 85, Generator Loss: 0.508942723274231, Discriminator Loss: 1.9320131540298462  
Epoch: 86, Generator Loss: 0.5214599370956421, Discriminator Loss: 1.8895044326782227  
Epoch: 87, Generator Loss: 0.5359059572219849, Discriminator Loss: 1.8706740140914917  
Epoch: 88, Generator Loss: 0.5441693067550659, Discriminator Loss: 1.8912113904953003  
Epoch: 89, Generator Loss: 0.5526143908500671, Discriminator Loss: 1.8730275630950928  
Epoch: 90, Generator Loss: 0.5570126175880432, Discriminator Loss: 1.8783923387527466  
Epoch: 91, Generator Loss: 0.5619910955429077, Discriminator Loss: 1.8808168172836304  
Epoch: 92, Generator Loss: 0.5604825615882874, Discriminator Loss: 1.8524006605148315  
Epoch: 93, Generator Loss: 0.5525741577148438, Discriminator Loss: 1.8538178205490112  
Epoch: 94, Generator Loss: 0.5485913157463074, Discriminator Loss: 1.8798120021820068  
Epoch: 95, Generator Loss: 0.5469285845756531, Discriminator Loss: 1.8844879865646362  
Epoch: 96, Generator Loss: 0.5451406240463257, Discriminator Loss: 1.8655368089675903  
Epoch: 97, Generator Loss: 0.5373668074607849, Discriminator Loss: 1.8591585159301758  
Epoch: 98, Generator Loss: 0.5433589816093445, Discriminator Loss: 1.8414385318756104  
Epoch: 99, Generator Loss: 0.5540968775749207, Discriminator Loss: 1.8172370195388794  
Epoch: 100, Generator Loss: 0.5645535588264465, Discriminator Loss: 1.8407418727874756  
Epoch: 101, Generator Loss: 0.5749638676643372, Discriminator Loss: 1.8057104349136353  
Epoch: 102, Generator Loss: 0.5700496435165405, Discriminator Loss: 1.8277219533920288  
Epoch: 103, Generator Loss: 0.5735805630683899, Discriminator Loss: 1.7969226837158203  
Epoch: 104, Generator Loss: 0.5604730248451233, Discriminator Loss: 1.8470449447631836  
Epoch: 105, Generator Loss: 0.5590295195579529, Discriminator Loss: 1.8898046016693115  
Epoch: 106, Generator Loss: 0.5458016395568848, Discriminator Loss: 1.8857128620147705  
Epoch: 107, Generator Loss: 0.5512093305587769, Discriminator Loss: 1.875548005104065  
Epoch: 108, Generator Loss: 0.5583423376083374, Discriminator Loss: 1.867981195449829  
Epoch: 109, Generator Loss: 0.5647979974746704, Discriminator Loss: 1.8331958055496216  
Epoch: 110, Generator Loss: 0.5678556561470032, Discriminator Loss: 1.8380311727523804  
Epoch: 111, Generator Loss: 0.5705403089523315, Discriminator Loss: 1.8400055170059204  
Epoch: 112, Generator Loss: 0.5687400698661804, Discriminator Loss: 1.865172028541565  
Epoch: 113, Generator Loss: 0.5678566694259644, Discriminator Loss: 1.8431841135025024  
Epoch: 114, Generator Loss: 0.5811198353767395, Discriminator Loss: 1.8377007246017456  
Epoch: 115, Generator Loss: 0.5826096534729004, Discriminator Loss: 1.7986491918563843  
Epoch: 116, Generator Loss: 0.5792993903160095, Discriminator Loss: 1.8398023843765259  
Epoch: 117, Generator Loss: 0.5840440392494202, Discriminator Loss: 1.8061217069625854  
Epoch: 118, Generator Loss: 0.5829824209213257, Discriminator Loss: 1.798681616783142  
Epoch: 119, Generator Loss: 0.5748141407966614, Discriminator Loss: 1.8183003664016724

Epoch: 120, Generator Loss: 0.579166054725647, Discriminator Loss: 1.8069028854370117  
Epoch: 121, Generator Loss: 0.5761149525642395, Discriminator Loss: 1.8490674495697021  
Epoch: 122, Generator Loss: 0.5651600360870361, Discriminator Loss: 1.8124849796295166  
Epoch: 123, Generator Loss: 0.5722929239273071, Discriminator Loss: 1.8468486070632935  
Epoch: 124, Generator Loss: 0.5626228451728821, Discriminator Loss: 1.7711504697799683  
Epoch: 125, Generator Loss: 0.5709100365638733, Discriminator Loss: 1.82460618019104  
Epoch: 126, Generator Loss: 0.5566639304161072, Discriminator Loss: 1.8116308450698853  
Epoch: 127, Generator Loss: 0.557690441608429, Discriminator Loss: 1.852997064590454  
Epoch: 128, Generator Loss: 0.5517714619636536, Discriminator Loss: 1.8209640979766846  
Epoch: 129, Generator Loss: 0.5520617365837097, Discriminator Loss: 1.8207871913909912  
Epoch: 130, Generator Loss: 0.5489395260810852, Discriminator Loss: 1.8778486251831055  
Epoch: 131, Generator Loss: 0.5518161654472351, Discriminator Loss: 1.85513436794281  
Epoch: 132, Generator Loss: 0.5678400993347168, Discriminator Loss: 1.8305803537368774  
Epoch: 133, Generator Loss: 0.569003701210022, Discriminator Loss: 1.7880452871322632  
Epoch: 134, Generator Loss: 0.573340892791748, Discriminator Loss: 1.7983888387680054  
Epoch: 135, Generator Loss: 0.5840587615966797, Discriminator Loss: 1.8284927606582642  
Epoch: 136, Generator Loss: 0.5904276967048645, Discriminator Loss: 1.7948226928710938  
Epoch: 137, Generator Loss: 0.5902224779129028, Discriminator Loss: 1.8270350694656372  
Epoch: 138, Generator Loss: 0.5911105871200562, Discriminator Loss: 1.8259629011154175  
Epoch: 139, Generator Loss: 0.58720862865448, Discriminator Loss: 1.78156578540802  
Epoch: 140, Generator Loss: 0.5888800024986267, Discriminator Loss: 1.7946158647537231  
Epoch: 141, Generator Loss: 0.597480297088623, Discriminator Loss: 1.7780158519744873  
Epoch: 142, Generator Loss: 0.5790091156959534, Discriminator Loss: 1.823628544807434  
Epoch: 143, Generator Loss: 0.5797544717788696, Discriminator Loss: 1.80972158908844  
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Epoch: 145, Generator Loss: 0.5740483403205872, Discriminator Loss: 1.817771077156067  
Epoch: 146, Generator Loss: 0.5724102854728699, Discriminator Loss: 1.8568506240844727  
Epoch: 147, Generator Loss: 0.5741368532180786, Discriminator Loss: 1.9016492366790771  
Epoch: 148, Generator Loss: 0.579916775226593, Discriminator Loss: 1.8537720441818237  
Epoch: 149, Generator Loss: 0.5835942029953003, Discriminator Loss: 1.8422173261642456  
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Epoch: 152, Generator Loss: 0.5880081057548523, Discriminator Loss: 1.8115910291671753  
Epoch: 153, Generator Loss: 0.5933859944343567, Discriminator Loss: 1.808287501335144  
Epoch: 154, Generator Loss: 0.5825670957565308, Discriminator Loss: 1.8200031518936157  
Epoch: 155, Generator Loss: 0.5794199109077454, Discriminator Loss: 1.835432767868042  
Epoch: 156, Generator Loss: 0.5831654667854309, Discriminator Loss: 1.8381356000900269  
Epoch: 157, Generator Loss: 0.580565333366394, Discriminator Loss: 1.8432129621505737  
Epoch: 158, Generator Loss: 0.5798083543777466, Discriminator Loss: 1.8292144536972046  
Epoch: 159, Generator Loss: 0.5763370394706726, Discriminator Loss: 1.7972300052642822  
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Epoch: 161, Generator Loss: 0.5730393528938293, Discriminator Loss: 1.8364251852035522  
Epoch: 162, Generator Loss: 0.5786271095275879, Discriminator Loss: 1.809244155883789  
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Epoch: 164, Generator Loss: 0.5763441920280457, Discriminator Loss: 1.8029909133911133  
Epoch: 165, Generator Loss: 0.5668936967849731, Discriminator Loss: 1.8254177570343018  
Epoch: 166, Generator Loss: 0.5783704519271851, Discriminator Loss: 1.8380842208862305  
Epoch: 167, Generator Loss: 0.5803117752075195, Discriminator Loss: 1.8156964778900146  
Epoch: 168, Generator Loss: 0.576206386089325, Discriminator Loss: 1.8534902334213257  
Epoch: 169, Generator Loss: 0.5804293751716614, Discriminator Loss: 1.8490601778030396  
Epoch: 170, Generator Loss: 0.5929244756698608, Discriminator Loss: 1.7944611310958862  
Epoch: 171, Generator Loss: 0.5895068049430847, Discriminator Loss: 1.8413585424423218  
Epoch: 172, Generator Loss: 0.5956119298934937, Discriminator Loss: 1.7647895812988281  
Epoch: 173, Generator Loss: 0.5717609524726868, Discriminator Loss: 1.838675618171692  
Epoch: 174, Generator Loss: 0.5926441550254822, Discriminator Loss: 1.8003720045089722  
Epoch: 175, Generator Loss: 0.5777339935302734, Discriminator Loss: 1.817586898803711  
Epoch: 176, Generator Loss: 0.5890185236930847, Discriminator Loss: 1.812300443649292  
Epoch: 177, Generator Loss: 0.580956757068634, Discriminator Loss: 1.797780990600586  
Epoch: 178, Generator Loss: 0.5740098357200623, Discriminator Loss: 1.7970234155654907  
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Epoch: 180, Generator Loss: 0.5785021185874939, Discriminator Loss: 1.7880767583847046  
Epoch: 181, Generator Loss: 0.5800935626029968, Discriminator Loss: 1.8522919416427612  
Epoch: 182, Generator Loss: 0.5867061018943787, Discriminator Loss: 1.822400450706482  
Epoch: 183, Generator Loss: 0.5795001983642578, Discriminator Loss: 1.8132468461990356  
Epoch: 184, Generator Loss: 0.5839903950691223, Discriminator Loss: 1.8034998178482056  
Epoch: 185, Generator Loss: 0.5902624130249023, Discriminator Loss: 1.8707809448242188  
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Epoch: 187, Generator Loss: 0.5832567811012268, Discriminator Loss: 1.8180426359176636  
Epoch: 188, Generator Loss: 0.5949293971061707, Discriminator Loss: 1.783767580986023  
Epoch: 189, Generator Loss: 0.5882362127304077, Discriminator Loss: 1.7780182361602783  
Epoch: 190, Generator Loss: 0.586202085018158, Discriminator Loss: 1.7669931650161743  
Epoch: 191, Generator Loss: 0.5955218076705933, Discriminator Loss: 1.7943665981292725  
Epoch: 192, Generator Loss: 0.5884971022605896, Discriminator Loss: 1.8553498983383179  
Epoch: 193, Generator Loss: 0.5864877104759216, Discriminator Loss: 1.814666509628296  
Epoch: 194, Generator Loss: 0.5878000855445862, Discriminator Loss: 1.8173978328704834  
Epoch: 195, Generator Loss: 0.5829865336418152, Discriminator Loss: 1.7766565084457397  
Epoch: 196, Generator Loss: 0.5855027437210083, Discriminator Loss: 1.780436396598816  
Epoch: 197, Generator Loss: 0.5868383049964905, Discriminator Loss: 1.8084920644760132  
Epoch: 198, Generator Loss: 0.575687050819397, Discriminator Loss: 1.8626261949539185  
Epoch: 199, Generator Loss: 0.5734561085700989, Discriminator Loss: 1.814003348350525  
Epoch: 200, Generator Loss: 0.5821380615234375, Discriminator Loss: 1.787900686264038  
Epoch: 201, Generator Loss: 0.5825676321983337, Discriminator Loss: 1.7975270748138428  
Epoch: 202, Generator Loss: 0.5872183442115784, Discriminator Loss: 1.8068798780441284  
Epoch: 203, Generator Loss: 0.589210033416748, Discriminator Loss: 1.7662280797958374  
Epoch: 204, Generator Loss: 0.5872465968132019, Discriminator Loss: 1.7544498443603516  
Epoch: 205, Generator Loss: 0.5852044224739075, Discriminator Loss: 1.799509882926941  
Epoch: 206, Generator Loss: 0.5848655700683594, Discriminator Loss: 1.800597071647644  
Epoch: 207, Generator Loss: 0.588655412197113, Discriminator Loss: 1.8246790170669556  
Epoch: 208, Generator Loss: 0.589668333530426, Discriminator Loss: 1.7993882894515991  
Epoch: 209, Generator Loss: 0.586122453212738, Discriminator Loss: 1.7980926036834717  
Epoch: 210, Generator Loss: 0.5811410546302795, Discriminator Loss: 1.8229830265045166  
Epoch: 211, Generator Loss: 0.5838125944137573, Discriminator Loss: 1.808951497077942  
Epoch: 212, Generator Loss: 0.5899124145507812, Discriminator Loss: 1.7909661531448364  
Epoch: 213, Generator Loss: 0.582482635974884, Discriminator Loss: 1.809408187866211  
Epoch: 214, Generator Loss: 0.5927814245223999, Discriminator Loss: 1.8122529983520508  
Epoch: 215, Generator Loss: 0.5919867753982544, Discriminator Loss: 1.812651515007019  
Epoch: 216, Generator Loss: 0.5774916410446167, Discriminator Loss: 1.8311737775802612  
Epoch: 217, Generator Loss: 0.5916158556938171, Discriminator Loss: 1.80137038230896  
Epoch: 218, Generator Loss: 0.587494969367981, Discriminator Loss: 1.801534652709961  
Epoch: 219, Generator Loss: 0.5914614796638489, Discriminator Loss: 1.7950834035873413  
Epoch: 220, Generator Loss: 0.5977410674095154, Discriminator Loss: 1.804827332496643  
Epoch: 221, Generator Loss: 0.5910537838935852, Discriminator Loss: 1.8259379863739014  
Epoch: 222, Generator Loss: 0.5911675691604614, Discriminator Loss: 1.785849690437317



Epoch: 223,	Generator Loss: 0.5902270674705505,	Discriminator Loss: 1.7956575155258179
Epoch: 224,	Generator Loss: 0.5870367288589478,	Discriminator Loss: 1.806010127067566
Epoch: 225,	Generator Loss: 0.576016902923584,	Discriminator Loss: 1.815130352973938
Epoch: 226,	Generator Loss: 0.5898144841194153,	Discriminator Loss: 1.8247593641281128
Epoch: 227,	Generator Loss: 0.5933632850646973,	Discriminator Loss: 1.7635691165924072
Epoch: 228,	Generator Loss: 0.5895825624465942,	Discriminator Loss: 1.7947477102279663
Epoch: 229,	Generator Loss: 0.592381477355957,	Discriminator Loss: 1.7785085439682007
Epoch: 230,	Generator Loss: 0.5900315046310425,	Discriminator Loss: 1.7768971920013428
Epoch: 231,	Generator Loss: 0.5998455882072449,	Discriminator Loss: 1.781646490097046
Epoch: 232,	Generator Loss: 0.5799124836921692,	Discriminator Loss: 1.7942339181900024
Epoch: 233,	Generator Loss: 0.5923317670822144,	Discriminator Loss: 1.7947653532028198
Epoch: 234,	Generator Loss: 0.5876646041870117,	Discriminator Loss: 1.8193113803863525
Epoch: 235,	Generator Loss: 0.5948984026908875,	Discriminator Loss: 1.7942699193954468
Epoch: 236,	Generator Loss: 0.5939916372299194,	Discriminator Loss: 1.8367494344711304
Epoch: 237,	Generator Loss: 0.6005646586418152,	Discriminator Loss: 1.7945114374160767
Epoch: 238,	Generator Loss: 0.5958216786384583,	Discriminator Loss: 1.775800108909607
Epoch: 239,	Generator Loss: 0.5972772836685181,	Discriminator Loss: 1.7939767837524414
Epoch: 240,	Generator Loss: 0.5876967310905457,	Discriminator Loss: 1.7859151363372803
Epoch: 241,	Generator Loss: 0.5910149812698364,	Discriminator Loss: 1.7957251071929932
Epoch: 242,	Generator Loss: 0.594523012638092,	Discriminator Loss: 1.7803630828857422
Epoch: 243,	Generator Loss: 0.5905736088752747,	Discriminator Loss: 1.8052161931991577
Epoch: 244,	Generator Loss: 0.6002391576766968,	Discriminator Loss: 1.8009215593338013
Epoch: 245,	Generator Loss: 0.5883274674415588,	Discriminator Loss: 1.8121471405029297
Epoch: 246,	Generator Loss: 0.5972622632980347,	Discriminator Loss: 1.7680219411849976
Epoch: 247,	Generator Loss: 0.6031440496444702,	Discriminator Loss: 1.7734832763671875
Epoch: 248,	Generator Loss: 0.5980311632156372,	Discriminator Loss: 1.7994674444198608
Epoch: 249,	Generator Loss: 0.590323805809021,	Discriminator Loss: 1.8139253854751587
Epoch: 250,	Generator Loss: 0.5961219072341919,	Discriminator Loss: 1.7915009260177612
Epoch: 251,	Generator Loss: 0.5905814170837402,	Discriminator Loss: 1.7939599752426147
Epoch: 252,	Generator Loss: 0.5965902209281921,	Discriminator Loss: 1.8055177927017212
Epoch: 253,	Generator Loss: 0.5936791300773621,	Discriminator Loss: 1.815978765487671
Epoch: 254,	Generator Loss: 0.5943019986152649,	Discriminator Loss: 1.7743269205093384
Epoch: 255,	Generator Loss: 0.593122661113739,	Discriminator Loss: 1.7929071187973022
Epoch: 256,	Generator Loss: 0.5907200574874878,	Discriminator Loss: 1.7806369066238403
Epoch: 257,	Generator Loss: 0.6039754152297974,	Discriminator Loss: 1.7606970071792603
Epoch: 258,	Generator Loss: 0.5951156616210938,	Discriminator Loss: 1.7829055786132812
Epoch: 259,	Generator Loss: 0.5951326489448547,	Discriminator Loss: 1.7482564449310303
Epoch: 260,	Generator Loss: 0.5952062606811523,	Discriminator Loss: 1.7963343858718872
Epoch: 261,	Generator Loss: 0.5938629508018494,	Discriminator Loss: 1.7968145608901978
Epoch: 262,	Generator Loss: 0.603729784488678,	Discriminator Loss: 1.7932924032211304
Epoch: 263,	Generator Loss: 0.6059321761131287,	Discriminator Loss: 1.768479347229004
Epoch: 264,	Generator Loss: 0.6058592200279236,	Discriminator Loss: 1.7418197393417358
Epoch: 265,	Generator Loss: 0.595417857170105,	Discriminator Loss: 1.8276987075805664
Epoch: 266,	Generator Loss: 0.5927332639694214,	Discriminator Loss: 1.812684416770935
Epoch: 267,	Generator Loss: 0.6015084981918335,	Discriminator Loss: 1.8017228841781616
Epoch: 268,	Generator Loss: 0.6034714579582214,	Discriminator Loss: 1.7694677114486694
Epoch: 269,	Generator Loss: 0.5930930376052856,	Discriminator Loss: 1.7757179737091064
Epoch: 270,	Generator Loss: 0.5910283327102661,	Discriminator Loss: 1.814226746559143
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Epoch: 273,	Generator Loss: 0.6087466478347778,	Discriminator Loss: 1.7920869588851929
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Epoch: 277,	Generator Loss: 0.5954179763793945,	Discriminator Loss: 1.8026812076568604
Epoch: 278,	Generator Loss: 0.5925002098083496,	Discriminator Loss: 1.7891557216644287
Epoch: 279,	Generator Loss: 0.5977622270584106,	Discriminator Loss: 1.7608896493911743
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Epoch: 282,	Generator Loss: 0.6092392802238464,	Discriminator Loss: 1.7389123439788818
Epoch: 283,	Generator Loss: 0.6055019497871399,	Discriminator Loss: 1.7935752868652344
Epoch: 284,	Generator Loss: 0.6162451505661011,	Discriminator Loss: 1.7142695188522339
Epoch: 285,	Generator Loss: 0.6078903079032898,	Discriminator Loss: 1.7878285646438599
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Epoch: 294,	Generator Loss: 0.6073796153068542,	Discriminator Loss: 1.7862082719802856
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Epoch: 299,	Generator Loss: 0.6053739190101624,	Discriminator Loss: 1.7611024379730225
Epoch: 300,	Generator Loss: 0.6076239347457886,	Discriminator Loss: 1.7657039165496826
Epoch: 301,	Generator Loss: 0.612251877784729,	Discriminator Loss: 1.8044030666351318
Epoch: 302,	Generator Loss: 0.5989183783531189,	Discriminator Loss: 1.793509840965271
Epoch: 303,	Generator Loss: 0.6009202003479004,	Discriminator Loss: 1.7637134790420532
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Epoch: 306,	Generator Loss: 0.5973915457725525,	Discriminator Loss: 1.7808406352996826
Epoch: 307,	Generator Loss: 0.6056591272354126,	Discriminator Loss: 1.7933681011199951
Epoch: 308,	Generator Loss: 0.5984299778938293,	Discriminator Loss: 1.8259941339492798
Epoch: 309,	Generator Loss: 0.6029558181762695,	Discriminator Loss: 1.7802554368972778
Epoch: 310,	Generator Loss: 0.5977792739868164,	Discriminator Loss: 1.7640111446380615
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Epoch: 312,	Generator Loss: 0.6121324896812439,	Discriminator Loss: 1.7436379194259644
Epoch: 313,	Generator Loss: 0.5970749855041504,	Discriminator Loss: 1.7878061532974243
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Epoch: 323,	Generator Loss: 0.6067332029342651,	Discriminator Loss: 1.8051669597625732
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Epoch: 407,	Generator Loss: 0.6211419701576233,	Discriminator Loss: 1.7493479251861572
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Epoch: 443,	Generator Loss: 0.6235308051109314,	Discriminator Loss: 1.7414175271987915
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Epoch: 452,	Generator Loss: 0.6147470474243164,	Discriminator Loss: 1.7443989515304565
Epoch: 453,	Generator Loss: 0.6179523468017578,	Discriminator Loss: 1.7810420989990234
Epoch: 454,	Generator Loss: 0.6179908514022827,	Discriminator Loss: 1.7675936222076416
Epoch: 455,	Generator Loss: 0.6148394346237183,	Discriminator Loss: 1.7166112661361694
Epoch: 456,	Generator Loss: 0.6114181876182556,	Discriminator Loss: 1.7492493391036987
Epoch: 457,	Generator Loss: 0.6164283752441406,	Discriminator Loss: 1.7421748638153076
Epoch: 458,	Generator Loss: 0.6054251790046692,	Discriminator Loss: 1.7229071855545044
Epoch: 459,	Generator Loss: 0.614006519317627,	Discriminator Loss: 1.7247982025146484
Epoch: 460,	Generator Loss: 0.6155251860618591,	Discriminator Loss: 1.7648149728775024
Epoch: 461,	Generator Loss: 0.6172952651977539,	Discriminator Loss: 1.740599274635315
Epoch: 462,	Generator Loss: 0.6145196557044983,	Discriminator Loss: 1.750741958618164
Epoch: 463,	Generator Loss: 0.6205253005027771,	Discriminator Loss: 1.749652624130249
Epoch: 464,	Generator Loss: 0.6111143827438354,	Discriminator Loss: 1.7226630449295044
Epoch: 465,	Generator Loss: 0.6090002059936523,	Discriminator Loss: 1.7591551542282104
Epoch: 466,	Generator Loss: 0.6217235922813416,	Discriminator Loss: 1.737836241722107
Epoch: 467,	Generator Loss: 0.6110173463821411,	Discriminator Loss: 1.759297251701355
Epoch: 468,	Generator Loss: 0.6279541254043579,	Discriminator Loss: 1.7185380458831787
Epoch: 469,	Generator Loss: 0.6204034090042114,	Discriminator Loss: 1.7575396299362183
Epoch: 470,	Generator Loss: 0.6204807162284851,	Discriminator Loss: 1.7681214809417725
Epoch: 471,	Generator Loss: 0.6224599480628967,	Discriminator Loss: 1.73287832736969
Epoch: 472,	Generator Loss: 0.6220912933349609,	Discriminator Loss: 1.7221338748931885
Epoch: 473,	Generator Loss: 0.60962975025177,	Discriminator Loss: 1.7238266468048096
Epoch: 474,	Generator Loss: 0.6188808679580688,	Discriminator Loss: 1.7116515636444092
Epoch: 475,	Generator Loss: 0.6108474731445312,	Discriminator Loss: 1.7549517154693604
Epoch: 476,	Generator Loss: 0.6133111119270325,	Discriminator Loss: 1.7273313999176025
Epoch: 477,	Generator Loss: 0.6197901368141174,	Discriminator Loss: 1.7072821855545044
Epoch: 478,	Generator Loss: 0.620763897895813,	Discriminator Loss: 1.7271863222122192
Epoch: 479,	Generator Loss: 0.6160798668861389,	Discriminator Loss: 1.7265211343765259
Epoch: 480,	Generator Loss: 0.6134710311889648,	Discriminator Loss: 1.7248725891113281
Epoch: 481,	Generator Loss: 0.6112031936645508,	Discriminator Loss: 1.7596149444580078
Epoch: 482,	Generator Loss: 0.6147740483283997,	Discriminator Loss: 1.7480839490890503
Epoch: 483,	Generator Loss: 0.6137107014656067,	Discriminator Loss: 1.7677900791168213
Epoch: 484,	Generator Loss: 0.6088793873786926,	Discriminator Loss: 1.7655359506607056
Epoch: 485,	Generator Loss: 0.6135033369064331,	Discriminator Loss: 1.753987431526184
Epoch: 486,	Generator Loss: 0.6132036447525024,	Discriminator Loss: 1.7402735948562622
Epoch: 487,	Generator Loss: 0.6220645308494568,	Discriminator Loss: 1.7374846935272217
Epoch: 488,	Generator Loss: 0.6206895112991333,	Discriminator Loss: 1.72329580783844
Epoch: 489,	Generator Loss: 0.6135781407356262,	Discriminator Loss: 1.7440016269683838
Epoch: 490,	Generator Loss: 0.6249958872795105,	Discriminator Loss: 1.7471237182617188
Epoch: 491,	Generator Loss: 0.6223009824752808,	Discriminator Loss: 1.7220293283462524
Epoch: 492,	Generator Loss: 0.62324059009552,	Discriminator Loss: 1.7169603109359741
Epoch: 493,	Generator Loss: 0.6269025802612305,	Discriminator Loss: 1.7153151035308838
Epoch: 494,	Generator Loss: 0.6228041648864746,	Discriminator Loss: 1.7440036535263062
Epoch: 495,	Generator Loss: 0.6235299706459045,	Discriminator Loss: 1.766105055809021
Epoch: 496,	Generator Loss: 0.6199068427085876,	Discriminator Loss: 1.7107280492782593
Epoch: 497,	Generator Loss: 0.6235290169715881,	Discriminator Loss: 1.758880376815796
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Epoch: 499,	Generator Loss: 0.6267810463905334,	Discriminator Loss: 1.726730465888977
Epoch: 500,	Generator Loss: 0.6221446990966797,	Discriminator Loss: 1.743272066116333
Epoch: 501,	Generator Loss: 0.6232017874717712,	Discriminator Loss: 1.7428091764450073
Epoch: 502,	Generator Loss: 0.6237085461616516,	Discriminator Loss: 1.696834683418274
Epoch: 503,	Generator Loss: 0.6205602884292603,	Discriminator Loss: 1.73643958568573
Epoch: 504,	Generator Loss: 0.6163774728775024,	Discriminator Loss: 1.7475694417953491
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Epoch: 506,	Generator Loss: 0.6225876212120056,	Discriminator Loss: 1.7749977111816406
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Epoch: 508,	Generator Loss: 0.6259216070175171,	Discriminator Loss: 1.7193433046340942
Epoch: 509,	Generator Loss: 0.630513072013855,	Discriminator Loss: 1.723427653312683
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Epoch: 511,	Generator Loss: 0.6227601170539856,	Discriminator Loss: 1.7016957998275757
Epoch: 512,	Generator Loss: 0.616567075252533,	Discriminator Loss: 1.725605845451355
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Epoch: 514,	Generator Loss: 0.6263751983642578,	Discriminator Loss: 1.7255312204360962
Epoch: 515,	Generator Loss: 0.6213749647140503,	Discriminator Loss: 1.7321051359176636
Epoch: 516,	Generator Loss: 0.6226465106010437,	Discriminator Loss: 1.7647168636322021
Epoch: 517,	Generator Loss: 0.6221932172775269,	Discriminator Loss: 1.7708631753921509
Epoch: 518,	Generator Loss: 0.6270681619644165,	Discriminator Loss: 1.7214332818984985
Epoch: 519,	Generator Loss: 0.6302257180213928,	Discriminator Loss: 1.7304818630218506
Epoch: 520,	Generator Loss: 0.6281509399414062,	Discriminator Loss: 1.7503926753997803
Epoch: 521,	Generator Loss: 0.6159775853157043,	Discriminator Loss: 1.7610857486724854
Epoch: 522,	Generator Loss: 0.6242669820785522,	Discriminator Loss: 1.739737629890442
Epoch: 523,	Generator Loss: 0.6308911442756653,	Discriminator Loss: 1.7126470804214478
Epoch: 524,	Generator Loss: 0.6280304789543152,	Discriminator Loss: 1.764251947402954
Epoch: 525,	Generator Loss: 0.6282770037651062,	Discriminator Loss: 1.7273848056793213
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Epoch: 528,	Generator Loss: 0.6219497323036194,	Discriminator Loss: 1.7454346418380737
Epoch: 529,	Generator Loss: 0.626629650592804,	Discriminator Loss: 1.7280441522598267
Epoch: 530,	Generator Loss: 0.6228533387184143,	Discriminator Loss: 1.769858479499817
Epoch: 531,	Generator Loss: 0.6283809542655945,	Discriminator Loss: 1.7304004430770874

Epoch: 532,	Generator Loss: 0.6206912994384766,	Discriminator Loss: 1.7668081521987915
Epoch: 533,	Generator Loss: 0.6227726936340332,	Discriminator Loss: 1.7046059370040894
Epoch: 534,	Generator Loss: 0.6244305372238159,	Discriminator Loss: 1.7429667711257935
Epoch: 535,	Generator Loss: 0.6191021203994751,	Discriminator Loss: 1.7525242567062378
Epoch: 536,	Generator Loss: 0.6323050260543823,	Discriminator Loss: 1.7009317874908447
Epoch: 537,	Generator Loss: 0.621911883354187,	Discriminator Loss: 1.7398103475570679
Epoch: 538,	Generator Loss: 0.6254562735557556,	Discriminator Loss: 1.7201707363128662
Epoch: 539,	Generator Loss: 0.6187002062797546,	Discriminator Loss: 1.728859782218933
Epoch: 540,	Generator Loss: 0.6200411915779114,	Discriminator Loss: 1.7095317840576172
Epoch: 541,	Generator Loss: 0.6234182715415955,	Discriminator Loss: 1.745928406715393
Epoch: 542,	Generator Loss: 0.6171955466270447,	Discriminator Loss: 1.7428785562515259
Epoch: 543,	Generator Loss: 0.6297994256019592,	Discriminator Loss: 1.7359458208084106
Epoch: 544,	Generator Loss: 0.6193410158157349,	Discriminator Loss: 1.7379485368728638
Epoch: 545,	Generator Loss: 0.6207083463668823,	Discriminator Loss: 1.7412545680999756
Epoch: 546,	Generator Loss: 0.6234694719314575,	Discriminator Loss: 1.6964908838272095
Epoch: 547,	Generator Loss: 0.6206778287887573,	Discriminator Loss: 1.721090316772461
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Epoch: 551,	Generator Loss: 0.6265654563903809,	Discriminator Loss: 1.747493863105774
Epoch: 552,	Generator Loss: 0.6248694658279419,	Discriminator Loss: 1.7509649991989136
Epoch: 553,	Generator Loss: 0.6265056729316711,	Discriminator Loss: 1.6871286630630493
Epoch: 554,	Generator Loss: 0.6324524879455566,	Discriminator Loss: 1.7089699506759644
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Epoch: 557,	Generator Loss: 0.6259313821792603,	Discriminator Loss: 1.6938756704330444
Epoch: 558,	Generator Loss: 0.6250706315040588,	Discriminator Loss: 1.724730134010315
Epoch: 559,	Generator Loss: 0.6294423341751099,	Discriminator Loss: 1.7369089126586914
Epoch: 560,	Generator Loss: 0.6171320080757141,	Discriminator Loss: 1.7288200855255127
Epoch: 561,	Generator Loss: 0.6212797164916992,	Discriminator Loss: 1.7310575246810913
Epoch: 562,	Generator Loss: 0.6280786395072937,	Discriminator Loss: 1.7302354574203491
Epoch: 563,	Generator Loss: 0.6242254376411438,	Discriminator Loss: 1.7039949893951416
Epoch: 564,	Generator Loss: 0.6238990426063538,	Discriminator Loss: 1.7236124277114868
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Epoch: 566,	Generator Loss: 0.6222588419914246,	Discriminator Loss: 1.718854308128357
Epoch: 567,	Generator Loss: 0.6303579211235046,	Discriminator Loss: 1.73778235912323
Epoch: 568,	Generator Loss: 0.6246781945228577,	Discriminator Loss: 1.7199134826660156
Epoch: 569,	Generator Loss: 0.6275518536567688,	Discriminator Loss: 1.7296644449234009
Epoch: 570,	Generator Loss: 0.6284518241882324,	Discriminator Loss: 1.705052137374878
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Epoch: 572,	Generator Loss: 0.6315063238143921,	Discriminator Loss: 1.7131783962249756
Epoch: 573,	Generator Loss: 0.6334465742111206,	Discriminator Loss: 1.7555664777755737
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Epoch: 589,	Generator Loss: 0.6301292777061462,	Discriminator Loss: 1.7176672220230103
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Epoch: 613,	Generator Loss: 0.6306142807006836,	Discriminator Loss: 1.7597010135650635
Epoch: 614,	Generator Loss: 0.6290102601051331,	Discriminator Loss: 1.7133055925369263
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Epoch: 618,	Generator Loss: 0.6354888081550598,	Discriminator Loss: 1.72796630859375
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Epoch: 620,	Generator Loss: 0.6364563703536987,	Discriminator Loss: 1.7468599081039429
Epoch: 621,	Generator Loss: 0.6356848478317261,	Discriminator Loss: 1.739676594734192
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Epoch: 623,	Generator Loss: 0.6344479918479919,	Discriminator Loss: 1.752522587776184
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Epoch: 627,	Generator Loss: 0.6380586624145508,	Discriminator Loss: 1.73490309715271
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Epoch: 629,	Generator Loss: 0.6367877125740051,	Discriminator Loss: 1.730812430381775
Epoch: 630,	Generator Loss: 0.6373490691184998,	Discriminator Loss: 1.7252196073532104
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Epoch: 632,	Generator Loss: 0.6409969329833984,	Discriminator Loss: 1.7141889333724976
Epoch: 633,	Generator Loss: 0.6438693404197693,	Discriminator Loss: 1.716483235359192
Epoch: 634,	Generator Loss: 0.6404929757118225,	Discriminator Loss: 1.718160629272461



Epoch: 635,	Generator Loss: 0.6418212056159973,	Discriminator Loss: 1.7059879302978516
Epoch: 636,	Generator Loss: 0.6402157545089722,	Discriminator Loss: 1.7414747476577759
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Epoch: 658,	Generator Loss: 0.6410382986068726,	Discriminator Loss: 1.7186020612716675
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Epoch: 661,	Generator Loss: 0.6335309147834778,	Discriminator Loss: 1.7083841562271118
Epoch: 662,	Generator Loss: 0.6374512910842896,	Discriminator Loss: 1.7228394746780396
Epoch: 663,	Generator Loss: 0.6304803490638733,	Discriminator Loss: 1.7619202136993408
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Epoch: 665,	Generator Loss: 0.6322416663169861,	Discriminator Loss: 1.7168642282485962
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Epoch: 668,	Generator Loss: 0.638225257396698,	Discriminator Loss: 1.7608778476715088
Epoch: 669,	Generator Loss: 0.6396397352218628,	Discriminator Loss: 1.7194257974624634
Epoch: 670,	Generator Loss: 0.6348310112953186,	Discriminator Loss: 1.7385785579681396
Epoch: 671,	Generator Loss: 0.6290569305419922,	Discriminator Loss: 1.6972054243087769
Epoch: 672,	Generator Loss: 0.6327473521232605,	Discriminator Loss: 1.7324298620224
Epoch: 673,	Generator Loss: 0.6367228627204895,	Discriminator Loss: 1.692736268043518
Epoch: 674,	Generator Loss: 0.6357859373092651,	Discriminator Loss: 1.7198865413665771
Epoch: 675,	Generator Loss: 0.6374610066413879,	Discriminator Loss: 1.7375496625900269
Epoch: 676,	Generator Loss: 0.640457272529602,	Discriminator Loss: 1.7108389139175415
Epoch: 677,	Generator Loss: 0.6399840712547302,	Discriminator Loss: 1.7124073505401611
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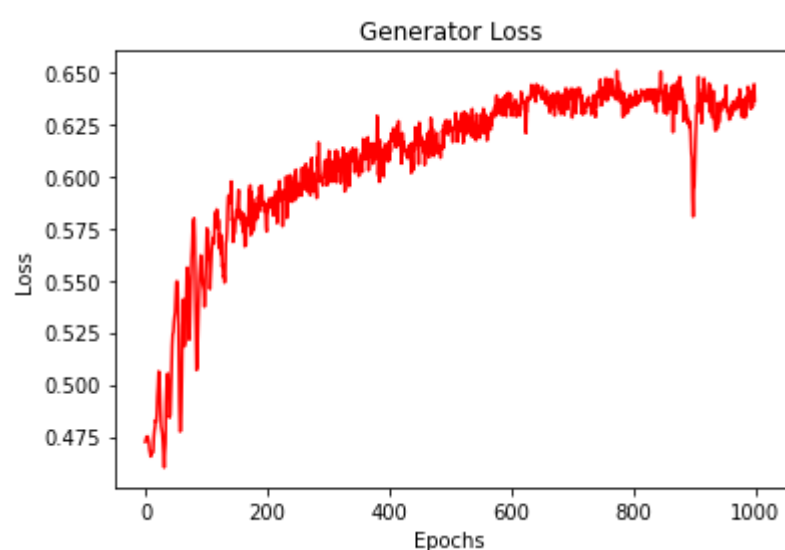


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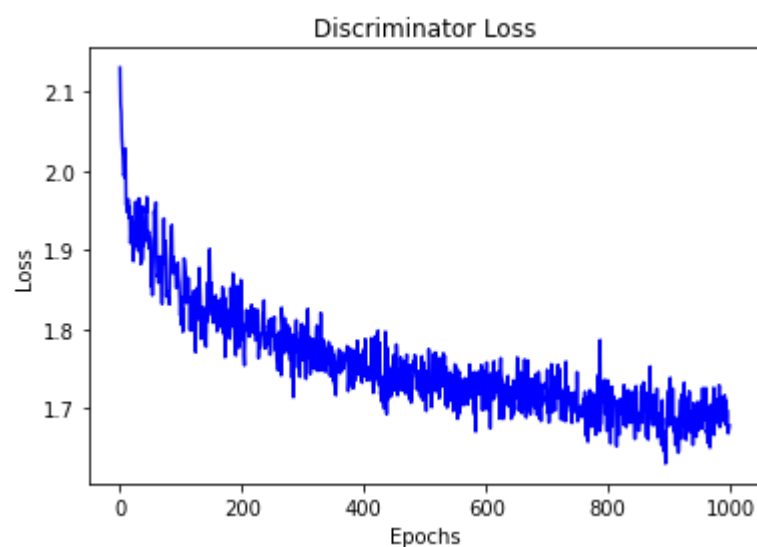
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Epoch: 896,	Generator Loss: 0.6089054346084595,	Discriminator Loss: 1.6878702640533447
Epoch: 897,	Generator Loss: 0.5893152952194214,	Discriminator Loss: 1.6784001588821411
Epoch: 898,	Generator Loss: 0.5806256532669067,	Discriminator Loss: 1.7031055688858032
Epoch: 899,	Generator Loss: 0.5936278700828552,	Discriminator Loss: 1.7227181196212769
Epoch: 900,	Generator Loss: 0.5950087308883667,	Discriminator Loss: 1.6783860921859741
Epoch: 901,	Generator Loss: 0.6084210276603699,	Discriminator Loss: 1.696806788444519
Epoch: 902,	Generator Loss: 0.6181274056434631,	Discriminator Loss: 1.739035725593567
Epoch: 903,	Generator Loss: 0.6269658207893372,	Discriminator Loss: 1.685637354850769
Epoch: 904,	Generator Loss: 0.6342068910598755,	Discriminator Loss: 1.686490774154663
Epoch: 905,	Generator Loss: 0.6317269206047058,	Discriminator Loss: 1.679091453552246
Epoch: 906,	Generator Loss: 0.6326245069503784,	Discriminator Loss: 1.7252031564712524
Epoch: 907,	Generator Loss: 0.6478039026260376,	Discriminator Loss: 1.6916368007659912
Epoch: 908,	Generator Loss: 0.6308037638664246,	Discriminator Loss: 1.6706141233444214
Epoch: 909,	Generator Loss: 0.6395400166511536,	Discriminator Loss: 1.6865588426589966
Epoch: 910,	Generator Loss: 0.6323443055152893,	Discriminator Loss: 1.6538845300674438
Epoch: 911,	Generator Loss: 0.6362345814704895,	Discriminator Loss: 1.688287615776062
Epoch: 912,	Generator Loss: 0.6255181431770325,	Discriminator Loss: 1.6665467023849487
Epoch: 913,	Generator Loss: 0.628047525882721,	Discriminator Loss: 1.6794970035552979
Epoch: 914,	Generator Loss: 0.6418572068214417,	Discriminator Loss: 1.6809141635894775
Epoch: 915,	Generator Loss: 0.6363096237182617,	Discriminator Loss: 1.6441090106964111
Epoch: 916,	Generator Loss: 0.6470140218734741,	Discriminator Loss: 1.6459091901779175
Epoch: 917,	Generator Loss: 0.6374820470809937,	Discriminator Loss: 1.6837809085845947
Epoch: 918,	Generator Loss: 0.637663722038269,	Discriminator Loss: 1.6946274042129517
Epoch: 919,	Generator Loss: 0.6363003849983215,	Discriminator Loss: 1.7117233276367188
Epoch: 920,	Generator Loss: 0.6385345458984375,	Discriminator Loss: 1.66178297996521
Epoch: 921,	Generator Loss: 0.6357702612876892,	Discriminator Loss: 1.718018651008606
Epoch: 922,	Generator Loss: 0.6381059288978577,	Discriminator Loss: 1.6883289813995361
Epoch: 923,	Generator Loss: 0.6421740651130676,	Discriminator Loss: 1.7118912935256958
Epoch: 924,	Generator Loss: 0.6446447372436523,	Discriminator Loss: 1.680925726890564
Epoch: 925,	Generator Loss: 0.6308678984642029,	Discriminator Loss: 1.732790231704712
Epoch: 926,	Generator Loss: 0.6432791352272034,	Discriminator Loss: 1.6762536764144897
Epoch: 927,	Generator Loss: 0.639890193939209,	Discriminator Loss: 1.6833150386810303
Epoch: 928,	Generator Loss: 0.6336304545402527,	Discriminator Loss: 1.6602153778076172
Epoch: 929,	Generator Loss: 0.634384274482727,	Discriminator Loss: 1.713458776473999
Epoch: 930,	Generator Loss: 0.628100574016571,	Discriminator Loss: 1.7039058208465576
Epoch: 931,	Generator Loss: 0.640991747379303,	Discriminator Loss: 1.681329607963562
Epoch: 932,	Generator Loss: 0.6284685730934143,	Discriminator Loss: 1.680267333984375
Epoch: 933,	Generator Loss: 0.6274628639221191,	Discriminator Loss: 1.7218033075332642
Epoch: 934,	Generator Loss: 0.62213534116745,	Discriminator Loss: 1.6702983379364014
Epoch: 935,	Generator Loss: 0.6218461990356445,	Discriminator Loss: 1.6963831186294556
Epoch: 936,	Generator Loss: 0.6280765533447266,	Discriminator Loss: 1.677954077720642
Epoch: 937,	Generator Loss: 0.6227008104324341,	Discriminator Loss: 1.6869243383407593
Epoch: 938,	Generator Loss: 0.6239262223243713,	Discriminator Loss: 1.685616135597229
Epoch: 939,	Generator Loss: 0.6353870630264282,	Discriminator Loss: 1.6538950204849243
Epoch: 940,	Generator Loss: 0.6255449652671814,	Discriminator Loss: 1.7068887948989868
Epoch: 941,	Generator Loss: 0.6268711686134338,	Discriminator Loss: 1.6749986410140991
Epoch: 942,	Generator Loss: 0.6303912997245789,	Discriminator Loss: 1.6767746210098267
Epoch: 943,	Generator Loss: 0.6338239908218384,	Discriminator Loss: 1.6887978315353394

Epoch: 944, Generator Loss: 0.6312969326972961, Discriminator Loss: 1.6725139617919922  
Epoch: 945, Generator Loss: 0.6357641220092773, Discriminator Loss: 1.664347767829895  
Epoch: 946, Generator Loss: 0.6355920433998108, Discriminator Loss: 1.6929203271865845  
Epoch: 947, Generator Loss: 0.6344780325889587, Discriminator Loss: 1.7087287902832031  
Epoch: 948, Generator Loss: 0.6370449662208557, Discriminator Loss: 1.6726773977279663  
Epoch: 949, Generator Loss: 0.6338468790054321, Discriminator Loss: 1.6801801919937134  
Epoch: 950, Generator Loss: 0.6355018615722656, Discriminator Loss: 1.6800497770309448  
Epoch: 951, Generator Loss: 0.6333072781562805, Discriminator Loss: 1.6958855390548706  
Epoch: 952, Generator Loss: 0.6434340476989746, Discriminator Loss: 1.7081499099731445  
Epoch: 953, Generator Loss: 0.6333805322647095, Discriminator Loss: 1.6935558319091797  
Epoch: 954, Generator Loss: 0.6309642791748047, Discriminator Loss: 1.6745455265045166  
Epoch: 955, Generator Loss: 0.6322129368782043, Discriminator Loss: 1.7257508039474487  
Epoch: 956, Generator Loss: 0.6317318677902222, Discriminator Loss: 1.6952502727508545  
Epoch: 957, Generator Loss: 0.6272238492965698, Discriminator Loss: 1.685602068901062  
Epoch: 958, Generator Loss: 0.6272782683372498, Discriminator Loss: 1.6854733228683472  
Epoch: 959, Generator Loss: 0.6281878352165222, Discriminator Loss: 1.704763650894165  
Epoch: 960, Generator Loss: 0.6337061524391174, Discriminator Loss: 1.7262060642242432  
Epoch: 961, Generator Loss: 0.6293194890022278, Discriminator Loss: 1.6699055433273315  
Epoch: 962, Generator Loss: 0.6295179724693298, Discriminator Loss: 1.6724413633346558  
Epoch: 963, Generator Loss: 0.63577800989151, Discriminator Loss: 1.6568288803100586  
Epoch: 964, Generator Loss: 0.6349766850471497, Discriminator Loss: 1.7035229206085205  
Epoch: 965, Generator Loss: 0.6352488398551941, Discriminator Loss: 1.6847354173660278  
Epoch: 966, Generator Loss: 0.6351518034934998, Discriminator Loss: 1.6948264837265015  
Epoch: 967, Generator Loss: 0.6317045092582703, Discriminator Loss: 1.6505043506622314  
Epoch: 968, Generator Loss: 0.6336820721626282, Discriminator Loss: 1.6887558698654175  
Epoch: 969, Generator Loss: 0.6333118081092834, Discriminator Loss: 1.7049213647842407  
Epoch: 970, Generator Loss: 0.637515127658844, Discriminator Loss: 1.6735632419586182  
Epoch: 971, Generator Loss: 0.6353568434715271, Discriminator Loss: 1.6840907335281372  
Epoch: 972, Generator Loss: 0.6334907412528992, Discriminator Loss: 1.7031806707382202  
Epoch: 973, Generator Loss: 0.6330669522285461, Discriminator Loss: 1.7264310121536255  
Epoch: 974, Generator Loss: 0.6417250633239746, Discriminator Loss: 1.6666183471679688  
Epoch: 975, Generator Loss: 0.6333022713661194, Discriminator Loss: 1.709949254989624  
Epoch: 976, Generator Loss: 0.6356392502784729, Discriminator Loss: 1.680402159690857  
Epoch: 977, Generator Loss: 0.6288182139396667, Discriminator Loss: 1.6912410259246826  
Epoch: 978, Generator Loss: 0.6300433278083801, Discriminator Loss: 1.6921145915985107  
Epoch: 979, Generator Loss: 0.6340363621711731, Discriminator Loss: 1.7116554975509644  
Epoch: 980, Generator Loss: 0.6366215944290161, Discriminator Loss: 1.6998025178909302  
Epoch: 981, Generator Loss: 0.630303680896759, Discriminator Loss: 1.698089599609375  
Epoch: 982, Generator Loss: 0.6280173063278198, Discriminator Loss: 1.7295455932617188  
Epoch: 983, Generator Loss: 0.6353344321250916, Discriminator Loss: 1.6763545274734497  
Epoch: 984, Generator Loss: 0.6382136940956116, Discriminator Loss: 1.695070505142212  
Epoch: 985, Generator Loss: 0.6287041306495667, Discriminator Loss: 1.7148630619049072  
Epoch: 986, Generator Loss: 0.6358261704444885, Discriminator Loss: 1.7039293050765991  
Epoch: 987, Generator Loss: 0.6369396448135376, Discriminator Loss: 1.710388422012329  
Epoch: 988, Generator Loss: 0.6430006623268127, Discriminator Loss: 1.7004451751708984  
Epoch: 989, Generator Loss: 0.641998827457428, Discriminator Loss: 1.6955468654632568  
Epoch: 990, Generator Loss: 0.6413463950157166, Discriminator Loss: 1.6835832595825195  
Epoch: 991, Generator Loss: 0.6373505592346191, Discriminator Loss: 1.7167655229568481  
Epoch: 992, Generator Loss: 0.63306725025177, Discriminator Loss: 1.682011365890503  
Epoch: 993, Generator Loss: 0.6322460770606995, Discriminator Loss: 1.7110320329666138  
Epoch: 994, Generator Loss: 0.6407507658004761, Discriminator Loss: 1.6788114309310913  
Epoch: 995, Generator Loss: 0.6386731266975403, Discriminator Loss: 1.6980780363082886  
Epoch: 996, Generator Loss: 0.6336122155189514, Discriminator Loss: 1.6756762266159058  
Epoch: 997, Generator Loss: 0.6423583626747131, Discriminator Loss: 1.6685248613357544  
Epoch: 998, Generator Loss: 0.6442269086837769, Discriminator Loss: 1.6736946105957031  
Epoch: 999, Generator Loss: 0.6363301277160645, Discriminator Loss: 1.6785545349121094

```
In [16]: plt.title('Generator Loss')
plt.plot(gen_losses, 'r-')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.show()
```



```
In [17]: plt.title('Discriminator Loss')
plt.plot(disc_losses, 'b-')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.show()
```



## Using the Discriminator for Classification

We will now evaluate the performance of discriminator on the original training data as a classifier. We will check both the classification accuracy and Area Under ROC Curve as the metrics.

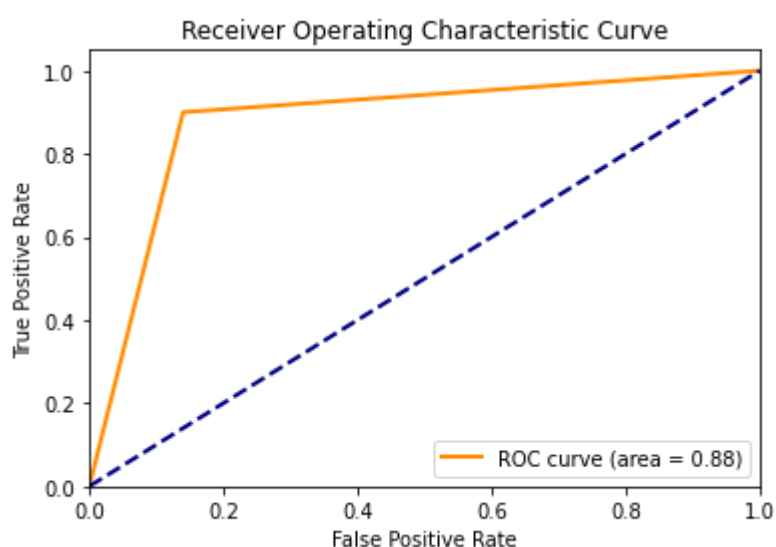
```
In [18]: _, train_predictions = discriminator(tf.convert_to_tensor(x_train))
         train_predictions.shape
```

```
Out[18]: TensorShape([100, 2])
```

```
In [19]: binary_accuracy = tf.keras.metrics.BinaryAccuracy()
         binary_accuracy.update_state(tf.one_hot(tf.squeeze(y_train), depth=2), train_predictions)
         print('Training Accuracy: %.4f %s' % (binary_accuracy.result().numpy()*100, '%'))
```

```
Training Accuracy: 88.0000 %
```

```
In [20]: fpr, tpr, _ = roc_curve(y_train, tf.argmax(train_predictions,1).numpy())
         roc_auc = auc(fpr, tpr)
         plt.figure()
         lw = 2
         plt.plot(fpr, tpr, color='darkorange',
                  lw=lw, label='ROC curve (area = %0.2f)' % roc_auc)
         plt.plot([0, 1], [0, 1], color='navy', lw=lw, linestyle='--')
         plt.xlim([0.0, 1.0])
         plt.ylim([0.0, 1.05])
         plt.xlabel('False Positive Rate')
         plt.ylabel('True Positive Rate')
         plt.title('Receiver Operating Characteristic Curve')
         plt.legend(loc="lower right")
         plt.show()
```



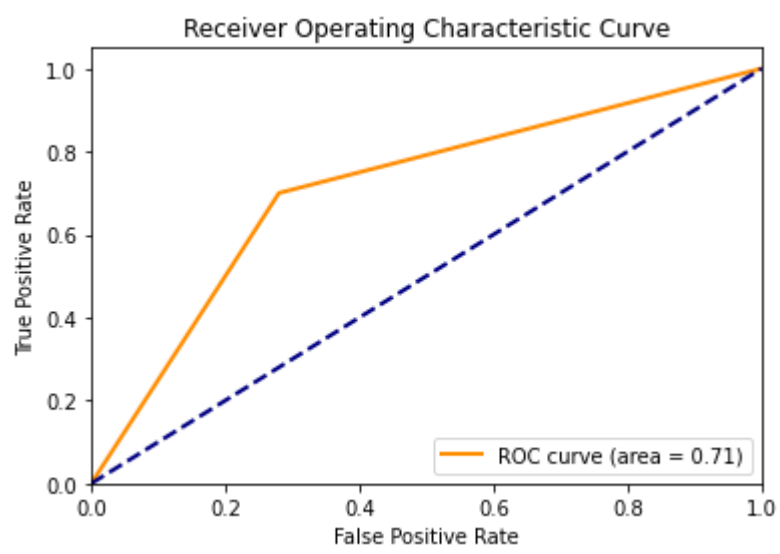
```
In [21]: _, test_predictions = discriminator(tf.convert_to_tensor(x_test))
         test_predictions.shape
```

```
Out[21]: TensorShape([100, 2])
```

```
In [22]: binary_accuracy = tf.keras.metrics.BinaryAccuracy()
         binary_accuracy.update_state(tf.one_hot(tf.squeeze(y_test), depth=2), test_predictions)
         print('Test Accuracy: %.4f %s' % (binary_accuracy.result().numpy()*100, '%'))
```

```
Test Accuracy: 71.0000 %
```

```
In [23]: fpr, tpr, _ = roc_curve(y_test, tf.argmax(test_predictions,1).numpy())
         roc_auc = auc(fpr, tpr)
         plt.figure()
         lw = 2
         plt.plot(fpr, tpr, color='darkorange',
                  lw=lw, label='ROC curve (area = %0.2f)' % roc_auc)
         plt.plot([0, 1], [0, 1], color='navy', lw=lw, linestyle='--')
         plt.xlim([0.0, 1.0])
         plt.ylim([0.0, 1.05])
         plt.xlabel('False Positive Rate')
         plt.ylabel('True Positive Rate')
         plt.title('Receiver Operating Characteristic Curve')
         plt.legend(loc="lower right")
         plt.show()
```



We will now look at the predictions on the generated synthetic data.

```
In [24]: generator_outputs = generator(random_data)
generator_outputs.shape
```

```
Out[24]: TensorShape([200, 5])
```

```
In [25]: _, predictions_synthetic = discriminator(generator_outputs)
predictions_synthetic.shape
```

```
Out[25]: TensorShape([200, 2])
```

```
In [26]: predicted_labels_synthetic = tf.argmax(predictions_synthetic, 1)
predicted_labels_synthetic[:20]
```

```
Out[26]: <tf.Tensor: shape=(20,), dtype=int64, numpy=array([1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 0, 0, 0])>
```