

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, 8.67MB/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
```

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
```

```
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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

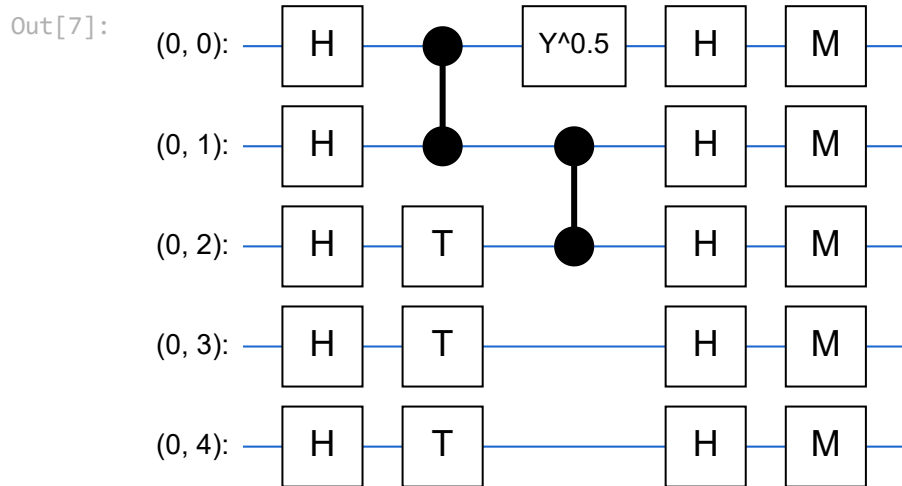
As provided in the dataset, each datapoint is 5-dimensional. Hence we will use 5 qubits and pass them through a random quantum circuit and then use these measurements as inputs to the GAN

```
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.
```



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

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

[illegible]

```
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[1, 1, 1, 1, 0]], dtype=int8)>
```

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, 2000)
```

```
Epoch: 0, Generator Loss: 0.47288545966148376, Discriminator Loss: 2.1426262855529785
Epoch: 1, Generator Loss: 0.47159355878829956, Discriminator Loss: 2.1388280391693115
Epoch: 2, Generator Loss: 0.470787912607193, Discriminator Loss: 2.0825936794281006
Epoch: 3, Generator Loss: 0.4702128767967224, Discriminator Loss: 2.075483798980713
Epoch: 4, Generator Loss: 0.47020336985588074, Discriminator Loss: 2.0505168437957764
Epoch: 5, Generator Loss: 0.4700762927532196, Discriminator Loss: 2.022904872894287
Epoch: 6, Generator Loss: 0.46946173906326294, Discriminator Loss: 2.0530457496643066
Epoch: 7, Generator Loss: 0.4677629768848419, Discriminator Loss: 2.0332977771759033
Epoch: 8, Generator Loss: 0.4693600833415985, Discriminator Loss: 2.048710346221924
Epoch: 9, Generator Loss: 0.4706823527812958, Discriminator Loss: 2.019632339477539
Epoch: 10, Generator Loss: 0.4711288809776306, Discriminator Loss: 2.0153427124023438
Epoch: 11, Generator Loss: 0.47589582204818726, Discriminator Loss: 2.0159380435943604
Epoch: 12, Generator Loss: 0.4789740741252899, Discriminator Loss: 2.0038421154022217
Epoch: 13, Generator Loss: 0.4811742901802063, Discriminator Loss: 1.968962550163269
Epoch: 14, Generator Loss: 0.48366862535476685, Discriminator Loss: 1.984475016593933
Epoch: 15, Generator Loss: 0.4791991710662842, Discriminator Loss: 2.003448009490967
Epoch: 16, Generator Loss: 0.4744584262371063, Discriminator Loss: 1.9951093196868896
Epoch: 17, Generator Loss: 0.4726622998714447, Discriminator Loss: 1.9844080209732056
Epoch: 18, Generator Loss: 0.4746064245700836, Discriminator Loss: 1.9852495193481445
Epoch: 19, Generator Loss: 0.4767344892024994, Discriminator Loss: 1.9912365674972534
Epoch: 20, Generator Loss: 0.47933536767959595, Discriminator Loss: 1.9573673009872437
Epoch: 21, Generator Loss: 0.4778843820095062, Discriminator Loss: 1.997721791267395
Epoch: 22, Generator Loss: 0.473391056060791, Discriminator Loss: 1.95980966091156
Epoch: 23, Generator Loss: 0.4726634919643402, Discriminator Loss: 1.9842766523361206
Epoch: 24, Generator Loss: 0.4760975241661072, Discriminator Loss: 1.9720042943954468
```

Epoch: 25, Generator Loss: 0.48795565962791443, Discriminator Loss: 1.9472404718399048
Epoch: 26, Generator Loss: 0.4994671046733856, Discriminator Loss: 1.9453903436660767
Epoch: 27, Generator Loss: 0.5054343342781067, Discriminator Loss: 1.9152615070343018
Epoch: 28, Generator Loss: 0.508525550365448, Discriminator Loss: 1.9260485172271729
Epoch: 29, Generator Loss: 0.5018197894096375, Discriminator Loss: 1.9515644311904907
Epoch: 30, Generator Loss: 0.48237642645835876, Discriminator Loss: 1.9889060258865356
Epoch: 31, Generator Loss: 0.47576358914375305, Discriminator Loss: 1.9954891204833984
Epoch: 32, Generator Loss: 0.47649702429771423, Discriminator Loss: 1.9981650114059448
Epoch: 33, Generator Loss: 0.47945308685302734, Discriminator Loss: 2.0044641494750977
Epoch: 34, Generator Loss: 0.48640182614326477, Discriminator Loss: 1.9839919805526733
Epoch: 35, Generator Loss: 0.5043705105781555, Discriminator Loss: 1.964692234992981
Epoch: 36, Generator Loss: 0.5061931610107422, Discriminator Loss: 1.9607325792312622
Epoch: 37, Generator Loss: 0.5090411305427551, Discriminator Loss: 1.9640862941741943
Epoch: 38, Generator Loss: 0.49888092279434204, Discriminator Loss: 2.0025503635406494
Epoch: 39, Generator Loss: 0.49890926480293274, Discriminator Loss: 1.9784700870513916
Epoch: 40, Generator Loss: 0.4987829327583313, Discriminator Loss: 1.9651585817337036
Epoch: 41, Generator Loss: 0.5023303627967834, Discriminator Loss: 1.9435651302337646
Epoch: 42, Generator Loss: 0.5030931830406189, Discriminator Loss: 1.970147967338562
Epoch: 43, Generator Loss: 0.5103368163108826, Discriminator Loss: 1.948770523071289
Epoch: 44, Generator Loss: 0.5141062140464783, Discriminator Loss: 1.9382458925247192
Epoch: 45, Generator Loss: 0.5192903280258179, Discriminator Loss: 1.923143982887268
Epoch: 46, Generator Loss: 0.5226637125015259, Discriminator Loss: 1.9440218210220337
Epoch: 47, Generator Loss: 0.5246140956878662, Discriminator Loss: 1.9339735507965088
Epoch: 48, Generator Loss: 0.5278750658035278, Discriminator Loss: 1.9330395460128784
Epoch: 49, Generator Loss: 0.5215190052986145, Discriminator Loss: 1.9442846775054932
Epoch: 50, Generator Loss: 0.5162323117256165, Discriminator Loss: 1.9721218347549438
Epoch: 51, Generator Loss: 0.5048933625221252, Discriminator Loss: 1.9678698778152466
Epoch: 52, Generator Loss: 0.509625256061554, Discriminator Loss: 1.9625767469406128
Epoch: 53, Generator Loss: 0.5198760628700256, Discriminator Loss: 1.9369432926177979
Epoch: 54, Generator Loss: 0.5260513424873352, Discriminator Loss: 1.9441606998443604
Epoch: 55, Generator Loss: 0.5376901626586914, Discriminator Loss: 1.936803936958313
Epoch: 56, Generator Loss: 0.5560902953147888, Discriminator Loss: 1.902709722518921
Epoch: 57, Generator Loss: 0.5605687499046326, Discriminator Loss: 1.8947279453277588
Epoch: 58, Generator Loss: 0.5672340393066406, Discriminator Loss: 1.898500680923462
Epoch: 59, Generator Loss: 0.5689089894294739, Discriminator Loss: 1.871029019355774
Epoch: 60, Generator Loss: 0.5697230696678162, Discriminator Loss: 1.8731046915054321
Epoch: 61, Generator Loss: 0.5583624839782715, Discriminator Loss: 1.8996940851211548
Epoch: 62, Generator Loss: 0.5345408320426941, Discriminator Loss: 1.9253835678100586
Epoch: 63, Generator Loss: 0.5130673050880432, Discriminator Loss: 1.9621416330337524
Epoch: 64, Generator Loss: 0.5060693621635437, Discriminator Loss: 1.965281367301941
Epoch: 65, Generator Loss: 0.523578941822052, Discriminator Loss: 1.9250215291976929
Epoch: 66, Generator Loss: 0.5341764688491821, Discriminator Loss: 1.9169458150863647
Epoch: 67, Generator Loss: 0.5437857508659363, Discriminator Loss: 1.8830159902572632
Epoch: 68, Generator Loss: 0.5410133004188538, Discriminator Loss: 1.9133960008621216
Epoch: 69, Generator Loss: 0.535211443901062, Discriminator Loss: 1.8671048879623413
Epoch: 70, Generator Loss: 0.5227625966072083, Discriminator Loss: 1.9147918224334717
Epoch: 71, Generator Loss: 0.5165602564811707, Discriminator Loss: 1.9021399021148682
Epoch: 72, Generator Loss: 0.5219352841377258, Discriminator Loss: 1.8909399509429932
Epoch: 73, Generator Loss: 0.5299494862556458, Discriminator Loss: 1.913786768913269
Epoch: 74, Generator Loss: 0.5370683073997498, Discriminator Loss: 1.8993290662765503
Epoch: 75, Generator Loss: 0.5543458461761475, Discriminator Loss: 1.886603593826294
Epoch: 76, Generator Loss: 0.5559374690055847, Discriminator Loss: 1.8833478689193726
Epoch: 77, Generator Loss: 0.5516044497489929, Discriminator Loss: 1.88387930393219
Epoch: 78, Generator Loss: 0.5634049773216248, Discriminator Loss: 1.8520065546035767
Epoch: 79, Generator Loss: 0.5627610087394714, Discriminator Loss: 1.8465543985366821
Epoch: 80, Generator Loss: 0.5510416030883789, Discriminator Loss: 1.8662376403808594
Epoch: 81, Generator Loss: 0.5503302216529846, Discriminator Loss: 1.915558099746704
Epoch: 82, Generator Loss: 0.5445582866668701, Discriminator Loss: 1.9156755208969116
Epoch: 83, Generator Loss: 0.5506776571273804, Discriminator Loss: 1.876555323600769
Epoch: 84, Generator Loss: 0.5673772692680359, Discriminator Loss: 1.8943994045257568
Epoch: 85, Generator Loss: 0.5826940536499023, Discriminator Loss: 1.8510185480117798
Epoch: 86, Generator Loss: 0.5903192758560181, Discriminator Loss: 1.828652262687683
Epoch: 87, Generator Loss: 0.5916497111320496, Discriminator Loss: 1.8171485662460327
Epoch: 88, Generator Loss: 0.5896720886230469, Discriminator Loss: 1.7961512804031372
Epoch: 89, Generator Loss: 0.5867503881454468, Discriminator Loss: 1.8081086874008179
Epoch: 90, Generator Loss: 0.561775803565979, Discriminator Loss: 1.8444185256958008
Epoch: 91, Generator Loss: 0.552556037902832, Discriminator Loss: 1.8795503377914429
Epoch: 92, Generator Loss: 0.544338583946228, Discriminator Loss: 1.8654581308364868
Epoch: 93, Generator Loss: 0.5510985255241394, Discriminator Loss: 1.845579981803894
Epoch: 94, Generator Loss: 0.5495144724845886, Discriminator Loss: 1.839232087135315
Epoch: 95, Generator Loss: 0.5556743741035461, Discriminator Loss: 1.8285958766937256
Epoch: 96, Generator Loss: 0.5433610081672668, Discriminator Loss: 1.8459646701812744
Epoch: 97, Generator Loss: 0.5369371771812439, Discriminator Loss: 1.8679707050323486
Epoch: 98, Generator Loss: 0.546063363520935, Discriminator Loss: 1.8344632387161255
Epoch: 99, Generator Loss: 0.5498455762863159, Discriminator Loss: 1.873538851737976
Epoch: 100, Generator Loss: 0.5569822788238525, Discriminator Loss: 1.8296430110931396
Epoch: 101, Generator Loss: 0.5649753212928772, Discriminator Loss: 1.8473527431488037
Epoch: 102, Generator Loss: 0.5755732655525208, Discriminator Loss: 1.8351280689239502
Epoch: 103, Generator Loss: 0.5833231210708618, Discriminator Loss: 1.8038426637649536
Epoch: 104, Generator Loss: 0.5890332460403442, Discriminator Loss: 1.8082283735275269
Epoch: 105, Generator Loss: 0.5832279920578003, Discriminator Loss: 1.8057630062103271
Epoch: 106, Generator Loss: 0.5815386176109314, Discriminator Loss: 1.821812391281128
Epoch: 107, Generator Loss: 0.5709091424942017, Discriminator Loss: 1.8217051029205322
Epoch: 108, Generator Loss: 0.5474334359169006, Discriminator Loss: 1.8874613046646118
Epoch: 109, Generator Loss: 0.5683592557907104, Discriminator Loss: 1.8294686079025269
Epoch: 110, Generator Loss: 0.5851566195487976, Discriminator Loss: 1.862564206123352
Epoch: 111, Generator Loss: 0.5988563299179077, Discriminator Loss: 1.8206329345703125
Epoch: 112, Generator Loss: 0.6115578413009644, Discriminator Loss: 1.773983359336853
Epoch: 113, Generator Loss: 0.6199137568473816, Discriminator Loss: 1.8008215427398682
Epoch: 114, Generator Loss: 0.6248680949211121, Discriminator Loss: 1.8012686967849731
Epoch: 115, Generator Loss: 0.6262296438217163, Discriminator Loss: 1.783456563949585
Epoch: 116, Generator Loss: 0.6282876133918762, Discriminator Loss: 1.7769858837127686
Epoch: 117, Generator Loss: 0.6285579800605774, Discriminator Loss: 1.7650648355484009
Epoch: 118, Generator Loss: 0.6294587254524231, Discriminator Loss: 1.7778254747390747
Epoch: 119, Generator Loss: 0.6305748820304871, Discriminator Loss: 1.7778427600860596
Epoch: 120, Generator Loss: 0.6291638612747192, Discriminator Loss: 1.775632619857788
Epoch: 121, Generator Loss: 0.6280948519706726, Discriminator Loss: 1.7537888288497925
Epoch: 122, Generator Loss: 0.6300249099731445, Discriminator Loss: 1.7844229936599731
Epoch: 123, Generator Loss: 0.6283208727836609, Discriminator Loss: 1.754599928855896
Epoch: 124, Generator Loss: 0.6298123002052307, Discriminator Loss: 1.7848894596099854
Epoch: 125, Generator Loss: 0.6309837698936462, Discriminator Loss: 1.7474391460418701
Epoch: 126, Generator Loss: 0.6320422887802124, Discriminator Loss: 1.7583450078964233
Epoch: 127, Generator Loss: 0.6400904059410095, Discriminator Loss: 1.7694214582443237

Epoch: 128,	Generator Loss: 0.6324629187583923,	Discriminator Loss: 1.7774016857147217
Epoch: 129,	Generator Loss: 0.6124916076660156,	Discriminator Loss: 1.8186702728271484
Epoch: 130,	Generator Loss: 0.5734853148460388,	Discriminator Loss: 1.837594747543335
Epoch: 131,	Generator Loss: 0.5636682510375977,	Discriminator Loss: 1.887058973312378
Epoch: 132,	Generator Loss: 0.5782691240310669,	Discriminator Loss: 1.8639087677001953
Epoch: 133,	Generator Loss: 0.5855530500411987,	Discriminator Loss: 1.8551642894744873
Epoch: 134,	Generator Loss: 0.5991559624671936,	Discriminator Loss: 1.8197938203811646
Epoch: 135,	Generator Loss: 0.6184874773025513,	Discriminator Loss: 1.8181065320968628
Epoch: 136,	Generator Loss: 0.6258505582809448,	Discriminator Loss: 1.8089030981063843
Epoch: 137,	Generator Loss: 0.6345445513725281,	Discriminator Loss: 1.8162752389907837
Epoch: 138,	Generator Loss: 0.6385933756828308,	Discriminator Loss: 1.8260458707809448
Epoch: 139,	Generator Loss: 0.6473274230957031,	Discriminator Loss: 1.7981773614883423
Epoch: 140,	Generator Loss: 0.6472809910774231,	Discriminator Loss: 1.7697031497955322
Epoch: 141,	Generator Loss: 0.650701642036438,	Discriminator Loss: 1.743865728378296
Epoch: 142,	Generator Loss: 0.6521008610725403,	Discriminator Loss: 1.7176873683929443
Epoch: 143,	Generator Loss: 0.6444106698036194,	Discriminator Loss: 1.7693579196929932
Epoch: 144,	Generator Loss: 0.641905665397644,	Discriminator Loss: 1.7705204486846924
Epoch: 145,	Generator Loss: 0.6374165415763855,	Discriminator Loss: 1.8058663606643677
Epoch: 146,	Generator Loss: 0.6235266923904419,	Discriminator Loss: 1.7381870746612549
Epoch: 147,	Generator Loss: 0.5892828702926636,	Discriminator Loss: 1.852325439453125
Epoch: 148,	Generator Loss: 0.5753353834152222,	Discriminator Loss: 1.8449815511703491
Epoch: 149,	Generator Loss: 0.6026539206504822,	Discriminator Loss: 1.7581708431243896
Epoch: 150,	Generator Loss: 0.6236670613288879,	Discriminator Loss: 1.760986089706421
Epoch: 151,	Generator Loss: 0.6250039339065552,	Discriminator Loss: 1.768956184387207
Epoch: 152,	Generator Loss: 0.6256861090660095,	Discriminator Loss: 1.7794551849365234
Epoch: 153,	Generator Loss: 0.6346012949943542,	Discriminator Loss: 1.760243535041809
Epoch: 154,	Generator Loss: 0.628298819065094,	Discriminator Loss: 1.749287724494934
Epoch: 155,	Generator Loss: 0.6368821859359741,	Discriminator Loss: 1.7152551412582397
Epoch: 156,	Generator Loss: 0.6314118504524231,	Discriminator Loss: 1.7351112365722656
Epoch: 157,	Generator Loss: 0.6265581250190735,	Discriminator Loss: 1.736602544784546
Epoch: 158,	Generator Loss: 0.6100559234619141,	Discriminator Loss: 1.7446779012680054
Epoch: 159,	Generator Loss: 0.5922154188156128,	Discriminator Loss: 1.7559831142425537
Epoch: 160,	Generator Loss: 0.5712250471115112,	Discriminator Loss: 1.8211967945098877
Epoch: 161,	Generator Loss: 0.5644485354423523,	Discriminator Loss: 1.8665589094161987
Epoch: 162,	Generator Loss: 0.6024867296218872,	Discriminator Loss: 1.8104267120361328
Epoch: 163,	Generator Loss: 0.6274945139884949,	Discriminator Loss: 1.7998268604278564
Epoch: 164,	Generator Loss: 0.643936038017273,	Discriminator Loss: 1.7096644639968872
Epoch: 165,	Generator Loss: 0.6404080986976624,	Discriminator Loss: 1.716945767402649
Epoch: 166,	Generator Loss: 0.6532421708106995,	Discriminator Loss: 1.7037891149520874
Epoch: 167,	Generator Loss: 0.6447615027427673,	Discriminator Loss: 1.7099530696868896
Epoch: 168,	Generator Loss: 0.6475247740745544,	Discriminator Loss: 1.6623265743255615
Epoch: 169,	Generator Loss: 0.6348186731338501,	Discriminator Loss: 1.6947166919708252
Epoch: 170,	Generator Loss: 0.6414856314659119,	Discriminator Loss: 1.6926909685134888
Epoch: 171,	Generator Loss: 0.6314753890037537,	Discriminator Loss: 1.660185694694519
Epoch: 172,	Generator Loss: 0.6261246800422668,	Discriminator Loss: 1.7072498798370361
Epoch: 173,	Generator Loss: 0.6210373640060425,	Discriminator Loss: 1.675012469291687
Epoch: 174,	Generator Loss: 0.5940043330192566,	Discriminator Loss: 1.7331515550613403
Epoch: 175,	Generator Loss: 0.5574861168861389,	Discriminator Loss: 1.7930545806884766
Epoch: 176,	Generator Loss: 0.542355477809906,	Discriminator Loss: 1.8148338794708252
Epoch: 177,	Generator Loss: 0.5822253823280334,	Discriminator Loss: 1.8181102275848389
Epoch: 178,	Generator Loss: 0.5935879349708557,	Discriminator Loss: 1.8004159927368164
Epoch: 179,	Generator Loss: 0.6095434427261353,	Discriminator Loss: 1.7807486057281494
Epoch: 180,	Generator Loss: 0.6232584714889526,	Discriminator Loss: 1.7791073322296143
Epoch: 181,	Generator Loss: 0.6337913274765015,	Discriminator Loss: 1.7705801725387573
Epoch: 182,	Generator Loss: 0.6357728242874146,	Discriminator Loss: 1.7532390356063843
Epoch: 183,	Generator Loss: 0.6398280262947083,	Discriminator Loss: 1.7407302856445312
Epoch: 184,	Generator Loss: 0.634765625,	Discriminator Loss: 1.7535192966461182
Epoch: 185,	Generator Loss: 0.63277667760849,	Discriminator Loss: 1.7463499307632446
Epoch: 186,	Generator Loss: 0.6328725218772888,	Discriminator Loss: 1.7686328887939453
Epoch: 187,	Generator Loss: 0.6205809712409973,	Discriminator Loss: 1.7650877237319946
Epoch: 188,	Generator Loss: 0.5941453576087952,	Discriminator Loss: 1.8217060565948486
Epoch: 189,	Generator Loss: 0.6100953817367554,	Discriminator Loss: 1.7752925157546997
Epoch: 190,	Generator Loss: 0.6226822733879089,	Discriminator Loss: 1.7728627920150757
Epoch: 191,	Generator Loss: 0.6314853429794312,	Discriminator Loss: 1.7534593343734741
Epoch: 192,	Generator Loss: 0.637579083442688,	Discriminator Loss: 1.7179620265960693
Epoch: 193,	Generator Loss: 0.6405450105667114,	Discriminator Loss: 1.725502848625183
Epoch: 194,	Generator Loss: 0.6397368311882019,	Discriminator Loss: 1.6983562707901
Epoch: 195,	Generator Loss: 0.6388319730758667,	Discriminator Loss: 1.7154982089996338
Epoch: 196,	Generator Loss: 0.6341049075126648,	Discriminator Loss: 1.728189468383789
Epoch: 197,	Generator Loss: 0.6432934403419495,	Discriminator Loss: 1.7179791927337646
Epoch: 198,	Generator Loss: 0.6484194993972778,	Discriminator Loss: 1.6843165159225464
Epoch: 199,	Generator Loss: 0.6386139988899231,	Discriminator Loss: 1.6859838962554932
Epoch: 200,	Generator Loss: 0.6301169991493225,	Discriminator Loss: 1.682997703552246
Epoch: 201,	Generator Loss: 0.6347073912620544,	Discriminator Loss: 1.6391927003860474
Epoch: 202,	Generator Loss: 0.629494309425354,	Discriminator Loss: 1.6566816568374634
Epoch: 203,	Generator Loss: 0.615505039691925,	Discriminator Loss: 1.699209213256836
Epoch: 204,	Generator Loss: 0.6223717927932739,	Discriminator Loss: 1.6770910024642944
Epoch: 205,	Generator Loss: 0.6162890195846558,	Discriminator Loss: 1.6603543758392334
Epoch: 206,	Generator Loss: 0.6068199872970581,	Discriminator Loss: 1.7019388675689697
Epoch: 207,	Generator Loss: 0.5835185050964355,	Discriminator Loss: 1.732129454612732
Epoch: 208,	Generator Loss: 0.5958709716796875,	Discriminator Loss: 1.735878825187683
Epoch: 209,	Generator Loss: 0.5849490761756897,	Discriminator Loss: 1.7640939950942993
Epoch: 210,	Generator Loss: 0.5637327432632446,	Discriminator Loss: 1.8124845027923584
Epoch: 211,	Generator Loss: 0.577876627445221,	Discriminator Loss: 1.8146675825119019
Epoch: 212,	Generator Loss: 0.5868808031082153,	Discriminator Loss: 1.812463402748108
Epoch: 213,	Generator Loss: 0.605700671672821,	Discriminator Loss: 1.7507508993148804
Epoch: 214,	Generator Loss: 0.6198753714561462,	Discriminator Loss: 1.7286328077316284
Epoch: 215,	Generator Loss: 0.6174247860908508,	Discriminator Loss: 1.7417566776275635
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Epoch: 217,	Generator Loss: 0.6264870762825012,	Discriminator Loss: 1.6827411651611328
Epoch: 218,	Generator Loss: 0.6183872222900391,	Discriminator Loss: 1.7059530019760132
Epoch: 219,	Generator Loss: 0.6173415184020996,	Discriminator Loss: 1.7229164838790894
Epoch: 220,	Generator Loss: 0.6050001978874207,	Discriminator Loss: 1.7366943359375
Epoch: 221,	Generator Loss: 0.6172733306884766,	Discriminator Loss: 1.674242377281189
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Epoch: 223,	Generator Loss: 0.610809862613678,	Discriminator Loss: 1.6950114965438843
Epoch: 224,	Generator Loss: 0.6104924082756042,	Discriminator Loss: 1.75283682346344
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Epoch: 229,	Generator Loss: 0.6126621961593628,	Discriminator Loss: 1.7203556299209595
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Epoch: 436, Generator Loss: 0.6436470150947571, Discriminator Loss: 1.6660109758377075

Epoch: 437,	Generator Loss: 0.6382003426551819,	Discriminator Loss: 1.7276619672775269
Epoch: 438,	Generator Loss: 0.6365179419517517,	Discriminator Loss: 1.7289892435073853
Epoch: 439,	Generator Loss: 0.6418127417564392,	Discriminator Loss: 1.6832600831985474
Epoch: 440,	Generator Loss: 0.6386955380439758,	Discriminator Loss: 1.7099024057388306
Epoch: 441,	Generator Loss: 0.6392078995704651,	Discriminator Loss: 1.7121803760528564
Epoch: 442,	Generator Loss: 0.6381601691246033,	Discriminator Loss: 1.6889714002609253
Epoch: 443,	Generator Loss: 0.6391387581825256,	Discriminator Loss: 1.6843321323394775
Epoch: 444,	Generator Loss: 0.6372507810592651,	Discriminator Loss: 1.6699146032333374
Epoch: 445,	Generator Loss: 0.6365130543708801,	Discriminator Loss: 1.6779212951660156
Epoch: 446,	Generator Loss: 0.6298976540565491,	Discriminator Loss: 1.6823819875717163
Epoch: 447,	Generator Loss: 0.6354244947433472,	Discriminator Loss: 1.6564441919326782
Epoch: 448,	Generator Loss: 0.6344457864761353,	Discriminator Loss: 1.7039587497711182
Epoch: 449,	Generator Loss: 0.6365236639976501,	Discriminator Loss: 1.681031584739685
Epoch: 450,	Generator Loss: 0.6305633187294006,	Discriminator Loss: 1.7422239780426025
Epoch: 451,	Generator Loss: 0.6382112503051758,	Discriminator Loss: 1.7130056619644165
Epoch: 452,	Generator Loss: 0.6380292177200317,	Discriminator Loss: 1.6965081691741943
Epoch: 453,	Generator Loss: 0.6336358189582825,	Discriminator Loss: 1.6863670349121094
Epoch: 454,	Generator Loss: 0.6311357617378235,	Discriminator Loss: 1.699590802192688
Epoch: 455,	Generator Loss: 0.6267305016517639,	Discriminator Loss: 1.7259668111801147
Epoch: 456,	Generator Loss: 0.6269058585166931,	Discriminator Loss: 1.7010345458984375
Epoch: 457,	Generator Loss: 0.6302587389945984,	Discriminator Loss: 1.7359391450881958
Epoch: 458,	Generator Loss: 0.6227053999900818,	Discriminator Loss: 1.7203015089035034
Epoch: 459,	Generator Loss: 0.6242478489875793,	Discriminator Loss: 1.7130452394485474
Epoch: 460,	Generator Loss: 0.6421509385108948,	Discriminator Loss: 1.7371852397918701
Epoch: 461,	Generator Loss: 0.6391928791999817,	Discriminator Loss: 1.7134233713150024
Epoch: 462,	Generator Loss: 0.6387771964073181,	Discriminator Loss: 1.746658205986023
Epoch: 463,	Generator Loss: 0.6373630166053772,	Discriminator Loss: 1.7320626974105835
Epoch: 464,	Generator Loss: 0.6409958004951477,	Discriminator Loss: 1.7239080667495728
Epoch: 465,	Generator Loss: 0.6380200982093811,	Discriminator Loss: 1.7392240762710571
Epoch: 466,	Generator Loss: 0.6382822394371033,	Discriminator Loss: 1.7268637418746948
Epoch: 467,	Generator Loss: 0.6472324728965759,	Discriminator Loss: 1.6907659769058228
Epoch: 468,	Generator Loss: 0.6422556638717651,	Discriminator Loss: 1.740857720375061
Epoch: 469,	Generator Loss: 0.6468260884284973,	Discriminator Loss: 1.7115331888198853
Epoch: 470,	Generator Loss: 0.6374098062515259,	Discriminator Loss: 1.7264858484268188
Epoch: 471,	Generator Loss: 0.6377214193344116,	Discriminator Loss: 1.7260189056396484
Epoch: 472,	Generator Loss: 0.6398425698280334,	Discriminator Loss: 1.72616708278656
Epoch: 473,	Generator Loss: 0.6440829038619995,	Discriminator Loss: 1.7271982431411743
Epoch: 474,	Generator Loss: 0.644637405872345,	Discriminator Loss: 1.6986690759658813
Epoch: 475,	Generator Loss: 0.6458317041397095,	Discriminator Loss: 1.7493088245391846
Epoch: 476,	Generator Loss: 0.6408771872520447,	Discriminator Loss: 1.7010904550552368
Epoch: 477,	Generator Loss: 0.6440266966819763,	Discriminator Loss: 1.6921608448028564
Epoch: 478,	Generator Loss: 0.6328639388084412,	Discriminator Loss: 1.7435247898101807
Epoch: 479,	Generator Loss: 0.6493088006973267,	Discriminator Loss: 1.6666240692138672
Epoch: 480,	Generator Loss: 0.6469473242759705,	Discriminator Loss: 1.741018533706665
Epoch: 481,	Generator Loss: 0.6483659148216248,	Discriminator Loss: 1.7095192670822144
Epoch: 482,	Generator Loss: 0.6544705629348755,	Discriminator Loss: 1.7004305124282837
Epoch: 483,	Generator Loss: 0.639735996723175,	Discriminator Loss: 1.6825374364852905
Epoch: 484,	Generator Loss: 0.6387744545936584,	Discriminator Loss: 1.7525376081466675
Epoch: 485,	Generator Loss: 0.6404043436050415,	Discriminator Loss: 1.7331864833831787
Epoch: 486,	Generator Loss: 0.6376029253005981,	Discriminator Loss: 1.7226918935775757
Epoch: 487,	Generator Loss: 0.6497175097465515,	Discriminator Loss: 1.718881607055664
Epoch: 488,	Generator Loss: 0.6383171677589417,	Discriminator Loss: 1.7296276092529297
Epoch: 489,	Generator Loss: 0.6386598348617554,	Discriminator Loss: 1.7561150789260864
Epoch: 490,	Generator Loss: 0.6334605813026428,	Discriminator Loss: 1.7275303602218628
Epoch: 491,	Generator Loss: 0.6460512280464172,	Discriminator Loss: 1.7396091222763062
Epoch: 492,	Generator Loss: 0.6466561555862427,	Discriminator Loss: 1.7021329402923584
Epoch: 493,	Generator Loss: 0.6545848846435547,	Discriminator Loss: 1.675658106803894
Epoch: 494,	Generator Loss: 0.6409793496131897,	Discriminator Loss: 1.7288497686386108
Epoch: 495,	Generator Loss: 0.6479927897453308,	Discriminator Loss: 1.7237962484359741
Epoch: 496,	Generator Loss: 0.6459988355636597,	Discriminator Loss: 1.7035281658172607
Epoch: 497,	Generator Loss: 0.6468120217323303,	Discriminator Loss: 1.732664942741394
Epoch: 498,	Generator Loss: 0.646313488483429,	Discriminator Loss: 1.7399671077728271
Epoch: 499,	Generator Loss: 0.6446083188056946,	Discriminator Loss: 1.7300862073898315
Epoch: 500,	Generator Loss: 0.6465867757797241,	Discriminator Loss: 1.7159841060638428
Epoch: 501,	Generator Loss: 0.6460285186767578,	Discriminator Loss: 1.6874383687973022
Epoch: 502,	Generator Loss: 0.6456257104873657,	Discriminator Loss: 1.7023175954818726
Epoch: 503,	Generator Loss: 0.643633246421814,	Discriminator Loss: 1.682584524154663
Epoch: 504,	Generator Loss: 0.6315022110939026,	Discriminator Loss: 1.712424397468567
Epoch: 505,	Generator Loss: 0.6404158473014832,	Discriminator Loss: 1.7217235565185547
Epoch: 506,	Generator Loss: 0.6407049894332886,	Discriminator Loss: 1.7395509481430054
Epoch: 507,	Generator Loss: 0.651261031627655,	Discriminator Loss: 1.7207889556884766
Epoch: 508,	Generator Loss: 0.6371370553970337,	Discriminator Loss: 1.7288981676101685
Epoch: 509,	Generator Loss: 0.6368877291679382,	Discriminator Loss: 1.733722448348999
Epoch: 510,	Generator Loss: 0.6415016055107117,	Discriminator Loss: 1.699857473373413
Epoch: 511,	Generator Loss: 0.6460474133491516,	Discriminator Loss: 1.7265273332595825
Epoch: 512,	Generator Loss: 0.6464323401451111,	Discriminator Loss: 1.691421627998352
Epoch: 513,	Generator Loss: 0.6431714296340942,	Discriminator Loss: 1.7233145236968994
Epoch: 514,	Generator Loss: 0.6478354334831238,	Discriminator Loss: 1.696202278137207
Epoch: 515,	Generator Loss: 0.6436597108840942,	Discriminator Loss: 1.689874529838562
Epoch: 516,	Generator Loss: 0.6445439457893372,	Discriminator Loss: 1.7291213274002075
Epoch: 517,	Generator Loss: 0.6450526118278503,	Discriminator Loss: 1.6791390180587769
Epoch: 518,	Generator Loss: 0.6417635679244995,	Discriminator Loss: 1.7001069784164429
Epoch: 519,	Generator Loss: 0.6416174173355103,	Discriminator Loss: 1.6857212781906128
Epoch: 520,	Generator Loss: 0.6346318125724792,	Discriminator Loss: 1.733219861984253
Epoch: 521,	Generator Loss: 0.6401599645614624,	Discriminator Loss: 1.7015329599380493
Epoch: 522,	Generator Loss: 0.6417166590690613,	Discriminator Loss: 1.7246837615966797
Epoch: 523,	Generator Loss: 0.6437986493110657,	Discriminator Loss: 1.7250064611434937
Epoch: 524,	Generator Loss: 0.6435602903366089,	Discriminator Loss: 1.714203119277954
Epoch: 525,	Generator Loss: 0.6505936980247498,	Discriminator Loss: 1.6878184080123901
Epoch: 526,	Generator Loss: 0.6451969742774963,	Discriminator Loss: 1.706188440322876
Epoch: 527,	Generator Loss: 0.6391844153404236,	Discriminator Loss: 1.71918785572052
Epoch: 528,	Generator Loss: 0.6497907638549805,	Discriminator Loss: 1.69139564037323
Epoch: 529,	Generator Loss: 0.6435853242874146,	Discriminator Loss: 1.7027615308761597
Epoch: 530,	Generator Loss: 0.6478977203369141,	Discriminator Loss: 1.6680095195770264
Epoch: 531,	Generator Loss: 0.6422362923622131,	Discriminator Loss: 1.6901931762695312
Epoch: 532,	Generator Loss: 0.6395028233528137,	Discriminator Loss: 1.7183085680007935
Epoch: 533,	Generator Loss: 0.6390719413757324,	Discriminator Loss: 1.752616286277771
Epoch: 534,	Generator Loss: 0.6461448073387146,	Discriminator Loss: 1.7244123220443726
Epoch: 535,	Generator Loss: 0.6382750272750854,	Discriminator Loss: 1.7053464651107788
Epoch: 536,	Generator Loss: 0.6468350291252136,	Discriminator Loss: 1.7276287078857422
Epoch: 537,	Generator Loss: 0.6451752781867981,	Discriminator Loss: 1.733986735343933
Epoch: 538,	Generator Loss: 0.6455855369567871,	Discriminator Loss: 1.7040364742279053
Epoch: 539,	Generator Loss: 0.6458898782730103,	Discriminator Loss: 1.7507258653640747

Epoch: 540,	Generator Loss: 0.6437700390815735,	Discriminator Loss: 1.6975432634353638
Epoch: 541,	Generator Loss: 0.6432673335075378,	Discriminator Loss: 1.682424783706665
Epoch: 542,	Generator Loss: 0.6449616551399231,	Discriminator Loss: 1.7289115190505981
Epoch: 543,	Generator Loss: 0.6366567611694336,	Discriminator Loss: 1.708222508430481
Epoch: 544,	Generator Loss: 0.6322803497314453,	Discriminator Loss: 1.7114955186843872
Epoch: 545,	Generator Loss: 0.6455966830253601,	Discriminator Loss: 1.6807993650436401
Epoch: 546,	Generator Loss: 0.6406574845314026,	Discriminator Loss: 1.7394542694091797
Epoch: 547,	Generator Loss: 0.6416850686073303,	Discriminator Loss: 1.724012017250061
Epoch: 548,	Generator Loss: 0.6401681303977966,	Discriminator Loss: 1.704384446144104
Epoch: 549,	Generator Loss: 0.6320453882217407,	Discriminator Loss: 1.7224096059799194
Epoch: 550,	Generator Loss: 0.6362686157226562,	Discriminator Loss: 1.7556642293930054
Epoch: 551,	Generator Loss: 0.6494402885437012,	Discriminator Loss: 1.6904728412628174
Epoch: 552,	Generator Loss: 0.6489729285240173,	Discriminator Loss: 1.7021461725234985
Epoch: 553,	Generator Loss: 0.649836540222168,	Discriminator Loss: 1.715810775756836
Epoch: 554,	Generator Loss: 0.6393277049064636,	Discriminator Loss: 1.7054554224014282
Epoch: 555,	Generator Loss: 0.6521444320678711,	Discriminator Loss: 1.72475266456604
Epoch: 556,	Generator Loss: 0.64891517162323,	Discriminator Loss: 1.6891615390777588
Epoch: 557,	Generator Loss: 0.6475425362586975,	Discriminator Loss: 1.7075157165527344
Epoch: 558,	Generator Loss: 0.6434658169746399,	Discriminator Loss: 1.7023178339004517
Epoch: 559,	Generator Loss: 0.6396093368530273,	Discriminator Loss: 1.6593021154403687
Epoch: 560,	Generator Loss: 0.6456161737442017,	Discriminator Loss: 1.7162034511566162
Epoch: 561,	Generator Loss: 0.6336517930030823,	Discriminator Loss: 1.7600843906402588
Epoch: 562,	Generator Loss: 0.6502593159675598,	Discriminator Loss: 1.6701890230178833
Epoch: 563,	Generator Loss: 0.6462160348892212,	Discriminator Loss: 1.7266788482666016
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Epoch: 588,	Generator Loss: 0.6446952819824219,	Discriminator Loss: 1.7126566171646118
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Epoch: 590,	Generator Loss: 0.6547861695289612,	Discriminator Loss: 1.688804268836975
Epoch: 591,	Generator Loss: 0.6581984162330627,	Discriminator Loss: 1.7197335958480835
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Epoch: 597,	Generator Loss: 0.6493585705757141,	Discriminator Loss: 1.7023932933807373
Epoch: 598,	Generator Loss: 0.650325357913971,	Discriminator Loss: 1.7073715925216675
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Epoch: 605,	Generator Loss: 0.6543483734130859,	Discriminator Loss: 1.717677354812622
Epoch: 606,	Generator Loss: 0.644430935382843,	Discriminator Loss: 1.7002851963043213
Epoch: 607,	Generator Loss: 0.6484087705612183,	Discriminator Loss: 1.6780575513839722
Epoch: 608,	Generator Loss: 0.6374434232711792,	Discriminator Loss: 1.6895710229873657
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Epoch: 610,	Generator Loss: 0.6450770497322083,	Discriminator Loss: 1.6905438899993896
Epoch: 611,	Generator Loss: 0.6390124559402466,	Discriminator Loss: 1.723897099494934
Epoch: 612,	Generator Loss: 0.6385976672172546,	Discriminator Loss: 1.7208298444747925
Epoch: 613,	Generator Loss: 0.6532154679298401,	Discriminator Loss: 1.721074104309082
Epoch: 614,	Generator Loss: 0.6480951309204102,	Discriminator Loss: 1.685648798942566
Epoch: 615,	Generator Loss: 0.6473840475082397,	Discriminator Loss: 1.7613219022750854
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Epoch: 618,	Generator Loss: 0.647883415222168,	Discriminator Loss: 1.7007532119750977
Epoch: 619,	Generator Loss: 0.6451229453086853,	Discriminator Loss: 1.7299894094467163
Epoch: 620,	Generator Loss: 0.6522132754325867,	Discriminator Loss: 1.7024046182632446
Epoch: 621,	Generator Loss: 0.6495028734207153,	Discriminator Loss: 1.7064999341964722
Epoch: 622,	Generator Loss: 0.6487794518470764,	Discriminator Loss: 1.7128114700317383
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Epoch: 628,	Generator Loss: 0.6520361304283142,	Discriminator Loss: 1.7396137714385986
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Epoch: 632,	Generator Loss: 0.6446418762207031,	Discriminator Loss: 1.6941732168197632
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Epoch: 635,	Generator Loss: 0.6495761871337891,	Discriminator Loss: 1.7349752187728882
Epoch: 636,	Generator Loss: 0.6406208276748657,	Discriminator Loss: 1.7139689922332764
Epoch: 637,	Generator Loss: 0.6434067487716675,	Discriminator Loss: 1.723318338394165
Epoch: 638,	Generator Loss: 0.6582432985305786,	Discriminator Loss: 1.7031503915786743
Epoch: 639,	Generator Loss: 0.6505247950553894,	Discriminator Loss: 1.724421501159668
Epoch: 640,	Generator Loss: 0.6423639059066772,	Discriminator Loss: 1.708424687385559
Epoch: 641,	Generator Loss: 0.6457765698432922,	Discriminator Loss: 1.6687899827957153
Epoch: 642,	Generator Loss: 0.6474562287330627,	Discriminator Loss: 1.7423897981643677

Epoch: 643, Generator Loss: 0.6507746577262878, Discriminator Loss: 1.7254942655563354
Epoch: 644, Generator Loss: 0.652487576007843, Discriminator Loss: 1.6841703653335571
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Epoch: 648, Generator Loss: 0.6482861638069153, Discriminator Loss: 1.7014007568359375
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Epoch: 650, Generator Loss: 0.641251266002655, Discriminator Loss: 1.7292425632476807
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Epoch: 652, Generator Loss: 0.6498850584030151, Discriminator Loss: 1.6765506267547607
Epoch: 653, Generator Loss: 0.6470620036125183, Discriminator Loss: 1.6961252689361572
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Epoch: 656, Generator Loss: 0.6552778482437134, Discriminator Loss: 1.7124086618423462
Epoch: 657, Generator Loss: 0.6496023535728455, Discriminator Loss: 1.7230451107025146
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Epoch: 662, Generator Loss: 0.6516863703727722, Discriminator Loss: 1.7263306379318237
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Epoch: 889,	Generator Loss: 0.6326988935470581,	Discriminator Loss: 1.657012701034546
Epoch: 890,	Generator Loss: 0.6267148852348328,	Discriminator Loss: 1.6859959363937378
Epoch: 891,	Generator Loss: 0.623721718788147,	Discriminator Loss: 1.6886694431304932
Epoch: 892,	Generator Loss: 0.6213251352310181,	Discriminator Loss: 1.7302616834640503
Epoch: 893,	Generator Loss: 0.635186493396759,	Discriminator Loss: 1.7061434984207153
Epoch: 894,	Generator Loss: 0.6342921257019043,	Discriminator Loss: 1.6842916011810303
Epoch: 895,	Generator Loss: 0.6303486824035645,	Discriminator Loss: 1.6999636888504028
Epoch: 896,	Generator Loss: 0.6277429461479187,	Discriminator Loss: 1.6979912519454956
Epoch: 897,	Generator Loss: 0.6398482322692871,	Discriminator Loss: 1.6644891500473022
Epoch: 898,	Generator Loss: 0.6475699543952942,	Discriminator Loss: 1.6782225370407104
Epoch: 899,	Generator Loss: 0.6417468190193176,	Discriminator Loss: 1.6812816858291626
Epoch: 900,	Generator Loss: 0.6446961164474487,	Discriminator Loss: 1.6953086853027344
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Epoch: 903,	Generator Loss: 0.6385378241539001,	Discriminator Loss: 1.6903635263442993
Epoch: 904,	Generator Loss: 0.6442316174507141,	Discriminator Loss: 1.6634455919265747
Epoch: 905,	Generator Loss: 0.6462773680686951,	Discriminator Loss: 1.663248062133789
Epoch: 906,	Generator Loss: 0.6412237882614136,	Discriminator Loss: 1.7047537565231323
Epoch: 907,	Generator Loss: 0.6442143321037292,	Discriminator Loss: 1.6794270277023315
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Epoch: 1342,	Generator Loss: 0.6514478921890259,	Discriminator Loss: 1.6120929718017578
Epoch: 1343,	Generator Loss: 0.6558846235275269,	Discriminator Loss: 1.6789289712905884
Epoch: 1344,	Generator Loss: 0.660625159740448,	Discriminator Loss: 1.6808301210403442
Epoch: 1345,	Generator Loss: 0.6547390818595886,	Discriminator Loss: 1.6274152994155884
Epoch: 1346,	Generator Loss: 0.6576013565063477,	Discriminator Loss: 1.6730738878250122
Epoch: 1347,	Generator Loss: 0.6549287438392639,	Discriminator Loss: 1.6392295360565186
Epoch: 1348,	Generator Loss: 0.6562065482139587,	Discriminator Loss: 1.6636428833007812
Epoch: 1349,	Generator Loss: 0.6492525935173035,	Discriminator Loss: 1.6764018535614014
Epoch: 1350,	Generator Loss: 0.6484156847000122,	Discriminator Loss: 1.6637922525405884
Epoch: 1351,	Generator Loss: 0.6601997017860413,	Discriminator Loss: 1.6507748365402222
Epoch: 1352,	Generator Loss: 0.6525670289993286,	Discriminator Loss: 1.6379822492599487
Epoch: 1353,	Generator Loss: 0.6520934700965881,	Discriminator Loss: 1.6746572256088257
Epoch: 1354,	Generator Loss: 0.6608067750930786,	Discriminator Loss: 1.6695268154144287
Epoch: 1355,	Generator Loss: 0.6557994484901428,	Discriminator Loss: 1.68948233127594
Epoch: 1356,	Generator Loss: 0.6560629606246948,	Discriminator Loss: 1.7012053728103638
Epoch: 1357,	Generator Loss: 0.6504091620445251,	Discriminator Loss: 1.6159236431121826
Epoch: 1358,	Generator Loss: 0.653484046459198,	Discriminator Loss: 1.6490404605865479
Epoch: 1359,	Generator Loss: 0.6490179896354675,	Discriminator Loss: 1.667814016342163
Epoch: 1360,	Generator Loss: 0.6563626527786255,	Discriminator Loss: 1.6430461406707764
Epoch: 1361,	Generator Loss: 0.6595810055732727,	Discriminator Loss: 1.6645545959472656
Epoch: 1362,	Generator Loss: 0.6518763303756714,	Discriminator Loss: 1.638771891593933
Epoch: 1363,	Generator Loss: 0.6547175049781799,	Discriminator Loss: 1.6517945528030396

Epoch: 1364,	Generator Loss: 0.6567093729972839,	Discriminator Loss: 1.6385873556137085
Epoch: 1365,	Generator Loss: 0.6515759825706482,	Discriminator Loss: 1.6978590488433838
Epoch: 1366,	Generator Loss: 0.6544405817985535,	Discriminator Loss: 1.673156976699829
Epoch: 1367,	Generator Loss: 0.6521363854408264,	Discriminator Loss: 1.6472216844558716
Epoch: 1368,	Generator Loss: 0.6503686904907227,	Discriminator Loss: 1.6593793630599976
Epoch: 1369,	Generator Loss: 0.6518344283103943,	Discriminator Loss: 1.6513633728027344
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Epoch: 1372,	Generator Loss: 0.6447911858558655,	Discriminator Loss: 1.7110360860824585
Epoch: 1373,	Generator Loss: 0.6529685854911804,	Discriminator Loss: 1.6396534442901611
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Epoch: 1376,	Generator Loss: 0.6506088376045227,	Discriminator Loss: 1.6556072235107422
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Epoch: 1379,	Generator Loss: 0.6529183983802795,	Discriminator Loss: 1.685502052307129
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Epoch: 1386,	Generator Loss: 0.6581485867500305,	Discriminator Loss: 1.6656635999679565
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Epoch: 1402,	Generator Loss: 0.6566607356071472,	Discriminator Loss: 1.6581367254257202
Epoch: 1403,	Generator Loss: 0.6620674729347229,	Discriminator Loss: 1.6969013214111328
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Epoch: 1418,	Generator Loss: 0.6563649773597717,	Discriminator Loss: 1.6141937971115112
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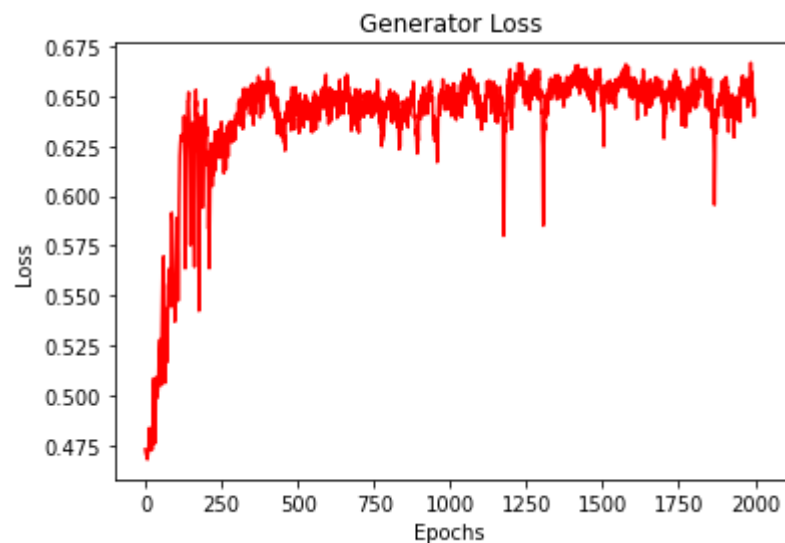
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Epoch: 1786, Generator Loss: 0.6467174887657166, Discriminator Loss: 1.6096153259277344
Epoch: 1787, Generator Loss: 0.642593502998352, Discriminator Loss: 1.6848869323730469
Epoch: 1788, Generator Loss: 0.6478058099746704, Discriminator Loss: 1.5978747606277466
Epoch: 1789, Generator Loss: 0.6453962326049805, Discriminator Loss: 1.6229517459869385
Epoch: 1790, Generator Loss: 0.6545789837837219, Discriminator Loss: 1.6232032775878906
Epoch: 1791, Generator Loss: 0.6558545231819153, Discriminator Loss: 1.638946533203125
Epoch: 1792, Generator Loss: 0.6539954543113708, Discriminator Loss: 1.6237809658050537
Epoch: 1793, Generator Loss: 0.651610791683197, Discriminator Loss: 1.6391575336456299
Epoch: 1794, Generator Loss: 0.6475487351417542, Discriminator Loss: 1.6100488901138306
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Epoch: 1831, Generator Loss: 0.6597766876220703, Discriminator Loss: 1.6219812631607056
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Epoch: 1833, Generator Loss: 0.6589912176132202, Discriminator Loss: 1.6011043787002563
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Epoch: 1836, Generator Loss: 0.6547761559486389, Discriminator Loss: 1.598307490348816
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Epoch: 1863, Generator Loss: 0.6423574090003967, Discriminator Loss: 1.6162844896316528
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Epoch: 1869, Generator Loss: 0.621296763420105, Discriminator Loss: 1.6153274774551392
Epoch: 1870, Generator Loss: 0.6404319405555725, Discriminator Loss: 1.6389122009277344
Epoch: 1871, Generator Loss: 0.6423466801643372, Discriminator Loss: 1.6409885883331299
Epoch: 1872, Generator Loss: 0.6432111859321594, Discriminator Loss: 1.674855351448059
Epoch: 1873, Generator Loss: 0.6328492760658264, Discriminator Loss: 1.6045619249343872
Epoch: 1874, Generator Loss: 0.6317957639694214, Discriminator Loss: 1.6952440738677979
Epoch: 1875, Generator Loss: 0.6436141133308411, Discriminator Loss: 1.6149686574935913
Epoch: 1876, Generator Loss: 0.6411986947059631, Discriminator Loss: 1.59356689453125
Epoch: 1877, Generator Loss: 0.6436057686805725, Discriminator Loss: 1.6040176153182983
Epoch: 1878, Generator Loss: 0.6478557586669922, Discriminator Loss: 1.6413203477859497

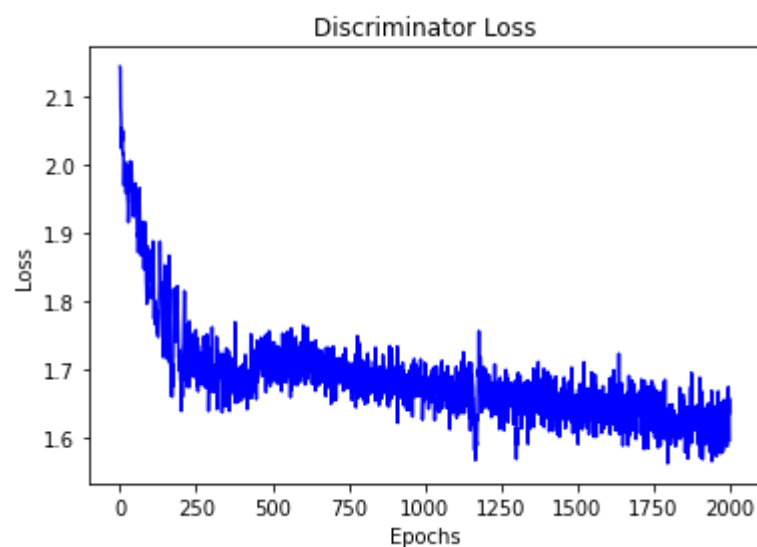
Epoch: 1879,	Generator Loss: 0.6430660486221313,	Discriminator Loss: 1.6245206594467163
Epoch: 1880,	Generator Loss: 0.6401670575141907,	Discriminator Loss: 1.6436097621917725
Epoch: 1881,	Generator Loss: 0.6490224599838257,	Discriminator Loss: 1.6252151727676392
Epoch: 1882,	Generator Loss: 0.6475142240524292,	Discriminator Loss: 1.6147280931472778
Epoch: 1883,	Generator Loss: 0.6481371521949768,	Discriminator Loss: 1.6107608079910278
Epoch: 1884,	Generator Loss: 0.6508674621582031,	Discriminator Loss: 1.6175956726074219
Epoch: 1885,	Generator Loss: 0.6484428644180298,	Discriminator Loss: 1.6458665132522583
Epoch: 1886,	Generator Loss: 0.6512245535850525,	Discriminator Loss: 1.635262370109558
Epoch: 1887,	Generator Loss: 0.6494889855384827,	Discriminator Loss: 1.6211844682693481
Epoch: 1888,	Generator Loss: 0.6458370089530945,	Discriminator Loss: 1.6414741277694702
Epoch: 1889,	Generator Loss: 0.6512726545333862,	Discriminator Loss: 1.617169976234436
Epoch: 1890,	Generator Loss: 0.6570948362350464,	Discriminator Loss: 1.6256872415542603
Epoch: 1891,	Generator Loss: 0.6492359042167664,	Discriminator Loss: 1.6153337955474854
Epoch: 1892,	Generator Loss: 0.6551958918571472,	Discriminator Loss: 1.6149423122406006
Epoch: 1893,	Generator Loss: 0.6541203260421753,	Discriminator Loss: 1.647684097290039
Epoch: 1894,	Generator Loss: 0.6483802795410156,	Discriminator Loss: 1.6085736751556396
Epoch: 1895,	Generator Loss: 0.6581233143806458,	Discriminator Loss: 1.624055027961731
Epoch: 1896,	Generator Loss: 0.6568870544433594,	Discriminator Loss: 1.613381266593933
Epoch: 1897,	Generator Loss: 0.6529243588447571,	Discriminator Loss: 1.590219497680664
Epoch: 1898,	Generator Loss: 0.6507320404052734,	Discriminator Loss: 1.639015793800354
Epoch: 1899,	Generator Loss: 0.6507376432418823,	Discriminator Loss: 1.6151853799819946
Epoch: 1900,	Generator Loss: 0.6434527635574341,	Discriminator Loss: 1.5976791381835938
Epoch: 1901,	Generator Loss: 0.6396297216415405,	Discriminator Loss: 1.6882750988006592
Epoch: 1902,	Generator Loss: 0.6587964296340942,	Discriminator Loss: 1.6309877634048462
Epoch: 1903,	Generator Loss: 0.6576092839241028,	Discriminator Loss: 1.6007518768310547
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Epoch: 1906,	Generator Loss: 0.6554492115974426,	Discriminator Loss: 1.597124695777893
Epoch: 1907,	Generator Loss: 0.6582861542701721,	Discriminator Loss: 1.6355226039886475
Epoch: 1908,	Generator Loss: 0.6541919708251953,	Discriminator Loss: 1.6220967769622803
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Epoch: 1911,	Generator Loss: 0.65174400806427,	Discriminator Loss: 1.5686525106430054
Epoch: 1912,	Generator Loss: 0.6526713371276855,	Discriminator Loss: 1.5829145908355713
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Epoch: 1915,	Generator Loss: 0.6511275172233582,	Discriminator Loss: 1.6339657306671143
Epoch: 1916,	Generator Loss: 0.6453272104263306,	Discriminator Loss: 1.6324776411056519
Epoch: 1917,	Generator Loss: 0.6458774209022522,	Discriminator Loss: 1.627583622932434
Epoch: 1918,	Generator Loss: 0.6396728754043579,	Discriminator Loss: 1.6132242679595947
Epoch: 1919,	Generator Loss: 0.6428807377815247,	Discriminator Loss: 1.6136847734451294
Epoch: 1920,	Generator Loss: 0.6474935412406921,	Discriminator Loss: 1.590140700340271
Epoch: 1921,	Generator Loss: 0.6481093168258667,	Discriminator Loss: 1.6420449018478394
Epoch: 1922,	Generator Loss: 0.6480216383934021,	Discriminator Loss: 1.5951385498046875
Epoch: 1923,	Generator Loss: 0.6464029550552368,	Discriminator Loss: 1.605172038078308
Epoch: 1924,	Generator Loss: 0.6449764966964722,	Discriminator Loss: 1.6111136674880981
Epoch: 1925,	Generator Loss: 0.647483229637146,	Discriminator Loss: 1.646208643913269
Epoch: 1926,	Generator Loss: 0.6510300636291504,	Discriminator Loss: 1.6020969152450562
Epoch: 1927,	Generator Loss: 0.6443389058113098,	Discriminator Loss: 1.5966521501541138
Epoch: 1928,	Generator Loss: 0.6492210030555725,	Discriminator Loss: 1.616578459739685
Epoch: 1929,	Generator Loss: 0.6477026343345642,	Discriminator Loss: 1.630889654159546
Epoch: 1930,	Generator Loss: 0.6396942138671875,	Discriminator Loss: 1.6506996154785156
Epoch: 1931,	Generator Loss: 0.6294507384300232,	Discriminator Loss: 1.6333032846450806
Epoch: 1932,	Generator Loss: 0.6442384719848633,	Discriminator Loss: 1.6143856048583984
Epoch: 1933,	Generator Loss: 0.6458913683891296,	Discriminator Loss: 1.5797702074050903
Epoch: 1934,	Generator Loss: 0.6406584978103638,	Discriminator Loss: 1.6194536685943604
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Epoch: 1940,	Generator Loss: 0.649987518787384,	Discriminator Loss: 1.6689327955245972
Epoch: 1941,	Generator Loss: 0.6461527943611145,	Discriminator Loss: 1.565750002861023
Epoch: 1942,	Generator Loss: 0.6483668684959412,	Discriminator Loss: 1.6500054597854614
Epoch: 1943,	Generator Loss: 0.6485314965248108,	Discriminator Loss: 1.6161988973617554
Epoch: 1944,	Generator Loss: 0.6473978757858276,	Discriminator Loss: 1.6287362575531006
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Epoch: 1950,	Generator Loss: 0.6371179819107056,	Discriminator Loss: 1.6446936130523682
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Epoch: 1974,	Generator Loss: 0.6558828949928284,	Discriminator Loss: 1.6174284219741821
Epoch: 1975,	Generator Loss: 0.6526843905448914,	Discriminator Loss: 1.6208572387695312
Epoch: 1976,	Generator Loss: 0.6447165608406067,	Discriminator Loss: 1.6345770359039307
Epoch: 1977,	Generator Loss: 0.6538957953453064,	Discriminator Loss: 1.6503320932388306
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Epoch: 1979,	Generator Loss: 0.6594002842903137,	Discriminator Loss: 1.6303014755249023
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Epoch: 1981,	Generator Loss: 0.6554898023605347,	Discriminator Loss: 1.6009682416915894

Epoch: 1982, Generator Loss: 0.6556205153465271, Discriminator Loss: 1.655796766281128
Epoch: 1983, Generator Loss: 0.6558471918106079, Discriminator Loss: 1.6093695163726807
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Epoch: 1987, Generator Loss: 0.6544974446296692, Discriminator Loss: 1.6112470626831055
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Epoch: 1989, Generator Loss: 0.6614161133766174, Discriminator Loss: 1.5976201295852661
Epoch: 1990, Generator Loss: 0.6475855708122253, Discriminator Loss: 1.629447102546692
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Epoch: 1992, Generator Loss: 0.6524730324745178, Discriminator Loss: 1.6025962829589844
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Epoch: 1994, Generator Loss: 0.645079493522644, Discriminator Loss: 1.599306344985962
Epoch: 1995, Generator Loss: 0.6447820663452148, Discriminator Loss: 1.6743837594985962
Epoch: 1996, Generator Loss: 0.6398566365242004, Discriminator Loss: 1.6614418029785156
Epoch: 1997, Generator Loss: 0.6429937481880188, Discriminator Loss: 1.6341878175735474
Epoch: 1998, Generator Loss: 0.6486613154411316, Discriminator Loss: 1.6576141119003296
Epoch: 1999, Generator Loss: 0.6412960886955261, Discriminator Loss: 1.5965783596038818

```
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
```

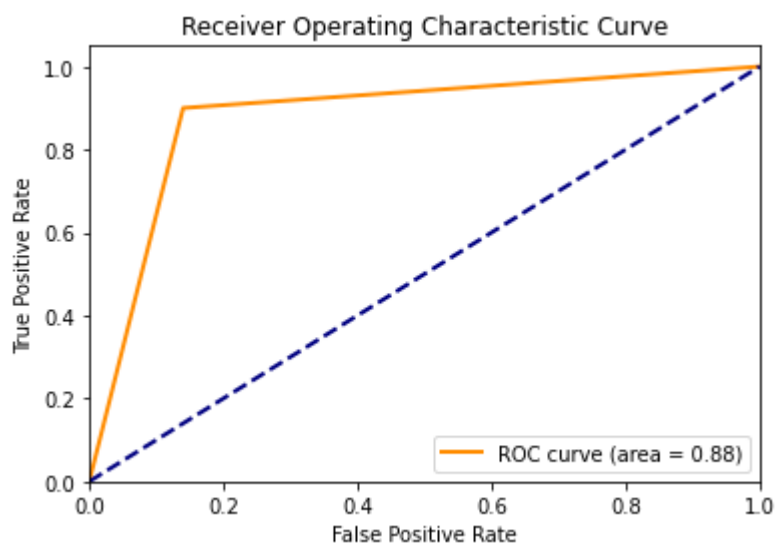
```
Out[18]: TensorShape([100, 2])
```

```
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()
```



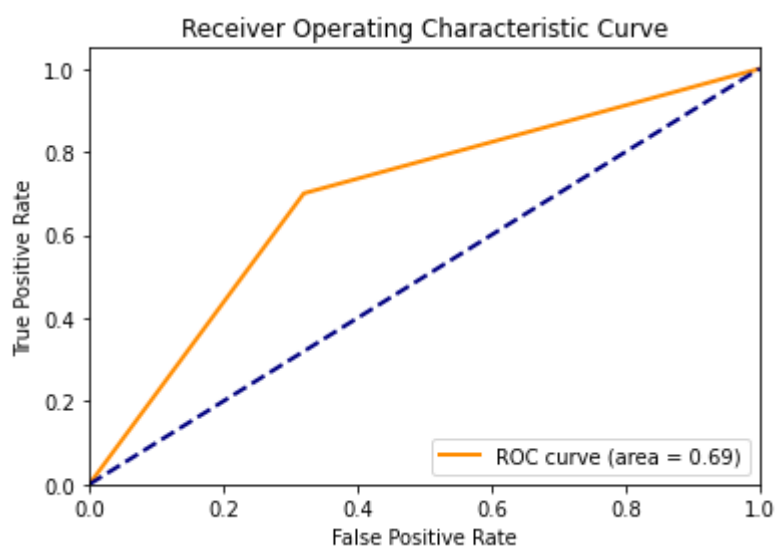
```
In [21]: _, test_predictions = discriminator(tf.convert_to_tensor(x_test))
test_predictions.shape
```

```
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: 69.0000 %
```

```
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, 0, 0, 0])>
```

Improving the Performance

It can be seen from the loss vs iterations plots that the generator has more or less converged, but the discriminator hasn't. The AUC scores suggest that the model is actually learning. This can be improved in the following ways:

1. Use slightly higher learning rates while training the discriminator.
2. As the generator converged, we can take the synthetic data generated by it and add to our original training set. We can again start training the GAN so that the discriminator becomes more robust.
3. Training for a larger number of epochs.

4. Using adaptive learning rates and learning rate scheduling.