P3_RajasekharanPillai_MuraliKrishnan

October 28, 2019

#Student Name: Murali Krishnan Rajasekharan Pillai #ECE 595 Machine Learning II #Project 3: GAN - Generative-Adversarial Networks

[1]:
```
!nvidia-smi
```

```
Mon Oct 28 18:53:35 2019
+-----------------------------------------------------------------------------+
| NVIDIA-SMI 430.50       Driver Version: 418.67       CUDA Version: 10.1     |
|-------------------------------+----------------------+----------------------+
| GPU  Name        Persistence-M| Bus-Id        Disp.A | Volatile Uncorr. ECC |
| Fan  Temp  Perf  Pwr:Usage/Cap|         Memory-Usage | GPU-Util  Compute M. |
|===============================+======================+======================|
|   0  Tesla K80           Off  | 00000000:00:04.0 Off |                    0 |
| N/A   72C    P8    33W / 149W |      0MiB / 11441MiB |      0%      Default |
+-------------------------------+----------------------+----------------------+

+-----------------------------------------------------------------------------+
| Processes:                                                       GPU Memory |
|  GPU       PID   Type   Process name                             Usage      |
|=============================================================================|
|  No running processes found                                                 |
+-----------------------------------------------------------------------------+
```

[2]:
```
from google.colab import drive
drive.mount('/content/gdrive')
```

```
Go to this URL in a browser: https://accounts.google.com/o/oauth2/auth?client_id
=947318989803-6bn6qk8qdgf4n4g3pfee6491hc0brc4i.apps.googleusercontent.com&redire
ct_uri=urn%3Aietf%3Awg%3Aoauth%3A2.0%3Aoob&scope=email%20https%3A%2F%2Fwww.googl
eapis.com%2Fauth%2Fdocs.test%20https%3A%2F%2Fwww.googleapis.com%2Fauth%2Fdrive%2
0https%3A%2F%2Fwww.googleapis.com%2Fauth%2Fdrive.photos.readonly%20https%3A%2F%2
Fwww.googleapis.com%2Fauth%2Fpeopleapi.readonly&response_type=code

Enter your authorization code:
··········
Mounted at /content/gdrive
```

[0]:

```
IMAGE_PATH = './gdrive/My Drive/ece595_ml2/images/'
MODEL_PATH = './gdrive/My Drive/ece595_ml2/models/'
```

[4]:

```
#Import necessary packages
import numpy as np
import keras
from keras.layers import Dense, Dropout, Input
from keras.models import Model,Sequential
from keras.datasets import mnist
from keras.layers.advanced_activations import LeakyReLU
from keras.optimizers import adam
from keras.models import load_model
import matplotlib.pyplot as plt
```

```
Using TensorFlow backend.
```

```
<IPython.core.display.HTML object>
```

#Part 1: Implementing the GAN

[0]:

```
#Load MNIST data and normalize to [-1, 1]
(X_train, y_train), (X_test, y_test) = mnist.load_data()
X_train = (X_train - 127.5) / 127.5
X_test = (X_test - 127.5) / 127.5
X_train = X_train.reshape(-1, 784)
```

```
Downloading data from https://s3.amazonaws.com/img-datasets/mnist.npz
11493376/11490434 [==============================] - 2s 0us/step
```

[0]:

```
# The D-dimensional noise vector length
latent_dim = 100
```

[0]:

```
# Optimizer for discriminator, which will have a higher learning rate than␣
 ↪adversarial model
gan_adam = adam(lr=2e-4)
dis_adam = adam(lr=5e-5, beta_1=0.5)
gen_adam = adam(lr=5e-5, beta_1=0.5)
```

[0]:

```
# Genrerator model
def create_generator(latent_dim):
    generator = Sequential()
    generator.add(Dense(250, input_dim=latent_dim))
    generator.add(LeakyReLU(0.5))
    generator.add(Dense(550))
    generator.add(LeakyReLU(0.5))
    generator.add(Dense(1100))
    generator.add(LeakyReLU(0.5))
    generator.add(Dense(784, activation='tanh'))
    generator.compile(loss='binary_crossentropy',
                      optimizer=gen_adam,
                      metrics=['accuracy'])
    return generator
```

[0]:

```
# Discriminator model
def create_discriminator(data_dim):
    discriminator = Sequential()
    discriminator.add(Dense(1100, input_dim=data_dim))
    discriminator.add(LeakyReLU(0.5))
    discriminator.add(Dropout(0.3))
    discriminator.add(Dense(550))
    discriminator.add(LeakyReLU(0.5))
    discriminator.add(Dropout(0.3))
    discriminator.add(Dense(250))
    discriminator.add(LeakyReLU(0.5))
    discriminator.add(Dense(1, activation='sigmoid'))
    discriminator.compile(loss='binary_crossentropy',
                          optimizer=dis_adam,
                          metrics=['accuracy'])
    return discriminator
```

[0]:

```
# Create adversarial model
def create_gan(discriminator, generator):
    discriminator.trainable = False
    ganInput = Input(shape=(latent_dim, ))
    x = generator(ganInput)
    ganOutput = discriminator(x)
    gan = Model(inputs=ganInput, outputs=ganOutput)
    gan.compile(loss='binary_crossentropy',
                optimizer=gan_adam,
                metrics=['accuracy'])
    return gan
```

[0]:

```
# Creating GAN
generator = create_generator(latent_dim)
discriminator = create_discriminator(X_train.shape[1])
gan = create_gan(discriminator, generator)
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:66: The name tf.get_default_graph
is deprecated. Please use tf.compat.v1.get_default_graph instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:541: The name tf.placeholder is
deprecated. Please use tf.compat.v1.placeholder instead.
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:4432: The name tf.random_uniform is
deprecated. Please use tf.random.uniform instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/optimizers.py:793: The name tf.train.Optimizer is deprecated.
Please use tf.compat.v1.train.Optimizer instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:3657: The name tf.log is
deprecated. Please use tf.math.log instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/tensorflow_core/python/ops/nn_impl.py:183: where (from
tensorflow.python.ops.array_ops) is deprecated and will be removed in a future
version.
Instructions for updating:
Use tf.where in 2.0, which has the same broadcast rule as np.where
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:148: The name
tf.placeholder_with_default is deprecated. Please use
tf.compat.v1.placeholder_with_default instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:3733: calling dropout (from
tensorflow.python.ops.nn_ops) with keep_prob is deprecated and will be removed
in a future version.
Instructions for updating:
Please use `rate` instead of `keep_prob`. Rate should be set to `rate = 1 -
keep_prob`.
```

[0]:

```
# Model and training parameters
#ASSIGN VALUES TO THE FOLLOWING VARIABLES
epochs = 100000
batch_size = 128
sample_interval = 10000

# Array to save training history
training_meta_data = np.zeros([epochs, 4])
```

[0]:

```
def saveModels(epoch):
    generator.save(MODEL_PATH + 'gan_generator_epoch_%d.h5' % epoch)
    discriminator.save(MODEL_PATH + 'gan_discriminator_epoch_%d.h5' % epoch)
```

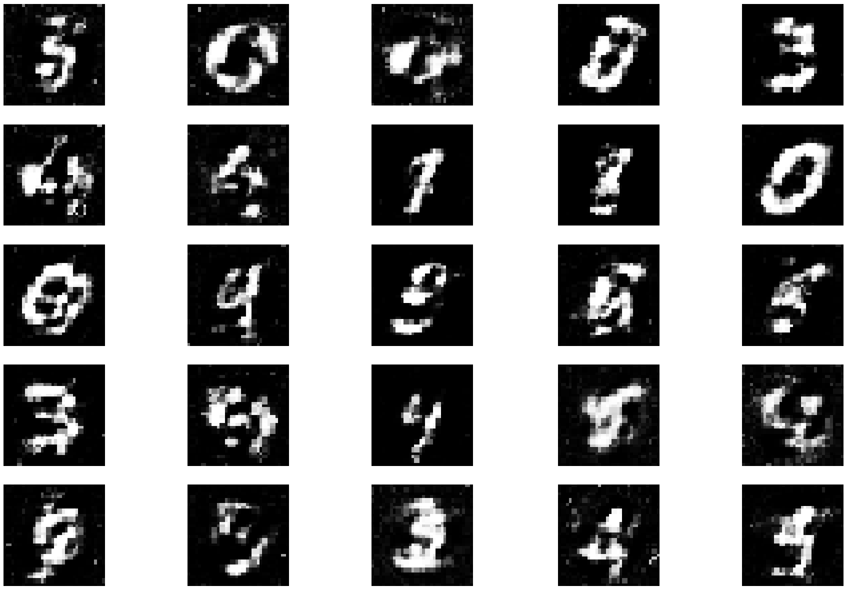
[0]:

```
# Training the GAN
for e in range(1, epochs+1):
```

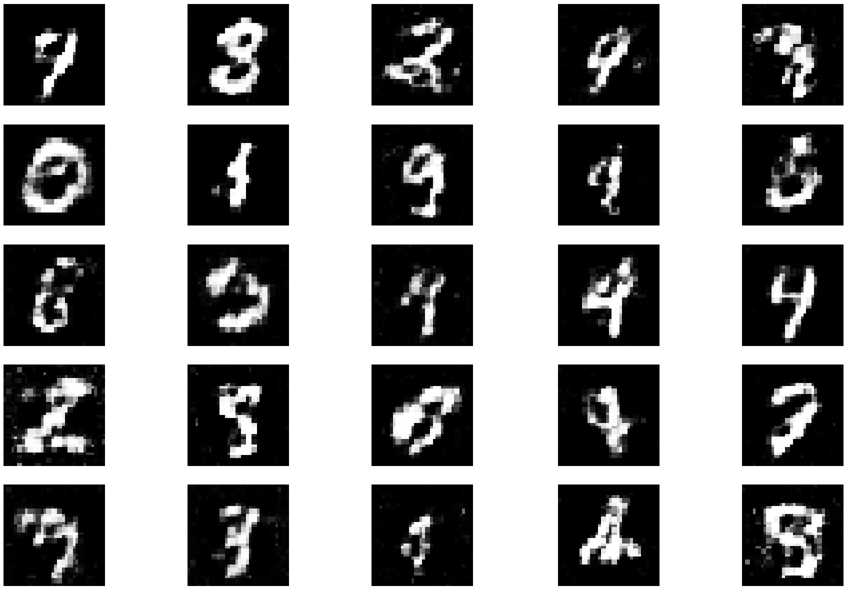
```
# Generate random noise as input
noise = np.random.normal(0, 1, size=[batch_size, latent_dim])
# Generate fake MNIST images from generated noise
generated_images = generator.predict(noise)

# Get a random set of real MNIST images
real_images = X_train[np.random.randint(0, X_train.shape[0], size=batch_size)]

# Concatenate real and fake images into a single array (or batch)
X = np.concatenate([real_images, generated_images])
# Assign training labels (assign high probability, but not 1, to real images)
yDis = np.zeros(2*batch_size)
yDis[:batch_size] = 0.9

# Allow discriminator parameters to be updated
discriminator.trainable = True

# Train discriminator on batch of real and fake images. Assign loss and accuracy to variable
d_loss = discriminator.train_on_batch(X, yDis)

# Train adversarial model and try to fool discriminator (with incorrect label)
# by generating a new batch of noise and assign them labels of real data
noise = np.random.normal(0, 1, size=[batch_size, latent_dim])
yGen = np.ones(batch_size)

# Keep discriminator weights constant while training generator
discriminator.trainable = False

# Train GAN (without updating discriminator weights) on new batch of fake images. Assign loss and accuracy to variable
gan_loss = gan.train_on_batch(noise, yGen)

# Save training status
# Discriminator and model loss
training_meta_data[e-1, 0] = d_loss[0]
training_meta_data[e-1, 1] = gan_loss[0]

# Discriminator and model accuracy
training_meta_data[e-1, 2] = d_loss[1]
training_meta_data[e-1, 3] = gan_loss[1]


# If at sample interval, print training status and save samples
if e % sample_interval == 0:
  # Print training status
  print("Epoch %d" %e)
  log_mesg = "%d: [Discriminator loss: %f, acc: %f]" % (e, d_loss[0],␣
↪d_loss[1])
  log_mesg = "%s  [GAN loss: %f, acc: %f]" % (log_mesg, gan_loss[0],␣
↪gan_loss[1])
  print(log_mesg)
  saveModels(e)

  # Plot images
  r, c = 5, 5

  # Create images from the noise (predict the outcome of the noise)
  gen_imgs = generator.predict(noise)
  # Rescale images 0 - 1
  gen_imgs = 0.5 * gen_imgs + 0.5

  fig, axs = plt.subplots(r, c)
  cnt = 0
  for i in range(r):
    for j in range(c):
      axs[i,j].imshow((gen_imgs[cnt].reshape(28, 28)), cmap='gray')
      axs[i,j].axis('off')
      cnt += 1
  plt.show()
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:3005: The name tf.Session is
deprecated. Please use tf.compat.v1.Session instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:190: The name
tf.get_default_session is deprecated. Please use
tf.compat.v1.get_default_session instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:197: The name tf.ConfigProto is
deprecated. Please use tf.compat.v1.ConfigProto instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:207: The name tf.global_variables
is deprecated. Please use tf.compat.v1.global_variables instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:216: The name
tf.is_variable_initialized is deprecated. Please use
tf.compat.v1.is_variable_initialized instead.
```

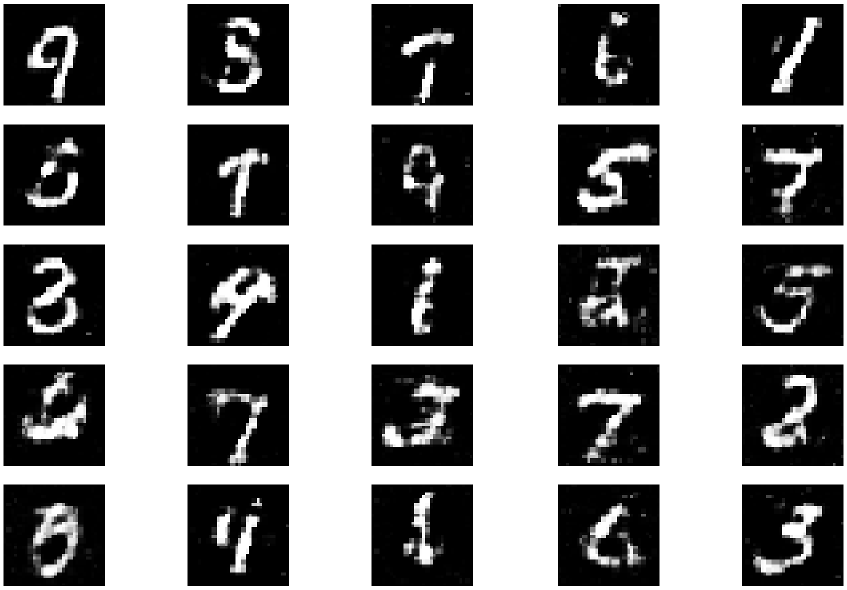
```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:223: The name
tf.variables_initializer is deprecated. Please use
tf.compat.v1.variables_initializer instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:1033: The name tf.assign_add is
deprecated. Please use tf.compat.v1.assign_add instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:1020: The name tf.assign is
deprecated. Please use tf.compat.v1.assign instead.

Epoch 10000
10000: [Discriminator loss: 0.521202, acc: 0.441406]  [GAN loss: 1.617595, acc:
0.093750]
```



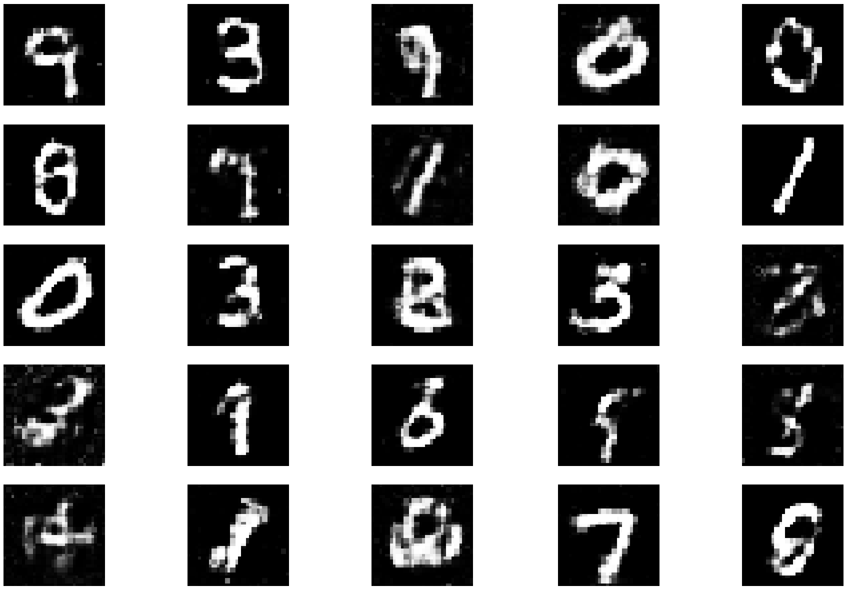
```
Epoch 20000
20000: [Discriminator loss: 0.578431, acc: 0.398438]  [GAN loss: 1.271461, acc:
0.132812]
```



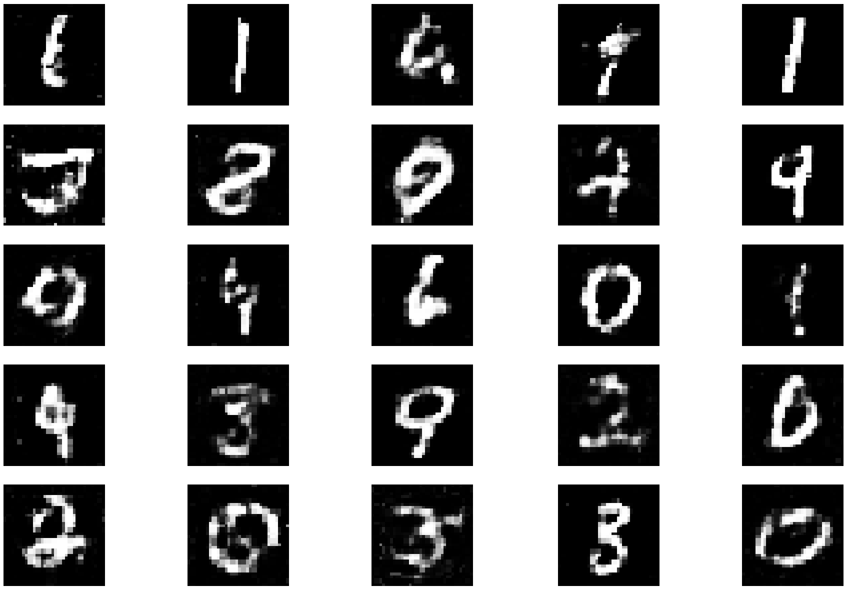
```
Epoch 30000
30000: [Discriminator loss: 0.608065, acc: 0.367188]  [GAN loss: 1.221969, acc:
0.203125]
```



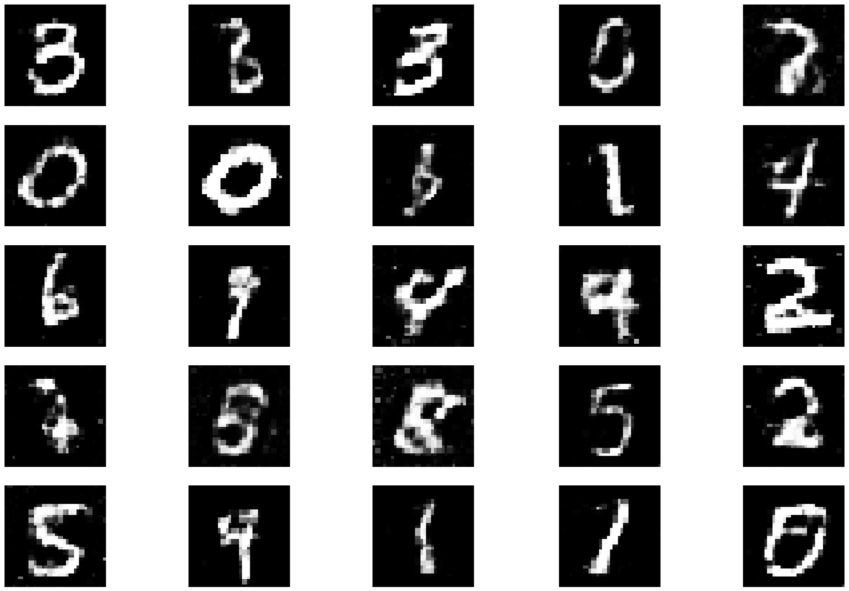
```
Epoch 40000
40000: [Discriminator loss: 0.574095, acc: 0.386719]  [GAN loss: 1.515417, acc:
0.101562]
```



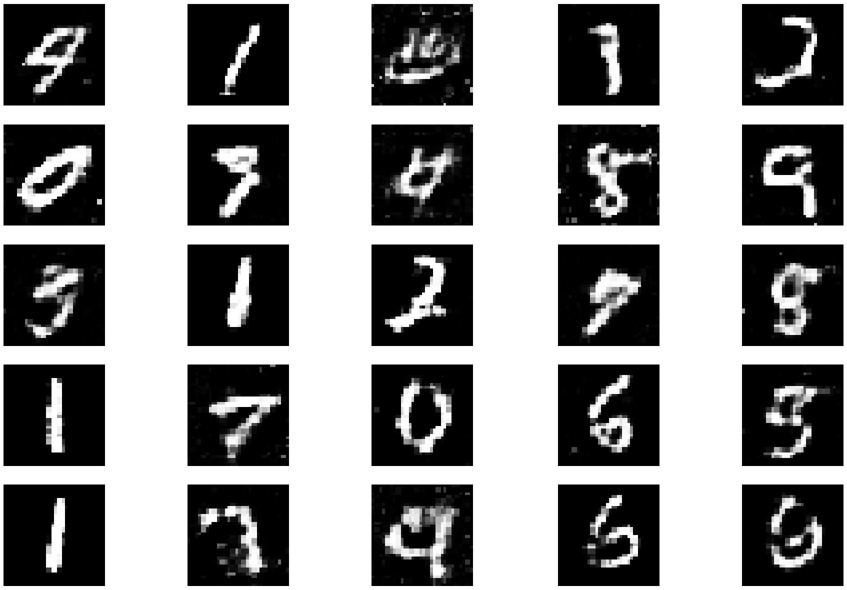
```
Epoch 50000
50000: [Discriminator loss: 0.532118, acc: 0.433594]  [GAN loss: 1.446576, acc:
0.109375]
```



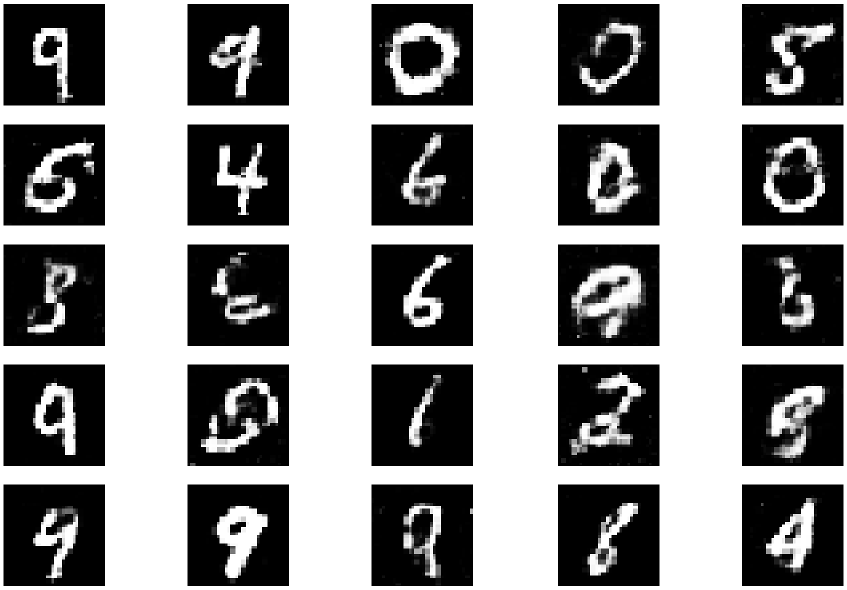
```
Epoch 60000
60000: [Discriminator loss: 0.598145, acc: 0.402344]  [GAN loss: 1.193942, acc:
0.132812]
```



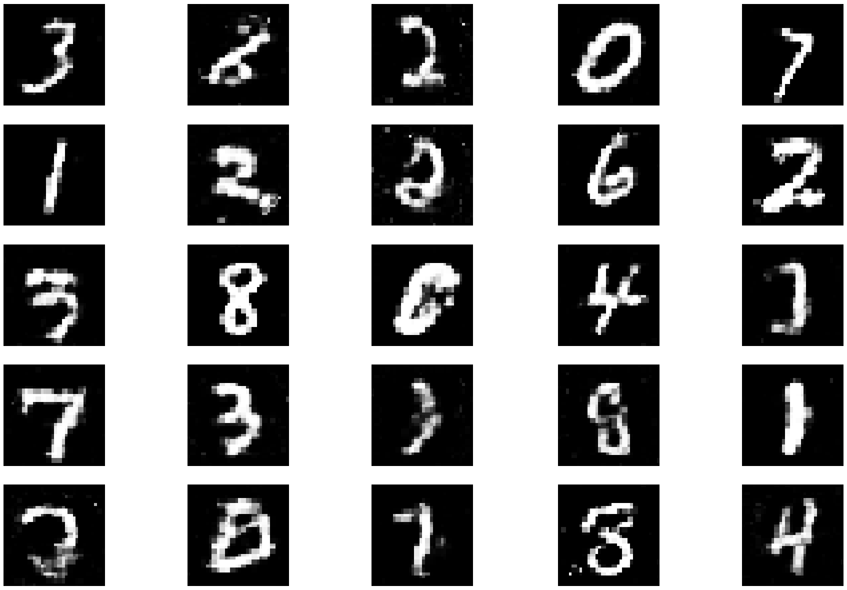
```
Epoch 70000
70000: [Discriminator loss: 0.541928, acc: 0.417969]  [GAN loss: 1.295970, acc:
0.179688]
```



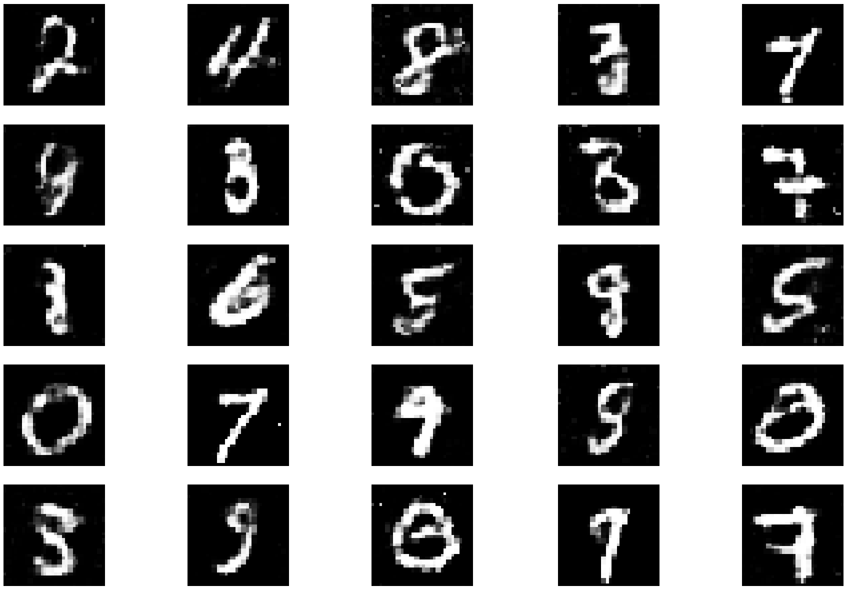
```
Epoch 80000
80000: [Discriminator loss: 0.548826, acc: 0.425781]  [GAN loss: 1.199958, acc:
0.234375]
```



```
Epoch 90000
90000: [Discriminator loss: 0.527998, acc: 0.402344]  [GAN loss: 1.254974, acc:
0.187500]
```



```
Epoch 100000
100000: [Discriminator loss: 0.542299, acc: 0.402344]  [GAN loss: 1.264699, acc:
0.218750]
```

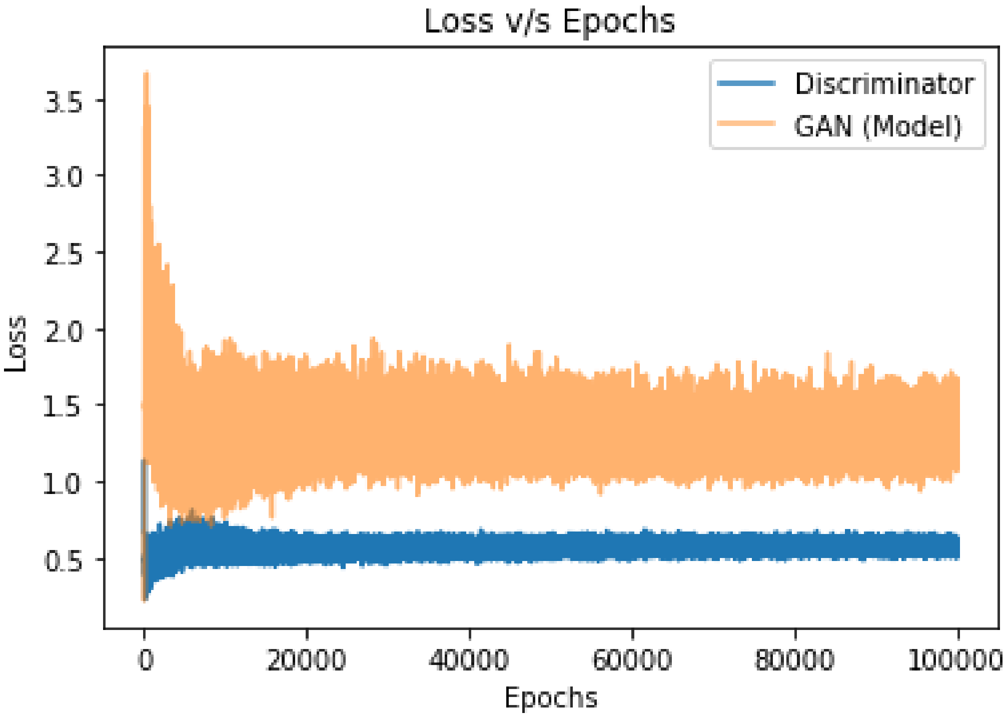


[0]:

```
import pickle
with open(MODEL_PATH + "gan_model_meta_data.pickle","wb") as f:
  pickle.dump(training_meta_data, f)
```

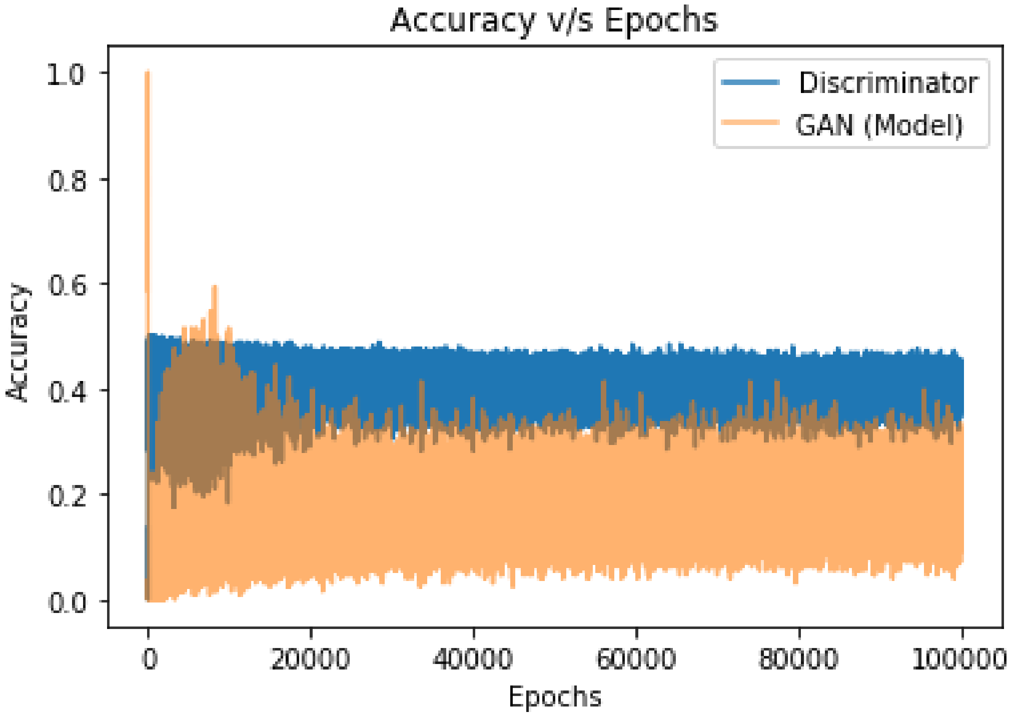
[0]:

```
# Plot model loss vs epoch
plt.plot(training_meta_data[:, 0], label="Discriminator")
plt.plot(training_meta_data[:, 1], label="GAN (Model)", alpha=0.6)
plt.title("Loss v/s Epochs")
plt.legend()
plt.xlabel("Epochs")
plt.ylabel("Loss")
plt.show()
fig.tight_layout()
```



[0]:

```
# Plot accuracy vs epoch
plt.plot(training_meta_data[:, 2], label="Discriminator")
plt.plot(training_meta_data[:, 3], label="GAN (Model)", alpha=0.6)
plt.title("Accuracy v/s Epochs")
plt.legend()
plt.xlabel("Epochs")
plt.ylabel("Accuracy")
plt.show()
fig.tight_layout()
```



Answer the following questions:

1. Why does the accuracy of the discriminator remain around 50%? Is this a good trait of the GAN?

ANS: As the generator improves with training, the discriminator performance gets worse because the discriminator cannot easily tell the difference between real and fake. If the generator succeeds perfectly, then the discriminator has a 50% accuracy which is equivalent to a completely blind guess.

2. How could this model be modified to produce cleaner (less noisy) images?

ANS: One method of developing a smooth generator (one that produces less noisy images) is to limit the input perturbation. This couples with a gradient penalized generator can generate stable and high-quality images.

#Part 2: Generating samples using trained generator

[5]:
```
generator = load_model(MODEL_PATH + 'gan_generator_epoch_100000.h5')
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:541: The name tf.placeholder is
deprecated. Please use tf.compat.v1.placeholder instead.
```

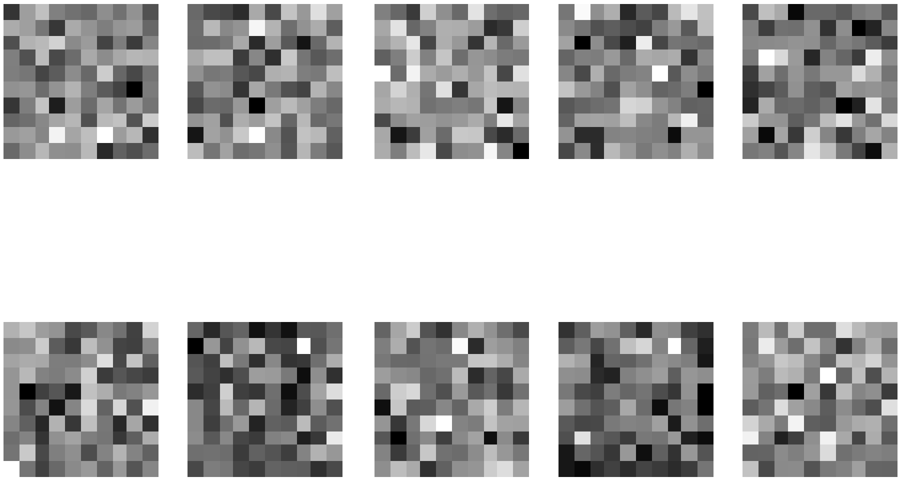
```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:4432: The name tf.random_uniform is
deprecated. Please use tf.random.uniform instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:190: The name
tf.get_default_session is deprecated. Please use
tf.compat.v1.get_default_session instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:197: The name tf.ConfigProto is
deprecated. Please use tf.compat.v1.ConfigProto instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:203: The name tf.Session is
deprecated. Please use tf.compat.v1.Session instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:207: The name tf.global_variables
is deprecated. Please use tf.compat.v1.global_variables instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:216: The name
tf.is_variable_initialized is deprecated. Please use
tf.compat.v1.is_variable_initialized instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:223: The name
tf.variables_initializer is deprecated. Please use
tf.compat.v1.variables_initializer instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/optimizers.py:793: The name tf.train.Optimizer is deprecated.
Please use tf.compat.v1.train.Optimizer instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/keras/backend/tensorflow_backend.py:3657: The name tf.log is
deprecated. Please use tf.math.log instead.

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-
packages/tensorflow_core/python/ops/nn_impl.py:183: where (from
tensorflow.python.ops.array_ops) is deprecated and will be removed in a future
version.
Instructions for updating:
Use tf.where in 2.0, which has the same broadcast rule as np.where
```

[0]:

```
# The D-dimensional noise vector length
latent_dim = 100
noise = np.random.normal(0, 1, size=[10, latent_dim])
# Generate fake MNIST images from generated noise
generated_images = generator.predict(noise)
g_scaled = generated_images.reshape(-1, 28, 28)
generated_images = (g_scaled * 127.5 + 127.5 ) / 255.
```

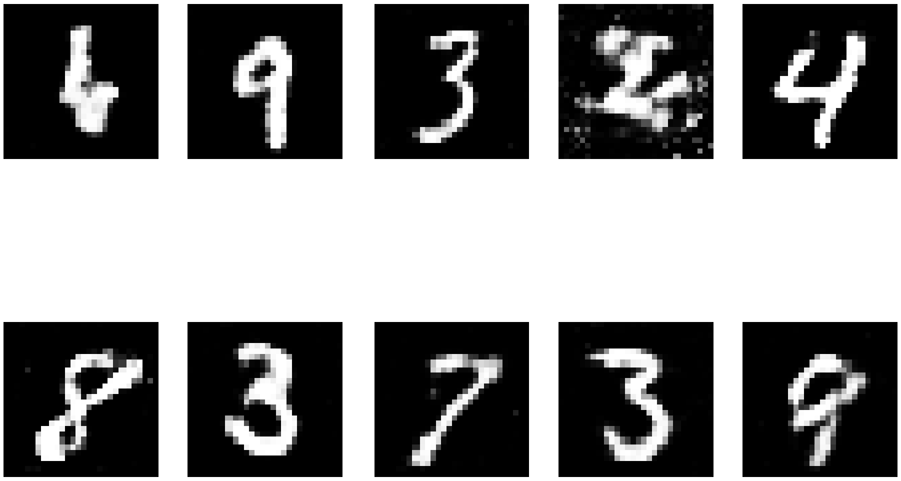
[23]:

```
# Visualize generated noise
r, c = 2, 5
fig, axs = plt.subplots(r, c)
cnt = 0
for i in range(r):
    for j in range(c):
        axs[i,j].imshow((noise[cnt].reshape(10, 10)), cmap='gray')
        axs[i,j].axis('off')
        cnt += 1
plt.show()
```



[24]:

```
# Visualize generated samples
r, c = 2, 5
fig, axs = plt.subplots(r, c)
cnt = 0
for i in range(r):
    for j in range(c):
        axs[i,j].imshow((generated_images[cnt].reshape(28, 28)), cmap='gray')
        axs[i,j].axis('off')
        cnt += 1
plt.show()
```



#Part 3: Testing accuracy of generated images on ten samples

[0]:

```
# Load mnist classifier and generated images
mnist_classifier = load_model('./gdrive/My Drive/ece595_ml2/mnist_classifier.h5')
```

[0]:

```
# ASSIGN CLASSES
labels = [4, 9, 3, 3, 4, 8, 3, 7, 3, 9]

# Convert integer labels to one-hot labels
labels = keras.utils.np_utils.to_categorical(labels, num_classes=10)
```

[0]:

```
print(mnist_classifier.model.summary())
```

```
Model: "sequential_1"

_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_1 (Dense)              (None, 256)               200960

_________________________________________________________________
dropout_1 (Dropout)          (None, 256)               0

_________________________________________________________________
dense_2 (Dense)              (None, 128)               32896

_________________________________________________________________
dropout_2 (Dropout)          (None, 128)               0

_________________________________________________________________
dense_3 (Dense)              (None, 10)                1290
=================================================================
Total params: 235,146
Trainable params: 235,146
Non-trainable params: 0

_________________________________________________________________
```

```
None

/usr/local/lib/python3.6/dist-packages/keras/engine/sequential.py:111:
UserWarning: `Sequential.model` is deprecated. `Sequential` is a subclass of
`Model`, you can just use your `Sequential` instance directly.
  warnings.warn('`Sequential.model` is deprecated. '
```

```
[27]: # Show classifications
      # k = mnist_classifier.predict(generated_images.reshape(-1,784))
      k = mnist_classifier.evaluate(generated_images.reshape(-1,784), labels)
```

```
10/10 [==============================] - 0s 15ms/step
```

```
[28]: print(k)
```

```
[0.6521979570388794, 0.800000011920929]
```

```
[0]: labels = [4, 9, 3, 3, 4, 8, 3, 7, 3, 9]
     kink = mnist_classifier.predict(generated_images.reshape(-1,784))
```

```
[0]: predictions = np.argmax(kink, axis=1)
```

```
[0]: accuracy = sum(labels == predictions)/ len(labels)
```

```
[54]: print("Accuracy of the classifier on the 10 generated images: ", accuracy * 100,␣
       ↪"%")
```

```
Accuracy of the classifier on the 10 generated images:  80.0 %
```

1. State the accuracy of the classifier on your ten generated images. Based on this accuracy, would you say your generator does well in producing images comparable to those in the MNIST dataset of hand-written digits? Why or why not?

ANS: The accuracy of the classifier on the 10 generated images is 80%. Based on this accuracy, it seems that the generator does a poor job in producing images compared to the MNIST dataset. I think this because the generated images from the generator are *noisy* in comparison to the original MNIST dataset. Hence, the classifier has not been trained to handle noisy datasets.

2. In this project, we only tested the performance of the pre-trained classifier on ten samples and used its result to determine the robustness of the generator. How could we better assess the quality of the generated images using this pre-trained classifier and the saved generator?

ANS: For better assessing the quality of the generated images, we would have to measure the accuracy over a larger dataset. But it would become cumbersome for humans to manually label all the generated images for testing it's accuracy with a trained MNIST classifier. We could develop a semi-supervised learner (SSL) for clustering similar images, where the human can manually label some data points and the SSL can be used to automatically label the generated dataset. This can then be used to evaluate the effectiveness of the generator, as we would have more instances of clustered data.

```
[0]:
```