MNIST-GANs

December 12, 2020

[1]:
```
import tensorflow as tf
import glob
import matplotlib.pyplot as plt
import numpy as np
import os
import PIL
from tensorflow.keras import layers
from tensorflow.keras.utils import to_categorical
import time

from IPython import display
```

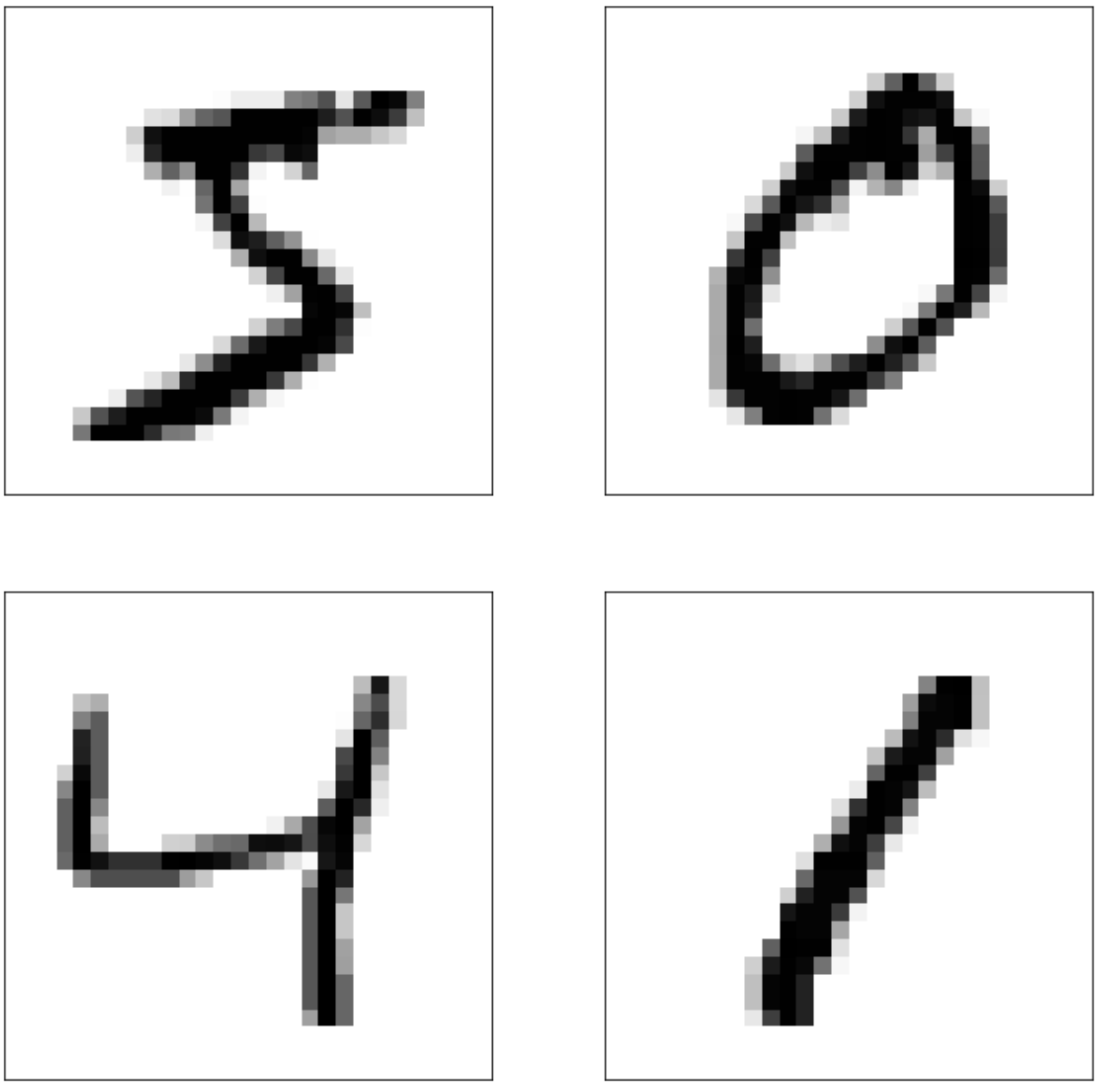
1 Load and Prepare MNIST Dataset

[266]:
```
(train_images, train_labels), (test_images, test_labels) = tf.keras.datasets.
↪mnist.load_data()
```

[267]:
```
# Reshape
train_images = train_images.reshape(train_images.shape[0], 28, 28, 1).
↪astype('float32')
test_images = test_images.reshape(test_images.shape[0], 28, 28, 1).
↪astype('float32')

# Normalize
train_images = (train_images - 127.5) / 127.5
test_images = (test_images - 127.5) / 127.5

# To categorical
train_labels = to_categorical(train_labels)
test_labels = to_categorical(test_labels)

print(train_images.shape, train_labels.shape)
print(test_images.shape, test_labels.shape)
```

```
(60000, 28, 28, 1) (60000, 10)
(10000, 28, 28, 1) (10000, 10)
```

[268]:
```
plt.figure(figsize=(10,10))
for i in range(4):
    plt.subplot(2,2,i+1)
    plt.xticks([])
    plt.yticks([])
    plt.grid(False)
    plt.imshow(train_images[i].squeeze(axis=2), cmap=plt.cm.binary)
plt.show()
```



2 Feed Forward Deep Neural Network (CNN)

2.1 Create CNN to train MNIST dataset

[269]:
```
def make_baseline_model():
    model = tf.keras.Sequential()
    model.add(layers.Conv2D(64, (5, 5), strides=(2, 2), padding='same',␣
 ↪input_shape=[28, 28, 1]))
    model.add(layers.LeakyReLU())
    model.add(layers.Dropout(0.3))

    model.add(layers.Conv2D(128, (5, 5), strides=(2, 2), padding='same'))
    model.add(layers.LeakyReLU())
    model.add(layers.Dropout(0.3))

    model.add(layers.Flatten())
#     model.add(layers.Dense(10))

    return model
```

[270]:
```
baseline = make_baseline_model()
baseline.add(layers.Dense(10, activation='softmax'))
```

2.2 Compile the model

[271]:
```
baseline.compile(optimizer='adam',
                 loss='categorical_crossentropy',
                 metrics=['accuracy'])
```

[272]:
```
baseline.summary()
```

```
Model: "sequential_37"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_20 (Conv2D)           (None, 14, 14, 64)        1664
_________________________________________________________________
leaky_re_lu_29 (LeakyReLU)   (None, 14, 14, 64)        0
_________________________________________________________________
dropout_20 (Dropout)         (None, 14, 14, 64)        0
_________________________________________________________________
conv2d_21 (Conv2D)           (None, 7, 7, 128)         204928
_________________________________________________________________
leaky_re_lu_30 (LeakyReLU)   (None, 7, 7, 128)         0
_________________________________________________________________
dropout_21 (Dropout)         (None, 7, 7, 128)         0
```

```
_________________________________________________________________
flatten_11 (Flatten)         (None, 6272)              0
_________________________________________________________________
dense_31 (Dense)             (None, 10)                62730
=================================================================
Total params: 269,322
Trainable params: 269,322
Non-trainable params: 0
_________________________________________________________________
```

2.3 Train the model

[273]:
```
baseline.fit(train_images, train_labels, batch_size=256, epochs=10)
```

```
Epoch 1/10
235/235 [==============================] - 40s 171ms/step - loss: 0.3215 -
accuracy: 0.9030
Epoch 2/10
235/235 [==============================] - 46s 196ms/step - loss: 0.1159 -
accuracy: 0.9659
Epoch 3/10
235/235 [==============================] - 46s 197ms/step - loss: 0.0925 -
accuracy: 0.9720
Epoch 4/10
235/235 [==============================] - 46s 198ms/step - loss: 0.0781 -
accuracy: 0.9758
Epoch 5/10
235/235 [==============================] - 38s 164ms/step - loss: 0.0713 -
accuracy: 0.9775
Epoch 6/10
235/235 [==============================] - 38s 160ms/step - loss: 0.0629 -
accuracy: 0.9805
Epoch 7/10
235/235 [==============================] - 32s 135ms/step - loss: 0.0610 -
accuracy: 0.9808
Epoch 8/10
235/235 [==============================] - 41s 174ms/step - loss: 0.0552 -
accuracy: 0.9823
Epoch 9/10
235/235 [==============================] - 42s 177ms/step - loss: 0.0513 -
accuracy: 0.9837
Epoch 10/10
235/235 [==============================] - 46s 194ms/step - loss: 0.0498 -
accuracy: 0.9840
```

[273]:
```
<tensorflow.python.keras.callbacks.History at 0x7f4859a4ac70>
```

2.4 Evaluate accuracy

[274]:
```
test_loss, test_acc = baseline.evaluate(test_images, test_labels, verbose=2)

print('\nTest accuracy:', test_acc)
```

```
313/313 - 2s - loss: 0.0461 - accuracy: 0.9848

Test accuracy: 0.9847999811172485
```

3 Create Discriminator and Generator Networks

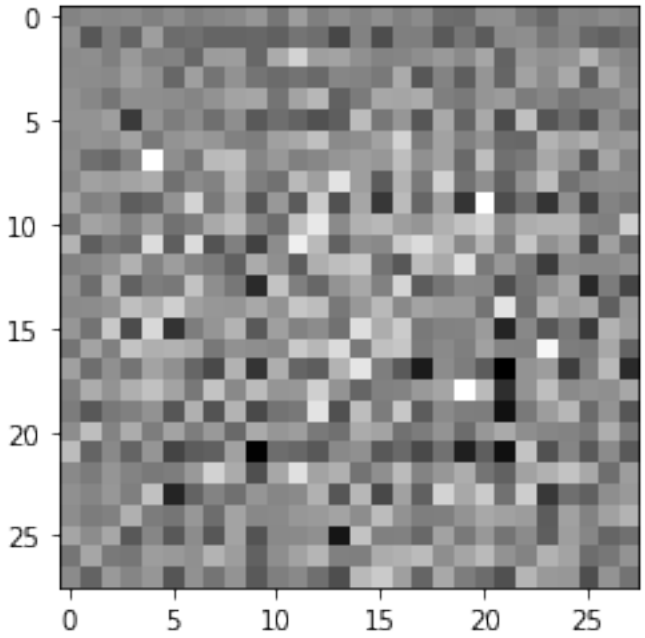
3.1 Generator

[86]:
```
def make_generator_model():
    model = tf.keras.Sequential()
    model.add(layers.Dense(7*7*256, use_bias=False, input_shape=(100,)))
    model.add(layers.BatchNormalization())
    model.add(layers.LeakyReLU())

    model.add(layers.Reshape((7, 7, 256)))
    assert model.output_shape == (None, 7, 7, 256) # Note: None is the batch␣
↪size

    model.add(layers.Conv2DTranspose(128, (5, 5), strides=(1, 1),␣
↪padding='same', use_bias=False))
    assert model.output_shape == (None, 7, 7, 128)
    model.add(layers.BatchNormalization())
    model.add(layers.LeakyReLU())

    model.add(layers.Conv2DTranspose(64, (5, 5), strides=(2, 2),␣
↪padding='same', use_bias=False))
    assert model.output_shape == (None, 14, 14, 64)
    model.add(layers.BatchNormalization())
    model.add(layers.LeakyReLU())

    model.add(layers.Conv2DTranspose(1, (5, 5), strides=(2, 2), padding='same',␣
↪use_bias=False, activation='tanh'))
    assert model.output_shape == (None, 28, 28, 1)

    return model
```

[87]:
```
generator = make_generator_model()

noise = tf.random.normal([1, 100])
```

```
generated_image = generator(noise, training=False)

plt.imshow(generated_image[0, :, :, 0], cmap='gray')
```

[87]: <matplotlib.image.AxesImage at 0x7f48d2f53970>



[282]:
```
generator.summary()
```

```
Model: "sequential_11"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense_13 (Dense)             (None, 12544)             1254400
_________________________________________________________________
batch_normalization_6 (Batch (None, 12544)             50176
_________________________________________________________________
leaky_re_lu_16 (LeakyReLU)   (None, 12544)             0
_________________________________________________________________
reshape_2 (Reshape)          (None, 7, 7, 256)         0
_________________________________________________________________
conv2d_transpose_6 (Conv2DTr (None, 7, 7, 128)         819200
_________________________________________________________________
batch_normalization_7 (Batch (None, 7, 7, 128)         512
_________________________________________________________________
leaky_re_lu_17 (LeakyReLU)   (None, 7, 7, 128)         0
_________________________________________________________________
```

```
conv2d_transpose_7 (Conv2DTr (None, 14, 14, 64)        204800
_________________________________________________________________
batch_normalization_8 (Batch (None, 14, 14, 64)        256
_________________________________________________________________
leaky_re_lu_18 (LeakyReLU)   (None, 14, 14, 64)        0
_________________________________________________________________
conv2d_transpose_8 (Conv2DTr (None, 28, 28, 1)         1600
=================================================================
Total params: 2,330,944
Trainable params: 2,305,472
Non-trainable params: 25,472
_________________________________________________________________
```

3.2 Discriminator

[168]:
```
discriminator = make_baseline_model()
discriminator.add(layers.Dense(1))

discriminator.summary()
```

```
Model: "sequential_29"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_18 (Conv2D)           (None, 14, 14, 64)        1664
_________________________________________________________________
leaky_re_lu_27 (LeakyReLU)   (None, 14, 14, 64)        0
_________________________________________________________________
dropout_18 (Dropout)         (None, 14, 14, 64)        0
_________________________________________________________________
conv2d_19 (Conv2D)           (None, 7, 7, 128)         204928
_________________________________________________________________
leaky_re_lu_28 (LeakyReLU)   (None, 7, 7, 128)         0
_________________________________________________________________
dropout_19 (Dropout)         (None, 7, 7, 128)         0
_________________________________________________________________
flatten_10 (Flatten)         (None, 6272)              0
_________________________________________________________________
dense_19 (Dense)             (None, 1)                 6273
=================================================================
Total params: 212,865
Trainable params: 212,865
Non-trainable params: 0
_________________________________________________________________
```

[169]:
```
decision = discriminator(generated_image)
print(decision)
```

```
tf.Tensor([[-7.5450385e-05]], shape=(1, 1), dtype=float32)
```

4 Define Loss and Optimization

[90]:
```
# This method returns a helper function to compute cross entropy loss
cross_entropy = tf.keras.losses.BinaryCrossentropy(from_logits=True)
```

[91]:
```
def discriminator_loss(real_output, fake_output):
    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
```

[92]:
```
def generator_loss(fake_output):
    return cross_entropy(tf.ones_like(fake_output), fake_output)
```

[93]:
```
generator_optimizer = tf.keras.optimizers.Adam(1e-4)
discriminator_optimizer = tf.keras.optimizers.Adam(1e-4)
```

[94]:
```
checkpoint_dir = './training_checkpoints'
checkpoint_prefix = os.path.join(checkpoint_dir, "ckpt")
checkpoint = tf.train.Checkpoint(generator_optimizer=generator_optimizer,
                                 ␣
 ↪discriminator_optimizer=discriminator_optimizer,
                                 generator=generator,
                                 discriminator=discriminator)
```

5 Train

[170]:
```
EPOCHS = 100
noise_dim = 100
num_examples_to_generate = 16

# We will reuse this seed overtime (so it's easier)
# to visualize progress in the animated GIF)
seed = tf.random.normal([num_examples_to_generate, noise_dim])
```

[96]:
```
# Notice the use of `tf.function`
# This annotation causes the function to be "compiled".
@tf.function
def train_step(images):
    noise = tf.random.normal([BATCH_SIZE, noise_dim])
```

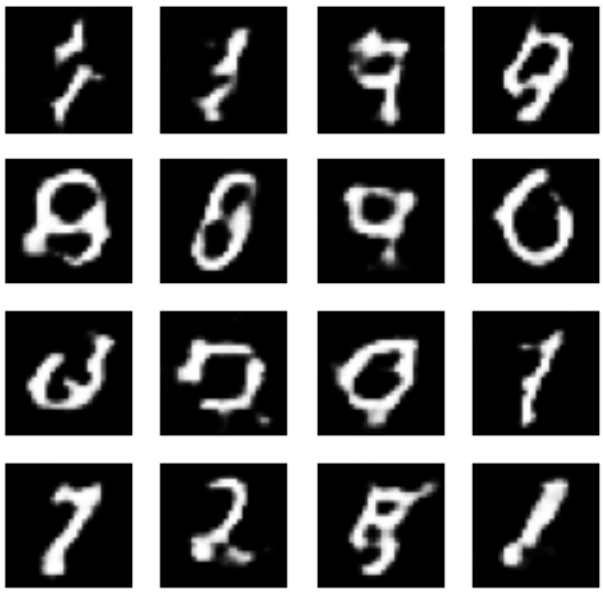
```
    with tf.GradientTape() as gen_tape, tf.GradientTape() as disc_tape:
        generated_images = generator(noise, training=True)

        real_output = discriminator(images, training=True)
        fake_output = discriminator(generated_images, training=True)

        gen_loss = generator_loss(fake_output)
        disc_loss = discriminator_loss(real_output, fake_output)

    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))

    return gen_loss, disc_loss
```

[97]:
```
def train(dataset, epochs):
    loss = []
    for epoch in range(epochs):
        epoch_loss = []
        start = time.time()

        for image_batch in dataset:
            gen_loss, disc_loss = train_step(image_batch)
            epoch_loss.append([gen_loss, disc_loss])
        loss.append(epoch_loss)

        # Produce images for the GIF as we go
        display.clear_output(wait=True)
        generate_and_save_images(generator, epoch + 1, seed)

        # Save the model every 15 epochs
        if (epoch + 1) % 15 == 0:
            checkpoint.save(file_prefix = checkpoint_prefix)

        print('Time for epoch {} is {} sec'.format(epoch + 1, time.
↪time()-start))

    loss.append(epoch_loss)

    # Generate after the final epoch
    display.clear_output(wait=True)
```

```
    generate_and_save_images(generator, epochs, seed)

    return loss
```

[98]:
```
def generate_and_save_images(model, epoch, test_input):
    # Notice `training` is set to False.
    # This is so all layers run in inference mode (batchnorm).
    predictions = model(test_input, training=False)

    fig = plt.figure(figsize=(4,4))

    for i in range(predictions.shape[0]):
        plt.subplot(4, 4, i+1)
        plt.imshow(predictions[i, :, :, 0] * 127.5 + 127.5, cmap='gray')
        plt.axis('off')

    plt.savefig('image_at_epoch_{:04d}.png'.format(epoch))
    plt.show()
```

[171]:
```
BUFFER_SIZE = 60000
BATCH_SIZE = 256

# Batch and shuffle the data
train_dataset = tf.data.Dataset.from_tensor_slices(train_images).
 ↪shuffle(BUFFER_SIZE).batch(BATCH_SIZE)

loss = train(train_dataset, EPOCHS)
```



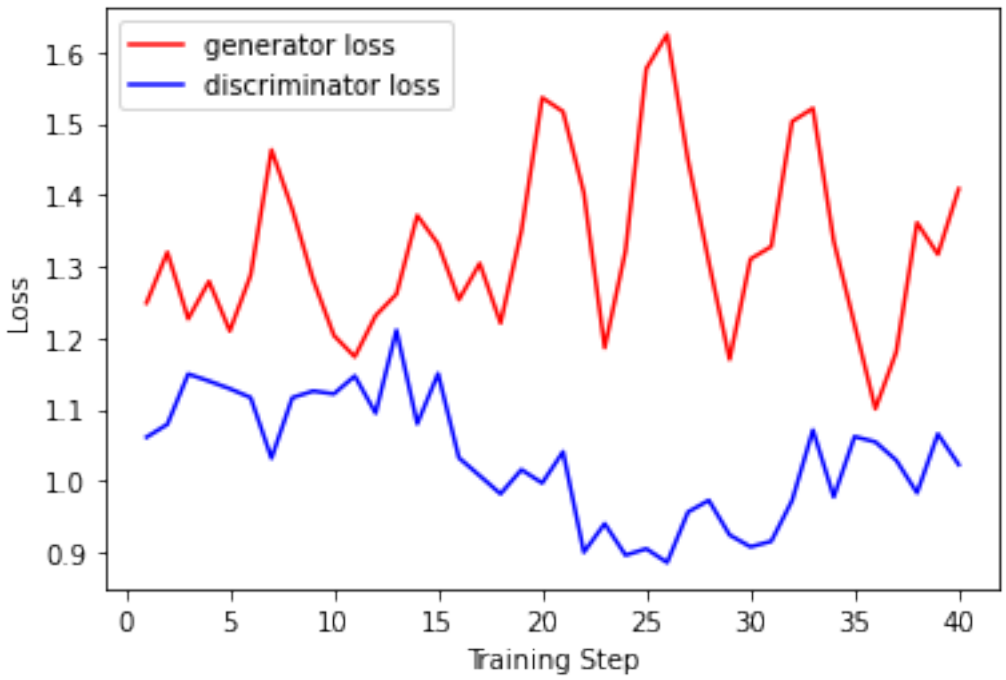
5.1 Evaluate Models

[172]:
```
l = np.array(loss)
```

[175]:
```
l.shape
```

[175]:
```
(101, 40, 2)
```

[200]:
```
t = range(1,41)

gen_loss = l[100,:,0]
disc_loss = l[100,:,1]

plt.plot(t, gen_loss, 'r', t, disc_loss, 'b')
plt.xlabel('Training Step')
plt.ylabel('Loss')
plt.legend(['generator loss', 'discriminator loss'])
plt.show()
```



5.2 Fine tune discriminator model

[275]:
```
model = tf.keras.Sequential()

for layer in discriminator.layers[:-1]: # go through until last layer
    layer.trainable = False
    model.add(layer)
model.add(layers.Dense(10, activation='softmax'))

model.summary()

model.compile(optimizer='adam',
              loss='categorical_crossentropy',
              metrics=['accuracy'])
```

```
Model: "sequential_38"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_18 (Conv2D)           (None, 14, 14, 64)        1664
_________________________________________________________________
leaky_re_lu_27 (LeakyReLU)   (None, 14, 14, 64)        0
_________________________________________________________________
dropout_18 (Dropout)         (None, 14, 14, 64)        0
_________________________________________________________________
conv2d_19 (Conv2D)           (None, 7, 7, 128)         204928
_________________________________________________________________
leaky_re_lu_28 (LeakyReLU)   (None, 7, 7, 128)         0
_________________________________________________________________
dropout_19 (Dropout)         (None, 7, 7, 128)         0
_________________________________________________________________
flatten_10 (Flatten)         (None, 6272)              0
_________________________________________________________________
dense_32 (Dense)             (None, 10)                62730
=================================================================
Total params: 269,322
Trainable params: 62,730
Non-trainable params: 206,592
_________________________________________________________________
```

[276]:
```
model.fit(train_images, train_labels, batch_size=256, epochs=10)
```

```
Epoch 1/10
235/235 [==============================] - 15s 63ms/step - loss: 0.8548 -
accuracy: 0.8064
Epoch 2/10
235/235 [==============================] - 15s 62ms/step - loss: 0.4339 -
accuracy: 0.8843
```

```
Epoch 3/10
235/235 [==============================] - 18s 76ms/step - loss: 0.3681 -
accuracy: 0.8987
Epoch 4/10
235/235 [==============================] - 19s 79ms/step - loss: 0.3342 -
accuracy: 0.9062
Epoch 5/10
235/235 [==============================] - 19s 80ms/step - loss: 0.3154 -
accuracy: 0.9101
Epoch 6/10
235/235 [==============================] - 19s 79ms/step - loss: 0.3002 -
accuracy: 0.9136
Epoch 7/10
235/235 [==============================] - 19s 81ms/step - loss: 0.2883 -
accuracy: 0.9177
Epoch 8/10
235/235 [==============================] - 17s 72ms/step - loss: 0.2784 -
accuracy: 0.9207
Epoch 9/10
235/235 [==============================] - 16s 67ms/step - loss: 0.2714 -
accuracy: 0.9212
Epoch 10/10
235/235 [==============================] - 19s 81ms/step - loss: 0.2637 -
accuracy: 0.9235
```

[276]:
```
<tensorflow.python.keras.callbacks.History at 0x7f485991ec70>
```

[277]:
```
disc_loss, disc_acc = model.evaluate(test_images, test_labels, verbose=2)

print('\nTest accuracy:', disc_acc)
```

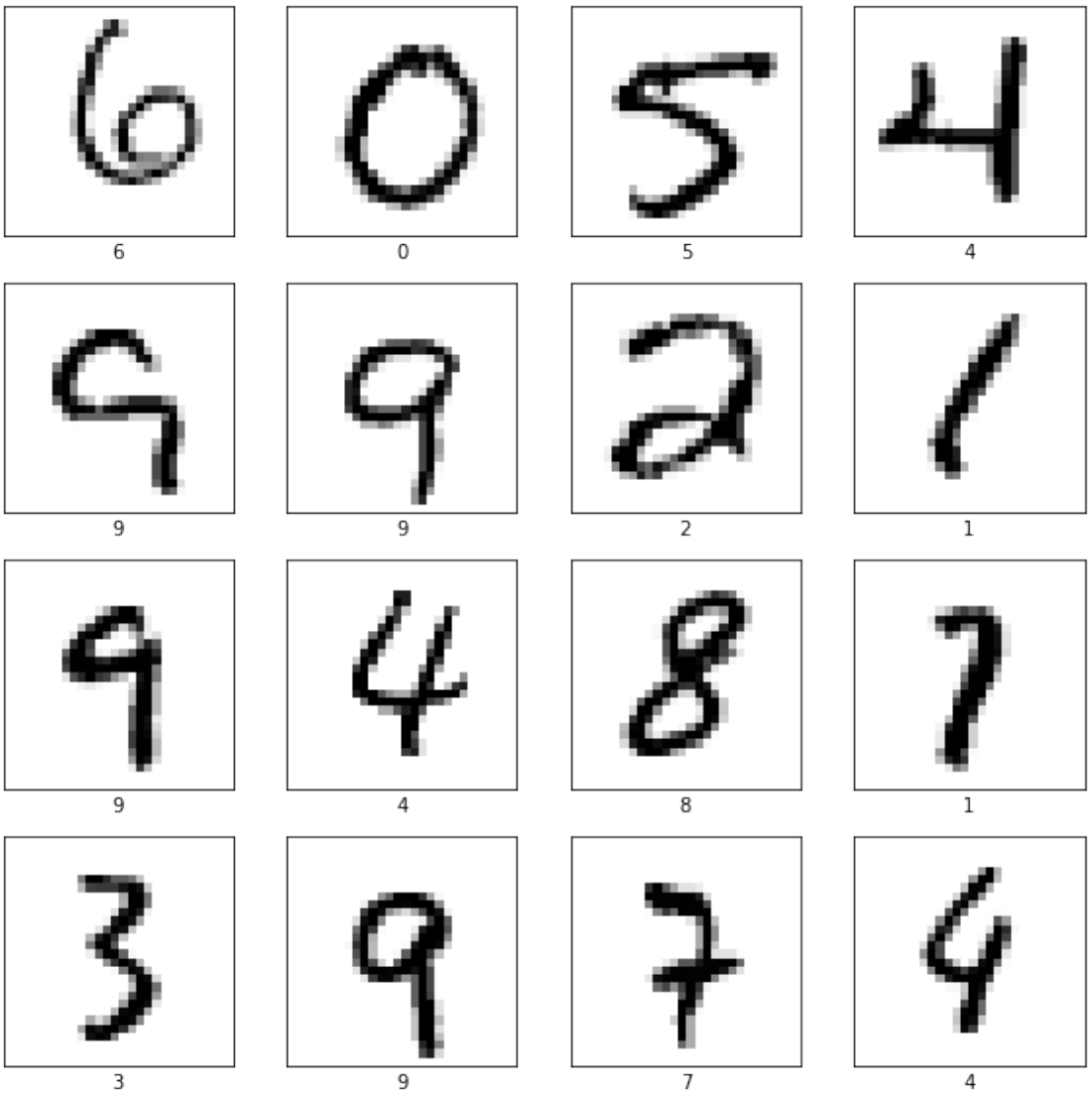
```
313/313 - 2s - loss: 0.2185 - accuracy: 0.9387

Test accuracy: 0.9387000203132629
```

[278]:
```
from sklearn import metrics

pred = model.predict(test_images)

true = np.argmax(test_labels, axis=1)
pred = np.argmax(pred, axis=1)

classification_metric = metrics.classification_report(true, pred)
print(classification_metric)
```

```
              precision    recall  f1-score   support

           0       0.95      0.99      0.97       980
```

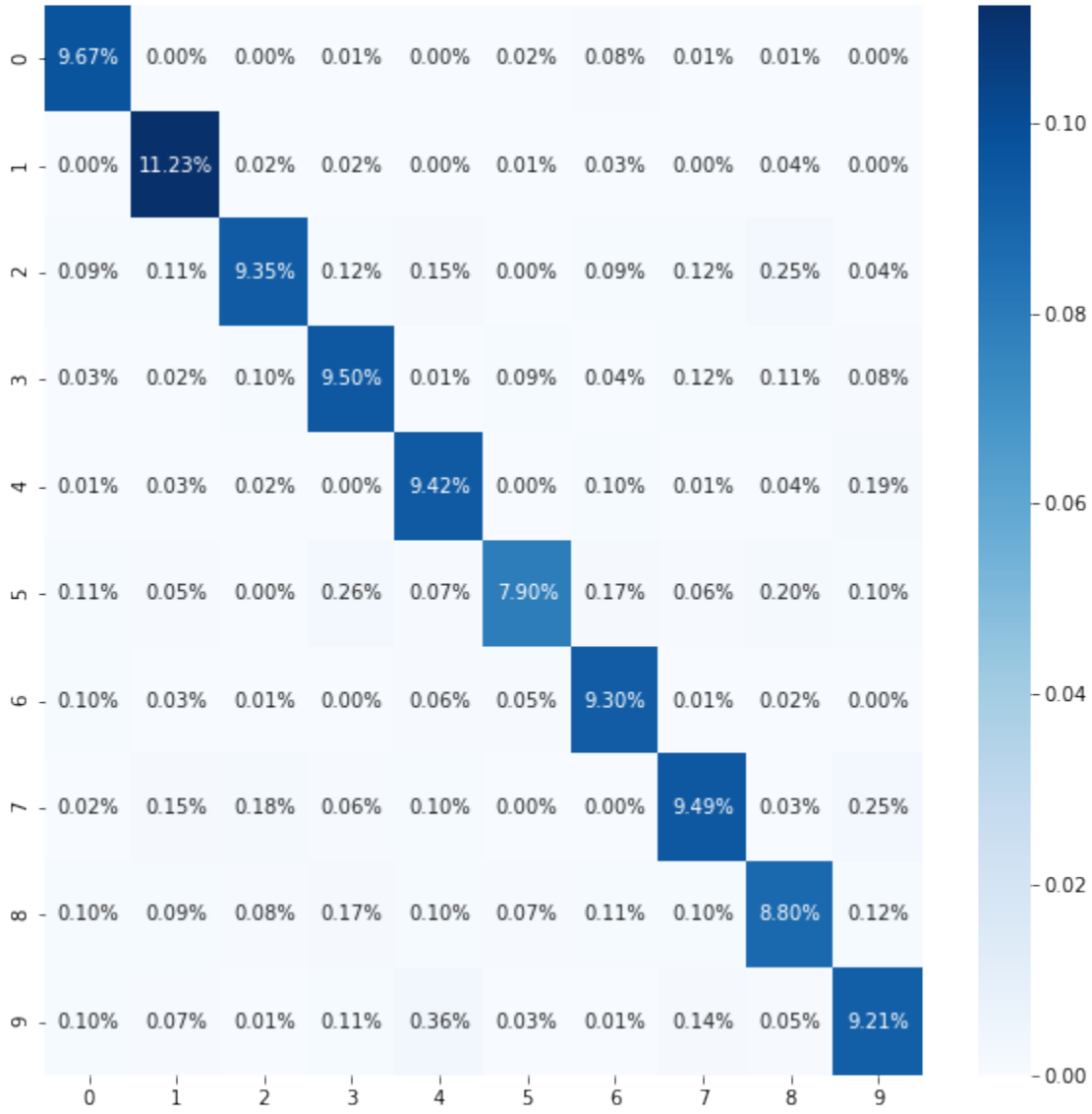
```
           1       0.95      0.99      0.97      1135
           2       0.96      0.91      0.93      1032
           3       0.93      0.94      0.93      1010
           4       0.92      0.96      0.94       982
           5       0.97      0.89      0.92       892
           6       0.94      0.97      0.95       958
           7       0.94      0.92      0.93      1028
           8       0.92      0.90      0.91       974
           9       0.92      0.91      0.92      1009

    accuracy                           0.94     10000
   macro avg       0.94      0.94      0.94     10000
weighted avg       0.94      0.94      0.94     10000
```

[232]:
```
offset = 100

plt.figure(figsize=(10,10))
for i in range(16):
    plt.subplot(4,4,i+1)
    plt.xticks([])
    plt.yticks([])
    plt.grid(False)
    plt.imshow(test_images[i+offset].squeeze(axis=2), cmap=plt.cm.binary)
    plt.xlabel(pred[i+offset])
plt.show()
```



[281]:
```
import seaborn as sns
from sklearn.metrics import confusion_matrix

cf_matrix = confusion_matrix(true, pred)

fig, ax = plt.subplots(figsize=(10,10))
sns.heatmap(cf_matrix/np.sum(cf_matrix), annot=True, fmt='.2%', cmap='Blues',␣
↪ax=ax)
```

[281]:
```
<matplotlib.axes._subplots.AxesSubplot at 0x7f4834084400>
```



6 Create GIFs

[26]:
```
# To create GIFs
!pip install git+https://github.com/tensorflow/docs
```

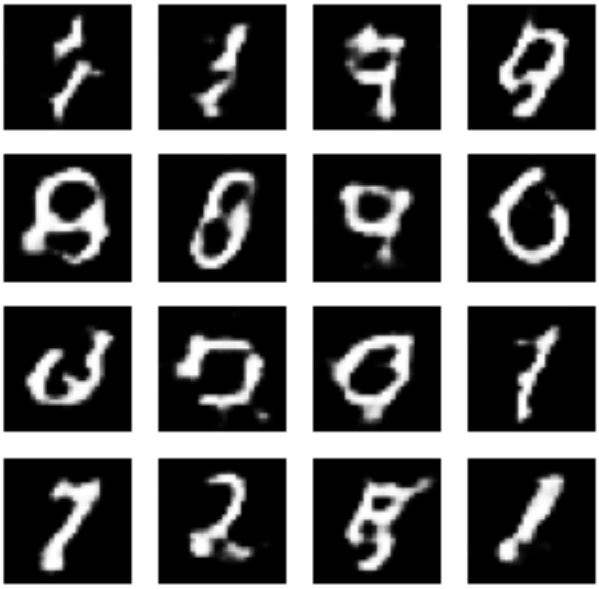
```
Requirement already satisfied: imageio in
/home/viggyravi/anaconda3/envs/jeff/lib/python3.8/site-packages (2.9.0)
Requirement already satisfied: numpy in
/home/viggyravi/anaconda3/envs/jeff/lib/python3.8/site-packages (from imageio)
(1.18.5)
Requirement already satisfied: pillow in
```

```
/home/viggyravi/anaconda3/envs/jeff/lib/python3.8/site-packages (from imageio)
(7.2.0)
Collecting git+https://github.com/tensorflow/docs
  Cloning https://github.com/tensorflow/docs to /tmp/pip-req-build-jbnco86p
  Running command git clone -q https://github.com/tensorflow/docs /tmp/pip-req-
build-jbnco86p
Requirement already satisfied (use --upgrade to upgrade): tensorflow-
docs===0.0.0b5de8b6909eadaaa5c4854d80ed8e75afd3083a4- from
git+https://github.com/tensorflow/docs in
/home/viggyravi/anaconda3/envs/jeff/lib/python3.8/site-packages
Requirement already satisfied: astor in
/home/viggyravi/anaconda3/envs/jeff/lib/python3.8/site-packages (from
tensorflow-docs===0.0.0b5de8b6909eadaaa5c4854d80ed8e75afd3083a4-) (0.8.1)
Requirement already satisfied: absl-py in
/home/viggyravi/anaconda3/envs/jeff/lib/python3.8/site-packages (from
tensorflow-docs===0.0.0b5de8b6909eadaaa5c4854d80ed8e75afd3083a4-) (0.9.0)
Requirement already satisfied: protobuf>=3.14 in
/home/viggyravi/anaconda3/envs/jeff/lib/python3.8/site-packages (from
tensorflow-docs===0.0.0b5de8b6909eadaaa5c4854d80ed8e75afd3083a4-) (3.14.0)
Requirement already satisfied: pyyaml in
/home/viggyravi/anaconda3/envs/jeff/lib/python3.8/site-packages (from
tensorflow-docs===0.0.0b5de8b6909eadaaa5c4854d80ed8e75afd3083a4-) (5.3.1)
Requirement already satisfied: six in
/home/viggyravi/anaconda3/envs/jeff/lib/python3.8/site-packages (from absl-
py->tensorflow-docs===0.0.0b5de8b6909eadaaa5c4854d80ed8e75afd3083a4-) (1.15.0)
Building wheels for collected packages: tensorflow-docs
  Building wheel for tensorflow-docs (setup.py) … done
  Created wheel for tensorflow-docs: filename=tensorflow_docs-0.0.0b5de8b6
909eadaaa5c4854d80ed8e75afd3083a4_-py3-none-any.whl size=142989
sha256=cb66ce8e4e3afa80d7c63472b418ac67efa7ab114e62b7604b5e9cb4eff9adef
  Stored in directory: /tmp/pip-ephem-wheel-cache-
wues058h/wheels/3b/ee/a2/ab4d36a9a4af495bcb936f3e849d4b497b65fa40548a68d6c3
Successfully built tensorflow-docs
```

[217]:
```
# Display a single image using the epoch number
def display_image(epoch_no):
    return PIL.Image.open('image_at_epoch_{:04d}.png'.format(epoch_no))
```

[218]:
```
display_image(EPOCHS)
```

[218]:



[219]:
```
import imageio
anim_file = 'dcgan.gif'

with imageio.get_writer(anim_file, mode='I') as writer:
    filenames = glob.glob('image*.png')
    filenames = sorted(filenames)
    for filename in filenames:
        image = imageio.imread(filename)
        writer.append_data(image)
    image = imageio.imread(filename)
    writer.append_data(image)
```

[142]:
```
import tensorflow_docs.vis.embed as embed
embed.embed_file(anim_file)
```

[142]:
```
<IPython.core.display.HTML object>
```