C2W2_Assignment

February 10, 2021

1 Breast Cancer Prediction

In this exercise, you will train a neural network on the Breast Cancer Dataset to predict if the tumor is malignant or benign.

If you get stuck, we recommend that you review the ungraded labs for this week.

1.1 Imports

[1]:
```
import tensorflow as tf
from tensorflow.keras.models import Model
from tensorflow.keras.layers import Dense, Input

import numpy as np
import matplotlib.pyplot as plt
import matplotlib.ticker as mticker
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.metrics import confusion_matrix
import itertools
from tqdm import tqdm
import tensorflow_datasets as tfds

tf.get_logger().setLevel('ERROR')
```

1.2 Load and Preprocess the Dataset

We first download the dataset and create a data frame using pandas. We explicitly specify the column names because the CSV file does not have column headers.

[2]:
```
DATASET_URL = "https://archive.ics.uci.edu/ml/machine-learning-databases/
↪breast-cancer-wisconsin/breast-cancer-wisconsin.data"
data_file = tf.keras.utils.get_file("breast_cancer.csv", DATASET_URL)
col_names = ["id", "clump_thickness", "un_cell_size", "un_cell_shape",␣
↪"marginal_adheshion", "single_eph_cell_size", "bare_nuclei",␣
↪"bland_chromatin", "normal_nucleoli", "mitoses", "class"]
```

```python
df = pd.read_csv(data_file, names=col_names, header=None)
```

[3]:
```python
df.head()
```

[3]:
```
        id  clump_thickness  un_cell_size  un_cell_shape  marginal_adheshion  \
0  1000025                5             1              1                   1
1  1002945                5             4              4                   5
2  1015425                3             1              1                   1
3  1016277                6             8              8                   1
4  1017023                4             1              1                   3

   single_eph_cell_size bare_nuclei  bland_chromatin  normal_nucleoli  \
0                     2           1                3                1
1                     7          10                3                2
2                     2           2                3                1
3                     3           4                3                7
4                     2           1                3                1

   mitoses  class
0        1      2
1        1      2
2        1      2
3        1      2
4        1      2
```

We have to do some preprocessing on the data. We first pop the id column since it is of no use for our problem at hand.

[4]:
```python
df.pop("id")
```

[4]:
```
0      1000025
1      1002945
2      1015425
3      1016277
4      1017023
        …
694     776715
695     841769
696     888820
697     897471
698     897471
Name: id, Length: 699, dtype: int64
```

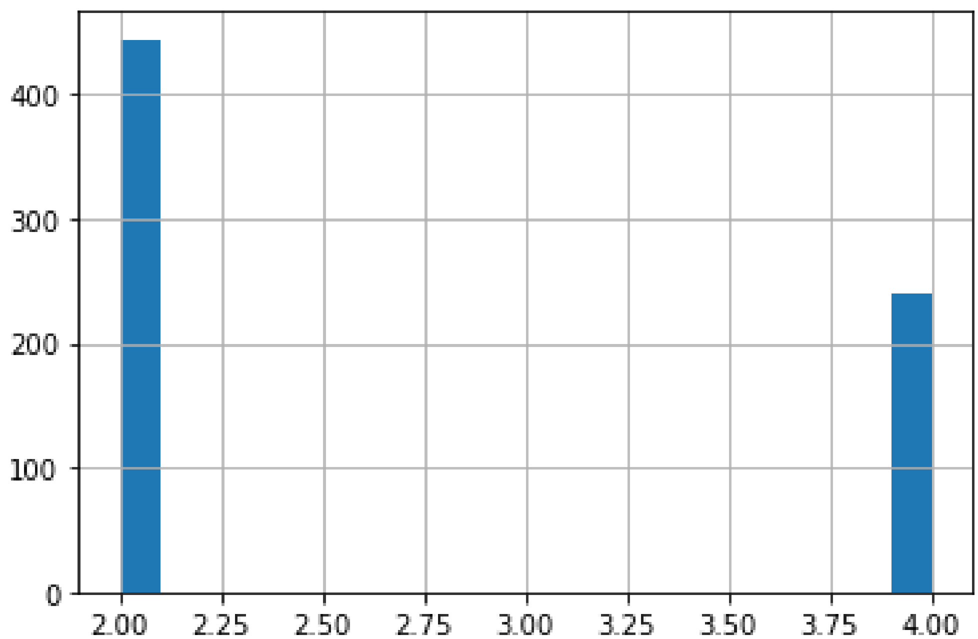
Upon inspection of data, you can see that some values of the **bare_nuclei** column are unknown. We drop the rows with these unknown values. We also convert the **bare_nuclei** column to numeric. This is required for training the model.

[5]:
```
df = df[df["bare_nuclei"] != '?' ]
df.bare_nuclei = pd.to_numeric(df.bare_nuclei)
```

We check the class distribution of the data. You can see that there are two classes, 2.0 and 4.0 According to the dataset: * **2.0 = benign** * **4.0 = malignant**

[6]:
```
df['class'].hist(bins=20)
```

[6]: <matplotlib.axes._subplots.AxesSubplot at 0x7f5d02cf5b90>



We are going to model this problem as a binary classification problem which detects whether the tumor is malignant or not. Hence, we change the dataset so that: * **benign(2.0) = 0** * **malignant(4.0) = 1**

[7]:
```
df['class'] = np.where(df['class'] == 2, 0, 1)
```

We then split the dataset into training and testing sets. Since the number of samples is small, we will perform validation on the test set.

[8]:
```
train, test = train_test_split(df, test_size = 0.2)
```

We get the statistics for training. We can look at statistics to get an idea about the distribution of plots. If you need more visualization, you can create additional data plots. We will also be using the mean and standard deviation from statistics for normalizing the data

[9]:
```
train_stats = train.describe()
train_stats.pop('class')
```

```
train_stats = train_stats.transpose()
```

We pop the class column from the training and test sets to create train and test outputs.

[10]:
```
train_Y = train.pop("class")
test_Y = test.pop("class")
```

Here we normalize the data by using the formula: **X = (X - mean(X)) / StandardDeviation(X)**

[11]:
```
def norm(x):
    return (x - train_stats['mean']) / train_stats['std']
```

[12]:
```
norm_train_X = norm(train)
norm_test_X = norm(test)
```

We now create Tensorflow datasets for training and test sets to easily be able to build and manage an input pipeline for our model.

[13]:
```
train_dataset = tf.data.Dataset.from_tensor_slices((norm_train_X.values,␣
 ↪train_Y.values))
test_dataset = tf.data.Dataset.from_tensor_slices((norm_test_X.values, test_Y.
 ↪values))
```

We shuffle and prepare a batched dataset to be used for training in our custom training loop.

[14]:
```
batch_size = 32
train_dataset = train_dataset.shuffle(buffer_size=len(train)).batch(batch_size)

test_dataset =  test_dataset.batch(batch_size=batch_size)
```

[15]:
```
a = enumerate(train_dataset)

print(len(list(a)))
```

```
18
```

1.3 Define the Model

Now we will define the model. Here, we use the Keras Functional API to create a simple network of two `Dense` layers. We have modelled the problem as a binary classification problem and hence we add a single layer with sigmoid activation as the final layer of the model.

[16]:
```
def base_model():
    inputs = tf.keras.layers.Input(shape=(len(train.columns)))

    x = tf.keras.layers.Dense(128, activation='relu')(inputs)
    x = tf.keras.layers.Dense(64, activation='relu')(x)
```

```
    outputs = tf.keras.layers.Dense(1, activation='sigmoid')(x)
    model = tf.keras.Model(inputs=inputs, outputs=outputs)
    return model

model = base_model()
```

1.4 Define Optimizer and Loss

We use RMSprop optimizer and binary crossentropy as our loss function.

[17]:
```
optimizer = tf.keras.optimizers.RMSprop(learning_rate=0.001)
loss_object = tf.keras.losses.BinaryCrossentropy()
```

1.5 Evaluate Untrained Model

We calculate the loss on the model before training begins.

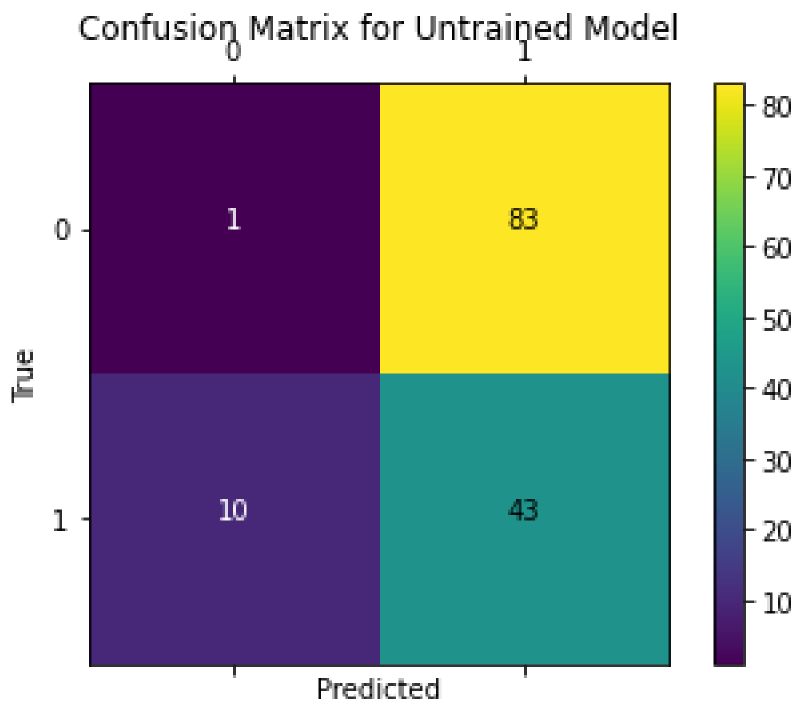
[18]:
```
outputs = model(norm_test_X.values)
loss_value = loss_object(y_true=test_Y.values, y_pred=outputs)
print("Loss before training %.4f" % loss_value.numpy())
```

```
Loss before training 0.7191
```

We also plot the confusion matrix to visualize the true outputs against the outputs predicted by the model.

[19]:
```
def plot_confusion_matrix(y_true, y_pred, title='', labels=[0,1]):
    cm = confusion_matrix(y_true, y_pred)
    fig = plt.figure()
    ax = fig.add_subplot(111)
    cax = ax.matshow(cm)
    plt.title(title)
    fig.colorbar(cax)
    ax.set_xticklabels([''] + labels)
    ax.set_yticklabels([''] + labels)
    plt.xlabel('Predicted')
    plt.ylabel('True')
    fmt = 'd'
    thresh = cm.max() / 2.
    for i, j in itertools.product(range(cm.shape[0]), range(cm.shape[1])):
          plt.text(j, i, format(cm[i, j], fmt),
                  horizontalalignment="center",
                  color="black" if cm[i, j] > thresh else "white")
    plt.show()
```

[20]:
```
plot_confusion_matrix(test_Y.values, tf.round(outputs), title='Confusion Matrix␣
↪for Untrained Model')
```



1.6 Define Metrics (Please complete this section)

1.6.1 Define Custom F1Score Metric

In this example, we will define a custom F1Score metric using the formula.

F1 Score = 2 * ((precision * recall) / (precision + recall))

precision = true_positives / (true_positives + false_positives)

recall = true_positives / (true_positives + false_negatives)

We use `confusion_matrix` defined in `tf.math` to calculate precision and recall.

Here you can see that we have subclassed `tf.keras.Metric` and implemented the three required methods `update_state`, `result` and `reset_states`.

1.6.2 Please complete the result() method:

[21]:
```python
class F1Score(tf.keras.metrics.Metric):

    def __init__(self, name='f1_score', **kwargs):
        '''initializes attributes of the class'''

        # call the parent class init
        super(F1Score, self).__init__(name=name, **kwargs)

        # Initialize Required variables
        # true positives
        self.tp = tf.Variable(0, dtype = 'int32')
        # false positives
        self.fp = tf.Variable(0, dtype = 'int32')
        # true negatives
        self.tn = tf.Variable(0, dtype = 'int32')
        # false negatives
        self.fn = tf.Variable(0, dtype = 'int32')

    def update_state(self, y_true, y_pred, sample_weight=None):
        '''
        Accumulates statistics for the metric

        Args:
            y_true: target values from the test data
            y_pred: predicted values by the model
        '''

        # Calulcate confusion matrix.
        conf_matrix = tf.math.confusion_matrix(y_true, y_pred, num_classes=2)

        # Update values of true positives, true negatives, false positives and␣
↪false negatives from confusion matrix.
        self.tn.assign_add(conf_matrix[0][0])
        self.tp.assign_add(conf_matrix[1][1])
        self.fp.assign_add(conf_matrix[0][1])
        self.fn.assign_add(conf_matrix[1][0])

    def result(self):
        '''Computes and returns the metric value tensor.'''

        # Calculate precision
        if (self.tp + self.fp == 0):
            precision = 1.0
        else:
            precision = self.tp / (self.tp + self.fp)
```

```
        # Calculate recall
        if (self.tp + self.fn == 0):
            recall = 1.0
        else:
            recall = self.tp / (self.tp + self.fn)

        # Return F1 Score

        f1_score = (2 * precision * recall) / (precision + recall)


        return f1_score

    def reset_states(self):
        '''Resets all of the metric state variables.'''

        # The state of the metric will be reset at the start of each epoch.
        self.tp.assign(0)
        self.tn.assign(0)
        self.fp.assign(0)
        self.fn.assign(0)
```

[22]:
```
# Test Code:

test_F1Score = F1Score()

test_F1Score.tp = tf.Variable(2, dtype = 'int32')
test_F1Score.fp = tf.Variable(5, dtype = 'int32')
test_F1Score.tn = tf.Variable(7, dtype = 'int32')
test_F1Score.fn = tf.Variable(9, dtype = 'int32')
test_F1Score.result()
```

[22]:
```
<tf.Tensor: shape=(), dtype=float64, numpy=0.2222222222222222>
```

Expected Output:

```
<tf.Tensor: shape=(), dtype=float64, numpy=0.2222222222222222>
```

We initialize the seprate metrics required for training and validation. In addition to our custom F1Score metric, we are also using `BinaryAccuracy` defined in `tf.keras.metrics`

[23]:
```
train_f1score_metric = F1Score()
val_f1score_metric = F1Score()

train_acc_metric = tf.keras.metrics.BinaryAccuracy()
val_acc_metric = tf.keras.metrics.BinaryAccuracy()
```

1.7 Apply Gradients (Please complete this section)

The core of training is using the model to calculate the logits on specific set of inputs and compute the loss(in this case **binary crossentropy**) by comparing the predicted outputs to the true outputs. We then update the trainable weights using the optimizer algorithm chosen. The optimizer algorithm requires our computed loss and partial derivatives of loss with respect to each of the trainable weights to make updates to the same.

We use gradient tape to calculate the gradients and then update the model trainable weights using the optimizer.

1.7.1 Please complete the following function:

[24]:
```
def apply_gradient(optimizer, loss_object, model, x, y):
    '''
    applies the gradients to the trainable model weights

    Args:
        optimizer: optimizer to update model weights
        loss_object: type of loss to measure during training
        model: the model we are training
        x: input data to the model
        y: target values for each input
    '''

    with tf.GradientTape() as tape:

        logits = model(x)
        loss_value = loss_object(y, logits)

    gradients = tape.gradient(loss_value, model.trainable_variables)
    optimizer.apply_gradients(zip(gradients, model.trainable_variables))

    return logits, loss_value
```

[25]:
```
# Test Code:

test_model = tf.keras.models.load_model('./test_model')
test_logits, test_loss = apply_gradient(optimizer, loss_object, test_model,␣
 ↪norm_test_X.values, test_Y.values)

print(test_logits.numpy()[:8])
print(test_loss.numpy())

del test_model
del test_logits
del test_loss
```

```
[[0.5286153 ]
 [0.5316665 ]
 [0.5388887 ]
 [0.54149145]
 [0.5619487 ]
 [0.5511852 ]
 [0.49819118]
 [0.5346711 ]]
0.7056287
```

Expected Output:

The output will be close to these values:

```
[[0.5516499 ]
 [0.52124363]
 [0.5412698 ]
 [0.54203206]
 [0.50022954]
 [0.5459626 ]
 [0.47841492]
 [0.54381996]]
0.7030578
```

1.8 Training Loop (Please complete this section)

This function performs training during one epoch. We run through all batches of training data in each epoch to make updates to trainable weights using our previous function. You can see that we also call `update_state` on our metrics to accumulate the value of our metrics.

We are displaying a progress bar to indicate completion of training in each epoch. Here we use `tqdm` for displaying the progress bar.

1.8.1 Please complete the following function:

[26]:
```
def train_data_for_one_epoch(train_dataset, optimizer, loss_object, model,
                             train_acc_metric, train_f1score_metric,␣
↪verbose=True):
    '''
    Computes the loss then updates the weights and metrics for one epoch.

    Args:
        train_dataset: the training dataset
        optimizer: optimizer to update model weights
        loss_object: type of loss to measure during training
        model: the model we are training
        train_acc_metric: calculates how often predictions match labels
        train_f1score_metric: custom metric we defined earlier
```

```
    '''
    losses = []

    #Iterate through all batches of training data
    for step, (x_batch_train, y_batch_train) in enumerate(train_dataset):

        #Calculate loss and update trainable variables using optimizer
        logits, loss_value = apply_gradient(optimizer, loss_object, model,␣
↪x_batch_train, y_batch_train)
        losses.append(loss_value)

        #Round off logits to nearest integer and cast to integer for calulating␣
↪metrics
        logits = tf.round(logits)
        logits = tf.cast(logits, 'int64')

        #Update the training metrics
        train_acc_metric.update_state(y_batch_train, logits)
        train_f1score_metric.update_state(y_batch_train, logits)

        #Update progress
        if verbose:
            print("Training loss for step %s: %.4f" % (int(step),␣
↪float(loss_value)))

    return losses
```

[27]:
```
# TEST CODE

test_model = tf.keras.models.load_model('./test_model')

test_losses = train_data_for_one_epoch(train_dataset, optimizer, loss_object,␣
↪test_model,
                                       train_acc_metric, train_f1score_metric,␣
↪verbose=False)

for test_loss in test_losses:
    print(test_loss.numpy())

del test_model
del test_losses
```

```
0.7539738
0.6419314
0.58887553
0.5035627
0.4273982
```

```
0.4079318
0.3473543
0.3937204
0.34644145
0.3356731
0.2498512
0.243137
0.2807573
0.23805186
0.19536051
0.23103704
0.25632873
0.18270835
```

Expected Output:

The losses should generally be decreasing and will start from around 0.75. For example:

```
0.7600615
0.6092045
0.5525634
0.4358902
0.4765755
0.43327087
0.40585428
0.32855004
0.35755336
0.3651728
0.33971977
0.27372319
0.25026917
0.29229593
0.242178
0.20602849
0.15887335
0.090397514
```

At the end of each epoch, we have to validate the model on the test dataset. The following function calculates the loss on test dataset and updates the states of the validation metrics.

[28]:
```python
def perform_validation():
    losses = []

    #Iterate through all batches of validation data.
    for x_val, y_val in test_dataset:

        #Calculate validation loss for current batch.
        val_logits = model(x_val)
        val_loss = loss_object(y_true=y_val, y_pred=val_logits)
```

```
        losses.append(val_loss)

        #Round off and cast outputs to either  or 1
        val_logits = tf.cast(tf.round(model(x_val)), 'int64')

        #Update validation metrics
        val_acc_metric.update_state(y_val, val_logits)
        val_f1score_metric.update_state(y_val, val_logits)

    return losses
```

Next we define the training loop that runs through the training samples repeatedly over a fixed number of epochs. Here we combine the functions we built earlier to establish the following flow: 1. Perform training over all batches of training data. 2. Get values of metrics. 3. Perform validation to calculate loss and update validation metrics on test data. 4. Reset the metrics at the end of epoch. 5. Display statistics at the end of each epoch.

Note : We also calculate the training and validation losses for the whole epoch at the end of the epoch.

[29]:
```
# Iterate over epochs.
epochs = 5
epochs_val_losses, epochs_train_losses = [], []

for epoch in range(epochs):
    print('Start of epoch %d' % (epoch,))
    #Perform Training over all batches of train data
    losses_train = train_data_for_one_epoch(train_dataset, optimizer,␣
 ↪loss_object, model, train_acc_metric, train_f1score_metric)

    # Get results from training metrics
    train_acc = train_acc_metric.result()
    train_f1score = train_f1score_metric.result()

    #Perform validation on all batches of test data
    losses_val = perform_validation()

    # Get results from validation metrics
    val_acc = val_acc_metric.result()
    val_f1score = val_f1score_metric.result()

    #Calculate training and validation losses for current epoch
    losses_train_mean = np.mean(losses_train)
    losses_val_mean = np.mean(losses_val)
    epochs_val_losses.append(losses_val_mean)
    epochs_train_losses.append(losses_train_mean)
```

```
    print('\n Epcoh %s: Train loss: %.4f  Validation Loss: %.4f, Train Accuracy:
↪ %.4f, Validation Accuracy %.4f, Train F1 Score: %.4f, Validation F1 Score:␣
↪%.4f' % (epoch, float(losses_train_mean), float(losses_val_mean),␣
↪float(train_acc), float(val_acc), train_f1score, val_f1score))

    #Reset states of all metrics
    train_acc_metric.reset_states()
    val_acc_metric.reset_states()
    val_f1score_metric.reset_states()
    train_f1score_metric.reset_states()
```

```
Start of epoch 0
Training loss for step 0: 0.7364
Training loss for step 1: 0.6804
Training loss for step 2: 0.5692
Training loss for step 3: 0.5474
Training loss for step 4: 0.4831
Training loss for step 5: 0.4534
Training loss for step 6: 0.3624
Training loss for step 7: 0.3654
Training loss for step 8: 0.3268
Training loss for step 9: 0.3505
Training loss for step 10: 0.3409
Training loss for step 11: 0.2937
Training loss for step 12: 0.3179
Training loss for step 13: 0.2359
Training loss for step 14: 0.2993
Training loss for step 15: 0.2572
Training loss for step 16: 0.2767
Training loss for step 17: 0.1549

 Epcoh 0: Train loss: 0.3918  Validation Loss: 0.2058, Train Accuracy: 0.9036,
Validation Accuracy 0.9812, Train F1 Score: 0.8648, Validation F1 Score: 0.9714
Start of epoch 1
Training loss for step 0: 0.2556
Training loss for step 1: 0.2055
Training loss for step 2: 0.2024
Training loss for step 3: 0.1929
Training loss for step 4: 0.1220
Training loss for step 5: 0.1820
Training loss for step 6: 0.2021
Training loss for step 7: 0.1225
Training loss for step 8: 0.1048
Training loss for step 9: 0.1095
Training loss for step 10: 0.1140
Training loss for step 11: 0.2008
Training loss for step 12: 0.0693
```

```
Training loss for step 13: 0.1141
Training loss for step 14: 0.1132
Training loss for step 15: 0.1364
Training loss for step 16: 0.1333
Training loss for step 17: 0.0382

 Epcoh 1: Train loss: 0.1455  Validation Loss: 0.0980, Train Accuracy: 0.9670,
Validation Accuracy 0.9812, Train F1 Score: 0.9499, Validation F1 Score: 0.9714
Start of epoch 2
Training loss for step 0: 0.1659
Training loss for step 1: 0.0990
Training loss for step 2: 0.0953
Training loss for step 3: 0.0699
Training loss for step 4: 0.0403
Training loss for step 5: 0.0399
Training loss for step 6: 0.0900
Training loss for step 7: 0.0357
Training loss for step 8: 0.1740
Training loss for step 9: 0.0560
Training loss for step 10: 0.0988
Training loss for step 11: 0.0873
Training loss for step 12: 0.1638
Training loss for step 13: 0.0267
Training loss for step 14: 0.0218
Training loss for step 15: 0.0864
Training loss for step 16: 0.2311
Training loss for step 17: 0.0133

 Epcoh 2: Train loss: 0.0886  Validation Loss: 0.0761, Train Accuracy: 0.9688,
Validation Accuracy 0.9812, Train F1 Score: 0.9524, Validation F1 Score: 0.9714
Start of epoch 3
Training loss for step 0: 0.0637
Training loss for step 1: 0.1064
Training loss for step 2: 0.0344
Training loss for step 3: 0.1149
Training loss for step 4: 0.0171
Training loss for step 5: 0.1539
Training loss for step 6: 0.0237
Training loss for step 7: 0.1295
Training loss for step 8: 0.0360
Training loss for step 9: 0.0679
Training loss for step 10: 0.0331
Training loss for step 11: 0.1399
Training loss for step 12: 0.0261
Training loss for step 13: 0.0141
Training loss for step 14: 0.0534
Training loss for step 15: 0.0096
Training loss for step 16: 0.2964
```

```
Training loss for step 17: 0.0014

 Epcoh 3: Train loss: 0.0734  Validation Loss: 0.0714, Train Accuracy: 0.9705,
Validation Accuracy 0.9812, Train F1 Score: 0.9549, Validation F1 Score: 0.9714
Start of epoch 4
Training loss for step 0: 0.1191
Training loss for step 1: 0.0183
Training loss for step 2: 0.0136
Training loss for step 3: 0.1705
Training loss for step 4: 0.1082
Training loss for step 5: 0.0251
Training loss for step 6: 0.0292
Training loss for step 7: 0.0563
Training loss for step 8: 0.0302
Training loss for step 9: 0.0363
Training loss for step 10: 0.0486
Training loss for step 11: 0.2072
Training loss for step 12: 0.1864
Training loss for step 13: 0.0173
Training loss for step 14: 0.0309
Training loss for step 15: 0.0268
Training loss for step 16: 0.0519
Training loss for step 17: 0.3100

 Epcoh 4: Train loss: 0.0825  Validation Loss: 0.0689, Train Accuracy: 0.9740,
Validation Accuracy 0.9812, Train F1 Score: 0.9604, Validation F1 Score: 0.9714
```

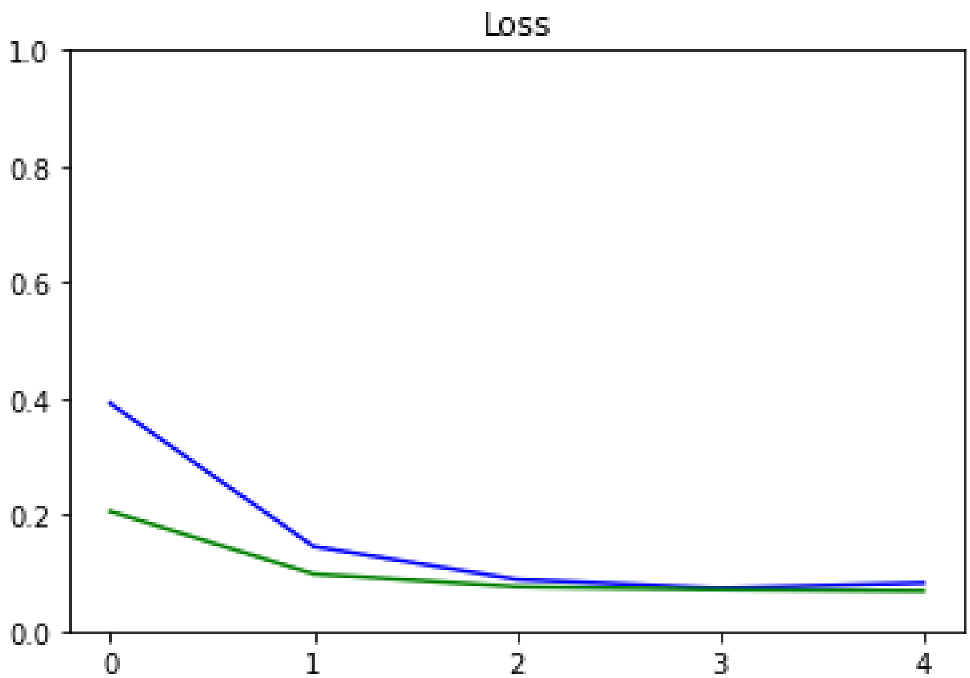
1.9 Evaluate the Model

1.9.1 Plots for Evaluation

We plot the progress of loss as training proceeds over number of epochs.

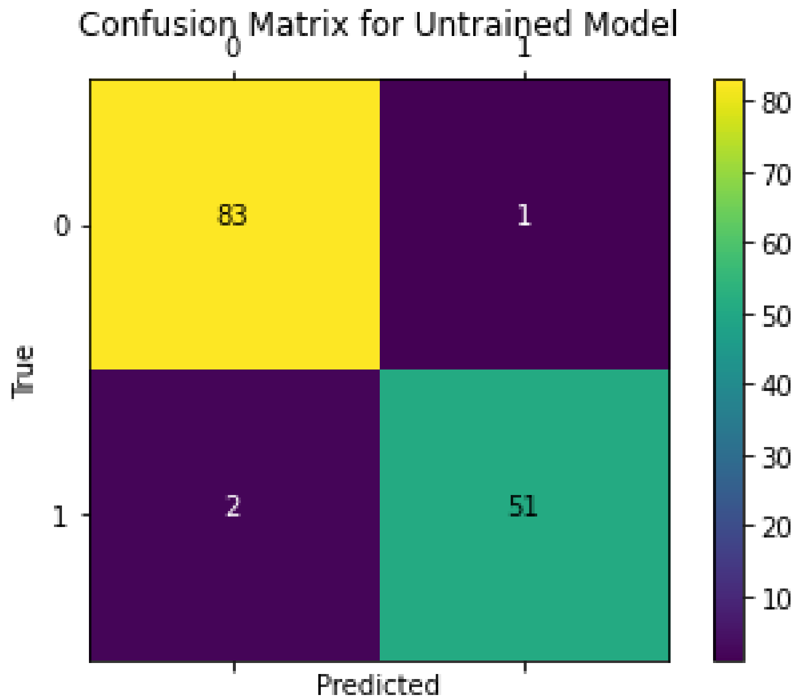
[30]:
```
def plot_metrics(train_metric, val_metric, metric_name, title, ylim=5):
    plt.title(title)
    plt.ylim(0,ylim)
    plt.gca().xaxis.set_major_locator(mticker.MultipleLocator(1))
    plt.plot(train_metric,color='blue',label=metric_name)
    plt.plot(val_metric,color='green',label='val_' + metric_name)

plot_metrics(epochs_train_losses, epochs_val_losses, "Loss", "Loss", ylim=1.0)
```



We plot the confusion matrix to visualize the true values against the values predicted by the model.

```
[31]: test_outputs = model(norm_test_X.values)
      plot_confusion_matrix(test_Y.values, tf.round(test_outputs), title='Confusion␣
       ↪Matrix for Untrained Model')
```


Confusion Matrix for Untrained Model
0
1
83
1
2
51
True
Predicted
80
70
60
50
40
30
20
10