



(https://colab.research.google.com/github/AnkurMali/IST597_Spring_2022/blob/main/IST597_Building_CNN.ipynb)

In [1]:

```
import tensorflow as tf
import numpy as np
import matplotlib.pyplot as plt

np.random.seed(1234)
```

In [2]:

```
(x_train, y_train), (x_test, y_test) = tf.keras.datasets.fashion_mnist.load_data()
x_val = x_train[50000:60000]
x_train = x_train[0:50000]
y_val = y_train[50000:60000]
y_train = y_train[0:50000]
x_train = x_train.astype(np.float32).reshape(-1,28,28,1) / 255.0
x_val = x_val.astype(np.float32).reshape(-1,28,28,1) / 255.0
x_test = x_test.astype(np.float32).reshape(-1,28,28,1) / 255.0
y_train = tf.one_hot(y_train, depth=10)
y_val = tf.one_hot(y_val, depth=10)
y_test = tf.one_hot(y_test, depth=10)
print(x_train.shape)
print(x_test.shape)
print(x_val.shape)
train_dataset = tf.data.Dataset.from_tensor_slices((x_train, y_train))
train_dataset = train_dataset.shuffle(buffer_size=1024).batch(128)
train_dataset_full = train_dataset.shuffle(buffer_size=1024).batch(len(train_dataset))
val_dataset = tf.data.Dataset.from_tensor_slices((x_val, y_val))
val_dataset = val_dataset.batch(128)
test_dataset = tf.data.Dataset.from_tensor_slices((x_test, y_test))
test_dataset = test_dataset.batch(128)
print(len(train_dataset))
print(len(test_dataset))
```

```
(50000, 28, 28, 1)
(10000, 28, 28, 1)
(10000, 28, 28, 1)
391
79
```

```
2022-03-22 20:16:25.834970: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:936] successful NUMA node read from SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
```

```
2022-03-22 20:16:25.838528: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:936] successful NUMA node read from SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
```

```
2022-03-22 20:16:25.838967: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:936] successful NUMA node read from SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
```

```
2022-03-22 20:16:25.839474: I tensorflow/core/platform/cpu_feature_guard.cc:151] This TensorFlow binary is optimized with oneAPI Deep Neural Network Library (oneDNN) to use the following CPU instructions in performance-critical operations: AVX2 FMA
To enable them in other operations, rebuild TensorFlow with the appropriate compiler flags.
```

```
2022-03-22 20:16:25.840833: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:936] successful NUMA node read from SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
```

```
2022-03-22 20:16:25.841194: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:936] successful NUMA node read from SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
```

```
2022-03-22 20:16:25.841442: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:936] successful NUMA node read from SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
```

```
2022-03-22 20:16:26.154622: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:936] successful NUMA node read from SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
```

```
2022-03-22 20:16:26.154937: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:936] successful NUMA node read from SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
```

```
2022-03-22 20:16:26.155272: I tensorflow/stream_executor/cuda/cuda_gpu_executor.cc:936] successful NUMA node read from SysFS had negative value (-1), but there must be at least one NUMA node, so returning NUMA node zero
```

```
2022-03-22 20:16:26.155551: I tensorflow/core/common_runtime/gpu/gpu_device.cc:1525] Created device /job:localhost/replica:0/task:0/device:GPU:0 with 7014 MB memory: -> device: 0, name: NVIDIA GeForce GTX 1070, pci bus id: 0000:01:00.0, compute capability: 6.1
```

In [3]:

```

class BatchNormalization(tf.keras.layers.Layer):
    def __init__(self, batch_size, training=False):
        super(BatchNormalization, self).__init__()

        self.convexCoeff = 0.9
        self.numCalls = 0
        self.batch_size = batch_size
        self.training = training

        self.gamma = self.add_weight(name='gamma', shape=[self.batch_size,], ini-
alizer=tf.initializers.ones, trainable=True)
        self.beta = self.add_weight(name='beta', shape=[self.batch_size,], ini-
alizer=tf.initializers.zeros, trainable=True)
        self.mean = self.add_weight(name='mean', shape=[self.batch_size,], ini-
alizer=tf.initializers.zeros, trainable=False)
        self.var = self.add_weight(name='var', shape=[self.batch_size,], ini-
alizer=tf.initializers.zeros, trainable=False)

    def batch_norm(self, inputs, training):
        self.numCalls += 1

        axes = list(range(len(inputs.shape) - 1))
        mean = tf.reduce_mean(inputs, axes, keepdims=True)
        var = tf.reduce_mean(tf.math.squared_difference(inputs, tf.stop_gradient(
mean)), axes, keepdims=True)

        if training:
            norm = tf.add(tf.multiply(self.gamma, tf.divide(tf.subtract(inputs, me-
an), tf.sqrt(var+1e-7))), self.beta)

            mean = tf.squeeze(mean, axes)
            var = tf.squeeze(var, axes)

            moving_avg_mean = ((self.convexCoeff/self.numCalls)*mean) + (1-(self.c-
onvexCoeff/self.numCalls)*self.mean)
            moving_avg_var = ((self.convexCoeff/self.numCalls)*var) + (1-(self.c-
onvexCoeff/self.numCalls)*self.var)

            self.mean.assign(moving_avg_mean)
            self.var.assign(moving_avg_var)

        else:
            norm = tf.add(tf.multiply(self.gamma, tf.divide(tf.subtract(inputs, me-
an), tf.sqrt(var+1e-7))), self.beta)

        return norm

```

In [4]:

```

class ImageRecognitionCNN(tf.keras.Model):

    def __init__(self, num_classes, device='cpu:0', checkpoint_directory=None):
        """ Define the parameterized layers used during forward-pass, the device
            where you would like to run the computation (GPU, TPU, CPU) on and the
            checkpoint directory.

            Args:
                num_classes: the number of labels in the network.
                device: string, 'cpu:n' or 'gpu:n' (n can vary). Default, 'cpu:0'.
                checkpoint_directory: the directory where you would like to save o

            restore a model.
        """
        super(ImageRecognitionCNN, self).__init__()

        # Initialize layers
        self.conv1 = tf.keras.layers.Conv2D(64, 3, padding='same', activation=None)

        self.conv2 = tf.keras.layers.Conv2D(64, 3, padding='same', activation=None)
        self.pool1 = tf.keras.layers.MaxPool2D()
        self.conv3 = tf.keras.layers.Conv2D(64, 3, padding='same', activation=None)

        self.conv4 = tf.keras.layers.Conv2D(64, 3, padding='same', activation=None)

        # self.pool2 = tf.keras.layers.MaxPool2D()
        # self.conv5 = tf.keras.layers.Conv2D(64, 3, padding='same', activation=None)

        # self.pool2 = tf.keras.layers.MaxPool2D()
        # self.conv6 = tf.keras.layers.Conv2D(64, 3, 2, padding='same', activation=None)

        # self.conv7 = tf.keras.layers.Conv2D(64, 1, padding='same', activation=None)

        self.conv8 = tf.keras.layers.Conv2D(num_classes, 1, padding='same', activation=None)
        self.BN = BatchNormalization(64)

        # Define the device
        self.device = device

        # Define the checkpoint directory
        self.checkpoint_directory = checkpoint_directory
        self.acc = tf.keras.metrics.Accuracy()

    def predict(self, images, training):
        """ Predicts the probability of each class, based on the input sample.

            Args:
                images: 4D tensor. Either an image or a batch of images.
                training: Boolean. Either the network is predicting in
                    training mode or not.

```

```

"""
x = self.conv1(images)

x = tf.nn.relu(x)
x = self.BN.batch_norm(x, training)
x = self.pool1(x)
x = self.conv2(x)
x = tf.nn.relu(x)
x = self.BN.batch_norm(x, training)
x = self.pool1(x)
x = self.conv3(x)
x = tf.nn.relu(x)
x = self.BN.batch_norm(x, training)
x = self.pool1(x)
x = self.conv4(x)
x = tf.nn.relu(x)
x = self.BN.batch_norm(x, training)
x = self.pool1(x)
x = self.conv8(x)
#x = tf.nn.relu(x)
#print(x.shape)
x = tf.reshape(x, (-1, 1, 10))
#x = tf.keras.layers.Flatten(x)
return x

```

```

def loss_fn(self, images, target, training):
    """ Defines the loss function used during
        training.
    """
    preds = self.predict(images, training)
    #print(preds.shape)
    #print(target.shape)
    loss = tf.nn.softmax_cross_entropy_with_logits(labels=target, logits=preds
)

    return loss

```

```

def grads_fn(self, images, target, training):
    """ Dynamically computes the gradients of the loss value
        with respect to the parameters of the model, in each
        forward pass.
    """
    with tf.GradientTape() as tape:
        loss = self.loss_fn(images, target, training)
    return tape.gradient(loss, self.variables)

```

```

def restore_model(self):
    """ Function to restore trained model.
    """
    with tf.device(self.device):
        # Run the model once to initialize variables
        dummy_input = tf.constant(tf.zeros((1,48,48,1)))
        dummy_pred = self.predict(dummy_input, training=False)
        # Restore the variables of the model

```

```

saver = tf.Saver(self.variables)
saver.restore(tf.train.latest_checkpoint
               (self.checkpoint_directory))

def save_model(self, global_step=0):
    """ Function to save trained model.
    """
    tf.Saver(self.variables).save(self.checkpoint_directory,
                                  global_step=global_step)

# def compute_accuracy(self, input_data):
#     """ Compute the accuracy on the input data.
#     """
#     with tf.device(self.device):
#         #acc = tf.metrics.Accuracy()
#         for step, (images, targets) in enumerate(input_data):
#             # Predict the probability of each class
#             #print(targets.shape)
#             logits = self.predict(images, training=False)
#             # Select the class with the highest probability
#             #print(logits.shape)
#             logits = tf.nn.softmax(logits)
#             logits = tf.reshape(logits, [-1, 10])
#             targets = tf.reshape(targets, [-1, 10])
#             preds = tf.argmax(logits, axis=1)

#             #m1.update_state
#             # Compute the accuracy
#             #print(preds.shape)
#             acc(tf.reshape(targets, preds))
#     return acc

def compute_accuracy_2(self, images, targets, training=False):
    """ Compute the accuracy on the input data.
    """
    with tf.device(self.device):

        # Predict the probability of each class
        logits = self.predict(images, training)
        # Select the class with the highest probability

        logits = tf.nn.softmax(logits)
        logits = tf.reshape(logits, [-1, 10])
        targets = tf.reshape(targets, [-1, 10])
        preds = tf.argmax(logits, axis=1)
        goal = tf.argmax(targets, axis=1)
        self.acc.update_state(goal, preds)
        # Compute the accuracy
        result = self.acc.result().numpy()
    return result

def fit_fc(self, training_data, eval_data, optimizer, num_epochs=500,
           early_stopping_rounds=10, verbose=10, train_from_scratch=False):
    """ Function to train the model, using the selected optimizer and
    for the desired number of epochs. You can either train from scratch

```

or load the latest model trained. Early stopping is used in order to mitigate the risk of overfitting the network.

Args:

training_data: the data you would like to train the model on.
Must be in the `tf.data.Dataset` format.

eval_data: the data you would like to evaluate the model on.
Must be in the `tf.data.Dataset` format.

optimizer: the optimizer used during training.

num_epochs: the maximum number of iterations you would like to train the model.

early_stopping_rounds: stop training if the loss on the eval dataset does not decrease after *n* epochs.

verbose: `int`. Specify how often to print the loss value of the net

work.

train_from_scratch: `boolean`. Whether to initialize variables of th

e
the last trained model or initialize them randomly.

"""

```
if train_from_scratch==False:
    self.restore_model()
```

```
# Initialize best loss. This variable will store the lowest loss on the
# eval dataset.
best_loss = 999
```

```
# Initialize classes to update the mean loss of train and eval
train_loss = tf.keras.metrics.Mean('train_loss')
eval_loss = tf.keras.metrics.Mean('eval_loss')
acc_train = tf.keras.metrics.Mean('train_acc')
acc_val = tf.keras.metrics.Mean('val_acc')
```

```
# Initialize dictionary to store the loss history
self.history = {}
self.history['train_loss'] = []
self.history['eval_loss'] = []
self.history['train_acc'] = []
self.history['val_acc'] = []
```

```
# Begin training
```

```
with tf.device(self.device):
```

```
    for i in range(num_epochs):
```

```
        # Training with gradient descent
```

```
        #training_data_x = training_data.shuffle(buffer_size=1024).batch(1
```

28)

```
        for step, (images, target) in enumerate(training_data):
            grads = self.grads_fn(images, target, True)
            optimizer.apply_gradients(zip(grads, self.variables))
```

```
        # Compute the loss on the training data after one epoch
```

```
        for step, (images, target) in enumerate(training_data):
            loss = self.loss_fn(images, target, False)
            accuracy = self.compute_accuracy_2(images, target)
            acc_train(accuracy)
```



```

        train_loss(loss)
    self.history['train_loss'].append(train_loss.result().numpy())
    self.history['train_acc'].append(acc_train.result().numpy())
    # Reset metrics
    train_loss.reset_states()
    acc_train.reset_states()

    # Compute the loss on the eval data after one epoch
    for step, (images, target) in enumerate(eval_data):
        loss = self.loss_fn(images, target, False)
        accuracy = self.compute_accuracy_2(images, target)
        acc_val(accuracy)
        eval_loss(loss)
    self.history['eval_loss'].append(eval_loss.result().numpy())
    self.history['val_acc'].append(acc_val.result().numpy())
    # Reset metrics
    eval_loss.reset_states()
    acc_val.reset_states()

    # Print train and eval losses
    if (i==0) | ((i+1)%verbose==0):
        print('Train loss at epoch %d: ' % (i+1), self.history['train_loss'][-1])
        print('Train Acc at epoch %d: ' % (i+1), self.history['train_acc'][-1])
        print('Eval loss at epoch %d: ' % (i+1), self.history['eval_loss'][-1])
        print('Eval Acc at epoch %d: ' % (i+1), self.history['val_acc'][-1])

    # Check for early stopping
    if self.history['eval_loss'][-1]<best_loss:
        best_loss = self.history['eval_loss'][-1]
        count = early_stopping_rounds
    else:
        count -= 1
    if count==0:
        break

```

In [5]:

```
# Specify the path where you want to save/restore the trained variables.
checkpoint_directory = 'models_checkpoints/fmnist/'

# Use the GPU if available.
device = 'gpu:0'

# Define optimizer.
optimizer = tf.compat.v1.train.AdamOptimizer(learning_rate=1e-4)

# Instantiate model. This doesn't initialize the variables yet.
model = ImageRecognitionCNN(num_classes=10, device=device,
                           checkpoint_directory=checkpoint_directory)

#model = ImageRecognitionCNN(num_classes=7, device=device)
```

In [6]:

```
# Train model
model.fit_fc(train_dataset, val_dataset, optimizer, num_epochs=10,
            early_stopping_rounds=2, verbose=2, train_from_scratch=True)
```

```
2022-03-22 20:16:26.809541: I tensorflow/stream_executor/cuda/cuda_dnn
n.cc:368] Loaded cuDNN version 8101
2022-03-22 20:16:26.957609: W tensorflow/stream_executor/gpu/asm_compil
er.cc:111] *** WARNING *** You are using ptxas 11.0.194, which is old
er than 11.1. ptxas before 11.1 is known to miscompile XLA code, leadi
ng to incorrect results or invalid-address errors.
```

You may not need to update to CUDA 11.1; cherry-picking the ptxas bina
ry is often sufficient.

```
Train loss at epoch 1: 0.41026157
Train Acc at epoch 1: 0.8554186
Eval loss at epoch 1: 0.4443981
Eval Acc at epoch 1: 0.8563569
Train loss at epoch 2: 0.3189753
Train Acc at epoch 2: 0.86368454
Eval loss at epoch 2: 0.37361443
Eval Acc at epoch 2: 0.8701817
Train loss at epoch 4: 0.24051118
Train Acc at epoch 4: 0.88404256
Eval loss at epoch 4: 0.3263564
Eval Acc at epoch 4: 0.88780504
Train loss at epoch 6: 0.19070514
Train Acc at epoch 6: 0.8964807
Eval loss at epoch 6: 0.31122127
Eval Acc at epoch 6: 0.89926594
Train loss at epoch 8: 0.15377894
Train Acc at epoch 8: 0.9062623
Eval loss at epoch 8: 0.3081991
Eval Acc at epoch 8: 0.90852356
```

In [11]:

```
# Specify the path where you want to save/restore the trained variables.
checkpoint_directory = 'models_checkpoints/fmnist/'

# Use the GPU if available.
device = 'gpu:0'

# Define optimizer.
optimizer = tf.compat.v1.train.AdamOptimizer(learning_rate=1e-4)

# Instantiate model. This doesn't initialize the variables yet.
model = ImageRecognitionCNN(num_classes=10, device=device,
                             checkpoint_directory=checkpoint_directory)

#model = ImageRecognitionCNN(num_classes=7, device=device)
```

In [12]:

```
# Train model
model.fit_fc(train_dataset, val_dataset, optimizer, num_epochs=10,
              early_stopping_rounds=2, verbose=2, train_from_scratch=True)
```

```
Train loss at epoch 1: 0.41337383
Train Acc at epoch 1: 0.85274947
Eval loss at epoch 1: 0.44156244
Eval Acc at epoch 1: 0.85180473
Train loss at epoch 2: 0.31967264
Train Acc at epoch 2: 0.8601113
Eval loss at epoch 2: 0.36695108
Eval Acc at epoch 2: 0.86685395
Train loss at epoch 4: 0.2348203
Train Acc at epoch 4: 0.88250804
Eval loss at epoch 4: 0.31358162
Eval Acc at epoch 4: 0.886872
Train loss at epoch 6: 0.1887469
Train Acc at epoch 6: 0.8964241
Eval loss at epoch 6: 0.3013297
Eval Acc at epoch 6: 0.89935774
Train loss at epoch 8: 0.15188707
Train Acc at epoch 8: 0.9066473
Eval loss at epoch 8: 0.2992423
Eval Acc at epoch 8: 0.9089874
Train loss at epoch 10: 0.12499459
Train Acc at epoch 10: 0.91481996
Eval loss at epoch 10: 0.30910924
Eval Acc at epoch 10: 0.9166085
```

In []:

In [17]:

```
# Specify the path where you want to save/restore the trained variables.
checkpoint_directory = 'models_checkpoints/fmnist/'

# Use the GPU if available.
device = 'gpu:0'

# Define optimizer.
optimizer = tf.compat.v1.train.AdamOptimizer(learning_rate=1e-4)

# Instantiate model. This doesn't initialize the variables yet.
model = ImageRecognitionCNN(num_classes=10, device=device,
                           checkpoint_directory=checkpoint_directory)

#model = ImageRecognitionCNN(num_classes=7, device=device)
```

In [18]:

```
# Train model
model.fit_fc(train_dataset, val_dataset, optimizer, num_epochs=10,
            early_stopping_rounds=2, verbose=2, train_from_scratch=True)
```

```
Train loss at epoch 1: 0.39473918
Train Acc at epoch 1: 0.8569706
Eval loss at epoch 1: 0.42880878
Eval Acc at epoch 1: 0.85936445
Train loss at epoch 2: 0.3098746
Train Acc at epoch 2: 0.8664856
Eval loss at epoch 2: 0.36494917
Eval Acc at epoch 2: 0.8729166
Train loss at epoch 4: 0.23083213
Train Acc at epoch 4: 0.88663375
Eval loss at epoch 4: 0.31804806
Eval Acc at epoch 4: 0.890514
Train loss at epoch 6: 0.19120531
Train Acc at epoch 6: 0.89926225
Eval loss at epoch 6: 0.3109435
Eval Acc at epoch 6: 0.90184706
```

In []: