In [33]:
```
import numpy as np
import matplotlib.pyplot as plt
from tqdm import tqdm # Displays a progress bar
import pandas as pd
import torch
from torch import nn
from torch import optim
import torch.nn.functional as F
from torchvision import datasets, transforms
from torch.utils.data import Dataset, Subset, DataLoader, random_split
```

In [3]:
```
# Load the dataset and train, val, test splits
print("Loading datasets...")
dataset_path = "C:/Users/Admin/Desktop/cse803_hw5"

FASHION_transform = transforms.Compose([
    transforms.ToTensor(), # Transform from [0,255] uint8 to [0,1] float
    transforms.Normalize([0.2859], [0.3530]) # Normalize to zero mean and unit vari
])
FASHION_trainval = datasets.FashionMNIST(
    dataset_path,
    download=True,
    train=True,
    transform=FASHION_transform
)
FASHION_train = Subset(FASHION_trainval, range(50000))
FASHION_val = Subset(FASHION_trainval, range(50000,60000))
FASHION_test = datasets.FashionMNIST(
    dataset_path,
    download=True,
    train=False,
    transform=FASHION_transform
)
print("Done!")

# Create dataloaders
# TODO: Experiment with different batch sizes
trainloader = DataLoader(FASHION_train, batch_size=64, shuffle=True)
valloader = DataLoader(FASHION_val, batch_size=64, shuffle=True)
testloader = DataLoader(FASHION_test, batch_size=64, shuffle=True)
```

```
Loading datasets...
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-images-
idx3-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-images-
idx3-ubyte.gz to C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw\train-images-idx
3-ubyte.gz
100%|████████████████████████████████████████| 26421880/26421880 [15:58<00:00, 2756
4.32it/s]
```

```
Extracting C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw\train-images-idx3-ubyt
e.gz to C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-labels-
idx1-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-labels-
idx1-ubyte.gz to C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw\train-labels-idx
1-ubyte.gz
100%|██████████████████████████████| 29515/29515 [00:00<00:00, 7356
3.12it/s]
Extracting C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw\train-labels-idx1-ubyt
e.gz to C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images-i
dx3-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images-i
dx3-ubyte.gz to C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw\t10k-images-idx3-
ubyte.gz
100%|███████████████████████████| 4422102/4422102 [00:36<00:00, 12273
5.87it/s]
Extracting C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw\t10k-images-idx3-ubyt
e.gz to C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels-i
dx1-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels-i
dx1-ubyte.gz to C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw\t10k-labels-idx1-
ubyte.gz
100%|███████████████████████████████████████| 5148/5148 [00:00
<?, ?it/s]
Extracting C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw\t10k-labels-idx1-ubyt
e.gz to C:/Users/Admin/Desktop/cse803_hw5\FashionMNIST\raw

Done!
```

In [28]:

```python
"""
Network class.
"""
class Network(nn.Module):
    def __init__(self):
        super().__init__()
        # TODO: Design your own network, define layers here.
        p_keep = 1.0
        k_size = 3

        # convolutional layers
        self.layer1 = nn.Sequential(
            nn.Conv2d(1, 32, kernel_size=k_size, stride=1, padding=1),
            nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Dropout(p=1.0 - p_keep),
        )
        self.layer2 = nn.Sequential(
            nn.Conv2d(32, 64, kernel_size=k_size, stride=1, padding=1),
            nn.ReLU(),
```

```
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Dropout(p=1.0 - p_keep),
        )
        self.layer3 = nn.Sequential(
            nn.Conv2d(64, 128, kernel_size=3, stride=1, padding=1),
            nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2, padding=1),
            nn.Dropout(p=1.0 - p_keep),
        )

        # linear layers
        self.fc1 = nn.Linear(4 * 4 * 128, 625, bias=True)
        self.fc2 = nn.Linear(625, 10, bias=True)

    def forward(self,x):
        # TODO: Design your own network, implement forward pass here
        x = self.layer1(x)
        x = self.layer2(x)
        x = self.layer3(x)
        x = x.view(x.size(0), -1)
        relu = nn.ReLU()
        x = self.fc1(x)
        x = self.fc2(relu(x))
        return x
```

In [29]:

```
"""
Hyperparameters.
"""
# configure device
device = "cuda" if torch.cuda.is_available() else "cpu"

# init model
model = Network().to(device)

# specify the loss layer
criterion = nn.CrossEntropyLoss()

# TODO: Modify the line below, experiment with different optimizers and parameters
optimizer = optim.Adam(
    model.parameters(),
    lr=0.001,
    weight_decay=1e-4
)

# TODO: choose an appropriate number of training epochs
num_epoch = 15
```

In [30]:

```
"""
Train & evaluation functions.
"""
def train(model, train_loader, val_loader, num_epoch = 10): # Train the model
    print("Start training...")
    train_losses = []
    val_losses = []
```

```
    for i in range(num_epoch):
        # Set the model to training mode
        model.train()
        running_loss = []
        for batch, label in tqdm(train_loader):
            # format data
            batch = batch.to(device)
            label = label.to(device)

            # Clear gradients from the previous iteration
            optimizer.zero_grad()

            # This will call Network.forward() that you implement
            pred = model(batch)

            # Calculate the training loss
            loss = criterion(pred, label)
            running_loss.append(loss.item())

            # Backprop gradients to all tensors in the network
            loss.backward()

            # Update trainable weights
            optimizer.step()

        # training loss
        train_loss = np.mean(running_loss)
        train_losses.append(train_loss)

        # validation loss
        _, val_loss = evaluate(model, val_loader)
        val_losses.append(val_loss)

        # report epoch results
        print(f"Epoch {i+1}: train_loss={train_loss}, val_loss={val_loss}") # Print

    # finished
    print("Done!")
    return train_losses, val_losses

def evaluate(model, val_loader): # Evaluate accuracy on validation / test set
    model.eval() # Set the model to evaluation mode
    running_loss = []
    correct = 0
    with torch.no_grad(): # Do not calculate grident to speed up computation
        for batch, label in tqdm(val_loader):
            # format data
            batch = batch.to(device)
            label = label.to(device)

            # make predictions
            pred = model(batch)

            # Calculate the validation loss
            loss = criterion(pred, label)
            running_loss.append(loss.item())
```

```
            # calculate batch accuracy
            correct += (torch.argmax(pred,dim=1)==label).sum().item()

    # averaged accuracy
    acc = correct / len(val_loader.dataset)

    # validation loss
    val_loss = np.mean(running_loss)

    # finished
    print("Evaluation accuracy: {}".format(acc))
    return acc, val_loss
```

In [31]:

```
"""
Train and evaluate model.
"""
# train
train_losses, val_losses = train(model, trainloader, valloader, num_epoch)

print("Evaluate on test set")
test_acc, test_loss = evaluate(model, testloader)
```

```
Start training...
100%|██████████████████████████████████████████| 782/782 [00:59<00:00, 1
3.18it/s]
100%|██████████████████████████████████████████| 157/157 [00:06<00:00, 2
5.79it/s]
Evaluation accuracy: 0.8854
Epoch 1: train_loss=0.4385190149554816, val_loss=0.3092915424305922
100%|██████████████████████████████████████████| 782/782 [00:57<00:00, 1
3.65it/s]
100%|██████████████████████████████████████████| 157/157 [00:06<00:00, 2
4.19it/s]
Evaluation accuracy: 0.9058
Epoch 2: train_loss=0.274183854136778, val_loss=0.2527780517176458
100%|██████████████████████████████████████████| 782/782 [01:07<00:00, 1
1.60it/s]
100%|██████████████████████████████████████████| 157/157 [00:08<00:00, 1
8.34it/s]
Evaluation accuracy: 0.9142
Epoch 3: train_loss=0.22963903001640612, val_loss=0.23309230263445788
100%|██████████████████████████████████████████| 782/782 [01:10<00:00, 1
1.07it/s]
100%|██████████████████████████████████████████| 157/157 [00:08<00:00, 1
9.00it/s]
Evaluation accuracy: 0.9154
Epoch 4: train_loss=0.19866147610689977, val_loss=0.23721835638876934
100%|██████████████████████████████████████████| 782/782 [01:11<00:00, 1
0.94it/s]
100%|██████████████████████████████████████████| 157/157 [00:08<00:00, 1
8.08it/s]
Evaluation accuracy: 0.9109
Epoch 5: train_loss=0.17507365926185534, val_loss=0.2526320010233837
```

```
100%|██████████████████████████| 782/782 [01:12<00:00, 1
0.86it/s]
100%|██████████████████████████| 157/157 [00:08<00:00, 1
7.87it/s]
Evaluation accuracy: 0.9175
Epoch 6: train_loss=0.15523434947232914, val_loss=0.234597207847864
100%|██████████████████████████| 782/782 [01:11<00:00, 1
0.97it/s]
100%|██████████████████████████| 157/157 [00:08<00:00, 1
8.99it/s]
Evaluation accuracy: 0.9116
Epoch 7: train_loss=0.13570667204478054, val_loss=0.24483280605191637
100%|██████████████████████████| 782/782 [01:11<00:00, 1
0.90it/s]
100%|██████████████████████████| 157/157 [00:08<00:00, 1
8.79it/s]
Evaluation accuracy: 0.9232
Epoch 8: train_loss=0.12238832301748416, val_loss=0.23161067946511468
100%|██████████████████████████| 782/782 [01:11<00:00, 1
0.95it/s]
100%|██████████████████████████| 157/157 [00:08<00:00, 1
8.84it/s]
Evaluation accuracy: 0.9189
Epoch 9: train_loss=0.1071148154211452, val_loss=0.251694498215891
100%|██████████████████████████| 782/782 [01:11<00:00, 1
1.01it/s]
100%|██████████████████████████| 157/157 [00:08<00:00, 1
9.05it/s]
Evaluation accuracy: 0.9154
Epoch 10: train_loss=0.0939529342279124, val_loss=0.26209185725659323
100%|██████████████████████████| 782/782 [01:14<00:00, 1
0.52it/s]
100%|██████████████████████████| 157/157 [00:09<00:00, 1
6.80it/s]
Evaluation accuracy: 0.9195
Epoch 11: train_loss=0.08425614969445216, val_loss=0.2584816863297657
100%|██████████████████████████| 782/782 [01:18<00:00,
9.93it/s]
100%|██████████████████████████| 157/157 [00:10<00:00, 1
5.53it/s]
Evaluation accuracy: 0.9195
Epoch 12: train_loss=0.07608472997063051, val_loss=0.26564337550454836
100%|██████████████████████████| 782/782 [01:25<00:00,
9.13it/s]
100%|██████████████████████████| 157/157 [00:11<00:00, 1
3.13it/s]
Evaluation accuracy: 0.9241
Epoch 13: train_loss=0.06682055746621983, val_loss=0.2705246946851539
100%|██████████████████████████| 782/782 [01:36<00:00,
8.10it/s]
100%|██████████████████████████| 157/157 [00:13<00:00, 1
1.39it/s]
```

```
Evaluation accuracy: 0.9187
Epoch 14: train_loss=0.0624846603490336, val_loss=0.30572927756246865
100%|██████████| 782/782 [01:40<00:00, 7.79it/s]
100%|██████████| 157/157 [00:14<00:00, 10.68it/s]
Evaluation accuracy: 0.9245
Epoch 15: train_loss=0.05878073636762788, val_loss=0.28560154841156904
Done!
Evaluate on test set
100%|██████████| 157/157 [00:14<00:00, 10.53it/s]
Evaluation accuracy: 0.9189
```

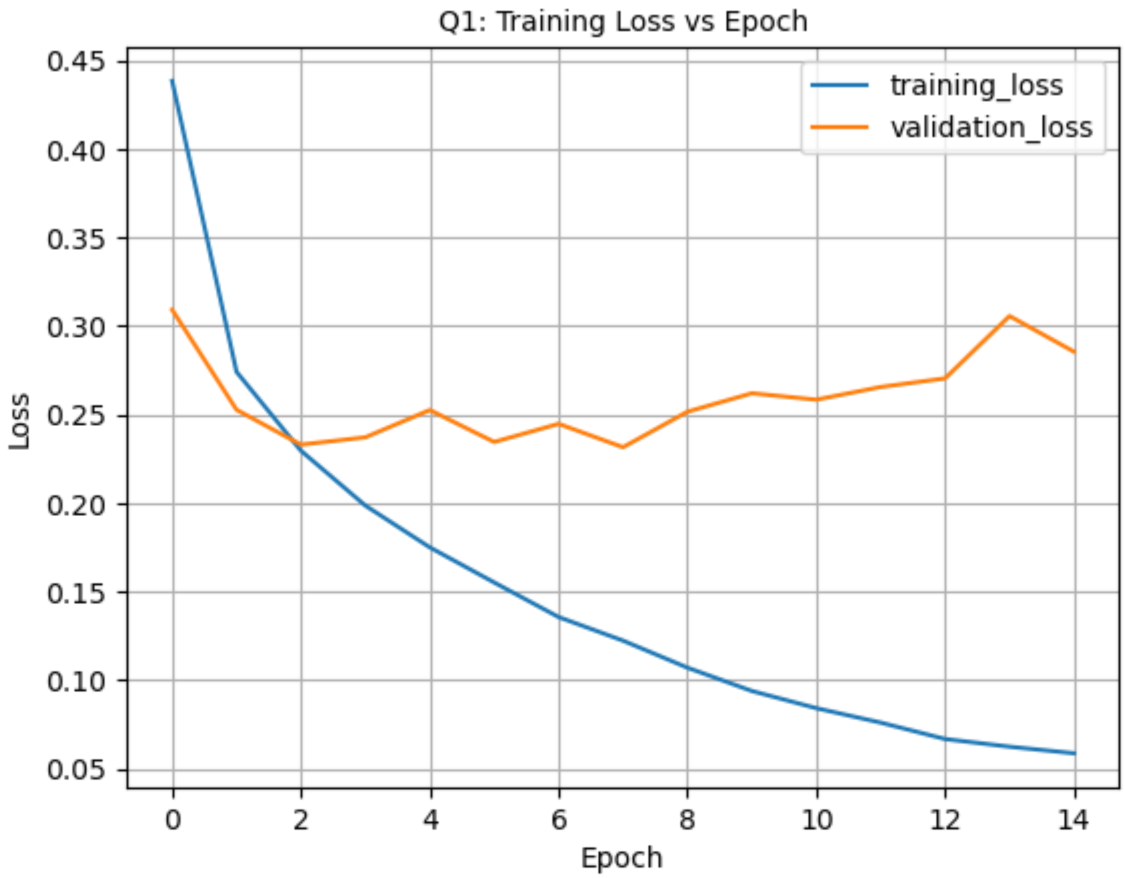
In [38]:

```python
"""
Analyze training & evaluation results.
"""
results = []
for i, (t_loss, v_loss) in enumerate(zip(train_losses, val_losses)):
    results.append({
        'epoch': i,
        'training_loss': t_loss,
        'validation_loss': v_loss,
    })

results_df = pd.DataFrame.from_records(results).set_index('epoch')
print(results_df)

# plot figure
results_df.plot(
    xlabel="Epoch",
    ylabel="Loss",
    grid=True,
)
plt.title("Q1: Training Loss vs Epoch", fontsize=10)
plt.savefig(f"./figures/{"q1_losses"}.png")
```

```
       training_loss  validation_loss
epoch
0           0.438519         0.309292
1           0.274184         0.252778
2           0.229639         0.233092
3           0.198661         0.237218
4           0.175074         0.252632
5           0.155234         0.234597
6           0.135707         0.244833
7           0.122388         0.231611
8           0.107115         0.251694
9           0.093953         0.262092
10          0.084256         0.258482
11          0.076085         0.265643
12          0.066821         0.270525
13          0.062485         0.305729
14          0.058781         0.285602
```


Q1: Training Loss vs Epoch
training_loss
validation_loss
Loss
Epoch
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0
2
4
6
8
10
12
14

```
In [ ]:
```