REAL-TIME MACHINE LEARNING(ECGR 5106)

HOMEWORK 2

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```
#install specific version of d2l
#install ptflops
!pip install d2l==1.0.0b0
!pip install ptflops
```

```
Requirement already satisfied: terminado>=0.8.3 in /usr/local/lib/python3.8/dist-packages (from notebook->jupyter->d2l==1.0.0b0) (0.1
Requirement already satisfied: pyzmq>=17 in /usr/local/lib/python3.8/dist-packages (from notebook->jupyter->d2l==1.0.0b0) (23.2.1)
Requirement already satisfied: Send2Trash>=1.5.0 in /usr/local/lib/python3.8/dist-packages (from notebook->jupyter->d2l==1.0.0b0) (1.8
Requirement already satisfied: prometheus-client in /usr/local/lib/python3.8/dist-packages (from notebook->jupyter->d2l==1.0.0b0) (0.1
Collecting qtpy>=2.0.1
  Downloading QtPy-2.3.0-py3-none-any.whl (83 kB)
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  Downloading jedi-0.18.2-py2.py3-none-any.whl (1.6 MB)
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Requirement already satisfied: MarkupSafe>=0.23 in /usr/local/lib/python3.8/dist-packages (from jinja2>=2.4->nbconvert->jupyter->d2l==
Requirement already satisfied: platformdirs>=2.5 in /usr/local/lib/python3.8/dist-packages (from jupyter-core->nbconvert->jupyter->d2l
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Requirement already satisfied: wcwidth in /usr/local/lib/python3.8/dist-packages (from prompt-toolkit!=3.0.0,!=3.0.1,<3.1.0,>=2.0.0->
Requirement already satisfied: packaging in /usr/local/lib/python3.8/dist-packages (from qtpy>=2.0.1->qtconsole->jupyter->d2l==1.0.0b0
Requirement already satisfied: ptyprocess in /usr/local/lib/python3.8/dist-packages (from terminado>=0.8.3->notebook->jupyter->d2l==1
Requirement already satisfied: typing-extensions in /usr/local/lib/python3.8/dist-packages (from torch>=1.11->linear-operator>=0.2.0-
Requirement already satisfied: argon2-cffi-bindings in /usr/local/lib/python3.8/dist-packages (from argon2-cffi->notebook->jupyter->d2
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Requirement already satisfied: parso<0.9.0,>=0.8.0 in /usr/local/lib/python3.8/dist-packages (from jedi>=0.10->ipython>=5.0.0->ipykern
Requirement already satisfied: pyrsistent!=0.17.0,!=0.17.1,!=0.17.2,>=0.14.0 in /usr/local/lib/python3.8/dist-packages (from jsonsche
Requirement already satisfied: importlib-resources>=1.4.0 in /usr/local/lib/python3.8/dist-packages (from jsonschema>=2.6->nbformat>=4
Requirement already satisfied: attrs>=17.4.0 in /usr/local/lib/python3.8/dist-packages (from jsonschema>=2.6->nbformat>=4.4->nbconvert
Requirement already satisfied: cffi>=1.0.1 in /usr/local/lib/python3.8/dist-packages (from argon2-cffi-bindings->argon2-cffi->notebook
Requirement already satisfied: pycparser in /usr/local/lib/python3.8/dist-packages (from cffi>=1.0.1->argon2-cffi-bindings->argon2-cffi
Requirement already satisfied: zipp>=3.1.0 in /usr/local/lib/python3.8/dist-packages (from importlib-resources>=1.4.0->jsonschema>=2.6
Building wheels for collected packages: gym
  Building wheel for gym (setup.py) ... done
  Created wheel for gym: filename=gym-0.21.0-py3-none-any.whl size=1616821 sha256=9a03678788ac84383aac2eb21ce60d0bfb50a4fb6893b7abe7bb
  Stored in directory: /root/.cache/pip/wheels/27/6d/b3/a3a6e10704795c9b9000f1ab2dc480dfe7bed42f5972806e73
Successfully built gym
Installing collected packages: qtpy, matplotlib-inline, jedi, gym, linear-operator, gpytorch, qtconsole, jupyter, d2l
  Attempting uninstall: gym
    Found existing installation: gym 0.25.2
    Uninstalling gym-0.25.2:
      Successfully uninstalled gym-0.25.2
Successfully installed d2l-1.0.0b0 gpytorch-1.9.1 gym-0.21.0 jedi-0.18.2 jupyter-1.0.0 linear-operator-0.3.0 matplotlib-inline-0.1.6 q
Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels/public/simple/
Collecting ptflops
  Downloading ptflops-0.6.9.tar.gz (12 kB)
  Preparing metadata (setup.py) ... done
Requirement already satisfied: torch in /usr/local/lib/python3.8/dist-packages (from ptflops) (1.13.1+cu116)
Requirement already satisfied: typing-extensions in /usr/local/lib/python3.8/dist-packages (from torch->ptflops) (4.5.0)
Building wheels for collected packages: ptflops
  Building wheel for ptflops (setup.py) ... done
  Created wheel for ptflops: filename=ptflops-0.6.9-py3-none-any.whl size=11712 sha256=944ee59b31135215747660d127a8430b117dded5ca3db80
  Stored in directory: /root/.cache/pip/wheels/b6/86/d5/cf62a3571b005f91cd9accefc5e10f40214538be997198afad
Successfully built ptflops
Installing collected packages: ptflops
Successfully installed ptflops-0.6.9
```

```
# Importing required libraries
%matplotlib inline
import torch
import torchvision
from torchvision import transforms
import torch.nn.functional as F
from torch import nn
```

```
from d2l import torch as d2l
import ptflops
from ptflops import get_model_complexity_info

d2l.use_svg_display()
```

PROBLEM 1

FashionMNIST baseline version

```
# Loading the FashionMNIST Dataset
class FashionMNIST(d2l.DataModule):
  def __init__(self, batch_size = 64, resize = (28, 28)):
    super().__init__()
    self.save_hyperparameters()
    trans = transforms.Compose([transforms.Resize(resize),
                                transforms.ToTensor()])
    self.train = torchvision.datasets.FashionMNIST(
        root = self.root, train = True, transform = trans, download = True)
    self.val = torchvision.datasets.FashionMNIST(
        root = self.root, train = False, transform = trans, download = True)


data = FashionMNIST(resize = (32, 32))
print("Training Images   = ", len(data.train))
print("Validation Images = ", len(data.val))

data.train[0][0].shape
```

```
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-images-idx3
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-images-idx3
100%                                          26421880/26421880 [00:02<00:00, 19267709.58it/s]
Extracting ../data/FashionMNIST/raw/train-images-idx3-ubyte.gz to ../data/FashionMNIST/r

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-labels-idx1
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-labels-idx1
100%                                          29515/29515 [00:00<00:00, 209020.12it/s]
Extracting ../data/FashionMNIST/raw/train-labels-idx1-ubyte.gz to ../data/FashionMNIST/r

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images-idx3-
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images-idx3-
100%                                          4422102/4422102 [00:01<00:00, 6680931.67it/s]
Extracting ../data/FashionMNIST/raw/t10k-images-idx3-ubyte.gz to ../data/FashionMNIST/ra

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels-idx1-
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels-idx1-
100%                                          5148/5148 [00:00<00:00, 167487.16it/s]
Extracting ../data/FashionMNIST/raw/t10k-labels-idx1-ubyte.gz to ../data/FashionMNIST/ra

Training Images   =  60000
Validation Images =  10000
torch.Size([1, 32, 32])
```

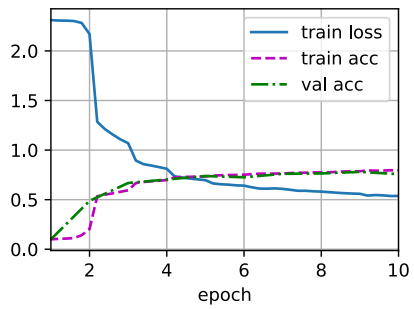
```
# Assigning labels to numerical values so its is easier to read
@d2l.add_to_class(FashionMNIST)
def text_labels(self, indices):
  labels = ['t-shirt', 'trouser', 'pullover', 'dress', 'coat',
            'sandal', 'shirt', 'sneaker', 'bag', 'ankle boot']
  return [labels[int(i)] for i in indices]


# Function to load either Training or Validation self
@d2l.add_to_class(FashionMNIST)
def get_dataloader(self, train):
  data = self.train if train else self.val
  return torch.utils.data.DataLoader(data, self.batch_size, shuffle = train,
                                     num_workers = self.num_workers)

X, Y = next(iter(data.train_dataloader()))
print(X.shape, X.dtype, Y.shape, Y.dtype)
```

```
/usr/local/lib/python3.8/dist-packages/torch/utils/data/dataloader.py:554: UserWarning: This DataLoader will create 4 worker processes i
  warnings.warn(_create_warning_msg(
torch.Size([64, 1, 32, 32]) torch.float32 torch.Size([64]) torch.int64
```

```
# Function that initialized the weights of the CNN model with Xavier Uniform Initialization
def init_cnn(module):
    """Initialize weights for CNNs."""
    if type(module) == nn.Linear or type(module) == nn.Conv2d:
        nn.init.xavier_uniform_(module.weight)


# The Baseline Convolution Neural Network
class LeNet_Base(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=5, padding=2), nn.Sigmoid(),
            nn.AvgPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=5), nn.Sigmoid(),
            nn.AvgPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.Sigmoid(),
            nn.LazyLinear(84), nn.Sigmoid(),
            nn.LazyLinear(num_classes))



# Function to print a Model's Layer Summary given the shape
@d2l.add_to_class(d2l.Classifier)
def layer_summary(self, X_shape):
    X = torch.randn(*X_shape)
    for layer in self.net:
        X = layer(X)
        print(layer.__class__.__name__, 'output shape:\t', X.shape)

model = LeNet_Base()
model.layer_summary((1, 1, 32, 32))
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Conv2d output shape:     torch.Size([1, 6, 32, 32])
Sigmoid output shape:    torch.Size([1, 6, 32, 32])
AvgPool2d output shape:  torch.Size([1, 6, 16, 16])
Conv2d output shape:     torch.Size([1, 16, 12, 12])
Sigmoid output shape:    torch.Size([1, 16, 12, 12])
AvgPool2d output shape:  torch.Size([1, 16, 6, 6])
Flatten output shape:    torch.Size([1, 576])
Linear output shape:     torch.Size([1, 120])
Sigmoid output shape:    torch.Size([1, 120])
Linear output shape:     torch.Size([1, 84])
Sigmoid output shape:    torch.Size([1, 84])
Linear output shape:     torch.Size([1, 10])
Sequential(
  82.83 k, 100.000% Params, 596.35 KMac, 100.000% MACs,
  (0): Conv2d(156, 0.188% Params, 159.74 KMac, 26.787% MACs, 1, 6, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (1): Sigmoid(0, 0.000% Params, 0.0 Mac, 0.000% MACs, )
  (2): AvgPool2d(0, 0.000% Params, 6.14 KMac, 1.030% MACs, kernel_size=2, stride=2, padding=0)
  (3): Conv2d(2.42 k, 2.917% Params, 347.9 KMac, 58.339% MACs, 6, 16, kernel_size=(5, 5), stride=(1, 1))
  (4): Sigmoid(0, 0.000% Params, 0.0 Mac, 0.000% MACs, )
  (5): AvgPool2d(0, 0.000% Params, 2.3 KMac, 0.386% MACs, kernel_size=2, stride=2, padding=0)
  (6): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (7): Linear(69.24 k, 83.597% Params, 69.24 KMac, 11.611% MACs, in_features=576, out_features=120, bias=True)
  (8): Sigmoid(0, 0.000% Params, 0.0 Mac, 0.000% MACs, )
  (9): Linear(10.16 k, 12.272% Params, 10.16 KMac, 1.704% MACs, in_features=120, out_features=84, bias=True)
  (10): Sigmoid(0, 0.000% Params, 0.0 Mac, 0.000% MACs, )
  (11): Linear(850, 1.026% Params, 850.0 Mac, 0.143% MACs, in_features=84, out_features=10, bias=True)
)
Computational complexity:       596.35 KMac
Number of parameters:           82.83 k
/usr/local/lib/python3.8/dist-packages/torch/nn/modules/lazy.py:180: UserWarning: Lazy modules are a new feature under heavy development
  warnings.warn('Lazy modules are a new feature under heavy development '
```

```
# Function to Evaluate the Model's Accuracy
def evaluate_accuracy_gpu(net, data_iter, device=None):
    if isinstance(net, nn.Module):
        net.eval()
        if not device:
            device = next(iter(net.parameters())).device

    # No. of correct predictions, no. of predictions
    metric = d2l.Accumulator(2)

    with torch.no_grad():
        for X, y in data_iter:
            if isinstance(X, list):
                X = [x.to(device) for x in X]
            else:
                X = X.to(device)
            y = y.to(device)
            metric.add(d2l.accuracy(net(X), y), y.numel())
    return metric[0] / metric[1]


# Training Function
def train(net, train_iter, val_iter, num_epochs, lr, device):
    def init_weights(m):
        if type(m) == nn.Linear or type(m) == nn.Conv2d:
            nn.init.xavier_uniform_(m.weight)
    net.apply(init_weights)
    net.to(device)
    optimizer = torch.optim.SGD(net.parameters(), lr=lr)
    loss = nn.CrossEntropyLoss()
    animator = d2l.Animator(xlabel='epoch', xlim=[1, num_epochs],
                            legend=['train loss', 'train acc', 'val acc'])
    timer, num_batches = d2l.Timer(), len(train_iter)
    for epoch in range(num_epochs):
        # Sum of training loss, sum of training accuracy, no. of examples
        metric = d2l.Accumulator(3)
        net.train()
        for i, (X, y) in enumerate(train_iter):
            timer.start()
            optimizer.zero_grad()
            X, y = X.to(device), y.to(device)
            y_hat = net(X)
            l = loss(y_hat, y)
            l.backward()
            optimizer.step()
            with torch.no_grad():
                metric.add(l * X.shape[0], d2l.accuracy(y_hat, y), X.shape[0])
            timer.stop()
            train_l = metric[0] / metric[2]
            train_acc = metric[1] / metric[2]
            if (i + 1) % (num_batches // 5) == 0 or i == num_batches - 1:
                animator.add(epoch + (i + 1) / num_batches,
                             (train_l, train_acc, None))
        val_acc = evaluate_accuracy_gpu(net, val_iter)
        animator.add(epoch + 1, (None, None, val_acc))


lr, num_epochs = 0.1, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```

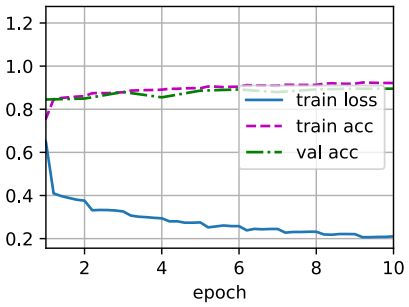


Taking the base model of FashionMNIST and replacing the average pooling with max-pooling Also replacing softmax layer with ReLU

```
# Modernized LeNet Model for Problem # 1
# For Problem # 1, The Average Pooling will be replaced with Max Pooling,
# and the Softmax/Sigmoid layer with ReLU

class LeNet_Modernize(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=5), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.LazyLinear(84), nn.ReLU(),
            nn.LazyLinear(num_classes))

model = LeNet_Modernize()
model.layer_summary((1, 1, 32, 32))
```

```
Conv2d output shape:     torch.Size([1, 6, 32, 32])
ReLU output shape:       torch.Size([1, 6, 32, 32])
MaxPool2d output shape:  torch.Size([1, 6, 16, 16])
Conv2d output shape:     torch.Size([1, 16, 12, 12])
ReLU output shape:       torch.Size([1, 16, 12, 12])
MaxPool2d output shape:  torch.Size([1, 16, 6, 6])
Flatten output shape:    torch.Size([1, 576])
Linear output shape:     torch.Size([1, 120])
ReLU output shape:       torch.Size([1, 120])
Linear output shape:     torch.Size([1, 84])
ReLU output shape:       torch.Size([1, 84])
Linear output shape:     torch.Size([1, 10])
```

```
lr, num_epochs = 0.1, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```



PROBLEM 2

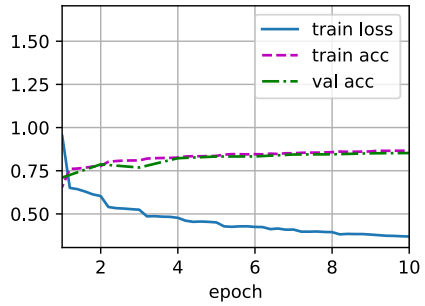
1. Adjust the convolution window size.

```
class LeNet_1(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=9, padding=3), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=7), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.LazyLinear(84), nn.ReLU(),
            nn.LazyLinear(num_classes))

model = LeNet_1()
model.layer_summary((1, 1, 32, 32))

# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
```

```
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
     Conv2d output shape:     torch.Size([1, 6, 30, 30])
     ReLU output shape:       torch.Size([1, 6, 30, 30])
     MaxPool2d output shape:  torch.Size([1, 6, 15, 15])
     Conv2d output shape:     torch.Size([1, 16, 9, 9])
     ReLU output shape:       torch.Size([1, 16, 9, 9])
     MaxPool2d output shape:  torch.Size([1, 16, 4, 4])
     Flatten output shape:    torch.Size([1, 256])
     Linear output shape:     torch.Size([1, 120])
     ReLU output shape:       torch.Size([1, 120])
     Linear output shape:     torch.Size([1, 84])
     ReLU output shape:       torch.Size([1, 84])
     Linear output shape:     torch.Size([1, 10])
     Sequential(
       47.07 k, 100.000% Params, 880.57 KMac, 100.000% MACs,
       (0): Conv2d(492, 1.045% Params, 442.8 KMac, 50.286% MACs, 1, 6, kernel_size=(9, 9), stride=(1, 1), padding=(3, 3))
       (1): ReLU(0, 0.000% Params, 5.4 KMac, 0.613% MACs, )
       (2): MaxPool2d(0, 0.000% Params, 5.4 KMac, 0.613% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
       (3): Conv2d(4.72 k, 10.028% Params, 382.32 KMac, 43.417% MACs, 6, 16, kernel_size=(7, 7), stride=(1, 1))
       (4): ReLU(0, 0.000% Params, 1.3 KMac, 0.147% MACs, )
       (5): MaxPool2d(0, 0.000% Params, 1.3 KMac, 0.147% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
       (6): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
       (7): Linear(30.84 k, 65.525% Params, 30.84 KMac, 3.502% MACs, in_features=256, out_features=120, bias=True)
       (8): ReLU(0, 0.000% Params, 120.0 Mac, 0.014% MACs, )
       (9): Linear(10.16 k, 21.595% Params, 10.16 KMac, 1.154% MACs, in_features=120, out_features=84, bias=True)
       (10): ReLU(0, 0.000% Params, 84.0 Mac, 0.010% MACs, )
       (11): Linear(850, 1.806% Params, 850.0 Mac, 0.097% MACs, in_features=84, out_features=10, bias=True)
     )
     Computational complexity:       880.57 KMac
     Number of parameters:           47.07 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```



2. Adjust the number of output channels (width of each layer).

```
class LeNet_2(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(4, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(8, kernel_size=5), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.LazyLinear(84), nn.ReLU(),
            nn.LazyLinear(num_classes))

model = LeNet_2()
model.layer_summary((1, 1, 32, 32))
```

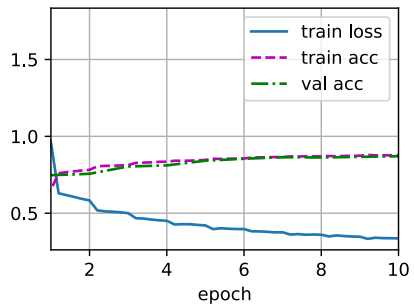
```
     Conv2d output shape:     torch.Size([1, 4, 32, 32])
     ReLU output shape:       torch.Size([1, 4, 32, 32])
     MaxPool2d output shape:  torch.Size([1, 4, 16, 16])
     Conv2d output shape:     torch.Size([1, 8, 12, 12])
     ReLU output shape:       torch.Size([1, 8, 12, 12])
     MaxPool2d output shape:  torch.Size([1, 8, 6, 6])
     Flatten output shape:    torch.Size([1, 288])
     Linear output shape:     torch.Size([1, 120])
```

```
ReLU output shape:       torch.Size([1, 120])
Linear output shape:     torch.Size([1, 84])
ReLU output shape:       torch.Size([1, 84])
Linear output shape:     torch.Size([1, 10])
/usr/local/lib/python3.8/dist-packages/torch/nn/modules/lazy.py:180: UserWarning: Lazy modules are a new feature under heavy development
  warnings.warn('Lazy modules are a new feature under heavy development '
```

```
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Sequential(
  46.61 k, 100.000% Params, 279.24 KMac, 100.000% MACs,
  (0): Conv2d(104, 0.223% Params, 106.5 KMac, 38.138% MACs, 1, 4, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (1): ReLU(0, 0.000% Params, 4.1 KMac, 1.467% MACs, )
  (2): MaxPool2d(0, 0.000% Params, 4.1 KMac, 1.467% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (3): Conv2d(808, 1.734% Params, 116.35 KMac, 41.667% MACs, 4, 8, kernel_size=(5, 5), stride=(1, 1))
  (4): ReLU(0, 0.000% Params, 1.15 KMac, 0.413% MACs, )
  (5): MaxPool2d(0, 0.000% Params, 1.15 KMac, 0.413% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (6): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (7): Linear(34.68 k, 74.411% Params, 34.68 KMac, 12.419% MACs, in_features=288, out_features=120, bias=True)
  (8): ReLU(0, 0.000% Params, 120.0 Mac, 0.043% MACs, )
  (9): Linear(10.16 k, 21.808% Params, 10.16 KMac, 3.640% MACs, in_features=120, out_features=84, bias=True)
  (10): ReLU(0, 0.000% Params, 84.0 Mac, 0.030% MACs, )
  (11): Linear(850, 1.824% Params, 850.0 Mac, 0.304% MACs, in_features=84, out_features=10, bias=True)
)
Computational complexity:       279.24 KMac
Number of parameters:           46.61 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```



3. Adjust the number of convolution layers.

```
class LeNet_3(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=5), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(32, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(64, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.LazyLinear(84), nn.ReLU(),
            nn.LazyLinear(num_classes))

model = LeNet_3()
model.layer_summary((1, 1, 32, 32))
```

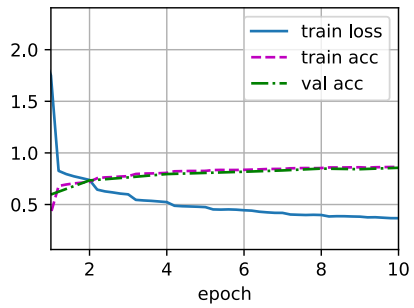
```
Conv2d output shape:     torch.Size([1, 6, 32, 32])
ReLU output shape:       torch.Size([1, 6, 32, 32])
MaxPool2d output shape:  torch.Size([1, 6, 16, 16])
Conv2d output shape:     torch.Size([1, 16, 12, 12])
ReLU output shape:       torch.Size([1, 16, 12, 12])
```

```
MaxPool2d output shape:  torch.Size([1, 16, 6, 6])
Conv2d output shape:     torch.Size([1, 32, 6, 6])
ReLU output shape:       torch.Size([1, 32, 6, 6])
MaxPool2d output shape:  torch.Size([1, 32, 3, 3])
Conv2d output shape:     torch.Size([1, 64, 3, 3])
ReLU output shape:       torch.Size([1, 64, 3, 3])
MaxPool2d output shape:  torch.Size([1, 64, 1, 1])
Flatten output shape:    torch.Size([1, 64])
Linear output shape:     torch.Size([1, 120])
ReLU output shape:       torch.Size([1, 120])
Linear output shape:     torch.Size([1, 84])
ReLU output shape:       torch.Size([1, 84])
Linear output shape:     torch.Size([1, 10])
```

```
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Sequential(
  85.48 k, 100.000% Params, 1.47 MMac, 100.000% MACs,
  (0): Conv2d(156, 0.182% Params, 159.74 KMac, 10.864% MACs, 1, 6, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (1): ReLU(0, 0.000% Params, 6.14 KMac, 0.418% MACs, )
  (2): MaxPool2d(0, 0.000% Params, 6.14 KMac, 0.418% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (3): Conv2d(2.42 k, 2.826% Params, 347.9 KMac, 23.661% MACs, 6, 16, kernel_size=(5, 5), stride=(1, 1))
  (4): ReLU(0, 0.000% Params, 2.3 KMac, 0.157% MACs, )
  (5): MaxPool2d(0, 0.000% Params, 2.3 KMac, 0.157% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (6): Conv2d(12.83 k, 15.011% Params, 461.95 KMac, 31.418% MACs, 16, 32, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (7): ReLU(0, 0.000% Params, 1.15 KMac, 0.078% MACs, )
  (8): MaxPool2d(0, 0.000% Params, 1.15 KMac, 0.078% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (9): Conv2d(51.26 k, 59.971% Params, 461.38 KMac, 31.379% MACs, 32, 64, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (10): ReLU(0, 0.000% Params, 576.0 Mac, 0.039% MACs, )
  (11): MaxPool2d(0, 0.000% Params, 576.0 Mac, 0.039% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (12): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (13): Linear(7.8 k, 9.125% Params, 7.8 KMac, 0.530% MACs, in_features=64, out_features=120, bias=True)
  (14): ReLU(0, 0.000% Params, 120.0 Mac, 0.008% MACs, )
  (15): Linear(10.16 k, 11.890% Params, 10.16 KMac, 0.691% MACs, in_features=120, out_features=84, bias=True)
  (16): ReLU(0, 0.000% Params, 84.0 Mac, 0.006% MACs, )
  (17): Linear(850, 0.994% Params, 850.0 Mac, 0.058% MACs, in_features=84, out_features=10, bias=True)
)
Computational complexity:       1.47 MMac
Number of parameters:           85.48 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```



4. Adjust the number of fully connected layers

```
class LeNet_4(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=5), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.LazyLinear(84), nn.ReLU(),
            nn.LazyLinear(64), nn.ReLU(),
            nn.LazyLinear(num_classes))
```

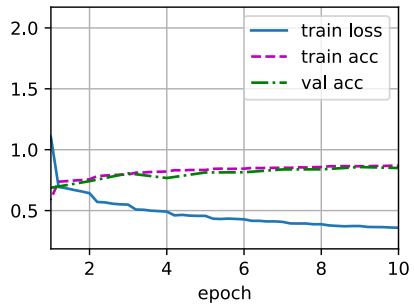
```
model = LeNet_4()
model.layer_summary((1, 1, 32, 32))
```

```
Conv2d output shape:     torch.Size([1, 6, 32, 32])
ReLU output shape:       torch.Size([1, 6, 32, 32])
MaxPool2d output shape:  torch.Size([1, 6, 16, 16])
Conv2d output shape:     torch.Size([1, 16, 12, 12])
ReLU output shape:       torch.Size([1, 16, 12, 12])
MaxPool2d output shape:  torch.Size([1, 16, 6, 6])
Flatten output shape:    torch.Size([1, 576])
Linear output shape:     torch.Size([1, 120])
ReLU output shape:       torch.Size([1, 120])
Linear output shape:     torch.Size([1, 84])
ReLU output shape:       torch.Size([1, 84])
Linear output shape:     torch.Size([1, 64])
ReLU output shape:       torch.Size([1, 64])
Linear output shape:     torch.Size([1, 10])
/usr/local/lib/python3.8/dist-packages/torch/nn/modules/lazy.py:180: UserWarning: Lazy modules are a new feature under heavy development
  warnings.warn('Lazy modules are a new feature under heavy development '
```

```
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Sequential(
  88.07 k, 100.000% Params, 610.31 KMac, 100.000% MACs,
  (0): Conv2d(156, 0.177% Params, 159.74 KMac, 26.174% MACs, 1, 6, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (1): ReLU(0, 0.000% Params, 6.14 KMac, 1.007% MACs, )
  (2): MaxPool2d(0, 0.000% Params, 6.14 KMac, 1.007% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (3): Conv2d(2.42 k, 2.743% Params, 347.9 KMac, 57.005% MACs, 6, 16, kernel_size=(5, 5), stride=(1, 1))
  (4): ReLU(0, 0.000% Params, 2.3 KMac, 0.378% MACs, )
  (5): MaxPool2d(0, 0.000% Params, 2.3 KMac, 0.378% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (6): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (7): Linear(69.24 k, 78.623% Params, 69.24 KMac, 11.345% MACs, in_features=576, out_features=120, bias=True)
  (8): ReLU(0, 0.000% Params, 120.0 Mac, 0.020% MACs, )
  (9): Linear(10.16 k, 11.541% Params, 10.16 KMac, 1.665% MACs, in_features=120, out_features=84, bias=True)
  (10): ReLU(0, 0.000% Params, 84.0 Mac, 0.014% MACs, )
  (11): Linear(5.44 k, 6.177% Params, 5.44 KMac, 0.891% MACs, in_features=84, out_features=64, bias=True)
  (12): ReLU(0, 0.000% Params, 64.0 Mac, 0.010% MACs, )
  (13): Linear(650, 0.738% Params, 650.0 Mac, 0.107% MACs, in_features=64, out_features=10, bias=True)
)
Computational complexity:       610.31 KMac
Number of parameters:           88.07 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```



5. Explore the learning rates

```
class LeNet_5(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=5), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.LazyLinear(84), nn.ReLU(),
```

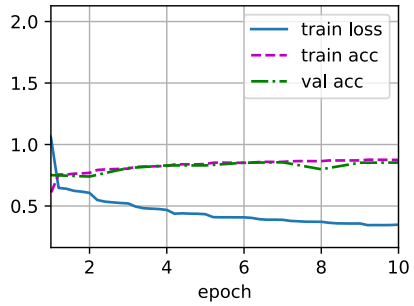
```
            nn.LazyLinear(num_classes))

model = LeNet_5()
model.layer_summary((1, 1, 32, 32))
```

```
     Conv2d output shape:     torch.Size([1, 6, 32, 32])
     ReLU output shape:       torch.Size([1, 6, 32, 32])
     MaxPool2d output shape:  torch.Size([1, 6, 16, 16])
     Conv2d output shape:     torch.Size([1, 16, 12, 12])
     ReLU output shape:       torch.Size([1, 16, 12, 12])
     MaxPool2d output shape:  torch.Size([1, 16, 6, 6])
     Flatten output shape:    torch.Size([1, 576])
     Linear output shape:     torch.Size([1, 120])
     ReLU output shape:       torch.Size([1, 120])
     Linear output shape:     torch.Size([1, 84])
     ReLU output shape:       torch.Size([1, 84])
     Linear output shape:     torch.Size([1, 10])
```

```
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
     Sequential(
       82.83 k, 100.000% Params, 605.0 KMac, 100.000% MACs,
       (0): Conv2d(156, 0.188% Params, 159.74 KMac, 26.404% MACs, 1, 6, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
       (1): ReLU(0, 0.000% Params, 6.14 KMac, 1.016% MACs, )
       (2): MaxPool2d(0, 0.000% Params, 6.14 KMac, 1.016% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
       (3): Conv2d(2.42 k, 2.917% Params, 347.9 KMac, 57.505% MACs, 6, 16, kernel_size=(5, 5), stride=(1, 1))
       (4): ReLU(0, 0.000% Params, 2.3 KMac, 0.381% MACs, )
       (5): MaxPool2d(0, 0.000% Params, 2.3 KMac, 0.381% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
       (6): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
       (7): Linear(69.24 k, 83.597% Params, 69.24 KMac, 11.445% MACs, in_features=576, out_features=120, bias=True)
       (8): ReLU(0, 0.000% Params, 120.0 Mac, 0.020% MACs, )
       (9): Linear(10.16 k, 12.272% Params, 10.16 KMac, 1.680% MACs, in_features=120, out_features=84, bias=True)
       (10): ReLU(0, 0.000% Params, 84.0 Mac, 0.014% MACs, )
       (11): Linear(850, 1.026% Params, 850.0 Mac, 0.140% MACs, in_features=84, out_features=10, bias=True)
     )
     Computational complexity:       605.0 KMac
     Number of parameters:           82.83 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```



PROBLEM 3

```
class LeNet_D1(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=9, padding=3), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=7), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(84), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(num_classes))
```

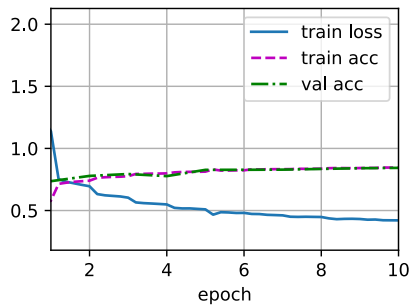
```
model = LeNet_D1()
model.layer_summary((1, 1, 32, 32))
```

```
Conv2d output shape:     torch.Size([1, 6, 30, 30])
ReLU output shape:       torch.Size([1, 6, 30, 30])
MaxPool2d output shape:  torch.Size([1, 6, 15, 15])
Conv2d output shape:     torch.Size([1, 16, 9, 9])
ReLU output shape:       torch.Size([1, 16, 9, 9])
MaxPool2d output shape:  torch.Size([1, 16, 4, 4])
Flatten output shape:    torch.Size([1, 256])
Linear output shape:     torch.Size([1, 120])
ReLU output shape:       torch.Size([1, 120])
Dropout output shape:    torch.Size([1, 120])
Linear output shape:     torch.Size([1, 84])
ReLU output shape:       torch.Size([1, 84])
Dropout output shape:    torch.Size([1, 84])
Linear output shape:     torch.Size([1, 10])
```

```
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Sequential(
  47.07 k, 100.000% Params, 880.57 KMac, 100.000% MACs,
  (0): Conv2d(492, 1.045% Params, 442.8 KMac, 50.286% MACs, 1, 6, kernel_size=(9, 9), stride=(1, 1), padding=(3, 3))
  (1): ReLU(0, 0.000% Params, 5.4 KMac, 0.613% MACs, )
  (2): MaxPool2d(0, 0.000% Params, 5.4 KMac, 0.613% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (3): Conv2d(4.72 k, 10.028% Params, 382.32 KMac, 43.417% MACs, 6, 16, kernel_size=(7, 7), stride=(1, 1))
  (4): ReLU(0, 0.000% Params, 1.3 KMac, 0.147% MACs, )
  (5): MaxPool2d(0, 0.000% Params, 1.3 KMac, 0.147% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (6): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (7): Linear(30.84 k, 65.525% Params, 30.84 KMac, 3.502% MACs, in_features=256, out_features=120, bias=True)
  (8): ReLU(0, 0.000% Params, 120.0 Mac, 0.014% MACs, )
  (9): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
  (10): Linear(10.16 k, 21.595% Params, 10.16 KMac, 1.154% MACs, in_features=120, out_features=84, bias=True)
  (11): ReLU(0, 0.000% Params, 84.0 Mac, 0.010% MACs, )
  (12): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
  (13): Linear(850, 1.806% Params, 850.0 Mac, 0.097% MACs, in_features=84, out_features=10, bias=True)
)
Computational complexity:       880.57 KMac
Number of parameters:           47.07 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```




```
class LeNet_D2(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(4, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(8, kernel_size=5), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(84), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(num_classes))
```

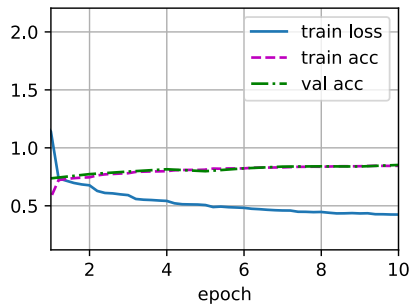
```
model = LeNet_D2()
model.layer_summary((1, 1, 32, 32))
```

```
Conv2d output shape:     torch.Size([1, 4, 32, 32])
ReLU output shape:       torch.Size([1, 4, 32, 32])
MaxPool2d output shape:  torch.Size([1, 4, 16, 16])
Conv2d output shape:     torch.Size([1, 8, 12, 12])
ReLU output shape:       torch.Size([1, 8, 12, 12])
MaxPool2d output shape:  torch.Size([1, 8, 6, 6])
Flatten output shape:    torch.Size([1, 288])
Linear output shape:     torch.Size([1, 120])
ReLU output shape:       torch.Size([1, 120])
Dropout output shape:    torch.Size([1, 120])
Linear output shape:     torch.Size([1, 84])
ReLU output shape:       torch.Size([1, 84])
Dropout output shape:    torch.Size([1, 84])
Linear output shape:     torch.Size([1, 10])
```

```
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Sequential(
  46.61 k, 100.000% Params, 279.24 KMac, 100.000% MACs,
  (0): Conv2d(104, 0.223% Params, 106.5 KMac, 38.138% MACs, 1, 4, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (1): ReLU(0, 0.000% Params, 4.1 KMac, 1.467% MACs, )
  (2): MaxPool2d(0, 0.000% Params, 4.1 KMac, 1.467% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (3): Conv2d(808, 1.734% Params, 116.35 KMac, 41.667% MACs, 4, 8, kernel_size=(5, 5), stride=(1, 1))
  (4): ReLU(0, 0.000% Params, 1.15 KMac, 0.413% MACs, )
  (5): MaxPool2d(0, 0.000% Params, 1.15 KMac, 0.413% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (6): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (7): Linear(34.68 k, 74.411% Params, 34.68 KMac, 12.419% MACs, in_features=288, out_features=120, bias=True)
  (8): ReLU(0, 0.000% Params, 120.0 Mac, 0.043% MACs, )
  (9): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
  (10): Linear(10.16 k, 21.808% Params, 10.16 KMac, 3.640% MACs, in_features=120, out_features=84, bias=True)
  (11): ReLU(0, 0.000% Params, 84.0 Mac, 0.030% MACs, )
  (12): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
  (13): Linear(850, 1.824% Params, 850.0 Mac, 0.304% MACs, in_features=84, out_features=10, bias=True)
)
Computational complexity:       279.24 KMac
Number of parameters:           46.61 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```



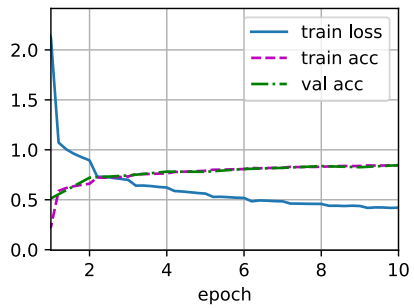

```
class LeNet_D3(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=5), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(32, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(64, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(84), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(num_classes),)
```

```
model = LeNet_D3()
model.layer_summary((1, 1, 32, 32))
     Conv2d output shape:     torch.Size([1, 6, 32, 32])
     ReLU output shape:       torch.Size([1, 6, 32, 32])
     MaxPool2d output shape:  torch.Size([1, 6, 16, 16])
     Conv2d output shape:     torch.Size([1, 16, 12, 12])
     ReLU output shape:       torch.Size([1, 16, 12, 12])
     MaxPool2d output shape:  torch.Size([1, 16, 6, 6])
     Conv2d output shape:     torch.Size([1, 32, 6, 6])
     ReLU output shape:       torch.Size([1, 32, 6, 6])
     MaxPool2d output shape:  torch.Size([1, 32, 3, 3])
     Conv2d output shape:     torch.Size([1, 64, 3, 3])
     ReLU output shape:       torch.Size([1, 64, 3, 3])
     MaxPool2d output shape:  torch.Size([1, 64, 1, 1])
     Flatten output shape:    torch.Size([1, 64])
     Linear output shape:     torch.Size([1, 120])
     ReLU output shape:       torch.Size([1, 120])
     Dropout output shape:    torch.Size([1, 120])
     Linear output shape:     torch.Size([1, 84])
     ReLU output shape:       torch.Size([1, 84])
     Dropout output shape:    torch.Size([1, 84])
     Linear output shape:     torch.Size([1, 10])
```

```
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
     Sequential(
       85.48 k, 100.000% Params, 1.47 MMac, 100.000% MACs,
       (0): Conv2d(156, 0.182% Params, 159.74 KMac, 10.864% MACs, 1, 6, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
       (1): ReLU(0, 0.000% Params, 6.14 KMac, 0.418% MACs, )
       (2): MaxPool2d(0, 0.000% Params, 6.14 KMac, 0.418% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
       (3): Conv2d(2.42 k, 2.826% Params, 347.9 KMac, 23.661% MACs, 6, 16, kernel_size=(5, 5), stride=(1, 1))
       (4): ReLU(0, 0.000% Params, 2.3 KMac, 0.157% MACs, )
       (5): MaxPool2d(0, 0.000% Params, 2.3 KMac, 0.157% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
       (6): Conv2d(12.83 k, 15.011% Params, 461.95 KMac, 31.418% MACs, 16, 32, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
       (7): ReLU(0, 0.000% Params, 1.15 KMac, 0.078% MACs, )
       (8): MaxPool2d(0, 0.000% Params, 1.15 KMac, 0.078% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
       (9): Conv2d(51.26 k, 59.971% Params, 461.38 KMac, 31.379% MACs, 32, 64, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
       (10): ReLU(0, 0.000% Params, 576.0 Mac, 0.039% MACs, )
       (11): MaxPool2d(0, 0.000% Params, 576.0 Mac, 0.039% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
       (12): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
       (13): Linear(7.8 k, 9.125% Params, 7.8 KMac, 0.530% MACs, in_features=64, out_features=120, bias=True)
       (14): ReLU(0, 0.000% Params, 120.0 Mac, 0.008% MACs, )
       (15): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
       (16): Linear(10.16 k, 11.890% Params, 10.16 KMac, 0.691% MACs, in_features=120, out_features=84, bias=True)
       (17): ReLU(0, 0.000% Params, 84.0 Mac, 0.006% MACs, )
       (18): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
       (19): Linear(850, 0.994% Params, 850.0 Mac, 0.058% MACs, in_features=84, out_features=10, bias=True)
     )
     Computational complexity:       1.47 MMac
     Number of parameters:           85.48 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```




```
class LeNet_D4(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=5), nn.ReLU(),
```

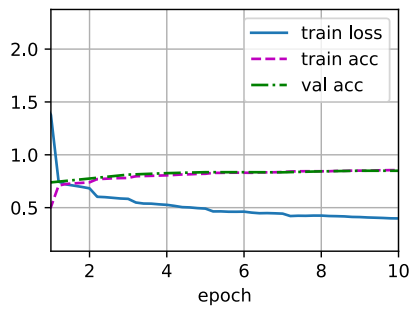
```
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(84), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(64), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(num_classes),)

model = LeNet_D4()
model.layer_summary((1, 1, 32, 32))
```

```
Conv2d output shape:     torch.Size([1, 6, 32, 32])
ReLU output shape:       torch.Size([1, 6, 32, 32])
MaxPool2d output shape:  torch.Size([1, 6, 16, 16])
Conv2d output shape:     torch.Size([1, 16, 12, 12])
ReLU output shape:       torch.Size([1, 16, 12, 12])
MaxPool2d output shape:  torch.Size([1, 16, 6, 6])
Flatten output shape:    torch.Size([1, 576])
Linear output shape:     torch.Size([1, 120])
ReLU output shape:       torch.Size([1, 120])
Dropout output shape:    torch.Size([1, 120])
Linear output shape:     torch.Size([1, 84])
ReLU output shape:       torch.Size([1, 84])
Dropout output shape:    torch.Size([1, 84])
Linear output shape:     torch.Size([1, 64])
ReLU output shape:       torch.Size([1, 64])
Dropout output shape:    torch.Size([1, 64])
Linear output shape:     torch.Size([1, 10])
```

```
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Sequential(
  88.07 k, 100.000% Params, 610.31 KMac, 100.000% MACs,
  (0): Conv2d(156, 0.177% Params, 159.74 KMac, 26.174% MACs, 1, 6, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (1): ReLU(0, 0.000% Params, 6.14 KMac, 1.007% MACs, )
  (2): MaxPool2d(0, 0.000% Params, 6.14 KMac, 1.007% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (3): Conv2d(2.42 k, 2.743% Params, 347.9 KMac, 57.005% MACs, 6, 16, kernel_size=(5, 5), stride=(1, 1))
  (4): ReLU(0, 0.000% Params, 2.3 KMac, 0.378% MACs, )
  (5): MaxPool2d(0, 0.000% Params, 2.3 KMac, 0.378% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (6): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (7): Linear(69.24 k, 78.623% Params, 69.24 KMac, 11.345% MACs, in_features=576, out_features=120, bias=True)
  (8): ReLU(0, 0.000% Params, 120.0 Mac, 0.020% MACs, )
  (9): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
  (10): Linear(10.16 k, 11.541% Params, 10.16 KMac, 1.665% MACs, in_features=120, out_features=84, bias=True)
  (11): ReLU(0, 0.000% Params, 84.0 Mac, 0.014% MACs, )
  (12): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
  (13): Linear(5.44 k, 6.177% Params, 5.44 KMac, 0.891% MACs, in_features=84, out_features=64, bias=True)
  (14): ReLU(0, 0.000% Params, 64.0 Mac, 0.010% MACs, )
  (15): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
  (16): Linear(650, 0.738% Params, 650.0 Mac, 0.107% MACs, in_features=64, out_features=10, bias=True)
)
Computational complexity:       610.31 KMac
Number of parameters:           88.07 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```




```
class LeNet_D5(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
```

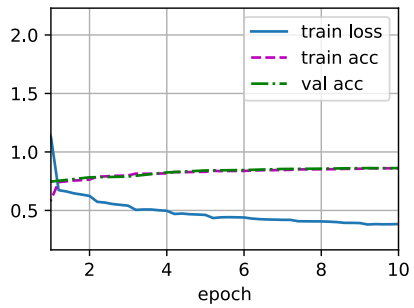
```
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(6, kernel_size=5, padding=2), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(16, kernel_size=5), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(120), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(84), nn.ReLU(),
            nn.Dropout(0.1),
            nn.LazyLinear(num_classes),)

model = LeNet_D5()
model.layer_summary((1, 1, 32, 32))
```

```
Conv2d output shape:     torch.Size([1, 6, 32, 32])
ReLU output shape:       torch.Size([1, 6, 32, 32])
MaxPool2d output shape:  torch.Size([1, 6, 16, 16])
Conv2d output shape:     torch.Size([1, 16, 12, 12])
ReLU output shape:       torch.Size([1, 16, 12, 12])
MaxPool2d output shape:  torch.Size([1, 16, 6, 6])
Flatten output shape:    torch.Size([1, 576])
Linear output shape:     torch.Size([1, 120])
ReLU output shape:       torch.Size([1, 120])
Dropout output shape:    torch.Size([1, 120])
Linear output shape:     torch.Size([1, 84])
ReLU output shape:       torch.Size([1, 84])
Dropout output shape:    torch.Size([1, 84])
Linear output shape:     torch.Size([1, 10])
```

```
# Printing the total Number of MACs and Parameters for the Model
macs, params = ptflops.get_model_complexity_info(model.net, (1, 32, 32))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Sequential(
  82.83 k, 100.000% Params, 605.0 KMac, 100.000% MACs,
  (0): Conv2d(156, 0.188% Params, 159.74 KMac, 26.404% MACs, 1, 6, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (1): ReLU(0, 0.000% Params, 6.14 KMac, 1.016% MACs, )
  (2): MaxPool2d(0, 0.000% Params, 6.14 KMac, 1.016% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (3): Conv2d(2.42 k, 2.917% Params, 347.9 KMac, 57.505% MACs, 6, 16, kernel_size=(5, 5), stride=(1, 1))
  (4): ReLU(0, 0.000% Params, 2.3 KMac, 0.381% MACs, )
  (5): MaxPool2d(0, 0.000% Params, 2.3 KMac, 0.381% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (6): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (7): Linear(69.24 k, 83.597% Params, 69.24 KMac, 11.445% MACs, in_features=576, out_features=120, bias=True)
  (8): ReLU(0, 0.000% Params, 120.0 Mac, 0.020% MACs, )
  (9): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
  (10): Linear(10.16 k, 12.272% Params, 10.16 KMac, 1.680% MACs, in_features=120, out_features=84, bias=True)
  (11): ReLU(0, 0.000% Params, 84.0 Mac, 0.014% MACs, )
  (12): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.1, inplace=False)
  (13): Linear(850, 1.026% Params, 850.0 Mac, 0.140% MACs, in_features=84, out_features=10, bias=True)
)
Computational complexity:       605.0 KMac
Number of parameters:           82.83 k
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```



PROBLEM 4

```
class AlexNet_Simplified(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(32, kernel_size=5, stride=1, padding=2),
            nn.ReLU(), nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(64, kernel_size=3, padding=1), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.LazyConv2d(128, kernel_size=3, padding=1), nn.ReLU(),
            nn.LazyConv2d(128, kernel_size=3, padding=1), nn.ReLU(),
            nn.LazyConv2d(64, kernel_size=3, padding=1), nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2), nn.Flatten(),
            nn.LazyLinear(256), nn.ReLU(), nn.Dropout(p=0.5),
            nn.LazyLinear(128), nn.ReLU(), nn.Dropout(p=0.5),
            nn.LazyLinear(num_classes))
        self.net.apply(d2l.init_cnn)

model = AlexNet_Simplified()
model.layer_summary((1, 1, 128, 128))
```

```
Conv2d output shape:     torch.Size([1, 32, 128, 128])
ReLU output shape:       torch.Size([1, 32, 128, 128])
MaxPool2d output shape:  torch.Size([1, 32, 64, 64])
Conv2d output shape:     torch.Size([1, 64, 64, 64])
ReLU output shape:       torch.Size([1, 64, 64, 64])
MaxPool2d output shape:  torch.Size([1, 64, 32, 32])
Conv2d output shape:     torch.Size([1, 128, 32, 32])
ReLU output shape:       torch.Size([1, 128, 32, 32])
Conv2d output shape:     torch.Size([1, 128, 32, 32])
ReLU output shape:       torch.Size([1, 128, 32, 32])
Conv2d output shape:     torch.Size([1, 64, 32, 32])
ReLU output shape:       torch.Size([1, 64, 32, 32])
MaxPool2d output shape:  torch.Size([1, 64, 16, 16])
Flatten output shape:    torch.Size([1, 16384])
Linear output shape:     torch.Size([1, 256])
ReLU output shape:       torch.Size([1, 256])
Dropout output shape:    torch.Size([1, 256])
Linear output shape:     torch.Size([1, 128])
ReLU output shape:       torch.Size([1, 128])
Dropout output shape:    torch.Size([1, 128])
Linear output shape:     torch.Size([1, 10])
/usr/local/lib/python3.8/dist-packages/torch/nn/modules/lazy.py:180: UserWarning: Lazy modules are a new feature under heavy development
  warnings.warn('Lazy modules are a new feature under heavy development '
```

```
macs, params = ptflops.get_model_complexity_info(model.net, (1, 128, 128))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Warning: variables __flops__ or __params__ are already defined for the moduleConv2d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleMaxPool2d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleConv2d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleMaxPool2d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleConv2d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleConv2d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleConv2d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleMaxPool2d ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleLinear ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleReLU ptflops can affect your code!
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Warning: variables __flops__ or __params__ are already defined for the moduleReLU ptflops can affect your code!
Warning: variables __flops__ or __params__ are already defined for the moduleLinear ptflops can affect your code!
Sequential(
  4.54 M, 100.000% Params, 397.9 MMac, 100.000% MACs,
  (0): Conv2d(832, 0.018% Params, 13.63 MMac, 3.426% MACs, 1, 32, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
  (1): ReLU(0, 0.000% Params, 524.29 KMac, 0.132% MACs, )
  (2): MaxPool2d(0, 0.000% Params, 524.29 KMac, 0.132% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (3): Conv2d(18.5 k, 0.407% Params, 75.76 MMac, 19.040% MACs, 32, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
  (4): ReLU(0, 0.000% Params, 262.14 KMac, 0.066% MACs, )
  (5): MaxPool2d(0, 0.000% Params, 262.14 KMac, 0.066% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (6): Conv2d(73.86 k, 1.626% Params, 75.63 MMac, 19.007% MACs, 64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
  (7): ReLU(0, 0.000% Params, 131.07 KMac, 0.033% MACs, )
  (8): Conv2d(147.58 k, 3.248% Params, 151.13 MMac, 37.981% MACs, 128, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
  (9): ReLU(0, 0.000% Params, 131.07 KMac, 0.033% MACs, )
  (10): Conv2d(73.79 k, 1.624% Params, 75.56 MMac, 18.990% MACs, 128, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
```
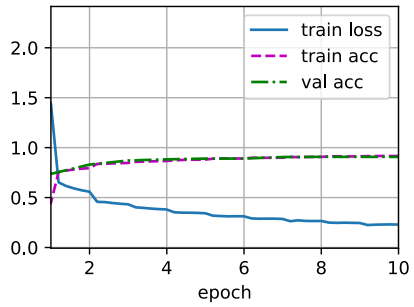

```
  (11): ReLU(0, 0.000% Params, 65.54 KMac, 0.016% MACs, )
  (12): MaxPool2d(0, 0.000% Params, 65.54 KMac, 0.016% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (13): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (14): Linear(4.19 M, 92.324% Params, 4.19 MMac, 1.054% MACs, in_features=16384, out_features=256, bias=True)
  (15): ReLU(0, 0.000% Params, 256.0 Mac, 0.000% MACs, )
  (16): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
  (17): Linear(32.9 k, 0.724% Params, 32.9 KMac, 0.008% MACs, in_features=256, out_features=128, bias=True)
  (18): ReLU(0, 0.000% Params, 128.0 Mac, 0.000% MACs, )
  (19): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
  (20): Linear(1.29 k, 0.028% Params, 1.29 KMac, 0.000% MACs, in_features=128, out_features=10, bias=True)
)
Computational complexity:       397.9 MMac
Number of parameters:           4.54 M
```

```
model = AlexNet_Simplified(lr=0.1)
data = d2l.FashionMNIST(batch_size=128, resize=(128, 128))
lr, num_epochs = 0.1, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```



PROBLEM 5

```
# Resizing the Images to 32x32
data = FashionMNIST(resize = (28, 28))
# Printing the # of Training & Validation Images
print("Training Images   = ", len(data.train))
print("Validation Images = ", len(data.val))

data.train[0][0].shape
```

```
Training Images   =  60000
Validation Images =  10000
torch.Size([1, 28, 28])
```

```
class MyModel(d2l.Classifier):
    def __init__(self, lr=0.1, num_classes=10):
        super().__init__()
        self.save_hyperparameters()
        self.net = nn.Sequential(
            nn.LazyConv2d(32, kernel_size=3, stride=1, padding=1),
            nn.ReLU(),
            nn.LazyConv2d(64, kernel_size=3, stride=1, padding=1),
            nn.ReLU(),
            nn.LazyConv2d(128, kernel_size=3, stride=1, padding=1),
            nn.ReLU(),
            nn.LazyConv2d(256, kernel_size=3, stride=1, padding=1),
            nn.ReLU(),
            nn.MaxPool2d(kernel_size=2, stride=2),
            nn.Flatten(),
            nn.LazyLinear(512),
            nn.ReLU(),
            nn.Dropout(p=0.5),
            nn.LazyLinear(num_classes)
        )
        self.net.apply(d2l.init_cnn)
```

```
model = MyModel()
model.layer_summary((1, 1, 28, 28))
```

```
Conv2d output shape:     torch.Size([1, 32, 28, 28])
ReLU output shape:       torch.Size([1, 32, 28, 28])
Conv2d output shape:     torch.Size([1, 64, 28, 28])
ReLU output shape:       torch.Size([1, 64, 28, 28])
Conv2d output shape:     torch.Size([1, 128, 28, 28])
ReLU output shape:       torch.Size([1, 128, 28, 28])
Conv2d output shape:     torch.Size([1, 256, 28, 28])
ReLU output shape:       torch.Size([1, 256, 28, 28])
MaxPool2d output shape:  torch.Size([1, 256, 14, 14])
Flatten output shape:    torch.Size([1, 50176])
Linear output shape:     torch.Size([1, 512])
ReLU output shape:       torch.Size([1, 512])
Dropout output shape:    torch.Size([1, 512])
Linear output shape:     torch.Size([1, 10])
```

```
macs, params = ptflops.get_model_complexity_info(model.net, (1, 28, 28))
print('{:<30}  {:<8}'.format('Computational complexity: ', macs))
print('{:<30}  {:<8}'.format('Number of parameters: ', params))
```

```
Sequential(
  26.08 M, 100.000% Params, 330.34 MMac, 100.000% MACs,
  (0): Conv2d(320, 0.001% Params, 250.88 KMac, 0.076% MACs, 1, 32, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
  (1): ReLU(0, 0.000% Params, 25.09 KMac, 0.008% MACs, )
  (2): Conv2d(18.5 k, 0.071% Params, 14.5 MMac, 4.390% MACs, 32, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
  (3): ReLU(0, 0.000% Params, 50.18 KMac, 0.015% MACs, )
  (4): Conv2d(73.86 k, 0.283% Params, 57.9 MMac, 17.528% MACs, 64, 128, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
  (5): ReLU(0, 0.000% Params, 100.35 KMac, 0.030% MACs, )
  (6): Conv2d(295.17 k, 1.132% Params, 231.41 MMac, 70.053% MACs, 128, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
  (7): ReLU(0, 0.000% Params, 200.7 KMac, 0.061% MACs, )
  (8): MaxPool2d(0, 0.000% Params, 200.7 KMac, 0.061% MACs, kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
  (9): Flatten(0, 0.000% Params, 0.0 Mac, 0.000% MACs, start_dim=1, end_dim=-1)
  (10): Linear(25.69 M, 98.493% Params, 25.69 MMac, 7.777% MACs, in_features=50176, out_features=512, bias=True)
  (11): ReLU(0, 0.000% Params, 512.0 Mac, 0.000% MACs, )
  (12): Dropout(0, 0.000% Params, 0.0 Mac, 0.000% MACs, p=0.5, inplace=False)
  (13): Linear(5.13 k, 0.020% Params, 5.13 KMac, 0.002% MACs, in_features=512, out_features=10, bias=True)
)
Computational complexity:       330.34 MMac
Number of parameters:           26.08 M
```

```
lr, num_epochs = 0.01, 10
train(model.net, data.get_dataloader(True), data.get_dataloader(False), num_epochs, lr, d2l.try_gpu())
```