

```

1 # Replace the average pooling with max-pooling.
2 # Replace the softmax layer with ReLU.
3 # Adjust the convolution window size.

```

```

1 import torch
2 !pip install d2l==1.0.0a0

```

```

Requirement already satisfied: idna<3,>=2.5 in /usr/local/lib/python3.8/dist-packages (from requests->d2l==1.0.0a0) (2.10)
Requirement already satisfied: chardet<5,>=3.0.2 in /usr/local/lib/python3.8/dist-packages (from requests->d2l==1.0.0a0) (4.0.0)
Requirement already satisfied: urllib3<1.27,>=1.21.1 in /usr/local/lib/python3.8/dist-packages (from requests->d2l==1.0.0a0) (1.24.
Requirement already satisfied: zipp>=0.5 in /usr/local/lib/python3.8/dist-packages (from importlib-metadata>=4.8.0->gym->d2l==1.0.0
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.8/dist-packages (from python-dateutil>=2.1->matplotlib->d2l==1.0.
Requirement already satisfied: ipython>=5.0.0 in /usr/local/lib/python3.8/dist-packages (from ipykernel->jupyter->d2l==1.0.0a0) (7.
Requirement already satisfied: jupyter-client in /usr/local/lib/python3.8/dist-packages (from ipykernel->jupyter->d2l==1.0.0a0) (6.
Requirement already satisfied: tornado>=4.2 in /usr/local/lib/python3.8/dist-packages (from ipykernel->jupyter->d2l==1.0.0a0) (6.2)
Requirement already satisfied: traitlets>=4.1.0 in /usr/local/lib/python3.8/dist-packages (from ipykernel->jupyter->d2l==1.0.0a0) (
Requirement already satisfied: jupyterlab-widgets>=1.0.0 in /usr/local/lib/python3.8/dist-packages (from ipywidgets->jupyter->d2l==
Requirement already satisfied: widgetsnbextension>=3.6.0 in /usr/local/lib/python3.8/dist-packages (from ipywidgets->jupyter->d2l==
Requirement already satisfied: ipython-genutils<=0.2.0 in /usr/local/lib/python3.8/dist-packages (from ipywidgets->jupyter->d2l==1.
Requirement already satisfied: pygments in /usr/local/lib/python3.8/dist-packages (from jupyter-console->jupyter->d2l==1.0.0a0) (2.
Requirement already satisfied: prompt-toolkit!=3.0.0,!<3.0.1,<3.1.0,>=2.0.0 in /usr/local/lib/python3.8/dist-packages (from jupyter
Requirement already satisfied: mistune<2,>=0.8.1 in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0a0)
Requirement already satisfied: jupyter-core in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0a0) (5.2.
Requirement already satisfied: entrypoints>=0.2.2 in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0a0)
Requirement already satisfied: defusedxml in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0a0) (0.7.1)
Requirement already satisfied: Jinja2>=2.4 in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0a0) (2.11.
Requirement already satisfied: pandocfilters>=1.4.1 in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0a
Requirement already satisfied: nbformat>=4.4 in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0a0) (5.7
Requirement already satisfied: testpath in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0a0) (0.6.0)
Requirement already satisfied: bleach in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0a0) (6.0.0)
Requirement already satisfied: Send2Trash>=1.5.0 in /usr/local/lib/python3.8/dist-packages (from notebook->jupyter->d2l==1.0.0a0) (
Requirement already satisfied: terminado>=0.8.3 in /usr/local/lib/python3.8/dist-packages (from notebook->jupyter->d2l==1.0.0a0) (0
Requirement already satisfied: pyzmq>=17 in /usr/local/lib/python3.8/dist-packages (from notebook->jupyter->d2l==1.0.0a0) (23.2.1)
Requirement already satisfied: prometheus-client in /usr/local/lib/python3.8/dist-packages (from notebook->jupyter->d2l==1.0.0a0) (
Requirement already satisfied: argon2-cffi in /usr/local/lib/python3.8/dist-packages (from notebook->jupyter->d2l==1.0.0a0) (21.3.0
Collecting qtpy>=2.0.1
  Downloading QtPy-2.3.0-py3-none-any.whl (83 kB)
      83.6/83.6 KB 11.7 MB/s eta 0:00:00
Requirement already satisfied: backcall in /usr/local/lib/python3.8/dist-packages (from ipython>=5.0.0->ipykernel->jupyter->d2l==1.
Collecting jedi>=0.10
  Downloading jedi-0.18.2-py2.py3-none-any.whl (1.6 MB)
      1.6/1.6 MB 70.6 MB/s eta 0:00:00
Requirement already satisfied: decorator in /usr/local/lib/python3.8/dist-packages (from ipython>=5.0.0->ipykernel->jupyter->d2l==1
Requirement already satisfied: setuptools>=18.5 in /usr/local/lib/python3.8/dist-packages (from ipython>=5.0.0->ipykernel->jupyter->d2l==1
Requirement already satisfied: pexpect in /usr/local/lib/python3.8/dist-packages (from ipython>=5.0.0->ipykernel->jupyter->d2l==1.0
Requirement already satisfied: pickleshare in /usr/local/lib/python3.8/dist-packages (from ipython>=5.0.0->ipykernel->jupyter->d2l=
Requirement already satisfied: MarkupSafe>=0.23 in /usr/local/lib/python3.8/dist-packages (from Jinja2>=2.4->nbconvert->jupyter->d2
Requirement already satisfied: platformdirs>=2.5 in /usr/local/lib/python3.8/dist-packages (from jupyter-core->nbconvert->jupyter->
Requirement already satisfied: jsonschema>=2.6 in /usr/local/lib/python3.8/dist-packages (from nbformat>=4.4->nbconvert->jupyter->d
Requirement already satisfied: fastjsonschema in /usr/local/lib/python3.8/dist-packages (from nbformat>=4.4->nbconvert->jupyter->d2
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.
Requirement already satisfied: ptyprocess in /usr/local/lib/python3.8/dist-packages (from terminado>=0.8.3->notebook->jupyter->d2l=
Requirement already satisfied: argon2-cffi-bindings in /usr/local/lib/python3.8/dist-packages (from argon2-cffi->notebook->jupyter-
Requirement already satisfied: webencodings in /usr/local/lib/python3.8/dist-packages (from bleach->nbconvert->jupyter->d2l==1.0.0a
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->ipyk
Requirement already satisfied: attrs>=17.4.0 in /usr/local/lib/python3.8/dist-packages (from jsonschema>=2.6->nbformat>=4.4->nbconv
Requirement already satisfied: importlib-resources>=1.4.0 in /usr/local/lib/python3.8/dist-packages (from jsonschema>=2.6->nbformat
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 jsonsc
Requirement already satisfied: cffi>=1.0.1 in /usr/local/lib/python3.8/dist-packages (from argon2-cffi-bindings->argon2-cffi->noteb
Requirement already satisfied: pycparser in /usr/local/lib/python3.8/dist-packages (from cffi>=1.0.1->argon2-cffi-bindings->argon2-
Installing collected packages: qtpy, jedi, qtconsole, jupyter, d2l
Successfully installed d2l-1.0.0a0 jedi-0.18.2 jupyter-1.0.0 qtconsole-5.4.0 qtpy-2.3.0

```

```

1 !pip install matplotlib
2 %matplotlib inline
3 !pip install matplotlib-inline
4 import sys
5 !{sys.executable} -m pip install matplotlib

```

```

Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels/public/simple/
Requirement already satisfied: matplotlib in /usr/local/lib/python3.8/dist-packages (3.2.2)
Requirement already satisfied: pyparsing!=2.0.4,!<2.1.2,!<2.1.6,>=2.0.1 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (3.6
Requirement already satisfied: cyycler>=0.10 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (0.11.0)
Requirement already satisfied: numpy>=1.11 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (1.21.6)
Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (1.4.4)
Requirement already satisfied: python-dateutil>=2.1 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (2.8.2)
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.8/dist-packages (from python-dateutil>=2.1->matplotlib) (1.15.0)

```

```

Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels/public/simple/
Collecting matplotlib-inline
  Downloading matplotlib_inline-0.1.6-py3-none-any.whl (9.4 kB)
Requirement already satisfied: traitlets in /usr/local/lib/python3.8/dist-packages (from matplotlib-inline) (5.7.1)
Installing collected packages: matplotlib-inline
Successfully installed matplotlib-inline-0.1.6
Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels/public/simple/
Requirement already satisfied: matplotlib in /usr/local/lib/python3.8/dist-packages (3.2.2)
Requirement already satisfied: cyycler>=0.10 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (0.11.0)
Requirement already satisfied: python-dateutil>=2.1 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (2.8.2)
Requirement already satisfied: numpy>=1.11 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (1.21.6)
Requirement already satisfied: pyparsing!=2.0.4,!=2.1.2,!=2.1.6,>=2.0.1 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (3.0.9)
Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/python3.8/dist-packages (from matplotlib) (1.4.4)
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.8/dist-packages (from python-dateutil>=2.1->matplotlib) (1.15.0)

```

```

1 import time
2 import numpy as np
3 import torch
4 import torchvision
5 from torchvision import transforms
6 from torch import nn
7 from d2l import torch as d2l
8 from torch.optim import lr_scheduler

```

```

1 def LeNet(num_classes=10):
2     net = nn.Sequential(nn.LazyConv2d(6, kernel_size=7, padding=2),
3         nn.ReLU(),
4         nn.MaxPool2d(kernel_size=2, stride=2),
5         nn.LazyConv2d(16, kernel_size=7, padding=2),
6         nn.ReLU(),
7         nn.MaxPool2d(kernel_size=2, stride=2),
8         nn.Flatten(),
9         nn.Linear(400, 120),
10        nn.ReLU(),
11        nn.Linear(120, 84),
12        nn.ReLU(),
13        nn.Linear(84, num_classes))
14    return net

```

```

1 def train(model, train_loader, test_loader, num_epochs, loss_fn, trainer):
2
3     animator = d2l.Animator(xlabel='epoch', xlim=[0, num_epochs], legend=['train loss', 'train accuracy', 'test accuracy'])
4     for epoch in range(num_epochs):
5         metric = d2l.Accumulator(3)
6         for i, (X, y) in enumerate(train_loader):
7             net.train()
8             trainer.zero_grad()
9             y_hat = net(X)
10            l = loss_fn(y_hat, y)
11            l.backward()
12            trainer.step()
13            with torch.no_grad():
14                metric.add(1 * X.shape[0], d2l.accuracy(y_hat, y), X.shape[0])
15            train_loss = metric[0] / metric[2]
16            train_acc = metric[1] / metric[2]
17            if (i + 1) % 50 == 0:
18                animator.add(epoch + i / len(train_loader),
19                    (train_loss, train_acc, None))
20
21        test_acc = d2l.evaluate_accuracy_gpu(model, test_loader)
22        animator.add(epoch+1, (None, None, test_acc))
23
24    print(f'train loss {train_loss:.3f}, train accuracy {train_acc:.3f}, 'f'test accuracy {test_acc:.3f}')

```

```

1 loss = nn.CrossEntropyLoss()
2 batch_size = 256
3 num_epochs = 10
4 lr=0.01

```

```

1 train_loader, test_loader = d2l.load_data_fashion_mnist(batch_size=batch_size)
2 net= LeNet(num_classes=10)
3 trainer = torch.optim.Adam(net.parameters(), lr=lr)

```

```

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
100% 26421880/26421880 [00:03<00:00, 13808658.45it/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-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-labels-idx1-ubyte.gz
100% 29515/29515 [00:00<00:00, 145814.47it/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-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images-idx3-ubyte.gz
100% 4422102/4422102 [00:01<00:00, 4609267.46it/s]
Extracting ../data/FashionMNIST/raw/t10k-images-idx3-ubyte.gz to ../data/FashionMNIST/r

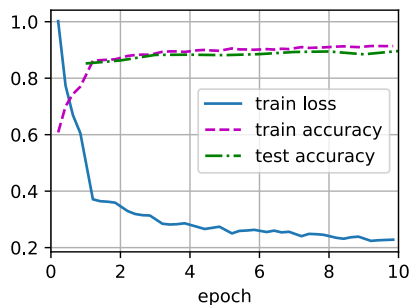
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels-idx1-ubyte.gz
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels-idx1-ubyte.gz
100% 5148/5148 [00:00<00:00, 313672.55it/s]
Extracting ../data/FashionMNIST/raw/t10k-labels-idx1-ubyte.gz to ../data/FashionMNIST/r

/usr/local/lib/python3.8/dist-packages/torch/utils/data/dataloader.py:554: UserWarning:
  warnings.warn(_create_warning_msg(
/usr/local/lib/python3.8/dist-packages/torch/nn/modules/lazy.py:180: UserWarning: Lazy n
  warnings.warn('Lazv modules are a new feature under heavv development '

```

```
1 train(net, train_loader, test_loader, num_epochs, loss, trainer)
```

```
train loss 0.231, train accuracy 0.913, test accuracy 0.896
```



```
1 # Measuring and comparing theoretical computation complexity (number of operations and parameters size)
```

```
1 pip install torchinfo
```

```

Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels/public/simple/
Collecting torchinfo
  Downloading torchinfo-1.7.2-py3-none-any.whl (22 kB)
Installing collected packages: torchinfo
Successfully installed torchinfo-1.7.2

```

```

1 from torchinfo import summary
2
3 model = LeNet()
4 batch_size = 256
5 summary(model, input_size=(batch_size, 1, 28, 28))

```

```

=====
Layer (type:depth-idx)                   Output Shape              Param #
=====
Sequential                               [256, 10]                 --
├─Conv2d: 1-1                             [256, 6, 26, 26]          300
├─ReLU: 1-2                               [256, 6, 26, 26]          --
├─MaxPool2d: 1-3                          [256, 6, 13, 13]          --
├─Conv2d: 1-4                             [256, 16, 11, 11]         4,720
├─ReLU: 1-5                               [256, 16, 11, 11]         --
├─MaxPool2d: 1-6                          [256, 16, 5, 5]           --
├─Flatten: 1-7                            [256, 400]                --
├─Linear: 1-8                             [256, 120]                48,120
├─ReLU: 1-9                               [256, 120]                --
├─Linear: 1-10                            [256, 84]                 10,164
├─ReLU: 1-11                             [256, 84]                 --
└─Linear: 1-12                            [256, 10]                 850
=====

```

```
Total params: 64,154
Trainable params: 64,154
Non-trainable params: 0
Total mult-adds (M): 213.26
=====
Input size (MB): 0.80
Forward/backward pass size (MB): 12.71
Params size (MB): 0.26
Estimated Total Size (MB): 13.77
=====
```

✓ 11s completed at 7:58 PM

×