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Applied Accelerated AI

Introduction to PyTorch

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What is PyTorch

- Open source machine learning library
- Developed by Facebook's AI Research lab
- It leverages the power of GPUs
- Automatic computation of gradients
- Makes it easier to test and develop new ideas.

Other libraries

PyTorch Tensor

- Similar to NumPy arrays
- They can also be used on a GPU
    - Faster computation
- Random matrix

```
import torch

x=torch.rand(2,3)
y=torch.rand(3,3)

print x
print y
```

PyTorch Tensor

- Similar to NumPy arrays
- They can also be used on a GPU
  - Faster computation
- All zeros
- Directly from data
- Size of a tensor

```
import torch

x = torch.zeros(5, 3)

x = torch.tensor([5.5, 3])

print x.size()
```

Operations

- Adding tensors
- Indexing

```
x = torch.randn(4, 4)

y = torch.randn(4, 4)

print(torch.add(x, y))

print(x[:, 1])
```

Operations

- Resizing
  - If you want to resize/reshape tensor

- `x = torch.randn(4, 4)`

- `y = x.view(16)`
- `z = x.view(-1, 8)`

- `print(x.size(), y.size(), z.size())`

- ***Output:***
- `torch.Size([4, 4])`
- `torch.Size([16])`
- `torch.Size([2, 8])`

```
x = torch.randn(1, 4, 32, 24)

y = x.view(8, 2, -1, 3, 8)

print(y.size())
```

Output shape?

Torch tensor vs NumPy array

- NumPy array
  - CPU
- Torch tensor
  - GPU

```
a = torch.ones(5)
tensor([1., 1., 1., 1., 1.])

b = a.numpy()

a = numpy.ones(5)
b = torch.from_numpy(a)
```

Matrix Multiplication in PyTorch

```
import torch

mat1=torch.randn(2,3)
mat2=torch.randn(3,3)
res=torch.mm(mat1,mat2)

print res.size()
```

Output: (2L, 3L)

Batch Matrix Multiplication in PyTorch

```
import torch

batch1=torch.randn(10,3,4)
batch2=torch.randn(10,4,5)
res=torch.bmm(batch1,batch2)

print res.size()

Output:  (10L, 3L, 5L)
```

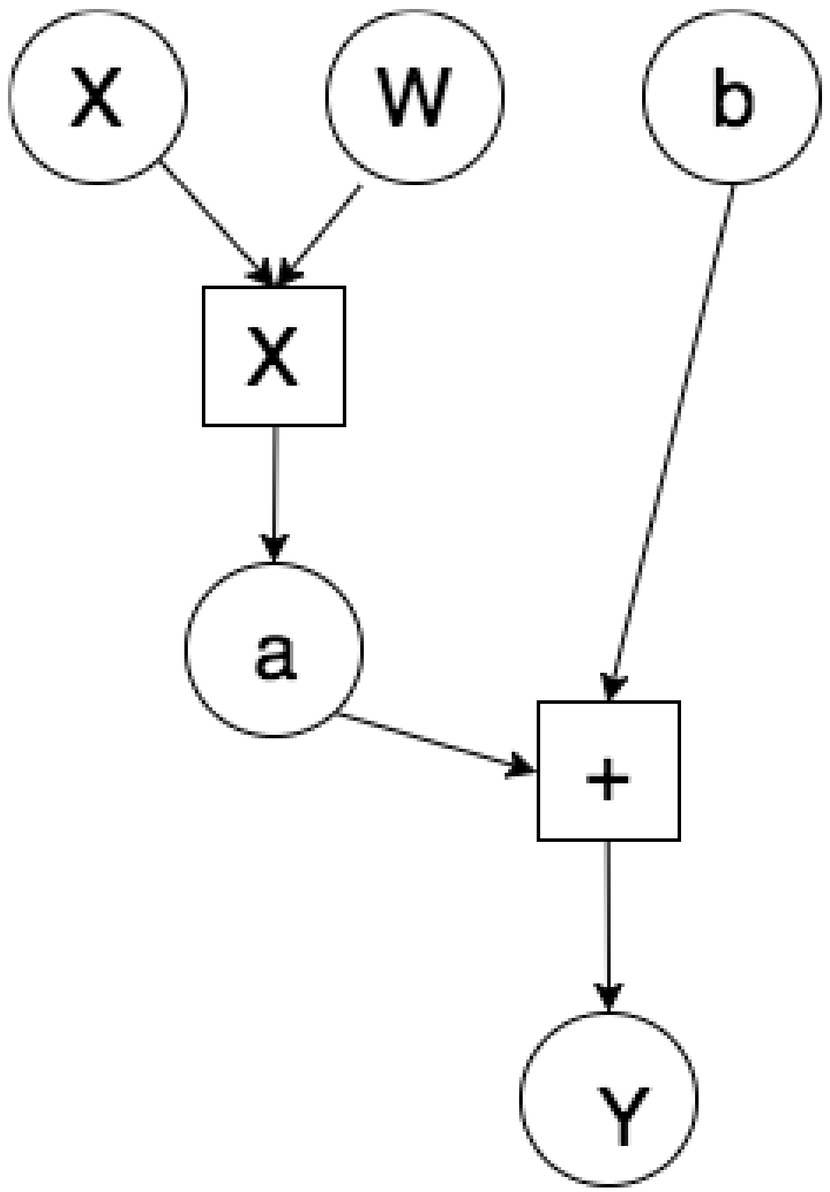
Many Tensor operations in PyTorch…

- torch.mm
- Matrix multiplication
- torch.bmm
- Batch matrix multiplication
- torch.cat
- Tensor Concatenation
- torch.sqeueeze/torch.unsqueeze
- Change Tensor dimensions
- …
- Check documentation at http://pytorch.org/docs/master/torch.html#tensors

Computational Graphs

```
import torch

x = torch.ones(2,2)
y = torch.ones(2,1)
w = torch.randn(2,1,requires_grad=True)
b = torch.randn(1,requires_grad=True)
```



Computational Graphs

```
p = torch.sigmoid(torch.mm(x, w) + b)   # prediction

loss = -y*torch.log(p)-(1-y)*torch.log(1-p)   # cross-entropy loss

cost = loss.mean()
# the cost to minimize
```

Automatic Gradient Computation

```
p = torch.sigmoid(torch.mm(x, w) + b)

loss = -y*torch.log(p)-(1-y)*torch.log(1-p)
cost = loss.mean()

cost.backward()

print w.grad
print b.grad
```

Training procedure

- Define the neural network
- Iterate over a dataset of inputs
- Process input through the network
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Build Neural Networks using PyTorch

Neural networks can be constructed using the torch.nn package.

- Forward
  - An nn.Module contains layers, and
  - A method forward(input) that returns the output
  - You can use any of the Tensor operations in the forward function
- Backward
  - nn depends on autograd
  - You just have to define the forward function

Define a Network Class

```
import torch
import torch.nn as nn
```

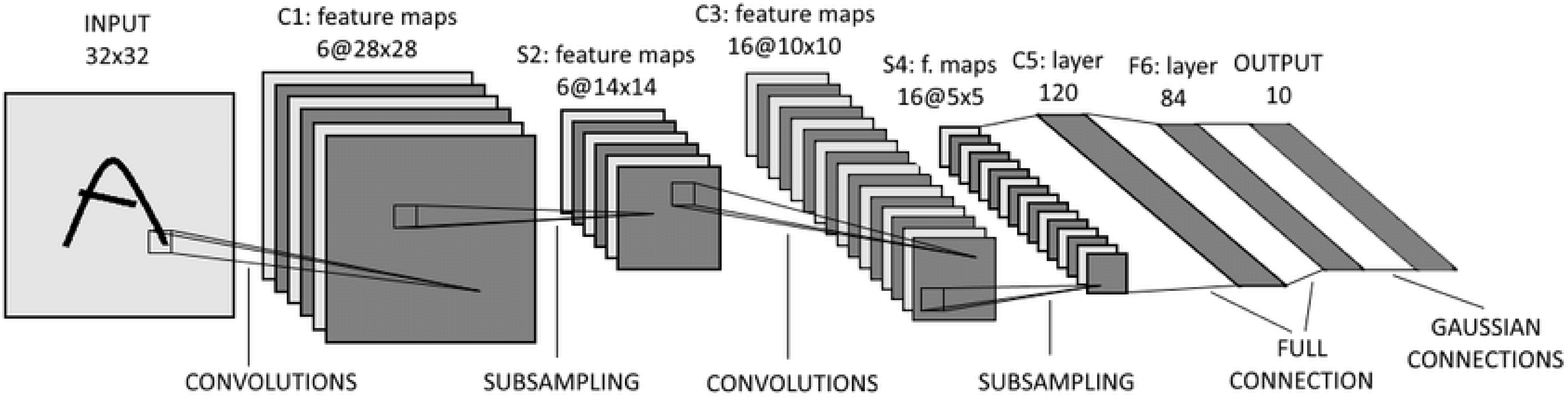
```
class Net(nn.Module):
```

```
    def_init__(self):
        super(Net, self).__init__()
        # create layers
```

```
    def forward(self, x):
        # define feed-forward function
```

You don’t need to define a backward function!

CNN for MNIST: A Full Example



https://medium.com/deep-learning-g/build-lenet-from-scratch-7bd0c67a151e

Define a CNN Network

```
class Net(nn.Module):

    def __init__(self):
        super(Net, self).__init__()
        # 1 input image channel, 6 output channels, 5x5 square convolutio
        # kernel
        self.conv1 = nn.Conv2d(1, 6, 5)
        self.conv2 = nn.Conv2d(6, 16, 5)
        # an affine operation: y = Wx + b
        self.fc1 = nn.Linear(16 * 5 * 5, 120)
        self.fc2 = nn.Linear(120, 84)
        self.fc3 = nn.Linear(84, 10)

    def forward(self, x):
        # Max pooling over a (2, 2) window
        x = F.max_pool2d(F.relu(self.conv1(x)), (2, 2))
        # If the size is a square you can only specify a single number
        x = F.max_pool2d(F.relu(self.conv2(x)), 2)
        x = x.view(-1, self.num_flat_features(x))
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = self.fc3(x)
        return x

    def num_flat_features(self, x):
        size = x.size()[1:]  # all dimensions except the batch dimension
        num_features = 1
        for s in size:
            num_features *= s
        return num_features
```

Define a CNN Network

```
def   init  (self):
        super(Net, self).__init__()
        # 1 input image channel, 6 output channels,
 5x5 square convolution kernel

        self.conv1 = nn.Conv2d(1, 6, 5)
        self.conv2 = nn.Conv2d(6, 16, 5)

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```

Define a CNN Network

```
def forward(self, x):
        # Max pooling over a (2, 2) window
        x = F.max_pool2d(F.relu(self.conv1(x)), (2, 2)) # If the size is
        #square you can only specify a single number
        x = F.max_pool2d(F.relu(self.conv2(x)), 2)
        x = x.view(-1, self.num_flat_features(x))
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = self.fc3(x)

        return x
```

Define a CNN Network

```
def num_flat_features(self, x):
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```

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Data

- For images
  - Pillow, OpenCV are useful
- For audio
  - Scipy and librosa
- For text
  - NLTK and SpaCy are useful

- Load data into memory as NumPy array
  - Then convert to tensor for GPU

Loading data - torchvision

- Torchvision
  - it’s extremely easy to load existing datasets

```
import torchvision
import torchvision.transforms as transforms
```

Loading data - torchvision

```
import torchvision
import torchvision.transforms as transforms

transform = transforms.Compose([transforms.ToTensor(),
transforms.Normalize((0.5,0.5,0.5), (0.5,0.5,0.5))])

trainset = torchvision.datasets.CIFAR10(root='./data',
train=True, download=True, transform=transform)
trainloader = torch.utils.data.DataLoader(trainset,
batch_size=4, shuffle=True, num_workers=2)
```

Loading data - torchvision

```
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import torchvision.transforms as transforms

transform = transforms.Compose([transforms.ToTensor(),
transforms.Normalize((0.5,0.5,0.5), (0.5,0.5,0.5))])


testset = torchvision.datasets.CIFAR10(root='./data',
train=False, download=True, transform=transform)
testloader = torch.utils.data.DataLoader(testset,
batch_size=4, shuffle=False, num_workers=2)
```

Training procedure

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Feed-forward

```
def forward(self, x):
        # Max pooling over a (2, 2) window
        x = F.max_pool2d(F.relu(self.conv1(x)), (2, 2))
        # If the size is a square you can only specify a
single number
        x = F.max_pool2d(F.relu(self.conv2(x)), 2)
        x = x.view(-1, self.num_flat_features(x))
        x = F.relu(self.fc1(x))
        x = F.relu(self.fc2(x))
        x = self.fc3(x)

        return x
```

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Loss function

- A loss function takes the (output, target) pair of inputs
- Computes a value that estimates how far away the output is from the target.
- There are several different loss functions under the nn package.
- A simple loss can be
  - nn.MSELoss
  - It computes the mean-squared error between the input and the target.

Loss function

```
output = net(input)
target = torch.randn(10)
# a dummy target, for example
target = target.view(1, -1)
# make it the same shape as output

criterion = nn.MSELoss()

loss = criterion(output, target)
```

Training procedure

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Gradient computation

```
output = net(input)

loss = criterion(output, target)

loss.backward()
```

Training procedure

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Update parameters

```
import torch.optim as optim

# create your optimizer
optimizer = optim.SGD(net.parameters(), lr=0.01)

# in your training loop:
optimizer.zero_grad()
output = net(input)
loss = criterion(output, target)
loss.backward()
optimizer.step()     # Does the update
```

- Total training samples = 80000 Batch-size = 50
- Each iteration takes 30 seconds
- How many hours for 3 epochs of training?

Full training

```
net = Net()

trainloader = torch.utils.data.DataLoader
                 (trainset, batch_size=4,
                  shuffle=True, num_workers=2)

criterion = nn.CrossEntropyLoss()

optimizer = optim.SGD(net.parameters(),
                lr=0.001, momentum=0.9)
```

Full training

```
for epoch in range(2):
# loop over the dataset multiple times

    running_loss = 0.0
    for i, data in enumerate(trainloader, 0):
        # training code for each batch

print('Finished Training')
```

Full training

```
for epoch in range(2):
    running_loss = 0.0
    for i, data in enumerate(trainloader, 0):
        # get the inputs;
        inputs, labels = data

        # zero the parameter gradients
        optimizer.zero_grad()
        ...
```

Full training

```
for epoch in range(2):
    for i, data in enumerate(trainloader, 0):
        ...
        # forward + backward + optimize
        outputs = net(inputs)
        loss = criterion(outputs, labels)
        loss.backward()
        optimizer.step()
        ...
```

Full training

```
for epoch in range(2):
    for i, data in enumerate(trainloader, 0):
        ...
        # print statistics
        running_loss += loss.item()
        if i % 2000 == 1999: # every 2000 batches
            print('[%d, %5d] loss: %.3f' %
                  (epoch+1,i+1,running_loss/2000))
            running_loss = 0.0
```

Full training

```
for epoch in range(2):
# loop over the dataset multiple times


        # training code for each batch
print('Finished Training')

PATH = './cifar_net.pth'
torch.save(net.state_dict(), PATH)
```

Testing

```
dataiter = iter(testloader)
images, labels = dataiter.next()

net = Net()
net.load_state_dict(torch.load(PATH))
outputs = net(images)

_, predicted = torch.max(outputs, 1)
```

Training on GPU

- Let's first define our device

```
device = torch.device("cuda:0" if
torch.cuda.is_available() else "cpu")

net.to(device)

inputs, labels = data[0].to(device),
data[1].to(device)
```

References

- Sources for this lecture include materials from pytorch.org

Thank You