

PS1-Synthetic-Handout

October 3, 2020

1 CS7180 Problem Set 1: Implement a teacher-student network setting for Gaussian inputs (20 points)

Welcome to CS7180!

Before you start, make sure to read the problem description in the handout pdf.

Collaborators: Apoorva Durai, Manaswini, Sinjini Bose. Discussed concepts.

```
[24]: # Dependencies
import argparse
import torch
import torch.nn.functional as F
import torch.optim as optim
from torchvision import datasets, transforms
import numpy as np

# hyper parameters
batch_size = 100
width = 5
d_input = 100
```

2 Part 1: Implement a two-layer neural network with ReLU activation (5 points)

```
[2]: class Net(torch.nn.Module):

    def __init__(self, d_input, width):

        super(Net, self).__init__()
        # -----
        # Write your implementation here.

        # Linear layer obtaining input to the hidden layer from the input layer
        self.fc1 = torch.nn.Linear(d_input, width)
```

```

        # Applying activation to the output of hidden layer before feeding into
        ↪ final layer
        self.act = torch.nn.ReLU()

        # Linear layer -> narrowing to 1 output from hidden layer
        self.fc2 = torch.nn.Linear(width,1)

        # -----

    def forward(self, x):

        x = x.view(-1, d_input)
        # -----
        # Write your implementation here.

        x = self.act(self.fc1(x))
        x = self.fc2(x)
        return x

        # -----

```

2.0.1 Generating the data

```

[21]: # sample size
N = 5 * width * d_input

# random data from standard normal distribution
x_train = torch.randn(N, d_input)
x_test = torch.randn(N, d_input)

# teacher network with random weights
teacher = Net(d_input, width)

# generate labels using the teacher network
y_train = torch.FloatTensor([teacher.forward(x) for x in x_train])
y_test = torch.FloatTensor([teacher.forward(x) for x in x_test])

# combine the data and labels into pytorch friendly format
train_data = torch.utils.data.TensorDataset(x_train, y_train)
test_data = torch.utils.data.TensorDataset(x_test, y_test)

# prepare data loaders
train_loader = torch.utils.data.DataLoader(train_data, batch_size=batch_size)
test_loader = torch.utils.data.DataLoader(test_data, batch_size=batch_size)

```

3 Part 2: Set up the quadratic loss function and an SGD optimizer (10 points)

```
[6]: n_epochs = 2000 # the number of epochs can be tuned for better performance

criterion = torch.nn.MSELoss()
optimizer = torch.optim.SGD(teacher.parameters(), lr=0.01)
teacher.train() # prep model for training

for epoch in range(n_epochs):
    train_loss = 0.0

    # train the model
    for idx, (data, labels) in enumerate(train_loader):
        # -----
        # Write your implementation here.

        # clear the gradients of all optimized variables
        optimizer.zero_grad()
        # forward pass: compute predicted outputs by passing inputs to the model
        output = teacher(data)
        # calculate the loss
        loss = criterion(output, labels)
        # backward pass: compute gradient of the loss with respect to model
        ↪ parameters
        loss.backward()
        # perform a single optimization step (parameter update)
        optimizer.step()
        # update running training loss
        train_loss += loss

    # -----

    # print the mean squared loss of the training dataset normalized by the
    ↪ mean square of the training dataset labels
    print('Epoch: {} \tTraining Loss: {:.6f}'.format(
        epoch+1,
        train_loss / torch.mean(torch.pow(y_train, 2))))
```

```
C:\Users\mouni\Anaconda3\lib\site-packages\torch\nn\modules\loss.py:431:
UserWarning: Using a target size (torch.Size([100])) that is different to the
input size (torch.Size([100, 1])). This will likely lead to incorrect results
due to broadcasting. Please ensure they have the same size.
    return F.mse_loss(input, target, reduction=self.reduction)
```

```
Epoch: 1          Training Loss: 21.061852
Epoch: 2          Training Loss: 19.397266
```

Epoch: 3	Training Loss: 18.120869
Epoch: 4	Training Loss: 17.117247
Epoch: 5	Training Loss: 16.312916
Epoch: 6	Training Loss: 15.657936
Epoch: 7	Training Loss: 15.116551
Epoch: 8	Training Loss: 14.664048
Epoch: 9	Training Loss: 14.281998
Epoch: 10	Training Loss: 13.956030
Epoch: 11	Training Loss: 13.675710
Epoch: 12	Training Loss: 13.432755
Epoch: 13	Training Loss: 13.220798
Epoch: 14	Training Loss: 13.034711
Epoch: 15	Training Loss: 12.870484
Epoch: 16	Training Loss: 12.724731
Epoch: 17	Training Loss: 12.594853
Epoch: 18	Training Loss: 12.478600
Epoch: 19	Training Loss: 12.374182
Epoch: 20	Training Loss: 12.280092
Epoch: 21	Training Loss: 12.194963
Epoch: 22	Training Loss: 12.117729
Epoch: 23	Training Loss: 12.047459
Epoch: 24	Training Loss: 11.983365
Epoch: 25	Training Loss: 11.924751
Epoch: 26	Training Loss: 11.871025
Epoch: 27	Training Loss: 11.821671
Epoch: 28	Training Loss: 11.776239
Epoch: 29	Training Loss: 11.734344
Epoch: 30	Training Loss: 11.695641
Epoch: 31	Training Loss: 11.659824
Epoch: 32	Training Loss: 11.626631
Epoch: 33	Training Loss: 11.595822
Epoch: 34	Training Loss: 11.567187
Epoch: 35	Training Loss: 11.540544
Epoch: 36	Training Loss: 11.515714
Epoch: 37	Training Loss: 11.492553
Epoch: 38	Training Loss: 11.470922
Epoch: 39	Training Loss: 11.450697
Epoch: 40	Training Loss: 11.431772
Epoch: 41	Training Loss: 11.414046
Epoch: 42	Training Loss: 11.397429
Epoch: 43	Training Loss: 11.381837
Epoch: 44	Training Loss: 11.367195
Epoch: 45	Training Loss: 11.353436
Epoch: 46	Training Loss: 11.340497
Epoch: 47	Training Loss: 11.328319
Epoch: 48	Training Loss: 11.316852
Epoch: 49	Training Loss: 11.306046
Epoch: 50	Training Loss: 11.295859

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Epoch: 122	Training Loss: 11.114350
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Epoch: 124	Training Loss: 11.113838
Epoch: 125	Training Loss: 11.113601
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Epoch: 1600	Training Loss: 11.108342
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Epoch: 1881	Training Loss: 11.108280
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Epoch: 1883	Training Loss: 11.108279
Epoch: 1884	Training Loss: 11.108278
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Epoch: 1922	Training Loss: 11.108271

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Epoch: 1941	Training Loss: 11.108267
Epoch: 1942	Training Loss: 11.108267
Epoch: 1943	Training Loss: 11.108267
Epoch: 1944	Training Loss: 11.108267
Epoch: 1945	Training Loss: 11.108267
Epoch: 1946	Training Loss: 11.108266
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Epoch: 1948	Training Loss: 11.108266
Epoch: 1949	Training Loss: 11.108265
Epoch: 1950	Training Loss: 11.108264
Epoch: 1951	Training Loss: 11.108265
Epoch: 1952	Training Loss: 11.108264
Epoch: 1953	Training Loss: 11.108264
Epoch: 1954	Training Loss: 11.108264
Epoch: 1955	Training Loss: 11.108265
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Epoch: 1961	Training Loss: 11.108262
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Epoch: 1983	Training Loss: 11.108257
Epoch: 1984	Training Loss: 11.108257
Epoch: 1985	Training Loss: 11.108257
Epoch: 1986	Training Loss: 11.108255
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Epoch: 1988	Training Loss: 11.108255
Epoch: 1989	Training Loss: 11.108255
Epoch: 1990	Training Loss: 11.108255
Epoch: 1991	Training Loss: 11.108255
Epoch: 1992	Training Loss: 11.108255
Epoch: 1993	Training Loss: 11.108254
Epoch: 1994	Training Loss: 11.108254
Epoch: 1995	Training Loss: 11.108254
Epoch: 1996	Training Loss: 11.108253
Epoch: 1997	Training Loss: 11.108254
Epoch: 1998	Training Loss: 11.108254
Epoch: 1999	Training Loss: 11.108254
Epoch: 2000	Training Loss: 11.108254

```
[ ]: # Test the performance of the trained model

teacher.eval()
test_loss = 0.0

for idx, (data, labels) in enumerate(test_loader):
    # forward pass
    output = teacher(data)
    test_loss += criterion(output, labels).item()

# print the mean squared loss of the test dataset normalized by the mean square
# of the test labels
print('Average mean squared error {:.6f}'.format(test_loss / torch.mean(torch.
    pow(y_test, 2))))
```

4 Part 3: Vary the width parameter, and plot the test error for different widths (5 points)

1. How does the test error vary as we change the width? In particular, consider varying the width of the student network from 1 to 20.
2. [Bonus] What happens if we vary the sample size?
3. [Bonus] How about adding a small amount of noise to the labels of the training dataset?

Report what you found and include the results in your submission.

```
[10]: n_epochs = 2000 # the number of epochs can be tuned for better performance
```

```
criterion = torch.nn.MSELoss()
```

```
[14]: def student_net(w):
    std_net = Net(d_input,w)
    std_net.train() # prep model for training
    optimizer = torch.optim.SGD(std_net.parameters(), lr=0.01)

    for epoch in range(n_epochs):
        train_loss = 0.0

        # train the model
        for idx, (data, labels) in enumerate(train_loader):
            # -----
            # Write your implementation here.

            # clear the gradients of all optimized variables
            optimizer.zero_grad()
            # forward pass: compute predicted outputs by passing inputs to the
            →model
            output = std_net(data)
            # calculate the loss
            loss = criterion(output,labels)
            # backward pass: compute gradient of the loss with respect to model
            →parameters
            loss.backward()
            # perform a single optimization step (parameter update)
            optimizer.step()
            # update running training loss
            train_loss += loss

            t_loss = train_loss / torch.mean(torch.pow(y_train, 2))

            # -----

        # Test the performance of the trained model
        std_net.eval()
```

```

test_loss = 0.0

for idx, (data, labels) in enumerate(test_loader):
    # forward pass
    output = std_net(data)
    test_loss += criterion(output, labels).item()

    # print the mean squared loss of the test dataset normalized by the mean
    ↳ square of the test labels
    print('Average mean squared error {:.6f}'.format(test_loss / torch.
    ↳ mean(torch.pow(y_test, 2))))

```

```

[17]: test_error = []
      for w in range(1,21):
          print("width:",w)
          test_error.append(student_net(w))

```

```

width: 1
Average mean squared error 10.930061
width: 2
Average mean squared error 10.916376
width: 3
Average mean squared error 10.914468
width: 4
Average mean squared error 10.910889
width: 5
Average mean squared error 10.913124
width: 6
Average mean squared error 10.910731
width: 7
Average mean squared error 10.910593
width: 8
Average mean squared error 10.910300
width: 9
Average mean squared error 10.910397
width: 10
Average mean squared error 10.910455
width: 11
Average mean squared error 10.910155
width: 12
Average mean squared error 10.910148
width: 13
Average mean squared error 10.909992
width: 14
Average mean squared error 10.909336
width: 15
Average mean squared error 10.910934

```

```

width: 16
Average mean squared error 10.909252
width: 17
Average mean squared error 10.909606
width: 18
Average mean squared error 10.909761
width: 19
Average mean squared error 10.908634
width: 20
Average mean squared error 10.908721

```

Varying Sample size

Having width as 20 and changing the Sample size

```

[18]: # sample size
N1 = 5 * 20 * d_input

# random data from standard normal distribution
x_train = torch.randn(N1, d_input)
x_test = torch.randn(N1, d_input)

# teacher network with random weights
teacher = Net(d_input, width)

# generate labels using the teacher network
y_train = torch.FloatTensor([teacher.forward(x) for x in x_train])
y_test = torch.FloatTensor([teacher.forward(x) for x in x_test])

# combine the data and labels into pytorch friendly format
train_data = torch.utils.data.TensorDataset(x_train, y_train)
test_data = torch.utils.data.TensorDataset(x_test, y_test)

# prepare data loaders
train_loader = torch.utils.data.DataLoader(train_data, batch_size=batch_size)
test_loader = torch.utils.data.DataLoader(test_data, batch_size=batch_size)

```

```

[19]: def student_net(w):
    std_net = Net(d_input, w)
    std_net.train() # prep model for training
    optimizer = torch.optim.SGD(std_net.parameters(), lr=0.01)

    for epoch in range(n_epochs):
        train_loss = 0.0

        # train the model
        for idx, (data, labels) in enumerate(train_loader):
            # -----

```



```

        # Write your implementation here.

        # clear the gradients of all optimized variables
        optimizer.zero_grad()
        # forward pass: compute predicted outputs by passing inputs to the
→model
        output = std_net(data)
        # calculate the loss
        loss = criterion(output, labels)
        # backward pass: compute gradient of the loss with respect to model
→parameters
        loss.backward()
        # perform a single optimization step (parameter update)
        optimizer.step()
        # update running training loss
        train_loss += loss

        t_loss = train_loss / torch.mean(torch.pow(y_train, 2))

        # -----

        # Test the performance of the trained model
        std_net.eval()
        test_loss = 0.0

        for idx, (data, labels) in enumerate(test_loader):
            # forward pass
            output = std_net(data)
            test_loss += criterion(output, labels).item()

            # print the mean squared loss of the test dataset normalized by the mean
→square of the test labels
            print('Average mean squared error {:.6f}'.format(test_loss / torch.
→mean(torch.pow(y_test, 2))))

```

```

[20]: test_error = []
      test_error.append(student_net(20))

```

Average mean squared error 87.164070

Varying sample size is increasing the *mean squared error*. However we can try for different vlaues of *Width* and *d_input* to experiment what actually happens for smaller to larger values of *N*(*Sample Size*)

```

[25]: # generate labels using the teacher network
      y_train = torch.FloatTensor([teacher.forward(x) for x in x_train])
      x_train = torch.randn(N, d_input)

```

```

dim1 = x_train.shape #to get the dimesion of the data
dim2 = y_train.shape

noise1 = np.random.rand(dim1)
noise2 = np.random.rand(dim2)

noisy_data_x = x_train + noise1
noisy_data_y = y_train + noise2 # to add noise the existing data

noisy_train_data = torch.utils.data.TensorDataset(noisy_data_x, noisy_data_y)

noisy_data_loader = torch.utils.data.DataLoader(noisy_train_data,
↪batch_size=batch_size)

```

```

↪-----

```

TypeError Traceback (most recent call
 ↪last)

```

<ipython-input-25-fa668226c435> in <module>
      6 dim1 = x_train.shape #to get the dimesion of the data
      7 dim2 = y_train.shape
----> 8 noise1 = np.random.rand(dim1)
      9 noise2 = np.random.rand(dim2)
     10

mtrand.pyx in mtrand.RandomState.rand()

mtrand.pyx in mtrand.RandomState.random_sample()

mtrand.pyx in mtrand.cont0_array()

TypeError: 'torch.Size' object cannot be interpreted as an integer

```