HW5

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1 Homework 5

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[233]:
```
# Library import code from book
%matplotlib inline
from matplotlib import pyplot as plt
import numpy as np
import torch
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim

# Personal imports
import pandas as pd
from sklearn.preprocessing import MinMaxScaler, StandardScaler
from sklearn.model_selection import train_test_split
```

1.1 Problem 1

[234]:
```
t_c = [0.5, 14.0, 15.0, 28.0, 11.0, 8.0, 3.0, -4.0, 6.0, 13.0, 21.0]
t_u = [35.7, 55.9, 58.2, 81.9, 56.3, 48.9, 33.9, 21.8, 48.4, 60.4, 68.4]
t_c = torch.tensor(t_c)
t_u = torch.tensor(t_u)
t_un = 0.1*t_u
```

[235]:
```
# Linear Model
def lin_model(t_u, w, b):
    return w * t_u + b
```

[236]:
```
# Non-Linear Model
def model(t_u, w1, w2, b):
    return w1 * t_u ** 2 + w2 * t_u + b
```

[237]:
```
# Calculate loss and provides average
def loss_fn(t_p, t_c):
    squared_diffs = (t_p - t_c)**2
```

```
    return squared_diffs.mean()
```

[238]:
```
# Linear model parameters
w = torch.ones(())
lin_b = torch.zeros(())
lin_t_p = lin_model(t_u, w, lin_b)
lin_t_p
```

[238]:
```
tensor([35.7000, 55.9000, 58.2000, 81.9000, 56.3000, 48.9000, 33.9000, 21.8000,
        48.4000, 60.4000, 68.4000])
```

[239]:
```
# Non-linear model parameters
w1 = torch.ones(())
w2 = torch.ones(())
b = torch.zeros(())
t_p = model(t_u, w1, w2, b)
t_p
```

[239]:
```
tensor([1310.1901, 3180.7100, 3445.4399, 6789.5103, 3225.9900, 2440.1101,
        1183.1101,  497.0399, 2390.9600, 3708.5601, 4746.9600])
```

[227]:
```
loss = loss_fn(t_p, t_c)
loss
```

[227]:
```
tensor(11709471.)
```

[228]:
```
# Non-linear training loop
def training_loop (n_epochs, optimizer, params, t_u, t_c, learning_rate):
    print(f'Learning Rate: {learning_rate}')
    for epoch in range(1, n_epochs+1):
        w1, w2, b = params
        t_p = model (t_u, w1, w2, b)
        loss = loss_fn(t_p, t_c)

        optimizer.zero_grad()
        loss.backward()
        optimizer.step()

        if epoch % 500 == 0:
            print ('Epoch %d, Loss %f' % (epoch, float(loss)))
    return params, loss

# Linear training loop
def lin_training_loop (n_epochs, optimizer, params, t_u, t_c):
    for epoch in range(1, n_epochs+1):
        t_p = lin_model (t_u, *params)
        loss = loss_fn(t_p, t_c)
```

```
        optimizer.zero_grad()
        loss.backward()
        optimizer.step()

        if epoch % 500 == 0:
            print ('Epoch %d, Loss %f' % (epoch, float(loss)))
    return params, loss
```

[229]:
```
learning_rate = [0.1, 0.01, 0.001, 0.0001]
train_params = torch.zeros(len(learning_rate), 3)
train_loss = torch.zeros(len(learning_rate), 1)
lin_train_params = torch.zeros(1, 2)
lin_train_loss = torch.zeros(1, 1)

for i in learning_rate:
    params = torch.tensor([1.0, 1.0, 0.0], requires_grad=True)
    optimizer = optim.SGD([params], lr=i)

    train_params[learning_rate.index(i)], train_loss[learning_rate.index(i)] =␣
 ↪training_loop(
        n_epochs = 5000,
        optimizer = optimizer,
        params = params,
        t_u = t_un,
        t_c = t_c,
        learning_rate = i)

# Compare with linear model
lin_params = torch.tensor([1.0, 0.0], requires_grad=True)
learning_rate = 0.0001
optimizer = optim.SGD([lin_params], lr=learning_rate)
print(f'Linear model with LR={learning_rate}')
lin_train_params, lin_train_loss = lin_training_loop(
    n_epochs = 5000,
    optimizer = optimizer,
    params = lin_params,
    t_u = t_un,
    t_c = t_c)
```

```
Learning Rate: 0.1
Epoch 500, Loss nan
Epoch 1000, Loss nan
Epoch 1500, Loss nan
Epoch 2000, Loss nan
Epoch 2500, Loss nan
Epoch 3000, Loss nan
Epoch 3500, Loss nan
```

```
Epoch 4000, Loss nan
Epoch 4500, Loss nan
Epoch 5000, Loss nan
Learning Rate: 0.01
Epoch 500, Loss nan
Epoch 1000, Loss nan
Epoch 1500, Loss nan
Epoch 2000, Loss nan
Epoch 2500, Loss nan
Epoch 3000, Loss nan
Epoch 3500, Loss nan
Epoch 4000, Loss nan
Epoch 4500, Loss nan
Epoch 5000, Loss nan
Learning Rate: 0.001
Epoch 500, Loss nan
Epoch 1000, Loss nan
Epoch 1500, Loss nan
Epoch 2000, Loss nan
Epoch 2500, Loss nan
Epoch 3000, Loss nan
Epoch 3500, Loss nan
Epoch 4000, Loss nan
Epoch 4500, Loss nan
Epoch 5000, Loss nan
Learning Rate: 0.0001
Epoch 500, Loss 10.708596
Epoch 1000, Loss 8.642083
Epoch 1500, Loss 7.171005
Epoch 2000, Loss 6.123477
Epoch 2500, Loss 5.377227
Epoch 3000, Loss 4.845285
Epoch 3500, Loss 4.465788
Epoch 4000, Loss 4.194724
Epoch 4500, Loss 4.000802
Epoch 5000, Loss 3.861744
Linear model with LR=0.0001
Epoch 500, Loss 29.505890
Epoch 1000, Loss 28.943773
Epoch 1500, Loss 28.505281
Epoch 2000, Loss 28.074451
Epoch 2500, Loss 27.650877
Epoch 3000, Loss 27.234444
Epoch 3500, Loss 26.825018
Epoch 4000, Loss 26.422497
Epoch 4500, Loss 26.026747
Epoch 5000, Loss 25.637671
```

[230]:
```
train_params
```

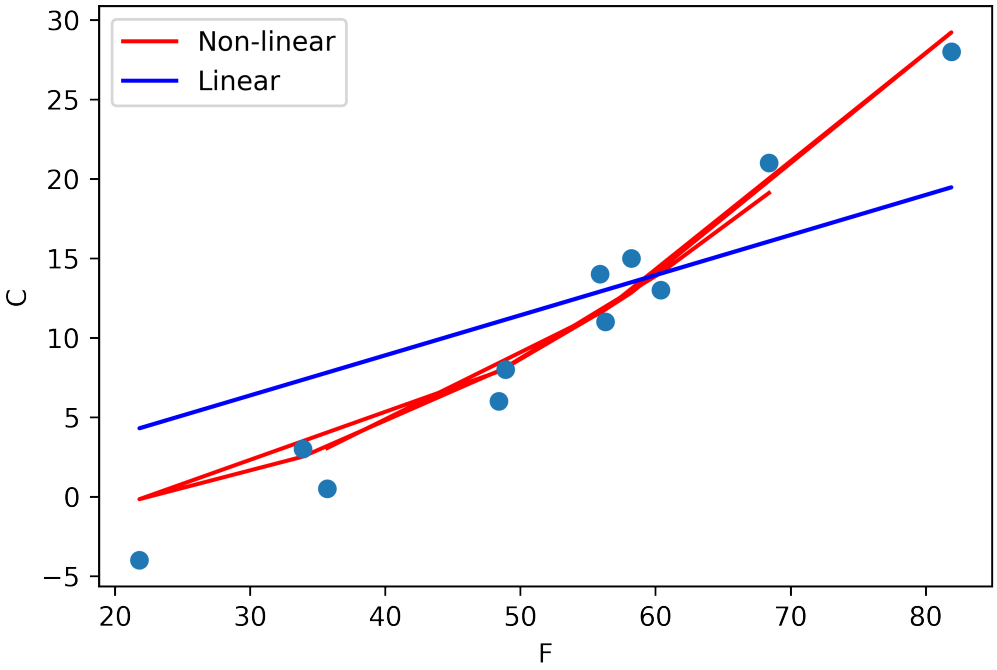
[230]:
```
tensor([[    nan,     nan,     nan],
        [    nan,     nan,     nan],
        [    nan,     nan,     nan],
        [ 0.5570, -0.8881, -0.8753]], grad_fn=<CopySlices>)
```

[232]:
```
# Due to valid losses only occuring with LR of 0.0001 (or greater),
# the last trained parameter set will be the best set
best_params = train_params[3]
t_p = model(t_un, *best_params)
lin_t_p = lin_model(t_un, *lin_train_params)

# Testing
# t_c = [0.5, 14.0, 15.0, 28.0, 11.0, 8.0, 3.0, -4.0, 6.0, 13.0, 21.0]

fig = plt.figure(dpi=600)
plt.xlabel('F')
plt.ylabel('C')
plt.plot(t_u.numpy(), t_p.detach().numpy(), 'r', label='Non-linear')
plt.plot(t_u.numpy(), lin_t_p.detach().numpy(), 'b', label='Linear')
plt.plot(t_u.numpy(), t_c.numpy(), 'o')
plt.legend()
```

[232]:
```
<matplotlib.legend.Legend at 0x1dbc13cdeb0>
```



1.2 Problem 2

[15]:
```
varlist = ['area', 'bedrooms', 'bathrooms', 'stories', 'parking','price']
housing = pd.DataFrame(pd.read_csv("./Housing.csv"), columns = varlist)
housing.shape
```

[15]: (545, 6)

[16]:
```
# Removing strings in dataset
housing.replace('yes', 1, inplace=True)
housing.replace('no', 0, inplace=True)
housing.replace('furnished', 2, inplace=True)
housing.replace('semi-furnished', 1, inplace=True)
housing.replace('unfurnished', 0, inplace=True)

housing = StandardScaler().fit_transform(housing)
# x = housing[varlist]
# y = housing['price']
y = housing[:,-1]
housing = np.delete(housing, housing.shape[1]-1, -1)
x = housing
x.shape
```

[16]: (545, 5)

[17]:
```
# norm_x = StandardScaler().fit_transform(x)
X_train, X_test, Y_train, Y_test = train_test_split(x, y, test_size=0.2,␣
 ↪random_state = 0)
print(X_train.shape, X_test.shape, Y_train.shape, Y_test.shape)
```

```
(436, 5) (109, 5) (436,) (109,)
```

[18]:
```
# Convert to tensors
Y_train = torch.tensor(Y_train.ravel())
X_train = torch.tensor(X_train)
X_train = torch.transpose(X_train, 0, 1)
X_train = torch.split(X_train, 1)

Y_test = torch.tensor(Y_test.ravel())
X_test = torch.tensor(X_test)
X_test = torch.transpose(X_test, 0, 1)
X_test = torch.split(X_test, 1)
```

[19]:
```
def lin_model_6(x5, x4, x3, x2, x1, w5, w4, w3, w2, w1, b):
    return w5 * x5 + w4* x4 + w3 * x3 + w2 * x2 + w1 * x1 + b

def loss_fn_6(t_p, y):
    squared_diff = (t_p - y)**2
```

```
    return squared_diff.mean()

def training_loop_6(n_epochs, optimizer, params, train_x, train_y, test_x,␣
 ↪test_y, learning_rate):
    print(f'Learning Rate: {learning_rate}')
    for epoch in range(1, n_epochs+1):
        t_p = lin_model_6 (*train_x, *params)
        t_p = torch.reshape(t_p, (-1,))
        loss = loss_fn_6(t_p, train_y)

        optimizer.zero_grad()
        loss.backward()
        optimizer.step()

        if epoch % 500 == 0:
            val_t_p = lin_model_6(*test_x, *params)
            val_t_p = torch.reshape(val_t_p, (-1,))
            val_loss = loss_fn_6(val_t_p, test_y)
            print (f'Epoch {epoch}: Training Loss = {loss}, Validation Loss =␣
 ↪{val_loss}')
    return params, loss
```

[20]:
```
learning_rate = [0.1, 0.01, 0.001, 0.0001]
train_params = torch.zeros(len(learning_rate), len(varlist))
train_loss = torch.zeros(len(learning_rate), 1)
lin_train_params = torch.zeros(1, 2)
lin_train_loss = torch.zeros(1, 1)

for i in learning_rate:
    params = torch.tensor([1.0, 1.0, 1.0, 1.0, 1.0, 0.0], requires_grad=True)
    optimizer = optim.SGD([params], lr=i)

    train_params[learning_rate.index(i)], train_loss[learning_rate.index(i)] =␣
 ↪training_loop_6(
        n_epochs = 5000,
        optimizer = optimizer,
        params = params,
        train_x = X_train,
        train_y = Y_train,
        test_x = X_test,
        test_y = Y_test,
        learning_rate = i)
```

```
Learning Rate: 0.1
Epoch 500: Training Loss = 0.4656211385036159, Validation Loss =
0.33612493606266414
Epoch 1000: Training Loss = 0.4656211385036159, Validation Loss =
```

```
0.33612493606266414
Epoch 1500: Training Loss = 0.4656211385036159, Validation Loss =
0.33612493606266414
Epoch 2000: Training Loss = 0.4656211385036159, Validation Loss =
0.33612493606266414
Epoch 2500: Training Loss = 0.4656211385036159, Validation Loss =
0.33612493606266414
Epoch 3000: Training Loss = 0.4656211385036159, Validation Loss =
0.33612493606266414
Epoch 3500: Training Loss = 0.4656211385036159, Validation Loss =
0.33612493606266414
Epoch 4000: Training Loss = 0.4656211385036159, Validation Loss =
0.33612493606266414
Epoch 4500: Training Loss = 0.4656211385036159, Validation Loss =
0.33612493606266414
Epoch 5000: Training Loss = 0.4656211385036159, Validation Loss =
0.33612493606266414
Learning Rate: 0.01
Epoch 500: Training Loss = 0.4656211911638495, Validation Loss =
0.33608939914455876
Epoch 1000: Training Loss = 0.4656211385053994, Validation Loss =
0.3361246801262018
Epoch 1500: Training Loss = 0.4656211385053993, Validation Loss =
0.33612468017729846
Epoch 2000: Training Loss = 0.4656211385053993, Validation Loss =
0.33612468017729846
Epoch 2500: Training Loss = 0.4656211385053993, Validation Loss =
0.33612468017729846
Epoch 3000: Training Loss = 0.4656211385053993, Validation Loss =
0.33612468017729846
Epoch 3500: Training Loss = 0.4656211385053993, Validation Loss =
0.33612468017729846
Epoch 4000: Training Loss = 0.4656211385053993, Validation Loss =
0.33612468017729846
Epoch 4500: Training Loss = 0.4656211385053993, Validation Loss =
0.33612468017729846
Epoch 5000: Training Loss = 0.4656211385053993, Validation Loss =
0.33612468017729846
Learning Rate: 0.001
Epoch 500: Training Loss = 0.5958591135965695, Validation Loss =
0.5246754716962263
Epoch 1000: Training Loss = 0.4702922581622703, Validation Loss =
0.3443575953609255
Epoch 1500: Training Loss = 0.46617636499456966, Validation Loss =
0.33440361284543263
Epoch 2000: Training Loss = 0.46575331713992985, Validation Loss =
0.3344553617000288
Epoch 2500: Training Loss = 0.4656565555889337, Validation Loss =
```

```
0.33514112657788514
Epoch 3000: Training Loss = 0.4656308043796804, Validation Loss =
0.3355980888324366
Epoch 3500: Training Loss = 0.4656237901638312, Validation Loss =
0.33585066519656703
Epoch 4000: Training Loss = 0.4656218677693654, Validation Loss =
0.3359836149290369
Epoch 4500: Training Loss = 0.46562133949321666, Validation Loss =
0.33605247592957704
Epoch 5000: Training Loss = 0.46562119412966596, Validation Loss =
0.3360877949161908
Learning Rate: 0.0001
Epoch 500: Training Loss = 4.234316403132837, Validation Loss =
4.558631478859912
Epoch 1000: Training Loss = 3.047319484760979, Validation Loss =
3.274183271843407
Epoch 1500: Training Loss = 2.235223821323195, Validation Loss =
2.387479698023647
Epoch 2000: Training Loss = 1.6794750637026417, Validation Loss =
1.7739929439900128
Epoch 2500: Training Loss = 1.2990205510347188, Validation Loss =
1.348407999508614
Epoch 3000: Training Loss = 1.0384622245113642, Validation Loss =
1.0522559859839897
Epoch 3500: Training Loss = 0.8599228673590468, Validation Loss =
0.8454234567758347
Epoch 4000: Training Loss = 0.7375058628429059, Validation Loss =
0.7003660886166537
Epoch 4500: Training Loss = 0.6535032127781812, Validation Loss =
0.5981467494850922
Epoch 5000: Training Loss = 0.5958039789120795, Validation Loss =
0.5257262447050344
```

[21]:
```
train_params
```

[21]:
```
tensor([[ 0.4027,  0.0904,  0.3196,  0.2440,  0.1612,  0.0037],
        [ 0.4027,  0.0904,  0.3196,  0.2440,  0.1612,  0.0037],
        [ 0.4025,  0.0905,  0.3194,  0.2440,  0.1613,  0.0036],
        [ 0.4699,  0.2353,  0.3802,  0.3575,  0.3443, -0.0025]],
       grad_fn=<CopySlices>)
```

1.3 Problem 3

1.3.1 Part A

[182]:
```
# Using data from Problem 2
# variables x and y contain normalized housing data
housing_df = pd.DataFrame(housing)
housing_df
```

[182]:

	0	1	2	3	4
0	1.046726	1.403419	1.421812	1.378217	1.517692
1	1.757010	1.403419	5.405809	2.532024	2.679409
2	2.218232	0.047278	1.421812	0.224410	1.517692
3	1.083624	1.403419	1.421812	0.224410	2.679409
4	1.046726	1.403419	-0.570187	0.224410	1.517692
..	…	…	…	…	…
540	-0.991879	-1.308863	-0.570187	-0.929397	1.517692
541	-1.268613	0.047278	-0.570187	-0.929397	-0.805741
542	-0.705921	-1.308863	-0.570187	-0.929397	-0.805741
543	-1.033389	0.047278	-0.570187	-0.929397	-0.805741
544	-0.599839	0.047278	-0.570187	0.224410	-0.805741

[545 rows x 5 columns]

[183]:
```
X_train, X_test, Y_train, Y_test = train_test_split(x, y, test_size=0.2,␣
 ↪random_state = 0)
print(X_train.shape, X_test.shape, Y_train.shape, Y_test.shape)
```

```
(436, 5) (109, 5) (436,) (109,)
```

[184]:
```
# Convert to tensors
Y_train = torch.tensor(Y_train.ravel())
X_train = torch.tensor(X_train)
# X_train = torch.transpose(X_train, 0, 1)
# X_train = torch.split(X_train, 1)

Y_test = torch.tensor(Y_test.ravel())
X_test = torch.tensor(X_test)
# X_test = torch.transpose(X_test, 0, 1)
# X_test = torch.split(X_test, 1)
```

[216]:
```
def loss_fn_nn(t_p, y):
    squared_diff = (t_p - y)**2
    return squared_diff.mean()

# NN Training Loop
def training_loop_nn(n_epochs, optimizer, model, train_x, train_y, test_x,␣
 ↪test_y):
    for epoch in range(1, n_epochs+1):
```

```
        t_p = model(train_x.float())
        t_p = torch.reshape(t_p, (-1,))
        loss = loss_fn_nn(t_p, train_y)

        optimizer.zero_grad()
        loss.backward()
        optimizer.step()

        if epoch % 50 == 0:
            val_t_p = model(test_x.float())
            val_t_p = torch.reshape(val_t_p, (-1,))
            val_loss = loss_fn_nn(val_t_p, test_y)
            print (f'Epoch {epoch}: Training Loss = {loss}, Validation Loss =␣
 ↪{val_loss}')
    return params, loss
```

[217]:
```
# Neural Network with 1 hidden layer
# 5 input features will output 8 with bias
# Output takes 8 inputs and output 1 with bias
model_one = nn.Sequential(nn.Linear(5, 8), nn.ReLU(), nn.Linear(8, 1))
model_one
```

[217]:
```
Sequential(
  (0): Linear(in_features=5, out_features=8, bias=True)
  (1): ReLU()
  (2): Linear(in_features=8, out_features=1, bias=True)
)
```

[218]:
```
optimizer = optim.SGD(model_one.parameters(), lr=0.07)
train_params_one = []
train_loss_one = []

train_params_one, train_loss_one = training_loop_nn(
    n_epochs = 200, optimizer = optimizer,
    model = model_one, train_x = X_train,
    train_y = Y_train, test_x = X_test,
    test_y = Y_test)
```

```
Epoch 50: Training Loss = 0.47148941289167073, Validation Loss =
0.33611141205837697
Epoch 100: Training Loss = 0.450174478223789, Validation Loss =
0.3290381312005883
Epoch 150: Training Loss = 0.44366449117398926, Validation Loss =
0.33176357222739494
Epoch 200: Training Loss = 0.43715101325502864, Validation Loss =
0.3327354334632003
```

[188]:
```
train_params_one
```

[188]:
```
tensor([ 0.4699,  0.2353,  0.3802,  0.3575,  0.3443, -0.0025],
       requires_grad=True)
```

[189]:
```
train_loss_one
```

[189]:
```
tensor(0.4331, dtype=torch.float64, grad_fn=<MeanBackward0>)
```

1.3.2 Part B

[213]:
```
# Neural Network with 3 hidden layers
# 5 input features will output 8 with bias
# Output takes 8 inputs and output 1 with bias
model_three = nn.Sequential(nn.Linear(5, 8), nn.ReLU(),
                            nn.Linear(8, 8), nn.ReLU(),
                            nn.Linear(8, 8), nn.ReLU(),
                            nn.Linear(8, 1))
model_three
```

[213]:
```
Sequential(
  (0): Linear(in_features=5, out_features=8, bias=True)
  (1): ReLU()
  (2): Linear(in_features=8, out_features=8, bias=True)
  (3): ReLU()
  (4): Linear(in_features=8, out_features=8, bias=True)
  (5): ReLU()
  (6): Linear(in_features=8, out_features=1, bias=True)
)
```

[214]:
```
optimizer = optim.SGD(model_three.parameters(), lr=0.09)
train_params_three = []
train_loss_three = []

train_params_three, train_loss_three = training_loop_nn(
    n_epochs = 200, optimizer = optimizer,
    model = model_three, train_x = X_train,
    train_y = Y_train, test_x = X_test,
    test_y = Y_test)
```

```
Epoch 50: Training Loss = 0.46459866631956587, Validation Loss =
0.338609394025321
Epoch 100: Training Loss = 0.44075205098537407, Validation Loss =
0.3332733334843175
Epoch 150: Training Loss = 0.42625675727643253, Validation Loss =
0.3354831613873975
Epoch 200: Training Loss = 0.41510950814978975, Validation Loss =
0.3367185847365864
```

[ ]:
```

```