Homework 5

In [2]:
```
#imports
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
```

In [3]:
```
wage_raw = pd.read_csv('Wage.csv')
```

1. K-Means

1. Instead of just having an indicator for job class we add an indicator for each of the categorical variables. The categorical variables are:

- sex
- maritl
- race
- education
- region
- jobclass
- health
- health_ins

In [3]:
```
cat_var = ['sex', 'maritl', 'race', 'education', 'region', 'jobclass', 'health', 'h
wage = pd.get_dummies(wage_raw, columns=cat_var, drop_first=True)
```

In [102…
```
wage
```

Out[102…

	year	age	logwage	wage	maritl_2. Married	maritl_3. Widowed	maritl_4. Divorced	maritl_5. Separated	race_2. Black
0	2006	18	4.318063	75.043154	False	False	False	False	False
1	2004	24	4.255273	70.476020	False	False	False	False	False
2	2003	45	4.875061	130.982177	True	False	False	False	False
3	2003	43	5.041393	154.685293	True	False	False	False	False
4	2005	50	4.318063	75.043154	False	False	True	False	False
...	...	...	...	...	...	...	...	...	...
2995	2008	44	5.041393	154.685293	True	False	False	False	False
2996	2007	30	4.602060	99.689464	True	False	False	False	False
2997	2005	27	4.193125	66.229408	True	False	False	False	True
2998	2005	27	4.477121	87.981033	False	False	False	False	False
2999	2009	55	4.505150	90.481913	False	False	False	True	False

3000 rows × 18 columns

2. Code

In [5]:

```
rng = np.random.default_rng()
train_idx = rng.binomial(1, 0.8, size = wage.shape[0]).astype(bool)
wage_train = wage[train_idx]
wage_test = wage[~train_idx]
```

3. We assume that everyone has completed middle school for a minimum of 9 years of schooling. If someone is a High School Grad that counts for 4 more years. If they have some college, we assume that's an associate degree. The cases where someone drops out at 1 year or 3 years average out to 2 years (most of the time). Some college should count for 2 years. College grad counts for 4 years. Advanced degreees can be masters or phds or professional degrees. Masters usually are 2 years, and Phds are usually 5-6, but often take much longer. We assume it adds a bit more years of schooling, say 4 years on average.

4. Code

In [104…

```
# make education years column
education_years = 9 + wage['education_2. HS Grad'] * 4 + wage['education_3. Some Co

# make kmeans data_frame
```

```
wage_kmeans = pd.DataFrame({'jobclass': wage['jobclass_2. Information'], 'age': wag

# standardize
wage_kmeans[['age', 'education_years', 'logwage']] = (wage_kmeans[['age', 'educatio

# split
wage_kmeans_train = wage_kmeans[train_idx]
wage_kmeans_test = wage_kmeans[~train_idx]
wage_kmeans
```

Out[104…

	jobclass	age	education_years	logwage
0	False	-2.115215	-1.888180	-0.954767
1	True	-1.595392	0.577880	-1.133275
2	False	0.223986	-0.038635	0.628727
3	True	0.050712	0.577880	1.101591
4	True	0.657171	-0.655150	-0.954767
...	...	...	...	...
2995	False	0.137349	-0.038635	1.101591
2996	False	-1.075570	-0.655150	-0.147391
2997	False	-1.335481	-1.888180	-1.309956
2998	False	-1.335481	-0.038635	-0.502580
2999	False	1.090356	-0.655150	-0.422897

3000 rows × 4 columns

5. Code

In [105…

```
import sklearn.cluster
num_clusters = 8
kmeans_clf = sklearn.cluster.KMeans(n_clusters = num_clusters)
kmeans_clf.fit(wage_kmeans_train)
```

Out[105…

```
▾ KMeans
KMeans()
```

6. Predict

In [106…

```
kmeans_weights = np.zeros(num_clusters)
for i in range(num_clusters):
    kmeans_weights[i] = np.mean(wage_kmeans_train.iloc[kmeans_clf.labels_ == i]['jo
print(kmeans_weights)
```

```
[0.66666667 0.50743494 0.8        0.29299363 0.46285714 0.39732143
 0.51923077 0.24096386]
```

7. Here is some code to investigate this:

In [107…

```
print(kmeans_clf.cluster_centers_)
```

```
[[ 0.66812227  1.25038882  0.95478894  0.2731773 ]
 [ 0.50743494 -0.77362873 -0.03634307 -0.0313303 ]
 [ 0.8        -0.09379251  1.81091033  1.06612075]
 [ 0.29299363  0.09320234 -1.88818023 -0.5036751 ]
 [ 0.46285714  0.37102111 -0.43672755 -1.42916273]
 [ 0.39732143  0.92133658 -0.49138822 -0.02732775]
 [ 0.51910828  0.08602857  0.29514711  1.09067936]
 [ 0.24096386 -1.44717001 -0.62543847 -1.19975317]]
```

As we can see, the first coordinate of each of the cluster centers (the part corresponding to the job) is exactly the fraction we calculated prior. This makes sense since each cluster center's should just be the mean of the group, otherwise the variance would increase.

8. Code

In [108…

```
kmeans_weights = kmeans_weights > 0.5
kmeans_preds_train = np.eye(num_clusters)[kmeans_clf.predict(wage_kmeans_train)] @
kmeans_err_train = np.mean(kmeans_preds_train != wage_kmeans_train['jobclass'])
print(f"The training error for the k-means classifier is {kmeans_err_train}")
```

```
The training error for the k-means classifier is 0.3831578947368421
```

9. Code

In [109…

```
kmeans_preds_test = np.eye(num_clusters)[kmeans_clf.predict(wage_kmeans_test)] @ km
```

10. Code

In [110…

```
kmeans_err_test = np.mean(kmeans_preds_test != wage_kmeans_test['jobclass'])
print(f"The test error for the k-means classifier is {kmeans_err_test}")
```

```
The test error for the k-means classifier is 0.384
```

2. Neural Networks

1. Code

In [4]:
```
import torch
import torch.nn as nn
import torch.optim as optim
import torch.functional as F
import torch.utils.data as data
```

In [9]:
```
device = torch.accelerator.current_accelerator().type if torch.accelerator.is_avail
print(f'Using device: {device}')
```

```
Using device: cuda
```

In [10]:
```
class Net(nn.Module):
    def __init__(self):
        super(Net, self).__init__()
        self.linear_relu_logit_stack = nn.Sequential(
            nn.Linear(3, 16),
            nn.ReLU(),
            nn.Linear(16, 16),
            nn.ReLU(),
            nn.Linear(16, 1),
            nn.Sigmoid()
        )
    def forward(self, x):
        return self.linear_relu_logit_stack(x)
```

In [114...
```
model = Net().to(device)
print(model)
```

```
Net(
  (linear_relu_logit_stack): Sequential(
    (0): Linear(in_features=3, out_features=16, bias=True)
    (1): ReLU()
    (2): Linear(in_features=16, out_features=16, bias=True)
    (3): ReLU()
    (4): Linear(in_features=16, out_features=1, bias=True)
    (5): Sigmoid()
  )
)
```

In [115...
```
loss_fn = nn.BCELoss()
optimizer = optim.Adam(model.parameters(), lr=10e-4)
```

In [11]:
```
wage_nn_train = torch.tensor(wage_kmeans_train[['age', 'education_years', 'logwage'
jobclass_nn_train = torch.tensor(wage_kmeans_train['jobclass'].values, dtype=torch.
jobclass_nn_train = jobclass_nn_train.view(-1, 1)
wage_nn_test = torch.tensor(wage_kmeans_test[['age', 'education_years', 'logwage']]
jobclass_nn_test = torch.tensor(wage_kmeans_test['jobclass'].values, dtype=torch.fl
jobclass_nn_test = jobclass_nn_test.view(-1, 1)
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
Cell In[11], line 1
----> 1 wage_nn_train = torch.tensor(wage_kmeans_train[['age', 'education_years', 'l
ogwage']].values, dtype=torch.float32).to(device)
      2 jobclass_nn_train = torch.tensor(wage_kmeans_train['jobclass'].values, dtype
=torch.float32).to(device)
      3 jobclass_nn_train = jobclass_nn_train.view(-1, 1)

NameError: name 'wage_kmeans_train' is not defined
```

In [5]:
```python
def train(X,y, batch_size, model, loss_fn, optimizer):
    model.train()
    for i in np.random.permutation(range(len(X)//batch_size)):
        Xi, yi = X[i*batch_size: (i+1)*batch_size], y[i*batch_size: (i+1)*batch_siz
        Xi, yi = Xi.to(device), yi.to(device)
        # pred
        pred = model(Xi)
        loss = loss_fn(pred, yi)
        # backprop
        loss.backward()
        optimizer.step()
        optimizer.zero_grad()

        # if i % 100 == 0:
        #     loss = loss.item()
        #     print(f"loss: {loss:>7f} [{i:>5d}/{len(X)}]")
```

In [6]:
```python
def test(X, y, model, loss_fn):
    model.eval()
    size = len(X)
    test_loss, correct = 0, 0
    with torch.no_grad():
        for Xi, yi in zip(X, y):
            Xi, yi = Xi.to(device), yi.to(device)
            pred = model(Xi)
            loss = loss_fn(pred, yi)
            test_loss += loss.item()
            correct += (pred.round() == yi).type(torch.float).item()
    test_loss /= size
    correct /= size
    print(f"Test Error: \n Accuracy: {(100*correct):>0.1f}%, Avg loss: {test_loss:>
    return correct, test_loss
```

In [6]:
```python
epochs = 5
for t in range(epochs):
    print(f"Epoch {t+1}\n-------------------------------")
    train(wage_nn_train, jobclass_nn_train, model, loss_fn, optimizer)
    test(wage_nn_train, jobclass_nn_train, model, loss_fn)
```

```
Epoch 1
-------------------------------
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
Cell In[6], line 4
      2 for t in range(epochs):
      3     print(f"Epoch {t+1}\n-------------------------------")
----> 4     train(wage_nn_train, jobclass_nn_train, model, loss_fn, optimizer)
      5     test(wage_nn_train, jobclass_nn_train, model, loss_fn)

NameError: name 'train' is not defined
```

2. Code

In [121…
```python
model.eval()
wage_nn_train_err = ((model(wage_nn_train) > 0.5) == jobclass_nn_train).sum().item(
print(f"The training error for the neural network is {1 - wage_nn_train_err}")
```

```
The training error for the neural network is 0.3701052631578947
```

3. Code

In [122…
```python
model.eval()
wage_nn_test_err = ((model(wage_nn_test) > 0.5) == jobclass_nn_test).sum().item()/l
print(f"The test error for the neural network is {1 - wage_nn_test_err}")
```

```
The test error for the neural network is 0.35840000000000005
```

3. Regression Trees

1. Code

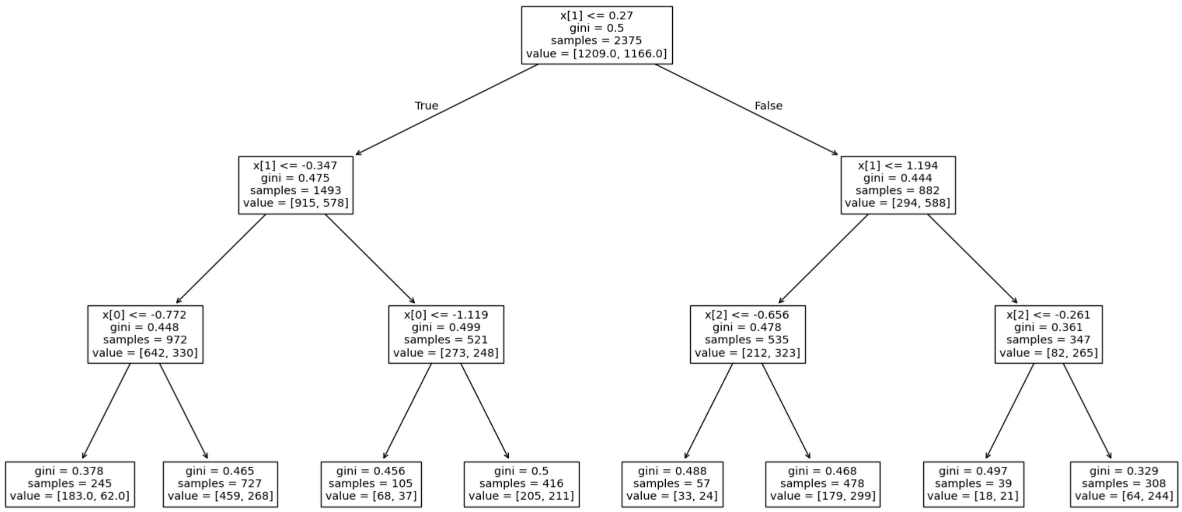
In [123…
```python
wage_dt_train = wage_kmeans_train[['age', 'education_years', 'logwage']]
jobclass_dt_train = wage_kmeans_train['jobclass']
wage_dt_test = wage_kmeans_test[['age', 'education_years', 'logwage']]
jobclass_dt_test = wage_kmeans_test['jobclass']
```

In [124…
```python
import sklearn.tree
dt_clf = sklearn.tree.DecisionTreeClassifier(max_depth = 3)
dt_clf.fit(wage_dt_train, jobclass_dt_train)
```

Out[124…
```
DecisionTreeClassifier
DecisionTreeClassifier(max_depth=3)
```

2. Code

In [125…
```python
plt.figure(figsize=(20,10))
sklearn.tree.plot_tree(dt_clf)
plt.show()
```



3. Code

In [126…

```
wage_dt_train_err = 1 - dt_clf.score(wage_dt_train, jobclass_dt_train)
print(f"The training error for the decision tree is {wage_dt_train_err}")
```

```
The training error for the decision tree is 0.36084210526315785
```

4. Code

In [127…

```
wage_dt_test_err = 1 - dt_clf.score(wage_dt_test, jobclass_dt_test)
print(f"The test error for the decision tree is {wage_dt_test_err}")
```

```
The test error for the decision tree is 0.36639999999999995
```

5. Code

In [128…

```
wage_dt = wage_kmeans[['age', 'education_years', 'logwage']]
jobclass_dt = wage_kmeans['jobclass']
dt_full_clf = sklearn.tree.DecisionTreeClassifier(max_depth = 3)
dt_full_clf.fit(wage_dt, jobclass_dt)
```

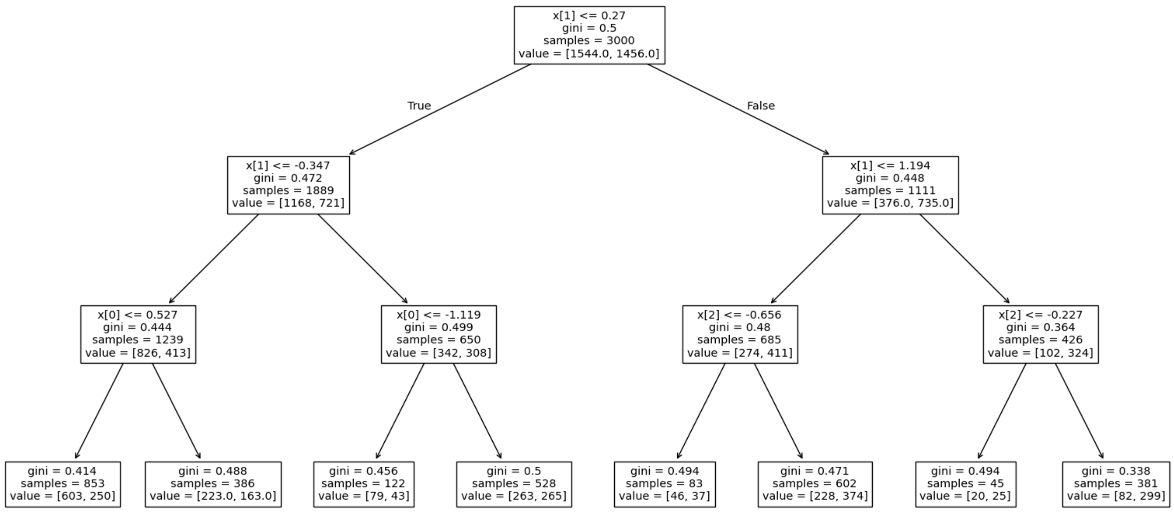
Out[128…

```
DecisionTreeClassifier
DecisionTreeClassifier(max_depth=3)
```

6. Code

In [129…

```
plt.figure(figsize=(20,10))
sklearn.tree.plot_tree(dt_full_clf)
plt.show()
```



7. Code

In [130…

```
wage_dt_full_train_err = 1 - dt_full_clf.score(wage_dt, jobclass_dt)
print(f"The error on the training set for the decision tree is {wage_dt_full_train_
```

```
The error on the training set for the decision tree is 0.362
```

8. Code

In [131…

```
wage_dt_full_test_err = 1 - dt_full_clf.score(wage_dt_test, jobclass_dt_test)
print(f"The error on the test set for the decision tree is {wage_dt_full_test_err}"
```

```
The error on the test set for the decision tree is 0.36639999999999995
```

4. Compare All Methods

1. Code

In [133…

```
results = pd.DataFrame({
    'kmeans': [kmeans_err_train, kmeans_err_test],
    'neural_network': [1 - wage_nn_train_err, 1 - wage_nn_test_err],
    'decision_tree': [wage_dt_train_err, wage_dt_test_err],
    'decision_tree_full': [wage_dt_full_train_err, wage_dt_full_test_err]
}, index = ['train', 'test'])
results
```

Out[133…

	kmeans	neural_network	decision_tree	decision_tree_full
train	0.383158	0.370105	0.360842	0.3620
test	0.384000	0.358400	0.366400	0.3664

2. All of the methods performed incredibly close to each other. They were all within 3e-2 of each other. The neural network did the best, which was expected, but all methods performed well. In theory, we should have expected the full decision tree to perform better than the standard decision tree, however, we only had 3 features, with max depth of 8, so the decision tree was quite constrained. The neural network performed the best, but not by as well as I expected. I chalk this up to there not being enough data and not using enough features.

3. (Optional) We are going to train a neural net with one more hidden layer and more intermediary nodes. We are also going to cross validate for the learning rate in the SGD optimizer and we are going to use the entire data set with the one-hot encoding.

In [ ]:
```
wage = wage.astype('float64')
wage_train = wage_train.astype('float64')
wage_test = wage_test.astype('float64')
wage
```

In [137…
```
class Net(nn.Module):
    def __init__(self):
        super(Net, self).__init__()
        self.linear_relu_logit_stack = nn.Sequential(
            nn.Linear(17, 32),
            nn.ReLU(),
            nn.Linear(32, 32),
            nn.ReLU(),
            nn.Linear(32, 32),
            nn.ReLU(),
            nn.Linear(32, 1),
            nn.Sigmoid()
        )
    def forward(self, x):
        return self.linear_relu_logit_stack(x)
model = Net().to(device)
print(model)
```

```
Net(
  (linear_relu_logit_stack): Sequential(
    (0): Linear(in_features=17, out_features=32, bias=True)
    (1): ReLU()
    (2): Linear(in_features=32, out_features=32, bias=True)
    (3): ReLU()
    (4): Linear(in_features=32, out_features=32, bias=True)
    (5): ReLU()
    (6): Linear(in_features=32, out_features=1, bias=True)
    (7): Sigmoid()
  )
)
```

In [22]:
```
wage_nn_train = torch.tensor(wage_train.drop(columns = 'jobclass_2. Information').v
jobclass_nn_train = torch.tensor(wage_train['jobclass_2. Information'].values, dtyp
jobclass_nn_train = jobclass_nn_train.view(-1, 1)
```

```
wage_nn_test = torch.tensor(wage_test.drop(columns = 'jobclass_2. Information').val
jobclass_nn_test = torch.tensor(wage_test['jobclass_2. Information'].values, dtype=
jobclass_nn_test = jobclass_nn_test.view(-1, 1)
```

In [151…

```
optimizer = optim.Adam(model.parameters(), lr=10e-5)
epochs = 25
```

In [152…

```
for t in range(epochs):
    print(f"Epoch {t+1}\n-------------------------------")
    train(wage_nn_train, jobclass_nn_train, model, loss_fn, optimizer)
    test(wage_nn_train, jobclass_nn_train, model, loss_fn)
```

```
Epoch 1
-------------------------------
Test Error: 
 Accuracy: 57.2%, Avg loss: 0.677338 

Epoch 2
-------------------------------
Test Error: 
 Accuracy: 57.1%, Avg loss: 0.673603 

Epoch 3
-------------------------------
Test Error: 
 Accuracy: 59.4%, Avg loss: 0.667718 

Epoch 4
-------------------------------
Test Error: 
 Accuracy: 57.2%, Avg loss: 0.672373 

Epoch 5
-------------------------------
Test Error: 
 Accuracy: 59.5%, Avg loss: 0.668015 

Epoch 6
-------------------------------
Test Error: 
 Accuracy: 56.8%, Avg loss: 0.676829 

Epoch 7
-------------------------------
Test Error: 
 Accuracy: 59.7%, Avg loss: 0.668202 

Epoch 8
-------------------------------
Test Error: 
 Accuracy: 57.7%, Avg loss: 0.668597 

Epoch 9
-------------------------------
Test Error: 
 Accuracy: 57.5%, Avg loss: 0.670710 

Epoch 10
-------------------------------
Test Error: 
 Accuracy: 59.6%, Avg loss: 0.667262 

Epoch 11
-------------------------------
Test Error: 
 Accuracy: 57.4%, Avg loss: 0.673629 

Epoch 12
```

```
-------------------------------
Test Error:
 Accuracy: 59.2%, Avg loss: 0.668041

Epoch 13
-------------------------------
Test Error:
 Accuracy: 59.7%, Avg loss: 0.671024

Epoch 14
-------------------------------
Test Error:
 Accuracy: 59.5%, Avg loss: 0.666076

Epoch 15
-------------------------------
Test Error:
 Accuracy: 58.1%, Avg loss: 0.668596

Epoch 16
-------------------------------
Test Error:
 Accuracy: 54.1%, Avg loss: 0.718041

Epoch 17
-------------------------------
Test Error:
 Accuracy: 58.5%, Avg loss: 0.667357

Epoch 18
-------------------------------
Test Error:
 Accuracy: 56.8%, Avg loss: 0.675292

Epoch 19
-------------------------------
Test Error:
 Accuracy: 60.0%, Avg loss: 0.665352

Epoch 20
-------------------------------
Test Error:
 Accuracy: 58.4%, Avg loss: 0.670422

Epoch 21
-------------------------------
Test Error:
 Accuracy: 56.4%, Avg loss: 0.676622

Epoch 22
-------------------------------
Test Error:
 Accuracy: 60.3%, Avg loss: 0.664770

Epoch 23
-------------------------------
```

```
Test Error:
 Accuracy: 59.6%, Avg loss: 0.664290

Epoch 24
-------------------------------
Test Error:
 Accuracy: 59.4%, Avg loss: 0.664646

Epoch 25
-------------------------------
Test Error:
 Accuracy: 56.8%, Avg loss: 0.675412
```

In [153…

```
model.eval()
wage_nn_train_err = ((model(wage_nn_train) > 0.5) == jobclass_nn_train).sum().item(
print(f"The training error for the neural network is {1 - wage_nn_train_err}")
wage_nn_test_err = ((model(wage_nn_test) > 0.5) == jobclass_nn_test).sum().item()/l
print(f"The test error for the neural network is {1 - wage_nn_test_err}")
```

```
The training error for the neural network is 0.43200000000000005
The test error for the neural network is 0.40480000000000005
```

It's clear that our nn is suffering. We will drop wages because they are codependent with logwages. We also demean year and age, since only the relative age and years matter

In [7]:

```
cat_var = ['sex', 'maritl', 'race', 'education', 'region', 'jobclass', 'health', 'h
wage = pd.get_dummies(wage_raw, columns=cat_var, drop_first=True)
wage = wage.astype('float64')
wage = wage.drop(columns = 'wage')
wage['year'] = wage['year'] - wage['year'].mean()
wage['age'] = wage['age'] - wage['age'].mean()
rng = np.random.default_rng()
train_idx = rng.binomial(1, 0.8, size = wage.shape[0]).astype(bool)
wage_train = wage[train_idx]
wage_test = wage[~train_idx]
wage
```

Out[7]:

	year	age	logwage	maritl_2. Married	maritl_3. Widowed	maritl_4. Divorced	maritl_5. Separated	race_2. Black	race As
0	0.209	-24.414667	4.318063	0.0	0.0	0.0	0.0	0.0	
1	-1.791	-18.414667	4.255273	0.0	0.0	0.0	0.0	0.0	
2	-2.791	2.585333	4.875061	1.0	0.0	0.0	0.0	0.0	
3	-2.791	0.585333	5.041393	1.0	0.0	0.0	0.0	0.0	
4	-0.791	7.585333	4.318063	0.0	0.0	1.0	0.0	0.0	
...	...	...	...	...	...	...	...	...	
2995	2.209	1.585333	5.041393	1.0	0.0	0.0	0.0	0.0	
2996	1.209	-12.414667	4.602060	1.0	0.0	0.0	0.0	0.0	
2997	-0.791	-15.414667	4.193125	1.0	0.0	0.0	0.0	1.0	
2998	-0.791	-15.414667	4.477121	0.0	0.0	0.0	0.0	0.0	
2999	3.209	12.585333	4.505150	0.0	0.0	0.0	1.0	0.0	

3000 rows × 17 columns

In [23]:

```
device = torch.accelerator.current_accelerator().type if torch.accelerator.is_avail
print(f'Using device: {device}')
wage_nn_train = torch.tensor(wage_train.drop(columns = 'jobclass_2. Information').v
jobclass_nn_train = torch.tensor(wage_train['jobclass_2. Information'].values, dtyp
jobclass_nn_train = jobclass_nn_train.view(-1, 1)
wage_nn_test = torch.tensor(wage_test.drop(columns = 'jobclass_2. Information').val
jobclass_nn_test = torch.tensor(wage_test['jobclass_2. Information'].values, dtype=
jobclass_nn_test = jobclass_nn_test.view(-1, 1)
```

```
Using device: cuda
```

In [10]:

```
wage_nn_train.shape
```

Out[10]:

```
torch.Size([2411, 16])
```

In [24]:

```
class Net(nn.Module):
    def __init__(self, d_in = 17):
        super(Net, self).__init__()
        self.linear_relu_logit_stack = nn.Sequential(
            nn.Linear(d_in, 32),
            nn.ReLU(),
            nn.Linear(32, 32),
            nn.ReLU(),
            nn.Linear(32, 64),
            nn.ReLU(),
            nn.Linear(64, 32),
            nn.ReLU(),
            nn.Linear(32, 16),
```

```
            nn.ReLU(),
            nn.Linear(16, 1),
            nn.Sigmoid()
        )
    def forward(self, x):
        return self.linear_relu_logit_stack(x)
```

In [52]:
```
loss_fn = nn.BCELoss()
# epochs = 25
batch_size = 32
model = Net(d_in = 16).to(device)
optimizer = optim.Adam(model.parameters(), lr=10e-4)
```

In [53]:
```
t = 0
accuracy = 0
accuracies = [0.5]
test_accuracies = [0.5]
while max(test_accuracies) < 0.6615384615384615:
    print(f"Epoch {t+1}\n-------------------------------")
    train(wage_nn_train, jobclass_nn_train, batch_size, model, loss_fn, optimizer)
    accuracy, loss = test(wage_nn_train, jobclass_nn_train, model, loss_fn)
    test_accuracy, test_loss = test(wage_nn_test, jobclass_nn_test, model, loss_fn)
    accuracies.append(accuracy)
    test_accuracies.append(test_accuracy)
    t += 1
```

```
Epoch 1
-------------------------------
Test Error: 
 Accuracy: 54.0%, Avg loss: 0.688912 

Test Error: 
 Accuracy: 51.5%, Avg loss: 0.692923 

Epoch 2
-------------------------------
Test Error: 
 Accuracy: 54.2%, Avg loss: 0.681890 

Test Error: 
 Accuracy: 55.4%, Avg loss: 0.680201 

Epoch 3
-------------------------------
Test Error: 
 Accuracy: 62.3%, Avg loss: 0.655133 

Test Error: 
 Accuracy: 60.3%, Avg loss: 0.660713 

Epoch 4
-------------------------------
Test Error: 
 Accuracy: 63.3%, Avg loss: 0.647987 

Test Error: 
 Accuracy: 62.4%, Avg loss: 0.647018 

Epoch 5
-------------------------------
Test Error: 
 Accuracy: 63.9%, Avg loss: 0.641303 

Test Error: 
 Accuracy: 63.4%, Avg loss: 0.637046 

Epoch 6
-------------------------------
Test Error: 
 Accuracy: 63.6%, Avg loss: 0.638212 

Test Error: 
 Accuracy: 63.1%, Avg loss: 0.633663 

Epoch 7
-------------------------------
Test Error: 
 Accuracy: 64.1%, Avg loss: 0.638521 

Test Error: 
 Accuracy: 63.4%, Avg loss: 0.638104 
```

```
Epoch 8
-------------------------------
Test Error:
 Accuracy: 64.0%, Avg loss: 0.634455

Test Error:
 Accuracy: 65.0%, Avg loss: 0.625823

Epoch 9
-------------------------------
Test Error:
 Accuracy: 64.7%, Avg loss: 0.633673

Test Error:
 Accuracy: 63.1%, Avg loss: 0.628517

Epoch 10
-------------------------------
Test Error:
 Accuracy: 64.9%, Avg loss: 0.633447

Test Error:
 Accuracy: 64.4%, Avg loss: 0.626766

Epoch 11
-------------------------------
Test Error:
 Accuracy: 64.4%, Avg loss: 0.632701

Test Error:
 Accuracy: 64.3%, Avg loss: 0.626422

Epoch 12
-------------------------------
Test Error:
 Accuracy: 64.7%, Avg loss: 0.630944

Test Error:
 Accuracy: 64.6%, Avg loss: 0.623650

Epoch 13
-------------------------------
Test Error:
 Accuracy: 64.5%, Avg loss: 0.631863

Test Error:
 Accuracy: 63.6%, Avg loss: 0.629885

Epoch 14
-------------------------------
Test Error:
 Accuracy: 63.4%, Avg loss: 0.638376

Test Error:
 Accuracy: 62.7%, Avg loss: 0.635124
```

```
Epoch 15
-------------------------------
Test Error: 
 Accuracy: 64.8%, Avg loss: 0.627940 

Test Error: 
 Accuracy: 62.9%, Avg loss: 0.630257 

Epoch 16
-------------------------------
Test Error: 
 Accuracy: 65.3%, Avg loss: 0.628684 

Test Error: 
 Accuracy: 62.9%, Avg loss: 0.631827 

Epoch 17
-------------------------------
Test Error: 
 Accuracy: 65.6%, Avg loss: 0.624737 

Test Error: 
 Accuracy: 65.1%, Avg loss: 0.624063 

Epoch 18
-------------------------------
Test Error: 
 Accuracy: 65.6%, Avg loss: 0.625201 

Test Error: 
 Accuracy: 63.2%, Avg loss: 0.627675 

Epoch 19
-------------------------------
Test Error: 
 Accuracy: 65.3%, Avg loss: 0.624729 

Test Error: 
 Accuracy: 64.8%, Avg loss: 0.626835 

Epoch 20
-------------------------------
Test Error: 
 Accuracy: 65.7%, Avg loss: 0.625187 

Test Error: 
 Accuracy: 63.4%, Avg loss: 0.629846 

Epoch 21
-------------------------------
Test Error: 
 Accuracy: 66.3%, Avg loss: 0.620099 

Test Error: 
 Accuracy: 63.4%, Avg loss: 0.627794 
```

```
Epoch 22
-------------------------------
Test Error: 
 Accuracy: 65.8%, Avg loss: 0.619355 

Test Error: 
 Accuracy: 64.4%, Avg loss: 0.627411 

Epoch 23
-------------------------------
Test Error: 
 Accuracy: 66.0%, Avg loss: 0.618179 

Test Error: 
 Accuracy: 62.4%, Avg loss: 0.629185 

Epoch 24
-------------------------------
Test Error: 
 Accuracy: 66.4%, Avg loss: 0.616349 

Test Error: 
 Accuracy: 63.1%, Avg loss: 0.629715 

Epoch 25
-------------------------------
Test Error: 
 Accuracy: 66.3%, Avg loss: 0.618377 

Test Error: 
 Accuracy: 64.6%, Avg loss: 0.627575 

Epoch 26
-------------------------------
Test Error: 
 Accuracy: 66.5%, Avg loss: 0.615430 

Test Error: 
 Accuracy: 63.4%, Avg loss: 0.623028 

Epoch 27
-------------------------------
Test Error: 
 Accuracy: 65.3%, Avg loss: 0.621508 

Test Error: 
 Accuracy: 62.9%, Avg loss: 0.631204 

Epoch 28
-------------------------------
Test Error: 
 Accuracy: 66.2%, Avg loss: 0.613335 

Test Error: 
 Accuracy: 64.3%, Avg loss: 0.626733 
```

```
Epoch 29
-------------------------------
Test Error: 
 Accuracy: 65.5%, Avg loss: 0.620411 

Test Error: 
 Accuracy: 63.8%, Avg loss: 0.632448 

Epoch 30
-------------------------------
Test Error: 
 Accuracy: 66.7%, Avg loss: 0.613138 

Test Error: 
 Accuracy: 63.8%, Avg loss: 0.627666 

Epoch 31
-------------------------------
Test Error: 
 Accuracy: 66.5%, Avg loss: 0.612773 

Test Error: 
 Accuracy: 61.5%, Avg loss: 0.637041 

Epoch 32
-------------------------------
Test Error: 
 Accuracy: 66.8%, Avg loss: 0.607241 

Test Error: 
 Accuracy: 62.9%, Avg loss: 0.627751 

Epoch 33
-------------------------------
Test Error: 
 Accuracy: 66.7%, Avg loss: 0.606945 

Test Error: 
 Accuracy: 64.1%, Avg loss: 0.629824 

Epoch 34
-------------------------------
Test Error: 
 Accuracy: 66.5%, Avg loss: 0.605591 

Test Error: 
 Accuracy: 65.5%, Avg loss: 0.627176 

Epoch 35
-------------------------------
Test Error: 
 Accuracy: 66.6%, Avg loss: 0.610121 

Test Error: 
 Accuracy: 60.9%, Avg loss: 0.636251 
```

```
Epoch 36
-------------------------------
Test Error: 
 Accuracy: 67.1%, Avg loss: 0.604154 

Test Error: 
 Accuracy: 61.9%, Avg loss: 0.635524 

Epoch 37
-------------------------------
Test Error: 
 Accuracy: 67.1%, Avg loss: 0.608591 

Test Error: 
 Accuracy: 61.9%, Avg loss: 0.633077 

Epoch 38
-------------------------------
Test Error: 
 Accuracy: 67.7%, Avg loss: 0.602258 

Test Error: 
 Accuracy: 62.6%, Avg loss: 0.626677 

Epoch 39
-------------------------------
Test Error: 
 Accuracy: 66.6%, Avg loss: 0.604702 

Test Error: 
 Accuracy: 62.1%, Avg loss: 0.631172 

Epoch 40
-------------------------------
Test Error: 
 Accuracy: 66.7%, Avg loss: 0.607520 

Test Error: 
 Accuracy: 61.9%, Avg loss: 0.635518 

Epoch 41
-------------------------------
Test Error: 
 Accuracy: 66.8%, Avg loss: 0.602754 

Test Error: 
 Accuracy: 62.6%, Avg loss: 0.636054 

Epoch 42
-------------------------------
Test Error: 
 Accuracy: 67.4%, Avg loss: 0.601970 

Test Error: 
 Accuracy: 62.6%, Avg loss: 0.643882 
```

```
Epoch 43
-------------------------------
Test Error: 
 Accuracy: 67.8%, Avg loss: 0.596927 

Test Error: 
 Accuracy: 63.4%, Avg loss: 0.635919 

Epoch 44
-------------------------------
Test Error: 
 Accuracy: 67.9%, Avg loss: 0.594442 

Test Error: 
 Accuracy: 63.6%, Avg loss: 0.632562 

Epoch 45
-------------------------------
Test Error: 
 Accuracy: 67.7%, Avg loss: 0.595256 

Test Error: 
 Accuracy: 65.5%, Avg loss: 0.624834 

Epoch 46
-------------------------------
Test Error: 
 Accuracy: 67.8%, Avg loss: 0.592588 

Test Error: 
 Accuracy: 62.9%, Avg loss: 0.630867 

Epoch 47
-------------------------------
Test Error: 
 Accuracy: 67.4%, Avg loss: 0.593409 

Test Error: 
 Accuracy: 64.8%, Avg loss: 0.635298 

Epoch 48
-------------------------------
Test Error: 
 Accuracy: 68.6%, Avg loss: 0.594090 

Test Error: 
 Accuracy: 63.8%, Avg loss: 0.637697 

Epoch 49
-------------------------------
Test Error: 
 Accuracy: 68.6%, Avg loss: 0.598494 

Test Error: 
 Accuracy: 63.6%, Avg loss: 0.634642 
```

```
Epoch 50
-------------------------------
Test Error:
 Accuracy: 67.5%, Avg loss: 0.592970

Test Error:
 Accuracy: 62.9%, Avg loss: 0.634516

Epoch 51
-------------------------------
Test Error:
 Accuracy: 68.7%, Avg loss: 0.584959

Test Error:
 Accuracy: 64.4%, Avg loss: 0.639305

Epoch 52
-------------------------------
Test Error:
 Accuracy: 67.2%, Avg loss: 0.600400

Test Error:
 Accuracy: 61.4%, Avg loss: 0.643227

Epoch 53
-------------------------------
Test Error:
 Accuracy: 69.1%, Avg loss: 0.592140

Test Error:
 Accuracy: 62.9%, Avg loss: 0.640318

Epoch 54
-------------------------------
Test Error:
 Accuracy: 69.2%, Avg loss: 0.583685

Test Error:
 Accuracy: 63.1%, Avg loss: 0.635839

Epoch 55
-------------------------------
Test Error:
 Accuracy: 69.5%, Avg loss: 0.582836

Test Error:
 Accuracy: 61.7%, Avg loss: 0.635465

Epoch 56
-------------------------------
Test Error:
 Accuracy: 69.4%, Avg loss: 0.578892

Test Error:
 Accuracy: 65.6%, Avg loss: 0.634814
```

```
Epoch 57
-------------------------------
Test Error: 
 Accuracy: 70.4%, Avg loss: 0.577554 

Test Error: 
 Accuracy: 63.2%, Avg loss: 0.644747 

Epoch 58
-------------------------------
Test Error: 
 Accuracy: 70.6%, Avg loss: 0.575099 

Test Error: 
 Accuracy: 62.9%, Avg loss: 0.642703 

Epoch 59
-------------------------------
Test Error: 
 Accuracy: 69.3%, Avg loss: 0.578011 

Test Error: 
 Accuracy: 62.6%, Avg loss: 0.653849 

Epoch 60
-------------------------------
Test Error: 
 Accuracy: 70.1%, Avg loss: 0.571171 

Test Error: 
 Accuracy: 61.7%, Avg loss: 0.646427 

Epoch 61
-------------------------------
Test Error: 
 Accuracy: 70.5%, Avg loss: 0.572552 

Test Error: 
 Accuracy: 63.9%, Avg loss: 0.652813 

Epoch 62
-------------------------------
Test Error: 
 Accuracy: 70.5%, Avg loss: 0.565000 

Test Error: 
 Accuracy: 63.8%, Avg loss: 0.647250 

Epoch 63
-------------------------------
Test Error: 
 Accuracy: 69.7%, Avg loss: 0.576659 

Test Error: 
 Accuracy: 63.2%, Avg loss: 0.664534 
```

```
Epoch 64
-------------------------------
Test Error:
 Accuracy: 71.1%, Avg loss: 0.569392

Test Error:
 Accuracy: 64.1%, Avg loss: 0.641037

Epoch 65
-------------------------------
Test Error:
 Accuracy: 70.2%, Avg loss: 0.571338

Test Error:
 Accuracy: 63.8%, Avg loss: 0.658674

Epoch 66
-------------------------------
Test Error:
 Accuracy: 69.2%, Avg loss: 0.568884

Test Error:
 Accuracy: 59.7%, Avg loss: 0.667272

Epoch 67
-------------------------------
Test Error:
 Accuracy: 71.3%, Avg loss: 0.562705

Test Error:
 Accuracy: 61.7%, Avg loss: 0.662775

Epoch 68
-------------------------------
Test Error:
 Accuracy: 71.7%, Avg loss: 0.557770

Test Error:
 Accuracy: 64.1%, Avg loss: 0.659682

Epoch 69
-------------------------------
Test Error:
 Accuracy: 71.3%, Avg loss: 0.556723

Test Error:
 Accuracy: 62.6%, Avg loss: 0.668302

Epoch 70
-------------------------------
Test Error:
 Accuracy: 69.9%, Avg loss: 0.567010

Test Error:
 Accuracy: 63.1%, Avg loss: 0.668768
```

```
Epoch 71
-------------------------------
Test Error: 
 Accuracy: 72.6%, Avg loss: 0.553586 

Test Error: 
 Accuracy: 63.1%, Avg loss: 0.658022 

Epoch 72
-------------------------------
Test Error: 
 Accuracy: 73.0%, Avg loss: 0.550672 

Test Error: 
 Accuracy: 64.3%, Avg loss: 0.660483 

Epoch 73
-------------------------------
Test Error: 
 Accuracy: 71.3%, Avg loss: 0.558513 

Test Error: 
 Accuracy: 64.3%, Avg loss: 0.682630 

Epoch 74
-------------------------------
Test Error: 
 Accuracy: 73.7%, Avg loss: 0.541067 

Test Error: 
 Accuracy: 63.4%, Avg loss: 0.659616 

Epoch 75
-------------------------------
Test Error: 
 Accuracy: 73.6%, Avg loss: 0.550955 

Test Error: 
 Accuracy: 63.9%, Avg loss: 0.665608 

Epoch 76
-------------------------------
Test Error: 
 Accuracy: 73.7%, Avg loss: 0.538043 

Test Error: 
 Accuracy: 66.3%, Avg loss: 0.664403 
```

In [54]:

```
import os
os.environ["KMP_DUPLICATE_LIB_OK"]="TRUE"
plt.figure()
plt.plot(accuracies, label = 'train')
plt.plot(test_accuracies, label = 'test')
plt.xlabel('Epoch')
plt.ylabel('Accuracy')
```

```
plt.title('Training Accuracy')
plt.legend()
plt.show()
print(np.argmax(test_accuracies))
print(np.max(test_accuracies))
```


```
76
0.6632478632478632
```

In [60]:
```
wage_nn_train = wage_nn_train.to(device)
jobclass_nn_train = jobclass_nn_train.to(device)
wage_nn_test = wage_nn_test.to(device)
jobclass_nn_test = jobclass_nn_test.to(device)
wage_nn_train_err = ((model(wage_nn_train.to(device)) > 0.5) == jobclass_nn_train).
print(f"The training error for the neural network is {1 - wage_nn_train_err}")
wage_nn_test_err = ((model(wage_nn_test) > 0.5) == jobclass_nn_test).sum().item()/l
print(f"The test error for the neural network is {1 - wage_nn_test_err}")
```

```
The training error for the neural network is 0.26252587991718423
The test error for the neural network is 0.3367521367521368
```

This test error beats our other test error by 3%!