ECGR 5106 - Homework 1

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Problem 1

1.a.

```
!pip install d2l==1.0.0b0
```

```
Looking in indexes: https://pypi.org/simple, https://us-python.pkg.dev/colab-wheels/public/simple/
Collecting d2l==1.0.0b0
  Downloading d2l-1.0.0b0-py3-none-any.whl (141 kB)
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Collecting jupyter
  Downloading jupyter-1.0.0-py2.py3-none-any.whl (2.7 kB)
Requirement already satisfied: requests in /usr/local/lib/python3.8/dist-packages (from d2l==1.0.0b0) (2.25.1)
Collecting matplotlib-inline
  Downloading matplotlib_inline-0.1.6-py3-none-any.whl (9.4 kB)
Collecting gym==0.21.0
  Downloading gym-0.21.0.tar.gz (1.5 MB)
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  Preparing metadata (setup.py) ... done
Requirement already satisfied: pandas in /usr/local/lib/python3.8/dist-packages (from d2l==1.0.0b0) (1.3.5)
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Collecting gpytorch
  Downloading gpytorch-1.9.1-py3-none-any.whl (250 kB)
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Requirement already satisfied: numpy in /usr/local/lib/python3.8/dist-packages (from d2l==1.0.0b0) (1.21.6)
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Requirement already satisfied: scikit-learn in /usr/local/lib/python3.8/dist-packages (from gpytorch->d2l==1.0.0b0) (1.0.2)
Collecting linear-operator>=0.2.0
  Downloading linear_operator-0.3.0-py3-none-any.whl (155 kB)
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Collecting qtconsole
  Downloading qtconsole-5.4.0-py3-none-any.whl (121 kB)
     ━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━━ 121.0/121.0 KB 7.4 MB/s eta 0:00:00
Requirement already satisfied: jupyter-console in /usr/local/lib/python3.8/dist-packages (from jupyter->d2l==1.0.0b0) (6.1.0)
Requirement already satisfied: notebook in /usr/local/lib/python3.8/dist-packages (from jupyter->d2l==1.0.0b0) (5.7.16)
Requirement already satisfied: ipywidgets in /usr/local/lib/python3.8/dist-packages (from jupyter->d2l==1.0.0b0) (7.7.1)
Requirement already satisfied: nbconvert in /usr/local/lib/python3.8/dist-packages (from jupyter->d2l==1.0.0b0) (5.6.1)
Requirement already satisfied: ipykernel in /usr/local/lib/python3.8/dist-packages (from jupyter->d2l==1.0.0b0) (5.3.4)
Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/python3.8/dist-packages (from matplotlib->d2l==1.0.0b0) (1.4.4)
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Requirement already satisfied: python-dateutil>=2.1 in /usr/local/lib/python3.8/dist-packages (from matplotlib->d2l==1.0.0b0) (2.8.2)
Requirement already satisfied: cycler>=0.10 in /usr/local/lib/python3.8/dist-packages (from matplotlib->d2l==1.0.0b0) (0.11.0)
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Requirement already satisfied: pytz>=2017.3 in /usr/local/lib/python3.8/dist-packages (from pandas->d2l==1.0.0b0) (2022.7.1)
Requirement already satisfied: certifi>=2017.4.17 in /usr/local/lib/python3.8/dist-packages (from requests->d2l==1.0.0b0) (2022.12.7)
Requirement already satisfied: idna<3,>=2.5 in /usr/local/lib/python3.8/dist-packages (from requests->d2l==1.0.0b0) (2.10)
Requirement already satisfied: urllib3<1.27,>=1.21.1 in /usr/local/lib/python3.8/dist-packages (from requests->d2l==1.0.0b0) (1.24.3)
Requirement already satisfied: chardet<5,>=3.0.2 in /usr/local/lib/python3.8/dist-packages (from requests->d2l==1.0.0b0) (4.0.0)
Requirement already satisfied: torch>=1.11 in /usr/local/lib/python3.8/dist-packages (from linear-operator>=0.2.0->gpytorch->d2l==1.0
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.8/dist-packages (from python-dateutil>=2.1->matplotlib->d2l==1.0.0b
Requirement already satisfied: tornado>=4.2 in /usr/local/lib/python3.8/dist-packages (from ipykernel->jupyter->d2l==1.0.0b0) (6.0.4)
Requirement already satisfied: jupyter-client in /usr/local/lib/python3.8/dist-packages (from ipykernel->jupyter->d2l==1.0.0b0) (6.1.
Requirement already satisfied: ipython>=5.0.0 in /usr/local/lib/python3.8/dist-packages (from ipykernel->jupyter->d2l==1.0.0b0) (7.9.
Requirement already satisfied: ipython-genutils~=0.2.0 in /usr/local/lib/python3.8/dist-packages (from ipywidgets->jupyter->d2l==1.0.
Requirement already satisfied: jupyterlab-widgets>=1.0.0 in /usr/local/lib/python3.8/dist-packages (from ipywidgets->jupyter->d2l==1.
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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-c
Requirement already satisfied: pygments in /usr/local/lib/python3.8/dist-packages (from jupyter-console->jupyter->d2l==1.0.0b0) (2.6.
Requirement already satisfied: jinja2>=2.4 in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0b0) (2.11.3)
Requirement already satisfied: testpath in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0b0) (0.6.0)
Requirement already satisfied: pandocfilters>=1.4.1 in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0b0)
Requirement already satisfied: nbformat>=4.4 in /usr/local/lib/python3.8/dist-packages (from nbconvert->jupyter->d2l==1.0.0b0) (5.7.3
```

```
# Importing all the Necessary Libraries

%matplotlib inline
import pandas as pd
import numpy as np

import matplotlib.pyplot as plt
import time
```

```
import torchvision
import torch.nn.functional as F
from torchvision import transforms
from d2l import torch as d2l
from torch import nn

import torch
torch.__version__
torch.cuda.current_device()
torch.cuda.get_device_name(0)

d2l.use_svg_display()

# Code Snippet to Ignore Warning

import warnings
warnings.filterwarnings("ignore")


# Loading the FashionMNIST Dataset
class FashionMNIST(d2l.DataModule):
  def __init__(self, batch_size = 64, resize = (28, 28)):
    super().__init__()
    self.save_hyperparameters()
    trans = transforms.Compose([transforms.Resize(resize),
                                transforms.ToTensor()])
    self.train = torchvision.datasets.FashionMNIST(
        root = self.root, train = True, transform = trans, download = True)
    self.val = torchvision.datasets.FashionMNIST(
        root = self.root, train = False, transform = trans, download = True)



data = FashionMNIST(resize = (32, 32))
print("Training Images   = ", len(data.train))
print("Validation Images = ", len(data.val))

data.train[0][0].shape
```

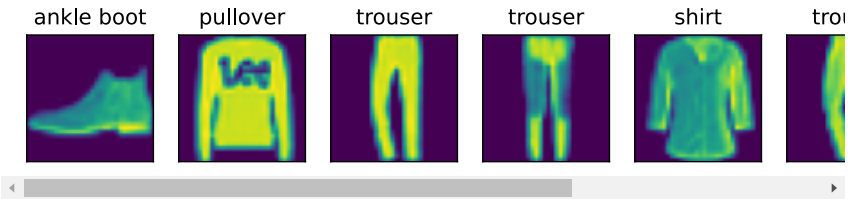
```
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-image
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-image
100%  26421880/26421880 [00:00<00:00,
129483839.45it/s]
Extracting ../data/FashionMNIST/raw/train-images-idx3-ubyte.gz to ../data/FashionM

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-label
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/train-label
100%  29515/29515 [00:00<00:00, 1017238.57it/s]
Extracting ../data/FashionMNIST/raw/train-labels-idx1-ubyte.gz to ../data/FashionM

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-images
100%  4422102/4422102 [00:00<00:00,
55520719.22it/s]
Extracting ../data/FashionMNIST/raw/t10k-images-idx3-ubyte.gz to ../data/FashionMN

Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels
Downloading http://fashion-mnist.s3-website.eu-central-1.amazonaws.com/t10k-labels
100%  5148/5148 [00:00<00:00, 322503.84it/s]
Extracting ../data/FashionMNIST/raw/t10k-labels-idx1-ubyte.gz to ../data/FashionMN
```

```
# Function that Converts between Numeric Labels and the Class Names
@d2l.add_to_class(FashionMNIST)
def text_labels(self, indices):
  labels = ['t-shirt', 'trouser', 'pullover', 'dress', 'coat',
            'sandal', 'shirt', 'sneaker', 'bag', 'ankle boot']
  return [labels[int(i)] for i in indices]


@d2l.add_to_class(FashionMNIST)
def get_dataloader(self, train):
  data = self.train if train else self.val
  return torch.utils.data.DataLoader(data, self.batch_size, shuffle = train,
                                     num_workers = self.num_workers)
```

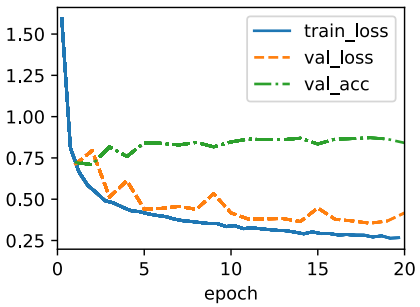
```
X, Y = next(iter(data.train_dataloader()))
print(X.shape, X.dtype, Y.shape, Y.dtype)
```

```
torch.Size([64, 1, 32, 32]) torch.float32 torch.Size([64]) torch.int64
```

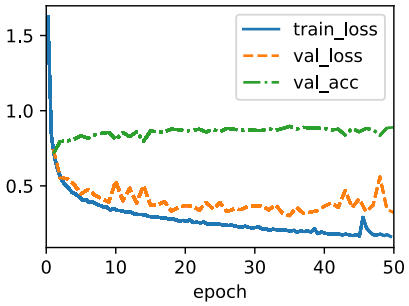
```
# Function to Display and Visualize the Images and their Corresponding Labels

def show_images(imgs, num_rows, num_cols, titles = None, scale = 1.5):
  raise NotImplementedError

@d2l.add_to_class(FashionMNIST)
def visualize(self, batch, nrows = 1, ncols = 8, labels = []):
  X, Y = batch
  if not labels:
    labels = self.text_labels(Y)
  d2l.show_images(X.squeeze(1), nrows, ncols, titles = labels)

batch = next(iter(data.val_dataloader()))
data.visualize(batch)
```




```
class Classifier(d2l.Module):
  def validation_step(self, batch):
    Y_hat = self(*batch[:-1])
    self.plot('Loss', self.loss(Y_hat, batch[-1]), train = False)
    self.plot('Acc', self.accuracy(Y_hat, batch[-1]), train = False)

@d2l.add_to_class(d2l.Module)
def configure_optimizers(self):
  return torch.optim.SGD(self.parameters(), lr = self.lr)

@d2l.add_to_class(Classifier)
def accuracy(self, Y_hat, Y, averaged = True):
  Y_hat = Y_hat.reshape((-1, Y_hat.shape[-1]))
  Preds = Y_hat.argmax(axis = 1).type(Y.dtype)
  compare = (Preds == Y.reshape(-1)).type(torch.float32)
  return compare.mean() if averaged else compare


class SoftmaxRegression(d2l.Classifier):
  def __init__(self, num_outputs, hidden_layer1, hidden_layer2, hidden_layer3, lr):
    super().__init__()
    self.save_hyperparameters()
    self.net = nn.Sequential(nn.Flatten(),
                             nn.LazyLinear(hidden_layer1),
                             nn.ReLU(),
                             nn.LazyLinear(hidden_layer2),
                             nn.ReLU(),
                             nn.LazyLinear(hidden_layer3),
                             nn.ReLU(),
                             nn.LazyLinear(num_outputs))
  def forward(self, X):
    return self.net(X)

@d2l.add_to_class(Classifier)
def loss(self, Y_hat, Y, averaged = True):
  Y_hat = Y_hat.reshape((-1, Y_hat.shape[-1]))
  Y = Y.reshape((-1))
  return F.cross_entropy(
      Y_hat, Y, reduction = 'mean' if averaged else 'none')


# Plotting over 20 Epochs (Basic Required for HW)
data = d2l.FashionMNIST(batch_size = 256)
model = SoftmaxRegression(num_outputs = 10, hidden_layer1 = 512, hidden_layer2 = 256, hidden_layer3 = 256, lr = 0.1)
trainer = d2l.Trainer(max_epochs = 20)
trainer.fit(model, data)
```




```
# Plotting over 50 Epochs for Comparison
data = d2l.FashionMNIST(batch_size = 256)
model = SoftmaxRegression(num_outputs = 10, hidden_layer1 = 512, hidden_layer2 = 256, hidden_layer3 = 256, lr = 0.1)
trainer = d2l.Trainer(max_epochs = 50)
trainer.fit(model, data)
```

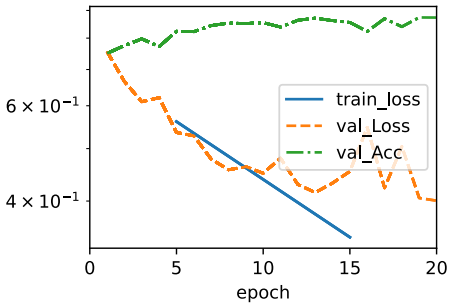


1.b.

```
# Defining the the l2 Norm Penalty
def l2_penalty(w):
  return (w ** 2).sum() / 2


# Defining the Model with Weight Decay Property added
class WeightDecay(Classifier):
  def __init__(self, num_outputs, hidden_layer1, hidden_layer2, hidden_layer3, wd, lr, sigma = 0.01):
    super().__init__(lr)
    self.save_hyperparameters()
    self.wd = wd
    self.weights = torch.normal(0, sigma, (hidden_layer1, 1), requires_grad=True)
    self.net = nn.Sequential(nn.Flatten(),
                             nn.LazyLinear(hidden_layer1),
                             nn.ReLU(),
                             nn.LazyLinear(hidden_layer2),
                             nn.ReLU(),
                             nn.LazyLinear(hidden_layer3),
                             nn.ReLU(),
                             nn.LazyLinear(num_outputs))
  def forward(self, X):
    return self.net(X)

  # Defining the Loss Function with Penalty Added
  def loss(self, Y_hat, Y, averaged = True):
    Y_hat = Y_hat.reshape((-1, Y_hat.shape[-1]))
    Y = Y.reshape((-1))
    return (super().loss(Y_hat, Y) +
            self.wd * l2_penalty(self.weights))

data = d2l.FashionMNIST(batch_size = 256)
trainer = d2l.Trainer(max_epochs = 20)

def train_scratch():
  t_0 = time.time()
  model.board.yscale = 'log'
  trainer.fit(model, data)
  t_1 = time.time()
  print("Total Training Time (From Saved Model): ", t_1 - t_0)
```

```
  print()
  print()

# Plotting the Results with Weight Decay Added
model = WeightDecay(num_outputs = 10, hidden_layer1 = 512, hidden_layer2 = 256, hidden_layer3 = 256, wd = 2, lr = 0.1)
train_scratch()

# Saving the Weight Decay Model Parameters for Future Use
torch.save(model.state_dict(), 'MLP_weightDecay.params')
```

```
     Total Training Time (From Saved Model):  249.53344559669495
```



1.c.

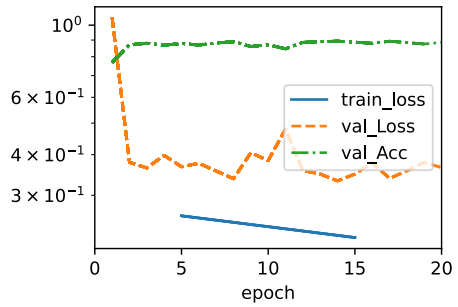
```
class DropoutMLP(d2l.Classifier):
  def __init__(self, num_outputs, hidden_layer1, hidden_layer2, hidden_layer3, dropout_1, dropout_2, dropout_3, lr):
    super().__init__()
    self.save_hyperparameters()
    self.net = nn.Sequential(nn.Flatten(),
                             nn.LazyLinear(hidden_layer1),
                             nn.ReLU(),
                             nn.Dropout(dropout_1),
                             nn.LazyLinear(hidden_layer2),
                             nn.ReLU(),
                             nn.Dropout(dropout_2),
                             nn.LazyLinear(hidden_layer3),
                             nn.ReLU(),
                             nn.Dropout(dropout_3),
                             nn.LazyLinear(num_outputs))
  def forward(self, X):
    return self.net(X)

@d2l.add_to_class(Classifier)
def loss(self, Y_hat, Y, averaged = True):
  Y_hat = Y_hat.reshape((-1, Y_hat.shape[-1]))
  Y = Y.reshape((-1))
  return F.cross_entropy(
      Y_hat, Y, reduction = 'mean' if averaged else 'none')


# Plotting over 20 Epochs
t_0 = time.time()
data = d2l.FashionMNIST(batch_size = 256)
model = DropoutMLP(num_outputs = 10, hidden_layer1 = 512, hidden_layer2 = 256, hidden_layer3 = 256, dropout_1 = 0.3, dropout_2 = 0.3, dropout
trainer = d2l.Trainer(max_epochs = 20)
trainer.fit(model, data)
t_1 = time.time()
print("Total Training Time (From Scratch): ", t_1 - t_0)
print()
print()

# Saving the Weight Decay Model Parameters for Future Use
torch.save(model.state_dict(), 'MLP_Dropout.params')
```

```
Total Training Time (From Scratch):  258.0815212726593
```

1.d.

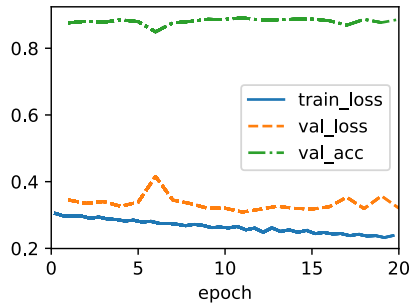

```
model = WeightDecay(num_outputs = 10, hidden_layer1 = 512, hidden_layer2 = 256, hidden_layer3 = 128, wd = 1, lr = 0.1)
model.load_state_dict(torch.load('MLP_weightDecay.params'))
train_scratch()
```

```
Total Training Time (From Saved Model):  248.07758355140686
```




```
# Plotting over 20 Epochs
t_0 = time.time()
model = DropoutMLP(num_outputs = 10, hidden_layer1 = 512, hidden_layer2 = 256, hidden_layer3 = 128, dropout_1 = 0.3, dropout_2 = 0.3, dropout
model.load_state_dict(torch.load('MLP_Dropout.params'))
#saved_MLP_WeightDecay.eval()
trainer = d2l.Trainer(max_epochs = 20)
trainer.fit(model, data)
t_1 = time.time()
print("Total Training Time (From Saved Model): ", t_1 - t_0)
print()
print()
```

```
Total Training Time (From Saved Model):  256.1456093788147
```



PROBLEM 2

2.a. Standardization is used on continuous numerical features when the dataset has different ranges or features are in different units. Standardization is used in our case to avoid the date from producing misleading results.

2.b.

```
# Downloading and Caching the Housing Dataset from Kaggle
class KaggleHouse(d2l.DataModule):
    def __init__(self, batch_size, train=None, val=None):
```

```
        super().__init__()
        self.save_hyperparameters()
        if self.train is None:
            self.raw_train = pd.read_csv(d2l.download(
                d2l.DATA_URL + 'kaggle_house_pred_train.csv', self.root,
                sha1_hash='585e9cc93e70b39160e7921475f9bcd7d31219ce'))
            self.raw_val = pd.read_csv(d2l.download(
                d2l.DATA_URL + 'kaggle_house_pred_test.csv', self.root,
                sha1_hash='fa19780a7b011d9b009e8bff8e99922a8ee2eb90'))
```

```
# Loading the Dataset
data = KaggleHouse(batch_size = 64)
print(data.raw_train.shape)
print(data.raw_val.shape)
```

```
Downloading ../data/kaggle_house_pred_train.csv from http://d2l-data.s3-accelerate.amazonaws.com/kaggle_house_pred_train.csv...
Downloading ../data/kaggle_house_pred_test.csv from http://d2l-data.s3-accelerate.amazonaws.com/kaggle_house_pred_test.csv...
(1460, 81)
(1459, 80)
```

```
@d2l.add_to_class(KaggleHouse)
def preprocess(self):
    # Removing the ID and label columns
    label = 'SalePrice'
    features = pd.concat(
        (self.raw_train.drop(columns=['Id', label]),
         self.raw_val.drop(columns=['Id'])))

    # Standardizing the numerical columns
    numeric_features = features.dtypes[features.dtypes != 'object'].index
    features[numeric_features] = features[numeric_features].apply(
        lambda x: (x - x.mean()) / (x.std()))

    # Replacing NAN numerical features by 0
    features[numeric_features] = features[numeric_features].fillna(0)

    # Replacing discrete features by one-hot encoding.
    features = pd.get_dummies(features, dummy_na=True)

    # Saving preprocessed features
    self.train = features[:self.raw_train.shape[0]].copy()
    self.train[label] = self.raw_train[label]
    self.val = features[self.raw_train.shape[0]:].copy()
```

```
# Preprocessing the Data
data.preprocess()
print(data.train.shape)
print(data.val.shape)
```

```
(1460, 332)
(1459, 331)
```

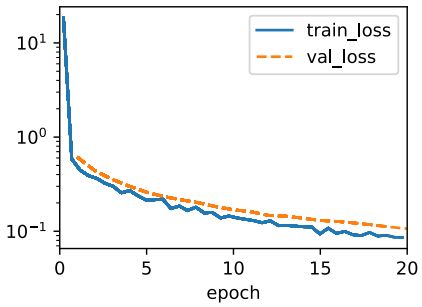
```
# Creation of a Dataloader Function
@d2l.add_to_class(KaggleHouse)
def get_dataloader(self, train):
    label = 'SalePrice'
    data = self.train if train else self.val
    if label not in data: return
    get_tensor = lambda x: torch.tensor(x.values, dtype=torch.float32)
    # Logarithm of prices
    tensors = (get_tensor(data.drop(columns=[label])),  # X
               torch.log(get_tensor(data[label])).reshape((-1, 1)))  # Y
    return self.get_tensorloader(tensors, train)
```

2.c.

```
# Defining the the l2 Norm Penalty for Weight Decay
def l2_penalty(w):
  return (w ** 2).sum() / 2

class LinearRegression(d2l.Module):
    def __init__(self, lr):
        self.save_hyperparameters()
```

```
            self.net = nn.LazyLinear(1024),
            self.net.ReLU(),
            self.net.Dropout(0.7),
            self.net.LazyLinear(512),
            self.net.ReLU(),
            self.net.Dropout(0.7),
            self.net.LazyLinear(128),
            self.net.ReLU(),
            self.net.Dropout(0.7),
            self.net.LazyLinear(32),
            self.net.ReLU(),
            self.net.Dropout(0.7),
            self.net.weight.data.normal_(0.5, 0.5),
            self.net.bias.data.fill_(0)

    @d2l.add_to_class(LinearRegression)
    def forward(self, X):
        return self.net(X)

       # Defining the Loss Function with Penalty Added
        def loss(self, Y_hat, Y, averaged = True):
          Y_hat = Y_hat.reshape((-1, Y_hat.shape[-1]))
          Y = Y.reshape((-1))
          return (super().loss(Y_hat, Y) +
                  self.wd * l2_penalty(self.weights))

    @d2l.add_to_class(LinearRegression)
    def configure_optimizers(self):
        return torch.optim.SGD(self.parameters(), self.lr)

    def k_fold_data(data, k):
        rets = []
        fold_size = data.train.shape[0] // k
        for j in range(k):
            idx = range(j * fold_size, (j+1) * fold_size)
            rets.append(KaggleHouse(data.batch_size, data.train.drop(index=idx),
                                    data.train.loc[idx]))
        return rets


    def k_fold(trainer, data, k, lr):
        val_loss, models = [], []
        for i, data_fold in enumerate(k_fold_data(data, k)):
            model = d2l.LinearRegression(lr)
            model.board.yscale='log'
            if i != 0: model.board.display = False
            trainer.fit(model, data_fold)
            val_loss.append(float(model.board.data['val_loss'][-1].y))
            models.append(model)
        print(f'average validation log mse = {sum(val_loss)/len(val_loss)}')
        return models


    # Plotting the Complex model with both Dropout and Weight Decay
    trainer = d2l.Trainer(max_epochs=20)
    models = k_fold(trainer, data, k=12, lr=0.01)
```

```
average validation log mse = 0.11221548200895388
```



2.d.

```
    # Getting the .csv File ready for submission on Kaggle
    preds = [model(torch.tensor(data.val.values, dtype=torch.float32))
             for model in models]
```

```
# Taking exponentiation of predictions in the logarithm scale
ensemble_preds = torch.exp(torch.cat(preds, 1)).mean(1)
submission = pd.DataFrame({'Id':data.raw_val.Id,
                           'SalePrice':ensemble_preds.detach().numpy()})
submission.to_csv('submission.csv', index=False)
```