

homework5

November 10, 2025

1 ECGR 4105-001, Homework 5

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```
[51]: import torch
import torch.optim as optim
import torch.nn as nn
import pandas as pd
import time
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import StandardScaler
import matplotlib.pyplot as plt
```

2 Problem 1

In our temperature prediction example, let's change our model to a nonlinear system. Consider the following description for our model:

$$w_2 * t_u^{**2} + w_1 * t_u + b.$$

1.a Modify the training loop properly to accommodate this redefinition.

```
[52]: # Data
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 = t_u * .1

# Model
def model_1a(t_u, w1, w2, b):
    return w2 * (t_u**2) + w1 * t_u + b

# Loss
def loss_fn(t_p, t_c):
    squared_diffs = (t_p-t_c)**2
    return squared_diffs.mean()
```

```
[53]: final_loss = 0.0

def training_loop(n_epochs, optimizer, params, t_u, t_c, model_fn):
    for epoch in range(1, n_epochs+1):
        # Forward
        t_p = model_fn(t_u, *params)

        # Loss
        loss = loss_fn(t_p, t_c)

        # Zero gradients before backward
        optimizer.zero_grad()

        # Backward
        loss.backward()

        # Update params
        optimizer.step()

        if epoch % 500 == 0:
            print(f'Epoch {epoch}, Loss {loss.item():.4f}')

        if epoch == n_epochs:
            final_loss = loss.item()

    print("---- Training Complete ---\n")
    return params, final_loss
```

1.b Use 5000 epochs for your training. Explore different learning rates from 0.1 to 0.0001 (you need four separate trainings). Report your loss for every 500 epochs per training.

```
[54]: from prompt_toolkit.styles import BaseStyle
learning_rates = [0.1, 0.01, 0.001, 0.0001]
n_epochs = 5000

# best model for 1c
best_loss = float('inf')
best_lr = None
best_params_nonlinear = None

for lr in learning_rates:
    # initialize paramters for each training run
    params = torch.tensor([1.0, 1.0, 0.0], requires_grad=True)

    optimizer = optim.Adam([params], lr=lr)

    final_params, final_loss = training_loop(
        n_epochs = n_epochs,
```

```

        optimizer = optimizer,
        params = params,
        t_u = t_u,
        t_c = t_c,
        model_fn = model_1a
    )

    if final_loss < best_loss:
        best_loss = final_loss
        best_lr = lr
        best_params_nonlinear = final_params

    print(f"\n--- Experiment Summary ---")
    print(f"Best non-linear model found with learning rate: {best_lr}")
    print(f"Best non-linear final loss: {best_loss:.4f}")
    print(f"Best parameters (w2, w1, b): {best_params_nonlinear.data}")

```

Epoch 500, Loss 4.8445
 Epoch 1000, Loss 3.7856
 Epoch 1500, Loss 3.4667
 Epoch 2000, Loss 3.4064
 Epoch 2500, Loss 3.3780
 Epoch 3000, Loss 3.3443
 Epoch 3500, Loss 3.3019
 Epoch 4000, Loss 3.2491
 Epoch 4500, Loss 3.1844
 Epoch 5000, Loss 3.1064
 --- Training Complete ---

Epoch 500, Loss 6.1087
 Epoch 1000, Loss 5.9844
 Epoch 1500, Loss 5.8090
 Epoch 2000, Loss 5.5863
 Epoch 2500, Loss 5.3209
 Epoch 3000, Loss 5.0213
 Epoch 3500, Loss 4.7013
 Epoch 4000, Loss 4.3808
 Epoch 4500, Loss 4.0834
 Epoch 5000, Loss 3.8327
 --- Training Complete ---

Epoch 500, Loss 3668163.0000
 Epoch 1000, Loss 768786.4375
 Epoch 1500, Loss 90021.1250
 Epoch 2000, Loss 4791.3398
 Epoch 2500, Loss 98.0142
 Epoch 3000, Loss 6.6097
 Epoch 3500, Loss 6.1173

```
Epoch 4000, Loss 6.0968
Epoch 4500, Loss 6.0711
Epoch 5000, Loss 6.0384
--- Training Complete ---
```

```
Epoch 500, Loss 10577728.0000
Epoch 1000, Loss 9524402.0000
Epoch 1500, Loss 8545122.0000
Epoch 2000, Loss 7634292.5000
Epoch 2500, Loss 6787368.0000
Epoch 3000, Loss 6000706.0000
Epoch 3500, Loss 5271407.5000
Epoch 4000, Loss 4597170.0000
Epoch 4500, Loss 3976134.2500
Epoch 5000, Loss 3406753.7500
--- Training Complete ---
```

```
--- Experiment Summary ---
Best non-linear model found with learning rate: 0.1
Best non-linear final loss: 3.1064
Best parameters (w2, w1, b): tensor([-0.0683,  0.0057, -2.5687])
```

1.c Pick the best non-linear model and compare your final best loss against the linear model that we did during the lecture. For this, visualize the non-linear model against the linear model over the input dataset, as we did during the lecture. Is the actual result better or worse than our baseline linear model?

```
[55]: # Linear model from lecture
def model_1c(t_u, w, b):
    return w * t_u + b

# Config
lr_lin = 1e-2
n_epochs_lin = 5000

params_linear = torch.tensor([1.0, 0.0], requires_grad=True)

optimizer_linear = optim.SGD([params_linear], lr=lr_lin)
```

```
[56]: # Training
params_linear_final, loss_linear_final = training_loop(
    n_epochs = n_epochs_lin,
    optimizer = optimizer_linear,
    params = params_linear,
    t_u = t_un,
    t_c = t_c,
    model_fn = model_1c
```

```

)
print(f"\n--- Baseline Summary ---")
print(f"Baseline linear model final loss: {loss_linear_final:.4f}")
print(f"Baseline parameters (w, b): {params_linear_final.data}")

```

Epoch 500, Loss 7.8601
 Epoch 1000, Loss 3.8285
 Epoch 1500, Loss 3.0922
 Epoch 2000, Loss 2.9577
 Epoch 2500, Loss 2.9331
 Epoch 3000, Loss 2.9286
 Epoch 3500, Loss 2.9278
 Epoch 4000, Loss 2.9277
 Epoch 4500, Loss 2.9277
 Epoch 5000, Loss 2.9276
 --- Training Complete ---

--- Baseline Summary ---
 Baseline linear model final loss: 2.9276
 Baseline parameters (w, b): tensor([5.3671, -17.3012])

[57]: # Visualization

```

t_u_sorted, indices = torch.sort(t_u)
t_c_sorted = t_c[indices]

with torch.no_grad():
    # Get predictions from the BEST non-linear model
    t_p_nonlinear = model_1a(t_u_sorted, *best_params_nonlinear)

    # Get predictions from the baseline linear model
    t_un_sorted = t_u_sorted * 0.1
    t_p_linear = model_1c(t_un_sorted, *params_linear_final)

# Plot the data and the two models
plt.figure(figsize=(10, 6))
plt.plot(t_u.numpy(), t_c.numpy(), 'o', label='Original Data')
plt.plot(t_u_sorted.numpy(), t_p_nonlinear.numpy(), '--', label=f'Best Non-Linear Fit (Loss: {best_loss:.4f})')
plt.plot(t_u_sorted.numpy(), t_p_linear.numpy(), '---', label=f'Baseline Linear Fit (Loss: {loss_linear_final:.4f})')

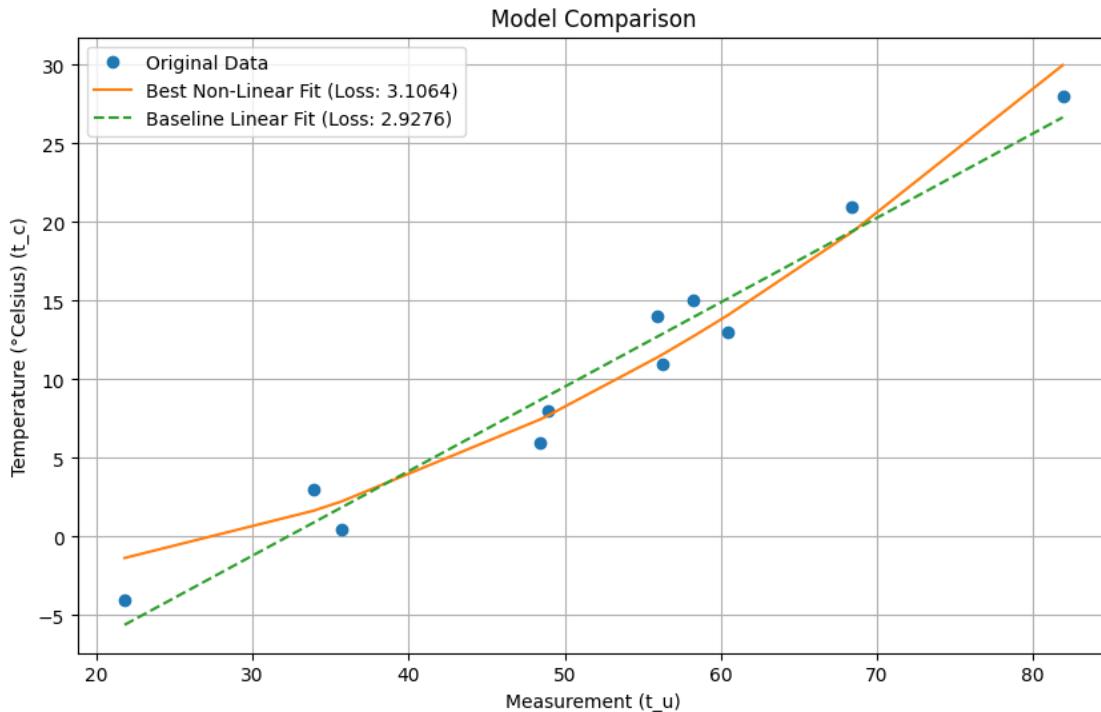
plt.xlabel('Measurement (t_u)')
plt.ylabel('Temperature (°Celsius) (t_c)')
plt.title('Model Comparison')

```

```

plt.legend()
plt.grid(True)
plt.show()

```



3 Problem 2:

```

[58]: # Load dataset
df = pd.read_csv('/Housing.csv')

# Define input and output
X_cols = ['area', 'bedrooms', 'bathrooms', 'stories', 'parking']
y_col = 'price'

df.info()

```

```

<class 'pandas.core.frame.DataFrame'>
RangeIndex: 545 entries, 0 to 544
Data columns (total 13 columns):
 #   Column           Non-Null Count  Dtype  
--- 
 0   price            545 non-null    int64  
 1   area              545 non-null    int64  
 2   bedrooms          545 non-null    int64  
 3   bathrooms         545 non-null    int64  

```

```

4   stories          545 non-null    int64
5   mainroad         545 non-null    object
6   guestroom        545 non-null    object
7   basement         545 non-null    object
8   hotwaterheating 545 non-null    object
9   airconditioning 545 non-null    object
10  parking          545 non-null    int64
11  prefarea         545 non-null    object
12  furnishingstatus 545 non-null    object
dtypes: int64(6), object(7)
memory usage: 55.5+ KB

```

```
[59]: X = df[X_cols].values
y = df[y_col].values.reshape(-1, 1)

# Normalize data
scaler_X = StandardScaler()
X_scaled = scaler_X.fit_transform(X)

scaler_y = StandardScaler()
y_scaled = scaler_y.fit_transform(y)

# 80% train, 20% validation split
X_train, X_val, y_train, y_val = train_test_split(
    X_scaled, y_scaled, test_size=0.2, random_state=42
)

# Convert to tensors
X_train_t = torch.tensor(X_train, dtype=torch.float32)
y_train_t = torch.tensor(y_train, dtype=torch.float32)
X_val_t = torch.tensor(X_val, dtype=torch.float32)
y_val_t = torch.tensor(y_val, dtype=torch.float32)
```

2.a. Develop preprocessing and a training loop to train a linear regression model that predicts housing price based on the following input variables:

area, bedrooms, bathrooms, stories, parking

For this, you need to use the housing dataset. For training and validation use 80% (training) and 20% (validation) split. Identify the best parameters for your linear regression model, based on the above input variables. In this case, you will have six parameters:

$$U = W_5 * X_5 + W_4 * X_4 + W_3 * X_3 + W_2 * X_2 + W_1 * X_1 + B$$

```
[60]: def model_housing(X, weights, bias):
    return torch.matmul(X, weights) + bias

# Mean Squared Error loss
loss_fn = nn.MSELoss()
```

2.b Use 5000 epochs for your training. Explore different learning rates from 0.1 to 0.0001 (you need four separate trainings). Report your loss and validation accuracy for every 500 epochs per each training. Pick the best linear model.

```
[61]: def training_loop_housing(
    n_epochs, optimizer, weights, bias,
    X_train, y_train, X_val, y_val
):

    # Store history
    train_losses = []
    val_losses = []

    # Training
    for epoch in range(1, n_epochs + 1):

        # Forward pass
        t_p_train = model_housing(X_train, weights, bias)

        # Compute loss
        loss_train = loss_fn(t_p_train, y_train)

        # Zero gradients, backward pass, optimizer step
        optimizer.zero_grad()
        loss_train.backward()
        optimizer.step()

        # Validation
        with torch.no_grad():
            t_p_val = model_housing(X_val, weights, bias)
            loss_val = loss_fn(t_p_val, y_val)

        if epoch % 500 == 0:
            print(f'Epoch {epoch:4d}, '
                  f'Train Loss: {loss_train.item():.4f}, '
                  f'Val Loss: {loss_val.item():.4f}')

        # Log losses
        train_losses.append(loss_train.item())
        val_losses.append(loss_val.item())

    print("--- Training Complete ---\n")
    return train_losses, val_losses, weights, bias
```

```
[62]: learning_rates = [0.1, 0.01, 0.001, 0.0001]
n_epochs = 5000
```

```

# Results
best_final_val_loss = float('inf')
best_lr = None
best_params = None
all_results = {}

n_features = X_train_t.shape[1]

for lr in learning_rates:

    # Initialize parameters for each run
    weights = torch.randn((n_features, 1), requires_grad=True)
    bias = torch.zeros(1, requires_grad=True)

    # Create optimizer
    optimizer = optim.SGD([weights, bias], lr=lr)

    # Run training loop
    train_loss_hist, val_loss_hist, final_w, final_b = training_loop_housing(
        n_epochs = n_epochs,
        optimizer = optimizer,
        weights = weights,
        bias = bias,
        X_train = X_train_t,
        y_train = y_train_t,
        X_val = X_val_t,
        y_val = y_val_t
    )

    # Store results
    final_val_loss = val_loss_hist[-1]
    all_results[lr] = {
        'train_loss': train_loss_hist,
        'val_loss': val_loss_hist,
        'final_val_loss': final_val_loss
    }

    # Check if this is the best model so far
    if final_val_loss < best_final_val_loss:
        best_final_val_loss = final_val_loss
        best_lr = lr
        best_params = (final_w, final_b)

```

Epoch 500, Train Loss: 0.3866, Val Loss: 0.6565
 Epoch 1000, Train Loss: 0.3866, Val Loss: 0.6565
 Epoch 1500, Train Loss: 0.3866, Val Loss: 0.6565
 Epoch 2000, Train Loss: 0.3866, Val Loss: 0.6565

```
Epoch 2500, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 3000, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 3500, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 4000, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 4500, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 5000, Train Loss: 0.3866, Val Loss: 0.6565
--- Training Complete ---
```

```
Epoch 500, Train Loss: 0.3866, Val Loss: 0.6572
Epoch 1000, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 1500, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 2000, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 2500, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 3000, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 3500, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 4000, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 4500, Train Loss: 0.3866, Val Loss: 0.6565
Epoch 5000, Train Loss: 0.3866, Val Loss: 0.6565
--- Training Complete ---
```

```
Epoch 500, Train Loss: 1.0161, Val Loss: 1.4955
Epoch 1000, Train Loss: 0.5310, Val Loss: 0.8970
Epoch 1500, Train Loss: 0.4287, Val Loss: 0.7455
Epoch 2000, Train Loss: 0.3995, Val Loss: 0.6925
Epoch 2500, Train Loss: 0.3906, Val Loss: 0.6722
Epoch 3000, Train Loss: 0.3878, Val Loss: 0.6638
Epoch 3500, Train Loss: 0.3870, Val Loss: 0.6601
Epoch 4000, Train Loss: 0.3867, Val Loss: 0.6584
Epoch 4500, Train Loss: 0.3866, Val Loss: 0.6575
Epoch 5000, Train Loss: 0.3866, Val Loss: 0.6571
--- Training Complete ---
```

```
Epoch 500, Train Loss: 1.8948, Val Loss: 2.7056
Epoch 1000, Train Loss: 1.5866, Val Loss: 2.3167
Epoch 1500, Train Loss: 1.3570, Val Loss: 2.0226
Epoch 2000, Train Loss: 1.1833, Val Loss: 1.7967
Epoch 2500, Train Loss: 1.0496, Val Loss: 1.6204
Epoch 3000, Train Loss: 0.9451, Val Loss: 1.4806
Epoch 3500, Train Loss: 0.8620, Val Loss: 1.3680
Epoch 4000, Train Loss: 0.7948, Val Loss: 1.2758
Epoch 4500, Train Loss: 0.7397, Val Loss: 1.1993
Epoch 5000, Train Loss: 0.6939, Val Loss: 1.1350
--- Training Complete ---
```

```
[63]: print(" --- Experiment Summary ---")
      print(f"Best model found with Learning Rate: {best_lr}")
```

```

print(f"Best Final Validation Loss: {best_final_val_loss:.4f}")

# Retrieve the best parameters
best_w, best_b = best_params

print("\n--- Best Model Parameters ---")
print(f"Weights (W1-W5): \n{best_w.data.numpy().flatten()}")
print(f"Bias (B): {best_b.data.item():.4f}")

```

--- Experiment Summary ---

Best model found with Learning Rate: 0.1

Best Final Validation Loss: 0.6565

--- Best Model Parameters ---

Weights (W1-W5):

[0.35835692 0.05968103 0.31853154 0.2296232 0.15553762]

Bias (B): -0.0119

[64]: # Visualization

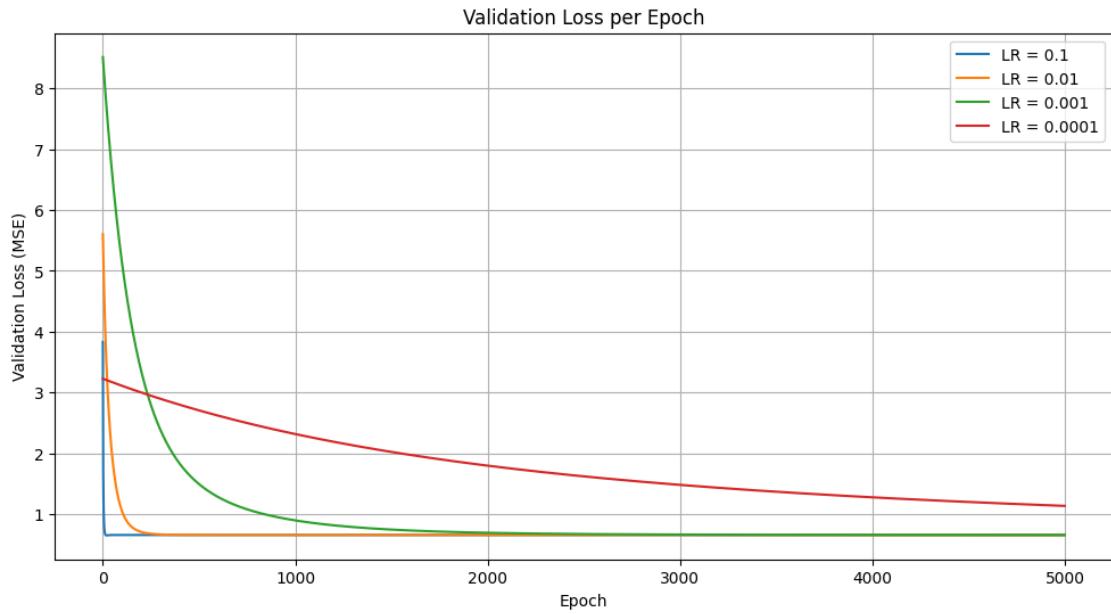
```

plt.figure(figsize=(12, 6))

for lr, results in all_results.items():
    # Plot validation loss
    plt.plot(results['val_loss'], label=f'LR = {lr}')

plt.title('Validation Loss per Epoch')
plt.xlabel('Epoch')
plt.ylabel('Validation Loss (MSE)')
plt.legend()
plt.grid(True)
plt.show()

```



4 Problem 3:

```
[65]: # Baseline Linear Model
class Net_Linear(nn.Module):
    def __init__(self):
        super(Net_Linear, self).__init__()
        self.layer = nn.Linear(5, 1) # 5 inputs, 1 output

    def forward(self, x):
        return self.layer(x)
```

```
[66]: # Load data
df = pd.read_csv('/Housing.csv')

X_cols = ['area', 'bedrooms', 'bathrooms', 'stories', 'parking']
y_col = 'price'

X = df[X_cols].values
y = df[y_col].values.reshape(-1, 1)

scaler_X = StandardScaler()
X_scaled = scaler_X.fit_transform(X)

scaler_y = StandardScaler()
y_scaled = scaler_y.fit_transform(y)
```

```

# 80% train, 20% validation split
X_train, X_val, y_train, y_val = train_test_split(
    X_scaled, y_scaled, test_size=0.2, random_state=42
)

# Convert to tensors
X_train_t = torch.tensor(X_train, dtype=torch.float32)
y_train_t = torch.tensor(y_train, dtype=torch.float32)
X_val_t = torch.tensor(X_val, dtype=torch.float32)
y_val_t = torch.tensor(y_val, dtype=torch.float32)

```

```

[67]: def count_parameters(model):
    """Counts the number of trainable parameters in a model."""
    return sum(p.numel() for p in model.parameters() if p.requires_grad)

def train_model(model, n_epochs, X_train, y_train, X_val, y_val, lr=0.01):
    """
    Trains a given nn.Module model.
    Returns a dictionary of results.
    """

    # Loss function (Mean Squared Error for regression)
    loss_fn = nn.MSELoss()

    # Optimizer
    optimizer = optim.Adam(model.parameters(), lr=lr)

    print(f"--- Training {model.__class__.__name__} for {n_epochs} epochs ---")

    # History for plotting
    history_train_loss = []
    history_val_loss = []

    start_time = time.time()

    for epoch in range(1, n_epochs + 1):

        # Training
        model.train()
        y_pred_train = model(X_train)
        loss_train = loss_fn(y_pred_train, y_train)
        optimizer.zero_grad()
        loss_train.backward()
        optimizer.step()

        # Validation
        model.eval()

```

```

    with torch.no_grad():
        y_pred_val = model(X_val)
        loss_val = loss_fn(y_pred_val, y_val)

    # Store history
    history_train_loss.append(loss_train.item())
    history_val_loss.append(loss_val.item())

    end_time = time.time()
    total_time = end_time - start_time

    # Results
    final_train_loss = history_train_loss[-1]
    final_val_loss = history_val_loss[-1]

    print(f"Training Complete.")

    return {
        'model_name': model.__class__.__name__,
        'model_object': model,
        'train_time': total_time,
        'train_loss': final_train_loss,
        'val_loss': final_val_loss,
        'history_train': history_train_loss,
        'history_val': history_val_loss,
        'params': count_parameters(model)
    }
}

```

3.a Build a fully connected neural network for the housing dataset you did in previous problem. For training and validation use 80% (training) and 20% (validation) split. For this part, only use one hidden layer with 8 nodes. Train your network for 200 epochs. Report your training time, training loss, and evaluation accuracy after 200 epochs. Analyze your results in your report. Make sure to submit your code by providing the GitHub URL of your course repository for this course. (15pts)

```
[68]: class Net_1_Hidden(nn.Module):
    def __init__(self):
        super(Net_1_Hidden, self).__init__()
        # Input layer (5 features) to hidden layer (8 nodes)
        self.hidden = nn.Linear(5, 8)
        # Activation function
        self.activation = nn.ReLU()
        # Hidden layer (8 nodes) to output layer (1 node)
        self.output = nn.Linear(8, 1)

    def forward(self, x):
        x = self.activation(self.hidden(x))
```

```

        x = self.output(x)
        return x

[69]: model_1_hidden = Net_1_Hidden()

# Training
results_1_hidden = train_model(
    model = model_1_hidden,
    n_epochs = 200,
    X_train = X_train_t,
    y_train = y_train_t,
    X_val = X_val_t,
    y_val = y_val_t
)

print("\n--- Problem 3.a Report ---")
print(f"Model: {results_1_hidden['model_name']}")  

print(f"Trainable Parameters: {results_1_hidden['params']}")  

print(f"Total Training Time: {results_1_hidden['train_time']:.4f} seconds")  

print(f"Final Training Loss: {results_1_hidden['train_loss']:.4f}")  

print(f"Final Validation Loss (Accuracy): {results_1_hidden['val_loss']:.4f}")

```

--- Training Net_1_Hidden for 200 epochs ---

Training Complete.

--- Problem 3.a Report ---

Model: Net_1_Hidden

Trainable Parameters: 57

Total Training Time: 0.1985 seconds

Final Training Loss: 0.3396

Final Validation Loss (Accuracy): 0.6365

3.b Extend your network with two more additional hidden layers, like the example we did in lecture. Train your network for 200 epochs. Report your training time, training loss, and evaluation accuracy after 200 epochs. Analyze your results in your report. Make sure to submit your code by providing the GitHub URL of your course repository for this course. Analyze your results in your report and compare your model size and accuracy over the baseline implementation in Problem1. a. Do you see any over-fitting? Make sure to submit your code by providing the GitHub URL of your course repository for this course. (25pts)

```

[70]: class Net_3_Hidden(nn.Module):
    def __init__(self):
        super(Net_3_Hidden, self).__init__()
        # 5 -> 8
        self.layer1 = nn.Linear(5, 8)
        self.act1 = nn.ReLU()
        # 8 -> 8
        self.layer2 = nn.Linear(8, 8)

```

```

    self.act2 = nn.ReLU()
    # 8 -> 8
    self.layer3 = nn.Linear(8, 8)
    self.act3 = nn.ReLU()
    # 8 -> 1
    self.output = nn.Linear(8, 1)

def forward(self, x):
    x = self.act1(self.layer1(x))
    x = self.act2(self.layer2(x))
    x = self.act3(self.layer3(x))
    x = self.output(x)
    return x

```

[71]: print("--- Starting Problem 3.b ---")

```

model_3_hidden = Net_3_Hidden()

# Training
results_3_hidden = train_model(
    model = model_3_hidden,
    n_epochs = 200,
    X_train = X_train_t,
    y_train = y_train_t,
    X_val = X_val_t,
    y_val = y_val_t
)

print("\n--- Problem 3.b Report ---")
print(f"Model: {results_3_hidden['model_name']} ")
print(f"Trainable Parameters: {results_3_hidden['params']} ")
print(f"Total Training Time: {results_3_hidden['train_time']:.4f} seconds")
print(f"Final Training Loss: {results_3_hidden['train_loss']:.4f}")
print(f"Final Validation Loss (Accuracy): {results_3_hidden['val_loss']:.4f}")

```

--- Starting Problem 3.b ---
--- Training Net_3_Hidden for 200 epochs ---
Training Complete.

--- Problem 3.b Report ---
Model: Net_3_Hidden
Trainable Parameters: 201
Total Training Time: 0.3312 seconds
Final Training Loss: 0.2741
Final Validation Loss (Accuracy): 0.6505

```
[72]: print("--- Running Baseline Linear Model for Comparison ---")

model_linear = Net_Linear()

# Training
results_linear = train_model(
    model = model_linear,
    n_epochs = 200,
    X_train = X_train_t,
    y_train = y_train_t,
    X_val = X_val_t,
    y_val = y_val_t
)

--- Running Baseline Linear Model for Comparison ---
--- Training Net_Linear for 200 epochs ---
Training Complete.

[80]: all_results = [results_linear, results_1_hidden, results_3_hidden]

# Plot Loss Curves
plt.figure(figsize=(18, 6))

for i, res in enumerate(all_results):
    plt.subplot(1, 3, i + 1)
    plt.title(f"{res['model_name']} (Params: {res['params']})")
    plt.plot(res['history_train'], label='Training Loss')
    plt.plot(res['history_val'], label='Validation Loss')
    plt.xlabel('Epoch')
    plt.ylabel('Loss (MSE)')
    plt.legend()
    plt.grid(True)
    plt.ylim(0, 1)

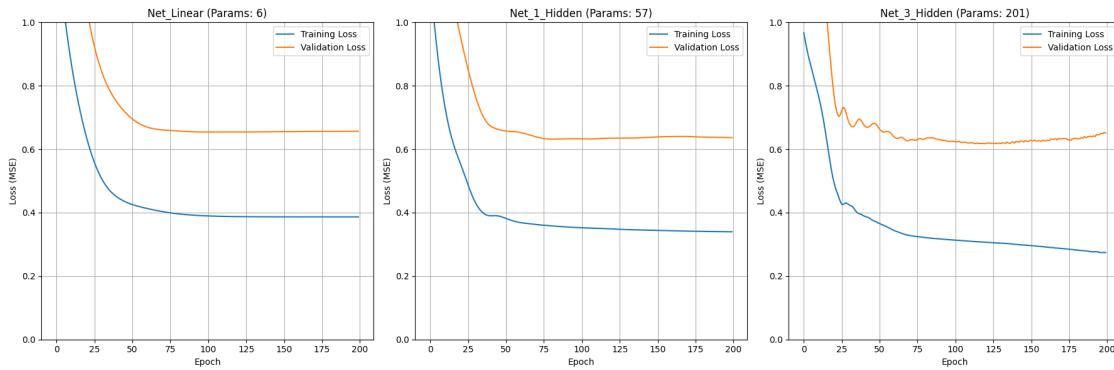
plt.tight_layout()
plt.show()

# Comparison
print("| Model | Trainable Parameters | Train Time (sec) | Final Train Loss |"
      "Final Validation Loss |")
print(f"| Net_Linear (Baseline) | {results_linear['params']} |"
      f" {results_linear['train_time']:.2f} | {results_linear['train_loss']:.4f} |"
      f" {results_linear['val_loss']:.4f} |")
print(f"| Net_1_Hidden (3.a) | {results_1_hidden['params']} |"
      f" {results_1_hidden['train_time']:.2f} | {results_1_hidden['train_loss']:.4f} |"
      f" {results_1_hidden['val_loss']:.4f} |")
```

```

print(f" | Net_3_Hidden (3.b)      | {results_3_hidden['params']} | "
    + f"{results_3_hidden['train_time']:.2f} | {results_3_hidden['train_loss']:.4f} | "
    + f"| {results_3_hidden['val_loss']:.4f} |")

```



Model	Trainable Parameters	Train Time (sec)	Final Train Loss	Final Validation Loss
Net_Linear (Baseline)	6	0.14	0.3866	0.6565
Net_1_Hidden (3.a)	57	0.20	0.3396	0.6365
Net_3_Hidden (3.b)	201	0.33	0.2741	0.6505