Experiment: Sensitivity Analysis

```
import torch

import torch.nn as nn

import torch.optim as optim

import torchvision

import torchvision.transforms as transforms

import numpy as np

import matplotlib.pyplot as plt


# ensure full NumPy prints

np.set_printoptions(threshold=np.inf, linewidth=200)


# Device

device = torch.device("cuda" if torch.cuda.is_available() else "cpu")


# Hyperparameter grids

lambdas = [0.0, 1e-4, 5e-4, 1e-3, 5e-3]   # λ values (rows)

lrs     = [1e-2, 5e-3, 1e-3, 5e-4, 1e-4]  # lr values (columns)


# CIFAR-10 data loaders

transform = transforms.Compose([

    transforms.ToTensor(),

    transforms.Normalize((0.4914, 0.4822, 0.4465),

                         (0.2470, 0.2435, 0.2616))

])

trainset = torchvision.datasets.CIFAR10(root='./data', train=True,
                                        download=True, transform=transform)
testset  = torchvision.datasets.CIFAR10(root='./data', train=False,
                                        download=True, transform=transform)
trainloader = torch.utils.data.DataLoader(trainset, batch_size=128,
                                          shuffle=True, num_workers=2)
testloader  = torch.utils.data.DataLoader(testset, batch_size=256,
                                          shuffle=False, num_workers=2)


# Simple CNN model
class SimpleCNN(nn.Module):
    def __init__(self):
        super().__init__()
        self.features = nn.Sequential(
            nn.Conv2d(3, 32, 3, padding=1), nn.ReLU(),
            nn.MaxPool2d(2),
            nn.Conv2d(32, 64, 3, padding=1), nn.ReLU(),
            nn.MaxPool2d(2),
        )
        self.classifier = nn.Sequential(
            nn.Flatten(),
            nn.Linear(64 * 8 * 8, 128), nn.ReLU(),
            nn.Linear(128, 10)
        )
    def forward(self, x):
        x = self.features(x)
        return self.classifier(x)
```

```
# Entropy regularization term
def entropy_reg(logits):
    p   = torch.softmax(logits, dim=1)
    ent = -torch.sum(p * torch.log(p + 1e-8), dim=1)
    return ent.mean()

# Number of independent runs and epochs
num_runs   = 50
num_epochs = 3

# Allocate array to store accuracy for each run, lr, λ
all_acc = np.zeros((num_runs, len(lrs), len(lambdas)))

for run in range(num_runs):
    torch.manual_seed(run)
    np.random.seed(run)

    for i, lr in enumerate(lrs):
        for j, lam in enumerate(lambdas):
            model     = SimpleCNN().to(device)
            optimizer = optim.SGD(model.parameters(), lr=lr, momentum=0.9)
            criterion = nn.CrossEntropyLoss()

            # Train
            for _ in range(num_epochs):
                model.train()
                for inputs, targets in trainloader:
                    inputs, targets = inputs.to(device), targets.to(device)
                    optimizer.zero_grad()
                    outputs = model(inputs)
                    loss    = criterion(outputs, targets)
                    if lam > 0:
                        loss += lam * entropy_reg(outputs)
                    loss.backward()
                    optimizer.step()

            # Evaluate
            model.eval()
            correct = total = 0
            with torch.no_grad():
                for inputs, targets in testloader:
                    inputs, targets = inputs.to(device), targets.to(device)
                    outputs = model(inputs)
                    _, preds = outputs.max(1)
                    correct += preds.eq(targets).sum().item()
                    total   += targets.size(0)
            all_acc[run, i, j] = 100. * correct / total

# Print the full array
print(f"Accuracy values for each of {num_runs} runs (shape {all_acc.shape}):")
print(all_acc)
```

Experiment: Sensitivity analysis - Plot Heatmap from accuracies obtained in previous code

```
import numpy as np
import matplotlib.pyplot as plt
# 5×5 hyperparameter grid
lambdas = [0.0, 1e-4, 5e-4, 1e-3, 5e-3]   # λ values (columns)
lrs     = [1e-2, 5e-3, 1e-3, 5e-4, 1e-4]  # η values (rows)

# Precomputed CIFAR-10 test accuracies for 50 runs: shape = (50, 5, 5)
all_acc = np.array([
   [[69.13, 67.33, 66.54, 67.49, 67.33],
    [63.15, 63.96, 64.01, 64.42, 62.14],
    [49.82, 48.08, 48.86, 48.69, 50.00],
    [39.97, 40.65, 41.14, 40.93, 42.01],
    [25.74, 25.54, 25.63, 27.99, 25.41]],

   [[68.07, 67.66, 65.83, 67.27, 68.48],
    [62.10, 62.49, 63.43, 63.27, 63.53],
    [49.28, 48.67, 48.49, 48.23, 48.51],
    [42.34, 39.75, 41.33, 39.25, 41.43],
    [25.27, 27.31, 27.93, 23.59, 28.35]],

   [[66.44, 68.40, 67.70, 67.24, 66.81],
    [63.74, 64.82, 64.01, 64.35, 63.71],
    [49.86, 48.54, 48.86, 48.21, 48.89],
    [41.41, 41.64, 42.74, 40.00, 41.82],
    [26.34, 28.86, 26.37, 26.99, 27.87]],

   [[68.57, 67.73, 66.68, 67.66, 67.24],
    [61.62, 63.34, 61.99, 63.73, 61.40],
    [49.49, 48.89, 49.56, 48.99, 47.64],
    [40.48, 42.88, 40.36, 40.63, 41.78],
    [24.94, 26.70, 25.35, 27.93, 27.42]],

   [[67.96, 68.15, 67.35, 66.21, 68.02],
    [65.14, 63.56, 63.48, 62.31, 61.90],
    [50.10, 48.29, 49.03, 49.41, 48.55],
    [41.49, 41.07, 40.22, 40.48, 41.58],
    [26.08, 27.79, 26.65, 25.33, 27.10]],

   [[66.26, 68.20, 67.00, 67.56, 66.58],
    [61.90, 63.33, 63.45, 63.43, 62.34],
    [48.76, 47.53, 48.72, 48.68, 49.14],
    [41.70, 42.30, 41.40, 40.77, 42.06],
    [26.23, 26.58, 26.29, 26.10, 27.54]],

   [[65.03, 68.38, 66.70, 67.95, 68.08],
    [63.85, 63.72, 62.84, 62.84, 59.91],
    [49.04, 49.10, 48.67, 48.71, 49.57],
    [42.47, 41.25, 41.76, 41.60, 41.63],
    [28.19, 27.86, 26.56, 26.24, 26.84]],
   [[68.15, 65.75, 66.67, 68.05, 66.79],
    [62.42, 63.86, 62.32, 61.74, 62.72],
    [49.48, 48.35, 49.27, 48.69, 48.40],
    [40.86, 43.47, 40.88, 41.51, 41.06],
    [26.06, 25.53, 26.05, 27.71, 23.56]],

   [[67.93, 66.36, 67.60, 67.94, 67.14],
    [63.32, 62.65, 62.66, 62.29, 62.64],
    [48.48, 48.92, 49.07, 48.59, 48.49],
    [41.51, 41.54, 40.35, 40.99, 41.85],
    [26.41, 26.84, 26.92, 27.20, 24.85]],

   [[67.39, 67.15, 67.14, 68.32, 68.16],
    [62.48, 62.33, 63.25, 63.38, 63.68],
    [49.54, 48.94, 48.79, 49.02, 48.76],
    [42.11, 41.13, 41.86, 42.43, 41.19],
    [27.56, 25.41, 26.49, 26.46, 26.50]],

   [[68.01, 67.30, 66.33, 65.97, 68.95],
    [62.25, 63.00, 64.15, 63.26, 64.06],
    [48.81, 48.27, 47.58, 50.36, 47.60],
    [40.41, 43.05, 40.77, 39.62, 41.60],
    [26.85, 27.44, 27.37, 24.76, 25.02]],

   [[67.04, 68.78, 68.06, 67.51, 66.88],
    [63.99, 62.81, 57.03, 63.94, 61.93],
    [48.04, 48.35, 49.92, 49.28, 48.15],
    [42.24, 43.01, 41.25, 41.27, 42.06],
    [28.39, 24.98, 26.23, 26.78, 26.06]],

   [[66.75, 66.86, 67.68, 68.17, 67.46],
    [64.55, 64.25, 63.79, 62.60, 64.59],
    [49.13, 48.42, 48.63, 49.61, 47.55],
    [40.48, 41.49, 41.20, 43.12, 42.11],
    [28.06, 25.27, 25.86, 27.44, 29.82]],

   [[67.40, 66.33, 68.45, 68.45, 67.79],
    [63.69, 61.80, 63.51, 63.62, 62.93],
    [49.96, 49.62, 48.11, 48.12, 48.73],
    [41.85, 42.51, 41.88, 40.81, 41.45],
    [26.91, 27.04, 28.82, 26.30, 26.18]],

   [[68.06, 68.10, 68.06, 67.95, 65.65],
    [61.98, 63.54, 61.82, 61.84, 62.97],
    [49.85, 48.58, 48.40, 47.36, 48.71],
    [41.94, 43.24, 39.96, 41.82, 42.76],
    [23.76, 28.26, 24.78, 24.21, 28.08]],

   [[67.53, 66.60, 67.19, 66.91, 65.90],
    [62.72, 63.12, 63.67, 63.66, 63.02],
    [48.58, 48.91, 48.41, 49.54, 48.24],
    [42.31, 41.80, 41.70, 40.95, 43.23],
    [26.47, 25.31, 26.48, 26.67, 25.99]],

   [[68.69, 66.19, 69.29, 67.23, 66.71],
    [61.81, 62.97, 63.04, 62.18, 63.20],
    [47.88, 49.21, 49.27, 49.09, 48.94],
    [40.06, 40.32, 40.85, 40.32, 40.95],
    [29.58, 24.76, 27.08, 24.66, 27.63]],

   [[66.25, 68.30, 67.73, 65.24, 67.49],
    [63.91, 61.74, 62.72, 62.27, 61.86],
    [49.19, 48.14, 49.85, 47.51, 49.06],
    [42.33, 41.98, 40.51, 41.79, 41.18],
    [30.05, 26.80, 25.19, 25.02, 26.76]],

   [[66.01, 67.69, 67.00, 66.79, 65.77],
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    [49.17, 49.35, 48.07, 48.68, 48.48],
    [41.18, 41.30, 41.65, 41.14, 40.82],
    [27.03, 26.81, 26.77, 26.85, 27.47]],

   [[66.71, 67.00, 67.27, 66.41, 67.44],
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    [49.35, 49.01, 49.63, 48.31, 48.60],
    [42.09, 40.61, 42.09, 41.05, 41.01],
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   [[67.11, 66.90, 67.39, 67.29, 67.44],
    [63.13, 63.80, 62.41, 62.24, 63.02],
    [49.51, 49.12, 47.55, 48.74, 50.60],
    [42.50, 41.54, 40.87, 41.65, 40.85],
    [25.88, 21.32, 26.31, 26.51, 26.87]],

   [[66.70, 67.14, 66.57, 68.11, 67.74],
    [63.20, 64.37, 63.77, 63.82, 64.03],
    [48.69, 47.38, 48.56, 49.10, 50.08],
    [40.42, 40.25, 42.04, 39.35, 41.21],
    [27.31, 23.72, 27.61, 26.12, 27.13]],

   [[66.42, 67.80, 69.05, 67.38, 67.50],
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    [49.08, 48.80, 48.95, 47.10, 49.81],
    [43.10, 40.63, 41.06, 40.10, 41.39],
    [26.71, 26.17, 26.62, 29.16, 28.08]],

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    [49.18, 48.78, 48.44, 50.46, 48.53],

    [40.68, 41.65, 41.30, 40.82, 42.14],

    [27.35, 26.07, 27.25, 28.58, 28.62]],


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    [40.85, 41.26, 42.27, 42.05, 43.25],

    [27.96, 26.21, 24.36, 28.01, 26.33]],


   [[67.34, 65.95, 68.24, 67.70, 66.74],

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    [40.35, 42.60, 42.52, 41.25, 40.84],

    [25.33, 26.38, 27.27, 26.29, 25.72]],


   [[66.96, 67.57, 67.41, 66.86, 66.34],

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    [42.33, 42.88, 41.76, 41.38, 41.58],

    [25.76, 27.27, 29.68, 25.81, 25.41]],


   [[67.01, 67.93, 69.42, 66.40, 67.69],

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   [[68.23, 64.60, 66.03, 67.38, 67.73],
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    [42.41, 41.60, 42.78, 42.13, 40.71],
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   [[67.19, 66.31, 67.44, 66.63, 67.06],
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    [62.24, 62.10, 61.59, 61.82, 62.43],
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    [26.69, 26.14, 26.44, 25.85, 27.55]],

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    [41.09, 40.92, 41.28, 40.10, 42.09],
    [26.95, 24.64, 25.09, 26.06, 26.16]],

   [[66.48, 68.03, 67.84, 68.07, 67.76],
    [62.40, 62.84, 62.26, 63.02, 63.50],
    [48.68, 48.83, 49.62, 49.38, 49.60],
    [40.99, 41.73, 40.00, 40.81, 40.96],
    [24.46, 27.61, 27.99, 26.64, 27.33]],

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    [63.36, 63.31, 61.76, 63.09, 62.33],
    [48.73, 49.01, 48.97, 49.53, 49.75],
    [39.76, 39.71, 40.59, 41.27, 41.92],
    [24.63, 27.43, 25.40, 26.25, 26.44]],

   [[68.21, 66.56, 68.05, 67.48, 65.68],
    [63.92, 63.69, 63.46, 62.40, 62.60],
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    [41.61, 39.71, 41.97, 41.17, 42.73],

    [25.55, 25.64, 25.21, 26.56, 25.68]],


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    [62.16, 63.05, 63.15, 63.96, 63.29],

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    [26.70, 26.99, 26.80, 26.83, 27.52]],


   [[67.22, 67.47, 65.57, 67.01, 68.28],

    [63.81, 62.58, 63.66, 63.02, 64.63],

    [48.38, 49.97, 49.03, 49.54, 48.57],

    [41.61, 41.91, 40.59, 41.56, 41.95],

    [26.47, 26.03, 24.72, 25.88, 26.10]],


   [[66.26, 66.79, 65.62, 68.03, 66.13],

    [63.65, 62.21, 61.46, 63.44, 63.89],

    [48.17, 47.76, 49.37, 47.95, 49.36],

    [41.32, 41.92, 41.48, 40.40, 38.74],

    [26.14, 25.99, 25.11, 27.20, 25.98]],


   [[67.88, 67.26, 67.34, 66.33, 66.62],

    [63.74, 62.41, 62.09, 63.95, 62.77],

    [47.55, 48.08, 49.27, 48.80, 48.38],

    [41.62, 39.03, 41.18, 41.95, 41.45],
    [27.36, 27.50, 26.20, 25.67, 25.91]],

   [[66.94, 68.26, 65.62, 66.84, 67.35],
    [62.35, 61.04, 62.17, 62.78, 62.76],
    [48.60, 50.31, 48.95, 48.28, 47.53],
    [40.86, 42.67, 41.22, 41.60, 42.26],
    [25.10, 24.95, 26.95, 28.25, 28.20]],

   [[67.33, 67.88, 69.13, 67.26, 66.77],
    [62.41, 62.22, 63.19, 61.55, 62.95],
    [48.07, 48.37, 49.33, 47.87, 48.76],
    [40.81, 42.65, 41.81, 42.61, 40.84],
    [27.06, 25.91, 25.30, 26.39, 26.35]],

   [[67.70, 66.89, 68.36, 67.16, 66.19],
    [64.02, 61.99, 62.39, 62.75, 61.82],
    [48.95, 48.58, 49.99, 47.77, 48.42],
    [40.76, 41.46, 41.86, 41.22, 42.30],
    [24.81, 25.54, 28.30, 27.97, 23.78]],

   [[67.77, 66.85, 65.79, 66.14, 66.58],
    [63.21, 63.52, 63.22, 62.48, 62.29],
    [48.86, 48.62, 48.44, 50.09, 48.78],
    [41.02, 42.23, 41.28, 40.31, 41.21],
    [27.20, 26.74, 24.74, 26.90, 26.39]],
    [[66.80, 66.32, 68.41, 64.91, 66.54],
     [61.78, 63.98, 61.30, 62.24, 62.86],
     [49.57, 49.12, 49.19, 49.80, 50.47],
     [40.42, 41.39, 39.20, 42.33, 41.50],
     [25.11, 27.48, 27.20, 22.98, 28.39]],

    [[67.25, 67.89, 67.40, 68.62, 66.67],
     [62.67, 62.32, 62.37, 63.10, 63.22],
     [48.88, 48.90, 48.88, 47.91, 49.13],
     [42.74, 40.59, 41.48, 41.64, 41.74],
     [25.22, 28.49, 26.35, 25.70, 27.49]],

    [[67.43, 67.36, 65.16, 66.56, 67.77],
     [63.50, 63.27, 62.24, 62.08, 61.47],
     [47.33, 48.73, 48.75, 47.91, 48.29],
     [40.60, 41.66, 42.46, 41.47, 42.60],
     [27.58, 24.63, 26.83, 26.78, 27.59]],

    [[68.66, 66.54, 67.12, 65.69, 67.36],
     [63.82, 62.68, 62.44, 61.66, 61.74],
     [48.97, 49.55, 47.89, 50.12, 48.59],
     [41.07, 41.72, 39.51, 41.59, 42.32],
     [25.55, 26.23, 25.43, 24.81, 26.45]]
])


# 4) Mean over the 50 runs → 5×5
```
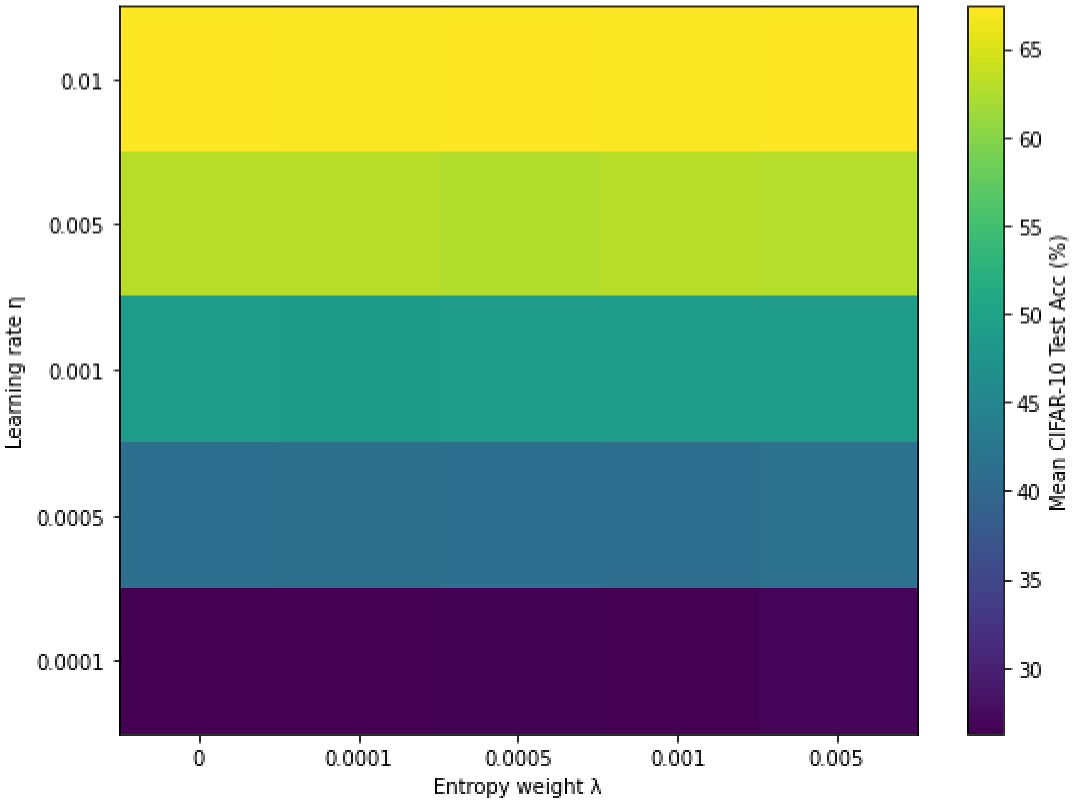

```
mean_acc = all_acc.mean(axis=0)

# 5) Plotting
fig, ax = plt.subplots(figsize=(8, 6))
im = ax.imshow(mean_acc, aspect='auto')

# colorbar
cbar = fig.colorbar(im, ax=ax)
cbar.set_label('Mean CIFAR-10 Test Acc (%)')

# ticks & labels
ax.set_xticks(np.arange(len(lambdas)))
ax.set_xticklabels([f'{v:g}' for v in lambdas])
ax.set_yticks(np.arange(len(lrs)))
ax.set_yticklabels([f'{v:g}' for v in lrs])

ax.set_xlabel('Entropy weight λ')
ax.set_ylabel('Learning rate η')
ax.set_title('CIFAR-10 Test Accuracy Heatmap')

# force a draw so tight_layout has a renderer
fig.canvas.draw()
plt.tight_layout()
plt.show()
```

Experiment 4 Results


Learning rate η
Entropy weight λ
Mean CIFAR-10 Test Acc (%)