

Student information:

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- Assignment-1: Video Classification

Assignment objective:

Using the customized dataset "UCF-101" to perform "Action recognition" for 3 different classes to predict the correct video class (Video Classification) using Classical Machine learning and Deep Learning Models.

Task: Action recognition:

1. Using Classical Machine Learning models.
2. Using Deep Learning Models

This python notebook file contains the code for following tasks:

1. Loading the dataset for 3 classes:
 - Class-1: PullUps
 - Class-2: Punch
 - Class-3: PullUps
 - The dataset is split into Train, Test and Validation.
 - For each category there is a separate CSV file.
2. Implementation of Deep Learning Learning models like 2D-CNN and 3D-CNN etc.
3. Model hyperparameter tuning
4. Performance evaluation and comparison

Environment Setup

1. Installing required modules
 - Before running this notebook, install dependencies using:

```
pip install -r requirements.txt
```

- (Ignore if already done)
2. importing modules and basic setup

```
In [1]: import os;
import torch
from torch.utils.data import DataLoader
from torchvision import transforms
from data_loader import VideoDataset2D
from models import ResNet18Temporal
from utils import train_one_epoch, eval_one_epoch, EarlyStopping
from tqdm import trange
import matplotlib.pyplot as plt
import seaborn as sns
import numpy as np
from sklearn.metrics import classification_report, confusion_matrix, accuracy_score
import time
import random
import psutil
from data_loader import VideoDataset3D
from models import ResNet3D

from sklearn.metrics import precision_recall_fscore_support
import json
import time
```

3. Reproducibility and Random Seed Initialization

```
In [2]: seed = 42
random.seed(seed)
np.random.seed(seed)
torch.manual_seed(seed)
torch.cuda.manual_seed_all(seed)

torch.backends.cudnn.deterministic = True
torch.backends.cudnn.benchmark = False
```

4. Creating required directories

```
In [3]: os.makedirs("../results", exist_ok=True);
os.makedirs("../results/confusion_matrices", exist_ok=True);
os.makedirs("../results/confusion_matrices/deep_learning", exist_ok=True);
os.makedirs("../results/performance_plots", exist_ok=True);
os.makedirs("../results/performance_plots/deep_learning", exist_ok=True);
os.makedirs("../results/feature_visualizations", exist_ok=True);
os.makedirs("../results/saved_models", exist_ok=True);
os.makedirs("../results/saved_models/deep_learning", exist_ok=True);
os.makedirs("../results/stats_deep_learning", exist_ok=True);
```

5. Directory path for saving trained models

```
In [4]: SAVE_DIR = "../results/saved_models/deep_learning";
os.makedirs(SAVE_DIR, exist_ok=True);

MODEL_2D_PATH = os.path.join(SAVE_DIR, "best_2d-cnn.pth");
MODEL_3D_PATH = os.path.join(SAVE_DIR, "best_3d-cnn.pth");

STATS_2D_PATH = "../results/stats_deep_learning/stats_2d.json";
STATS_3D_PATH = "../results/stats_deep_learning/stats_3d.json";
```

6. Transforms

```
In [5]: train_tfms = transforms.Compose([
    transforms.ToPILImage(),
    transforms.RandomResizedCrop(224),
    transforms.RandomHorizontalFlip(),
    transforms.ColorJitter(brightness=0.3, contrast=0.3, saturation=0.3),
    transforms.RandomRotation(10),
    transforms.ToTensor(),
    transforms.Normalize([0.485, 0.456, 0.406], [0.229, 0.224, 0.225])
])

val_tfms = transforms.Compose([
    transforms.ToPILImage(),
    transforms.Resize(256),
    transforms.CenterCrop(224),
    transforms.ToTensor(),
    transforms.Normalize([0.485, 0.456, 0.406], [0.229, 0.224, 0.225])
])
```

7. Dataset & loaders

```
In [6]: class_map = {"PullUps": 0, "Punch": 1, "PushUps": 2}
num_classes = len(class_map)

dataset_root = "../dataset_info/dataset"

train_ds_2d = VideoDataset2D("../dataset_info/dataset/splits/train.csv",
                             dataset_root, class_map,
                             num_frames=20, transform=train_tfms, train=True)

val_ds_2d = VideoDataset2D("../dataset_info/dataset/splits/val.csv",
                            dataset_root, class_map,
                            num_frames=20, transform=val_tfms, train=False)
```

```

test_ds_2d = VideoDataset2D("../dataset_info/dataset/splits/test.csv",
                             dataset_root, class_map,
                             num_frames=20, transform=val_tfms, train=False)

train_loader_2d = DataLoader(train_ds_2d, batch_size=4, shuffle=True, num_workers=4)
val_loader_2d   = DataLoader(val_ds_2d, batch_size=4, shuffle=False, num_workers=4)
test_loader_2d  = DataLoader(test_ds_2d, batch_size=4, shuffle=False, num_workers=4)

```

Deep Learning Algorithms

Implementing following Deep Learning Models

- 2D-CNN - with temporal pooling (ResNet18 pretrained on ImageNet)
- 3D-CNN - pre-trained 3D ResNet-18 (R3D-18), which is an I3D-style 3D CNN architecture

1. 2D CNN with Temporal Pooling

- Use pre-trained 2D CNN (ResNet-18, ResNet-50, or EfficientNet-B0) for frame-level features
- Extract features from sampled frames (e.g., 16-32 frames per video)

2D CNN: Model, optimizer and scheduler selection

```

In [7]: device = "cuda" if torch.cuda.is_available() else "cpu"

model_2d = ResNet18Temporal(num_classes=num_classes, pooling="avg", dropout=0.5).to(device)

criterion = torch.nn.CrossEntropyLoss(label_smoothing=0.9)

# Using Adam as optimizer
optimizer = torch.optim.Adam(model_2d.parameters(), lr=1e-4, weight_decay=1e-4)
# Learning rate scheduling
scheduler = torch.optim.lr_scheduler.StepLR(optimizer, step_size=5, gamma=0.5)
# Early stopping
early_stop = EarlyStopping(patience=3)

```

2D CNN: Training loop (with early stopping)

- This will take around 30 minutes to complete.

```

In [8]: start_time = time.time()

EPOCHS = 8
best_val_acc = 0.0

train_losses_2d = []
val_losses_2d   = []
train_accs_2d   = []
val_accs_2d     = []

# ===== LOAD IF EXISTS =====
if os.path.exists(MODEL_2D_PATH):

    print("Found saved 2D model. Loading...")

    model_2d.load_state_dict(torch.load(MODEL_2D_PATH, map_location=device))
    model_2d.to(device)
    model_2d.eval()

    if os.path.exists(STATS_2D_PATH):
        with open(STATS_2D_PATH, "r") as f:
            stats = json.load(f)

        # ---- SAFE LOAD (no KeyError) ----
        train_losses_2d = stats.get("train_losses", [])
        val_losses_2d    = stats.get("val_losses", [])
        train_accs_2d    = stats.get("train_accs", [])
        val_accs_2d      = stats.get("val_accs", [])
        best_val_acc     = max(val_accs_2d) if len(val_accs_2d) > 0 else 0.0

    print("Loaded training curves from stats_2d.json")
else:
    print("stats_2d.json not found → curves unavailable")

```

```

# ===== TRAIN IF NOT EXISTS =====
else:
    print("No saved 2D model found. Starting training...")

    for epoch in trange(EPOCHS, desc="2D CNN Epochs"):

        train_loss, train_acc = train_one_epoch(
            model_2d, train_loader_2d, optimizer, criterion, device)

        val_loss, val_acc = eval_one_epoch(
            model_2d, val_loader_2d, criterion, device)

        scheduler.step()

        print(
            f"\nEpoch [{epoch+1}/{EPOCHS}] "
            f"Train Loss: {train_loss:.4f} | Train Acc: {train_acc:.4f} || "
            f"Val Loss: {val_loss:.4f} | Val Acc: {val_acc:.4f}"
        )

        train_losses_2d.append(train_loss)
        val_losses_2d.append(val_loss)
        train_accs_2d.append(train_acc)
        val_accs_2d.append(val_acc)

        if val_acc > best_val_acc:
            best_val_acc = val_acc
            torch.save(model_2d.state_dict(), MODEL_2D_PATH)

        early_stop(val_loss)
        if early_stop.stop:
            print("■ Early stopping triggered")
            break

    print("2D CNN Training complete. Best Val Acc:", best_val_acc)

# ===== SAVE TRAINING CURVES =====
stats_2d = {
    "train_losses": train_losses_2d,
    "val_losses": val_losses_2d,
    "train_accs": train_accs_2d,
    "val_accs": val_accs_2d,
    "best_val_acc": best_val_acc
}

with open(STATS_2D_PATH, "w") as f:
    json.dump(stats_2d, f, indent=4)

print("Training curves saved to stats_2d.json")

end_time = time.time()
train_time_2d = end_time - start_time

np.save("../results/stats_deep_learning/train_time_2d.npy", train_time_2d)
print("2D CNN Training Time (seconds):", train_time_2d)

```

No saved 2D model found. Starting training...

2D CNN Epochs: 12%	1/8 [07:21<51:32, 441.80s/it]
Epoch [1/8] Train Loss: 1.2189 Train Acc: 0.4391 Val Loss: 1.1740 Val Acc: 0.4444	
2D CNN Epochs: 25%	2/8 [15:12<45:51, 458.58s/it]
Epoch [2/8] Train Loss: 1.1574 Train Acc: 0.4244 Val Loss: 1.1128 Val Acc: 0.4000	
2D CNN Epochs: 38%	3/8 [22:57<38:28, 461.77s/it]
Epoch [3/8] Train Loss: 1.1278 Train Acc: 0.4834 Val Loss: 1.0941 Val Acc: 0.8000	
2D CNN Epochs: 50%	4/8 [30:47<30:59, 464.82s/it]
Epoch [4/8] Train Loss: 1.1132 Train Acc: 0.4317 Val Loss: 1.0938 Val Acc: 0.8667	
2D CNN Epochs: 62%	5/8 [38:35<23:18, 466.21s/it]
Epoch [5/8] Train Loss: 1.1100 Train Acc: 0.5055 Val Loss: 1.0925 Val Acc: 0.9333	
2D CNN Epochs: 75%	6/8 [46:21<15:32, 466.12s/it]
Epoch [6/8] Train Loss: 1.1095 Train Acc: 0.4613 Val Loss: 1.0934 Val Acc: 0.8889	
2D CNN Epochs: 88%	7/8 [54:07<07:46, 466.14s/it]
Epoch [7/8] Train Loss: 1.1073 Train Acc: 0.5683 Val Loss: 1.0918 Val Acc: 0.9556	
2D CNN Epochs: 100%	8/8 [1:01:57<00:00, 464.73s/it]

Epoch [8/8] Train Loss: 1.1057 | Train Acc: 0.5793 || Val Loss: 1.0913 | Val Acc: 0.9333
2D CNN Training complete. Best Val Acc: 0.9555555555555556
Training curves saved to stats_2d.json
2D CNN Training Time (seconds): 3717.864061832428

2D CNN: Loading best model

```
In [9]: # Load best saved model
model_2d.load_state_dict(torch.load(MODEL_2D_PATH, map_location=device))
model_2d.eval()

print("Model loaded successfully")
print("Backbone: ResNet-18 (ImageNet pretrained)")
print("Input: fixed-length RGB frame sequences (224x224)")
print("Temporal aggregation: Temporal pooling")
print("Classifier head: Dropout → Fully Connected (3 classes)")

print("Trainable parameters:",
      sum(p.numel() for p in model_2d.parameters() if p.requires_grad))

print("Total parameters:",
      sum(p.numel() for p in model_2d.parameters()))
```

Model loaded successfully
Backbone: ResNet-18 (ImageNet pretrained)
Input: fixed-length RGB frame sequences (224x224)
Temporal aggregation: Temporal pooling
Classifier head: Dropout → Fully Connected (3 classes)
Trainable parameters: 11178051
Total parameters: 11178051

2D CNN: Test set evaluation

```
In [10]: all_preds_2d = []
all_labels_2d = []

with torch.no_grad():
    for x, y in test_loader_2d:
        x, y = x.to(device), y.to(device)
        out = model_2d(x)
        preds = torch.argmax(out, dim=1)

        all_preds_2d.extend(preds.cpu().numpy())
        all_labels_2d.extend(y.cpu().numpy())

all_preds_2d = np.array(all_preds_2d)
all_labels_2d = np.array(all_labels_2d)
```

2D CNN: Evaluation metrics

```
In [11]: print("2D CNN Test Accuracy:", accuracy_score(all_labels_2d, all_preds_2d))

print("\nClassification Report:")
print(classification_report(all_labels_2d, all_preds_2d, target_names=list(class_map.keys())))
```

2D CNN Test Accuracy: 0.9565217391304348

Classification Report:

	precision	recall	f1-score	support
PullUps	1.00	0.92	0.96	13
Punch	0.91	1.00	0.95	20
PushUps	1.00	0.92	0.96	13
accuracy			0.96	46
macro avg	0.97	0.95	0.96	46
weighted avg	0.96	0.96	0.96	46

2D CNN: Confusion matrix

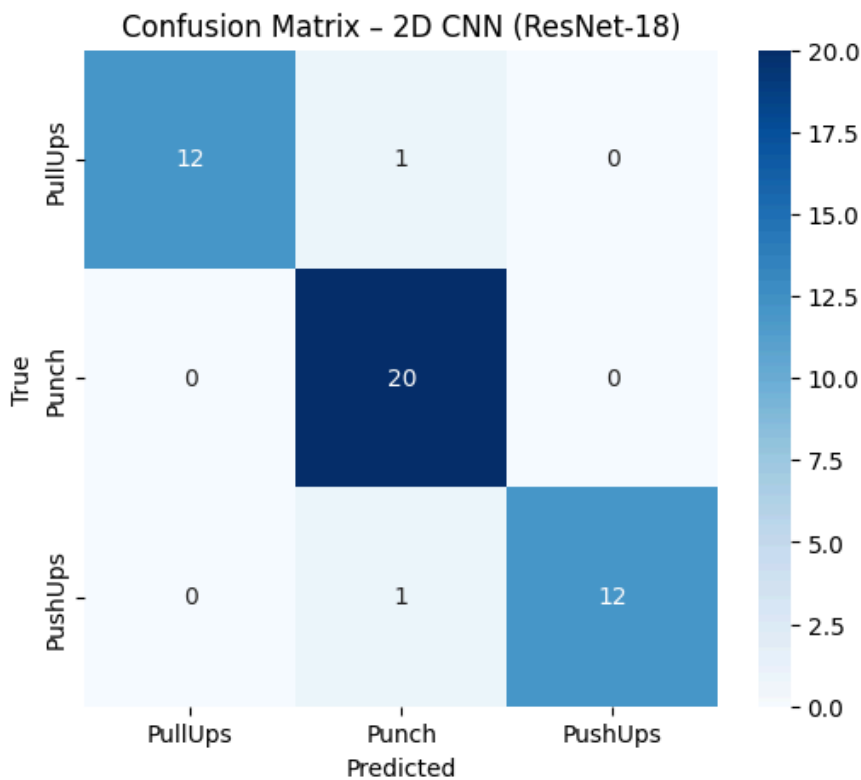
```
In [12]: conf_matrix_2d = confusion_matrix(all_labels_2d, all_preds_2d)

plt.figure(figsize=(6,5))
sns.heatmap(conf_matrix_2d, annot=True, fmt="d",
            xticklabels=class_map.keys(),
```

```

        yticklabels=class_map.keys(),
        cmap="Blues")
plt.xlabel("Predicted")
plt.ylabel("True")
plt.title("Confusion Matrix - 2D CNN (ResNet-18)")
plt.savefig("../results/confusion_matrices/deep_learning/2d_resnet18_confusion_matrix.png")
plt.show()
plt.close();

```



2D CNN: Learning curves

```

In [13]: #print("Train losses:", train_losses_2d)
#print("Val losses:", val_losses_2d)
#print("Train accs:", train_accs_2d)
#print("Val accs:", val_accs_2d)

#print(len(train_losses_2d), len(val_losses_2d), len(train_accs_2d), len(val_accs_2d))

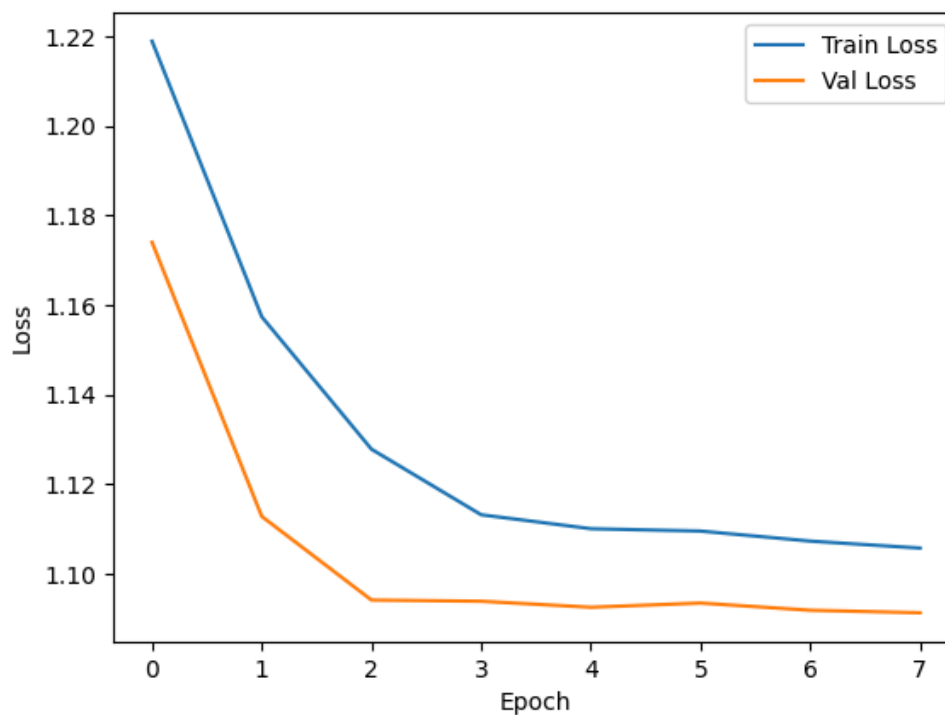
plt.figure()
plt.plot(train_losses_2d, label="Train Loss")
plt.plot(val_losses_2d, label="Val Loss")
plt.xlabel("Epoch")
plt.ylabel("Loss")
plt.title("Loss Curve - 2D CNN")
plt.legend()
plt.savefig("../results/performance_plots/deep_learning/2d_cnn_loss_curve.png", dpi=300, bbox_inches="tight");
plt.show()
plt.close()

plt.figure()
plt.plot(train_accs_2d, label="Train Accuracy")
plt.plot(val_accs_2d, label="Validation Accuracy")
plt.xlabel("Epoch")
plt.ylabel("Accuracy")
plt.title("Accuracy Curve - 2D CNN")
plt.legend()

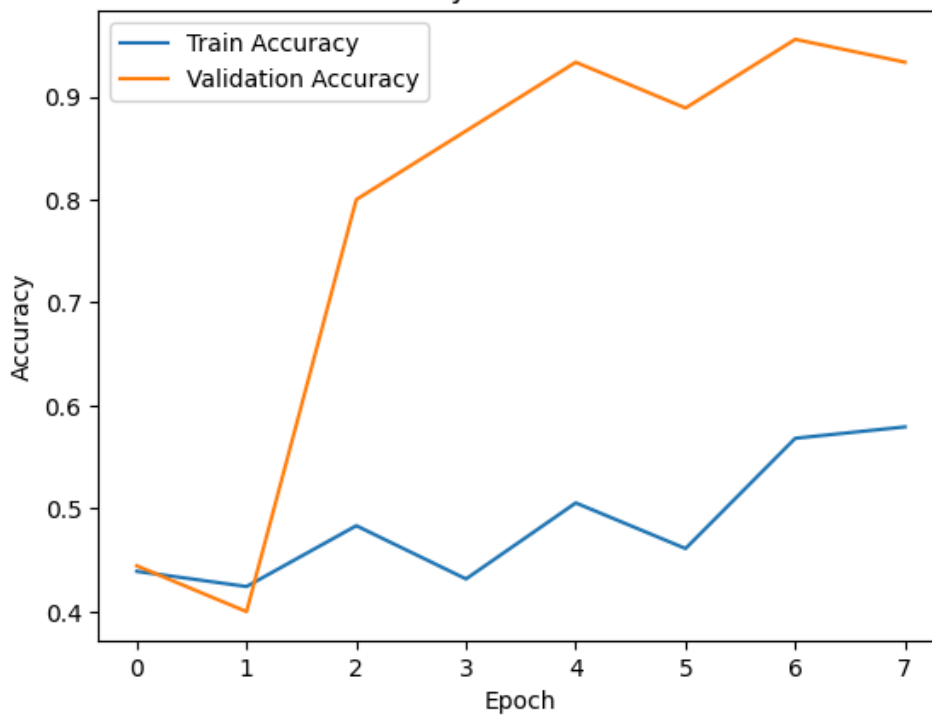
plt.savefig("../results/performance_plots/deep_learning/2d_cnn_accuracy_curve.png", dpi=300, bbox_inches="tight")
plt.show()
plt.close()

```

Loss Curve - 2D CNN



Accuracy Curve - 2D CNN



2D CNN: Inference time (computational analysis)

```
In [14]: x, y = next(iter(test_loader_2d));
x = x.to(device);

start = time.time();
with torch.no_grad():
    _ = model_2d(x)
end = time.time();

inf_time_2d = (end - start) / x.size(0) ;

np.save("../results/stats_deep_learning/inf_time_2d.npy", inf_time_2d);
print("Inference time per batch (seconds):", end-start);
print("Approx inference time per video (seconds):", inf_time_2d);
```

Inference time per batch (seconds): 1.9521634578704834

Approx inference time per video (seconds): 0.48804086446762085

2D CNN: Model size (parameter count)

```
In [15]: total_params_2d = sum(p.numel() for p in model_2d.parameters())
trainable_params_2d = sum(p.numel() for p in model_2d.parameters() if p.requires_grad)

print("Total parameters:", total_params_2d)
print("Trainable parameters:", trainable_params_2d)
```

Total parameters: 11178051
Trainable parameters: 11178051

2D CNN: Error analysis

```
In [16]: wrong_idx = np.where(all_preds_2d != all_labels_2d)[0]
print("Wrong predictions:", len(wrong_idx))

if len(wrong_idx) > 0:
    for i in wrong_idx[:5]:

        row = test_ds_2d.data.iloc[i]    # CSV row
        video_path = row["clip_path"]

        true_label = list(class_map.keys())[all_labels_2d[i]]
        pred_label = list(class_map.keys())[all_preds_2d[i]]

        print("Video:", video_path)
        print("True:", true_label, "| Pred:", pred_label)
        print("-"*50)
```

Wrong predictions: 2
Video: /PullUps/v_PullUps_g07_c04.avi
True: PullUps | Pred: Punch

Video: /PushUps/v_PushUps_g07_c04.avi
True: PushUps | Pred: Punch

2D CNN: File size on disk

```
In [17]: model_path = MODEL_2D_PATH
file_size_mb_2d = os.path.getsize(model_path) / (1024 * 1024)
np.save("../results/stats_deep_learning/model_size_2d.npy", file_size_mb_2d)
print("Saved model file size: {:.2f} MB".format(file_size_mb_2d))
```

Saved model file size: 42.72 MB

2D CNN: Memory usage

```
In [18]: print("CUDA available:", torch.cuda.is_available())
print("Torch CUDA version:", torch.version.cuda)
print("GPU name:", torch.cuda.get_device_name(0) if torch.cuda.is_available() else "No GPU detected")

if torch.cuda.is_available():
    print("GPU memory allocated:",
          torch.cuda.memory_allocated() / (1024**2), "MB")
    print("GPU memory reserved:",
          torch.cuda.memory_reserved() / (1024**2), "MB")

process = psutil.Process(os.getpid())
ram_mb = process.memory_info().rss / (1024 * 1024)

print("Current RAM usage:", ram_mb, "MB")
```

CUDA available: False
Torch CUDA version: None
GPU name: No GPU detected
Current RAM usage: 3266.21875 MB

2D CNN: Saving the results for comparative analysis

```
In [19]: acc2d = accuracy_score(all_labels_2d, all_preds_2d)
p2d, r2d, f12d, _ = precision_recall_fscore_support(all_labels_2d, all_preds_2d, average="macro")

stats_2d = {
    "accuracy": acc2d,
    "precision": p2d,
    "recall": r2d,
    "f1": f12d,
```



```

    "inference_time": inf_time_2d,
    "params": total_params_2d,
    "model_size_mb": file_size_mb_2d
}

with open("../results/stats_deep_learning/stats_2d.json", "w") as f:
    json.dump(stats_2d, f, indent=4)

```

2. 3D Convolutional Networks

- I3D Architecture
- Implement or use pre-trained 3D CNN
- Process video clips (e.g., 16 frames) as 3D volumes
- Fine-tune on your dataset

3D CNN: Dataloaders

```

In [20]: train_ds_3d = VideoDataset3D("../dataset_info/dataset/splits/train.csv", dataset_root, class_map,
                                     num_frames=16, transform=train_tfms, train=True)

val_ds_3d  = VideoDataset3D("../dataset_info/dataset/splits/val.csv", dataset_root, class_map,
                             num_frames=16, transform=val_tfms, train=False)

test_ds_3d = VideoDataset3D("../dataset_info/dataset/splits/test.csv", dataset_root, class_map,
                             num_frames=16, transform=val_tfms, train=False)

train_loader_3d = DataLoader(train_ds_3d, batch_size=2, shuffle=True, num_workers=4)
val_loader_3d   = DataLoader(val_ds_3d, batch_size=2, shuffle=False, num_workers=4)
test_loader_3d  = DataLoader(test_ds_3d, batch_size=2, shuffle=False, num_workers=4)

x3d, _ = next(iter(test_loader_3d))
print(x3d.shape)

```

torch.Size([2, 3, 16, 224, 224])

3D CNN: Model, loss, optimizer

```

In [21]: class_map = {"PullUps": 0, "Punch": 1, "PushUps": 2}
num_classes = len(class_map)

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

model_3d = ResNet3D(num_classes=num_classes, dropout=0.5, freeze_backbone=True).to(device)

criterion = torch.nn.CrossEntropyLoss(label_smoothing=0.9)
# Using Adam as optimizer
optimizer = torch.optim.Adam(model_3d.parameters(), lr=1e-4, weight_decay=1e-4)
# Learning rate scheduling
scheduler = torch.optim.lr_scheduler.StepLR(optimizer, step_size=5, gamma=0.5)
# Early stopping
early_stop = EarlyStopping(patience=4)

out = model_3d(x3d.to(device))
print(out.shape)

```

torch.Size([2, 3])

3D CNN: Training loop (With early stopping)

- This will take around 30 minutes to complete

```

In [22]: start_time = time.time()

EPOCHS = 8
best_val_acc = 0.0

train_losses_3d = []
val_losses_3d   = []
train_accs_3d   = []
val_accs_3d     = []

# ===== LOAD IF EXISTS =====

```

```

if os.path.exists(MODEL_3D_PATH):

    print("Found saved 3D model. Loading...")

    model_3d.load_state_dict(torch.load(MODEL_3D_PATH, map_location=device))
    model_3d.to(device)
    model_3d.eval()

    if os.path.exists(STATS_3D_PATH):
        with open(STATS_3D_PATH, "r") as f:
            stats = json.load(f)

        # ---- SAFE LOAD ----
        train_losses_3d = stats.get("train_losses", [])
        val_losses_3d = stats.get("val_losses", [])
        train_accs_3d = stats.get("train_accs", [])
        val_accs_3d = stats.get("val_accs", [])
        best_val_acc = max(val_accs_3d) if len(val_accs_3d) > 0 else 0.0

        print("Loaded training curves from stats_3d.json")
    else:
        print("stats_3d.json not found → curves unavailable")

# ===== TRAIN IF NOT EXISTS =====
else:
    print("No saved 3D model found. Starting training...")

    for epoch in trange(EPOCHS, desc="3D CNN Epochs"):

        train_loss, train_acc = train_one_epoch(
            model_3d, train_loader_3d, optimizer, criterion, device)

        val_loss, val_acc = eval_one_epoch(
            model_3d, val_loader_3d, criterion, device)

        scheduler.step()

        print(
            f"\nEpoch [{epoch+1}/{EPOCHS}] "
            f"Train Loss: {train_loss:.4f} | Train Acc: {train_acc:.4f} || "
            f"Val Loss: {val_loss:.4f} | Val Acc: {val_acc:.4f}"
        )

        train_losses_3d.append(train_loss)
        val_losses_3d.append(val_loss)
        train_accs_3d.append(train_acc)
        val_accs_3d.append(val_acc)

        if val_acc > best_val_acc:
            best_val_acc = val_acc
            torch.save(model_3d.state_dict(), MODEL_3D_PATH)

        early_stop(val_loss)
        if early_stop.stop:
            print("■ Early stopping triggered")
            break

    print("3D CNN Training complete. Best Val Acc:", best_val_acc)

# ===== SAVE TRAINING CURVES =====
stats_3d = {
    "train_losses": train_losses_3d,
    "val_losses": val_losses_3d,
    "train_accs": train_accs_3d,
    "val_accs": val_accs_3d,
    "best_val_acc": best_val_acc
}

with open(STATS_3D_PATH, "w") as f:
    json.dump(stats_3d, f, indent=4)

    print("Training curves saved to stats_3d.json")

end_time = time.time()
train_time_3d = end_time - start_time

np.save("../results/stats_deep_learning/train_time_3d.npy", train_time_3d)

```

```
print("3D CNN Training Time (seconds):", train_time_3d)
```

No saved 3D model found. Starting training...

```
3D CNN Epochs: 12%|███| 1/8 [08:47<1:01:35, 527.96s/it]
Epoch [1/8] Train Loss: 1.1636 | Train Acc: 0.3542 || Val Loss: 1.1350 | Val Acc: 0.4222
3D CNN Epochs: 25%|████| 2/8 [17:29<52:24, 524.15s/it]
Epoch [2/8] Train Loss: 1.1577 | Train Acc: 0.3764 || Val Loss: 1.1366 | Val Acc: 0.4222
3D CNN Epochs: 38%|██████| 3/8 [25:45<42:36, 511.37s/it]
Epoch [3/8] Train Loss: 1.1526 | Train Acc: 0.3579 || Val Loss: 1.1120 | Val Acc: 0.5111
3D CNN Epochs: 50%|███████| 4/8 [33:41<33:10, 497.52s/it]
Epoch [4/8] Train Loss: 1.1503 | Train Acc: 0.3506 || Val Loss: 1.1140 | Val Acc: 0.5778
3D CNN Epochs: 62%|████████| 5/8 [41:40<24:32, 490.77s/it]
Epoch [5/8] Train Loss: 1.1443 | Train Acc: 0.4096 || Val Loss: 1.1172 | Val Acc: 0.4889
3D CNN Epochs: 75%|█████████| 6/8 [49:39<16:13, 486.79s/it]
Epoch [6/8] Train Loss: 1.1479 | Train Acc: 0.3948 || Val Loss: 1.1139 | Val Acc: 0.4667
3D CNN Epochs: 88%|██████████| 7/8 [57:38<08:04, 484.29s/it]
Epoch [7/8] Train Loss: 1.1417 | Train Acc: 0.3321 || Val Loss: 1.1102 | Val Acc: 0.6444
3D CNN Epochs: 100%|███████████| 8/8 [1:05:36<00:00, 492.10s/it]
Epoch [8/8] Train Loss: 1.1484 | Train Acc: 0.3506 || Val Loss: 1.1082 | Val Acc: 0.5778
3D CNN Training complete. Best Val Acc: 0.6444444444444445
Training curves saved to stats_3d.json
3D CNN Training Time (seconds): 3936.8292112350464
```

3D CNN: Loading best model

```
In [23]: model_3d.load_state_dict(torch.load(MODEL_3D_PATH, map_location=device))
model_3d.eval()

print("Model loaded successfully")
print("Backbone: ResNet-3D (r3d_18, Kinetics pretrained)")
print("Input: video clips as 3D volumes (C x T x H x W)")
print("Temporal modeling: 3D convolutions")
print("Classifier head: Dropout → Fully Connected (3 classes)")

print("Trainable parameters:",
      sum(p.numel() for p in model_3d.parameters() if p.requires_grad))

print("Total parameters:",
      sum(p.numel() for p in model_3d.parameters()))
```

Model loaded successfully
Backbone: ResNet-3D (r3d_18, Kinetics pretrained)
Input: video clips as 3D volumes (C x T x H x W)
Temporal modeling: 3D convolutions
Classifier head: Dropout → Fully Connected (3 classes)
Trainable parameters: 1539
Total parameters: 33167811

3D CNN: Test set evaluation

```
In [24]: model_3d.load_state_dict(torch.load(MODEL_3D_PATH, map_location=device))
model_3d.eval()

all_preds_3d, all_labels_3d = [], []

with torch.no_grad():
    for x, y in test_loader_3d:
        x, y = x.to(device), y.to(device)
        out = model_3d(x)
        preds = torch.argmax(out, dim=1)

        all_preds_3d.extend(preds.cpu().numpy())
        all_labels_3d.extend(y.cpu().numpy())
```

3D CNN: Evaluation metrics

```
In [25]: print("3D CNN Test Accuracy:", accuracy_score(all_labels_3d, all_preds_3d))
print("\nClassification Report:")
print(classification_report(all_labels_3d, all_preds_3d, target_names=class_map.keys()))
```

3D CNN Test Accuracy: 0.5

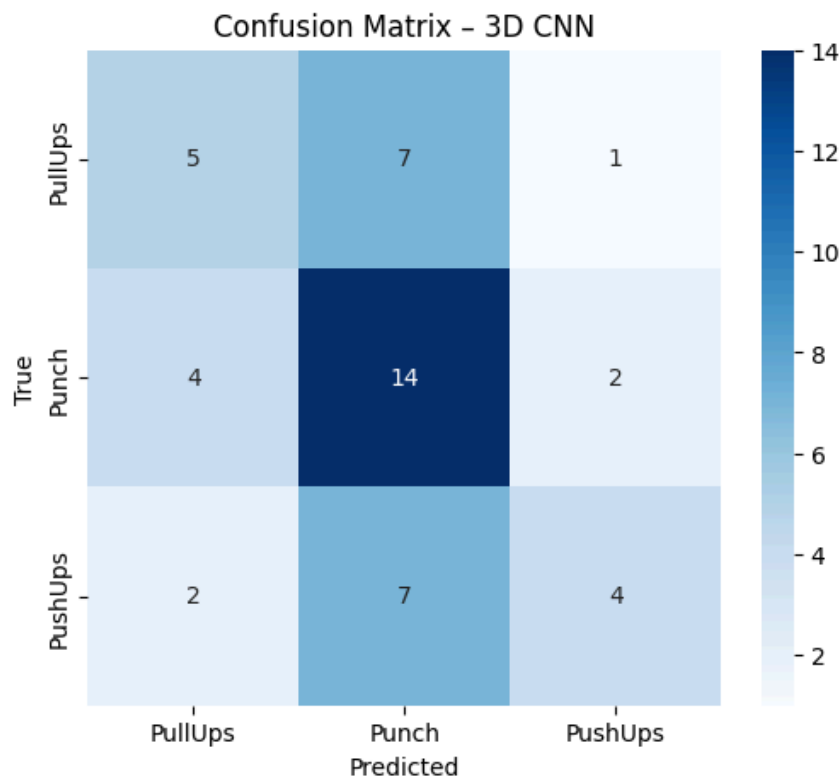
Classification Report:

	precision	recall	f1-score	support
PullUps	0.45	0.38	0.42	13
Punch	0.50	0.70	0.58	20
PushUps	0.57	0.31	0.40	13
accuracy			0.50	46
macro avg	0.51	0.46	0.47	46
weighted avg	0.51	0.50	0.48	46

3D CNN: Confusion Matrix

```
In [26]: conf_matrix_3d = confusion_matrix(all_labels_3d, all_preds_3d)

plt.figure(figsize=(6,5))
sns.heatmap(conf_matrix_3d, annot=True, fmt="d", cmap="Blues",
            xticklabels=class_map.keys(),
            yticklabels=class_map.keys())
plt.title("Confusion Matrix - 3D CNN")
plt.xlabel("Predicted")
plt.ylabel("True")
plt.savefig("../results/confusion_matrices/deep_learning/3d_resnet3d_confusion_matrix.png");
plt.show()
plt.close()
```

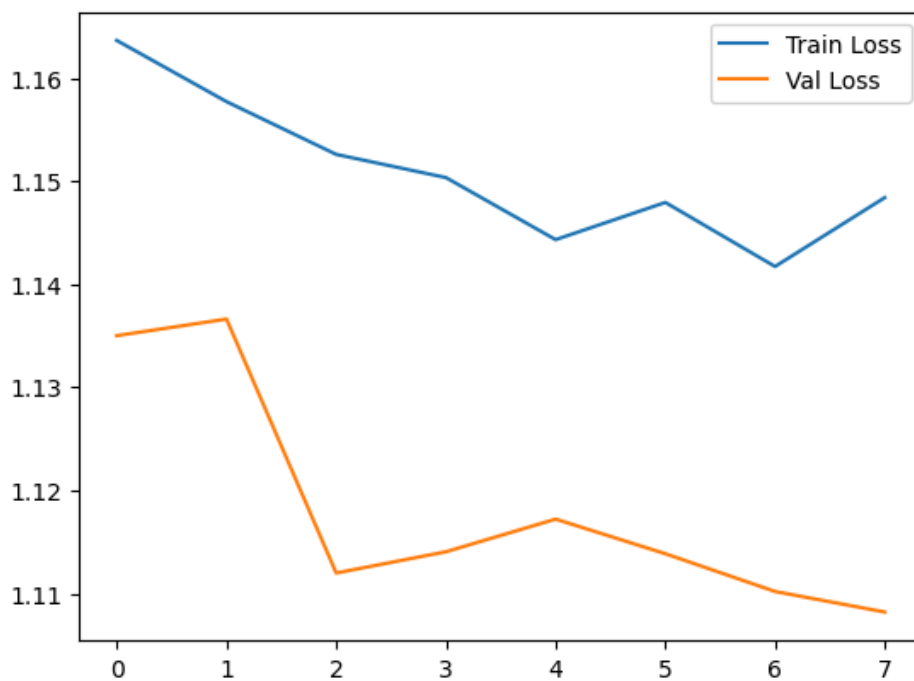


3D CNN: Learning curves

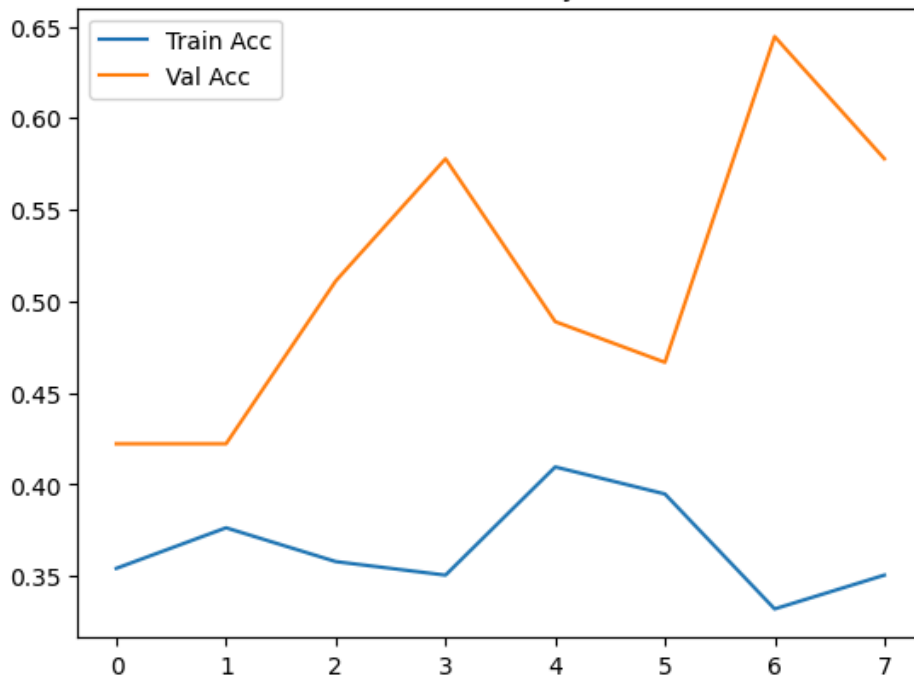
```
In [27]: plt.figure()
plt.plot(train_losses_3d, label="Train Loss")
plt.plot(val_losses_3d, label="Val Loss")
plt.title("3D CNN Loss Curve")
plt.legend()
plt.savefig("../results/performance_plots/deep_learning/3d_cnn_loss_curve.png");
plt.show()
plt.close()

plt.figure()
plt.plot(train_accs_3d, label="Train Acc")
plt.plot(val_accs_3d, label="Val Acc")
plt.title("3D CNN Accuracy Curve")
plt.legend()
plt.savefig("../results/performance_plots/deep_learning/3d_cnn_accuracy_curve.png");
plt.show()
```

3D CNN Loss Curve



3D CNN Accuracy Curve



3D CNN: Inference time (computational analysis)

```
In [28]: x, y = next(iter(test_loader_3d))
x = x.to(device)

start = time.time()
with torch.no_grad():
    _ = model_3d(x)
end = time.time()

inf_time_3d = (end - start) / x.size(0)

np.save("../results/stats_deep_learning/inf_time_3d.npy", inf_time_3d)
print("Inference time per batch:", end-start)
print("Approx inference time per video:", inf_time_3d)
```

Inference time per batch: 2.5213372707366943

Approx inference time per video: 1.2606686353683472

3D CNN: Model size (parameter count)

```
In [29]: total_params_3d = sum(p.numel() for p in model_3d.parameters())
trainable_params_3d = sum(p.numel() for p in model_3d.parameters() if p.requires_grad)
```

```
print("3D CNN Total parameters:", total_params_3d)
print("3D CNN Trainable parameters:", trainable_params_3d)
```

3D CNN Total parameters: 33167811

3D CNN Trainable parameters: 1539

3D CNN: Error Analysis

```
In [30]: wrong_idx = np.where(np.array(all_preds_3d) != np.array(all_labels_3d))[0]
print("Total wrong predictions (3D CNN):", len(wrong_idx))

if len(wrong_idx) > 0:
    #for i in wrong_idx[:5]:
    for i in wrong_idx:
        row = test_ds_3d.data.iloc[i]
        video_path = row["clip_path"]

        true_label = list(class_map.keys())[all_labels_3d[i]]
        pred_label = list(class_map.keys())[all_preds_3d[i]]

        print("Video:", video_path)
        print("True:", true_label, "| Pred:", pred_label)
        print("-"*50)
```

```

Total wrong predictions (3D CNN): 23
Video: /PullUps/v_PullUps_g19_c02.avi
True: PullUps | Pred: Punch
-----
Video: /PullUps/v_PullUps_g02_c04.avi
True: PullUps | Pred: Punch
-----
Video: /PullUps/v_PullUps_g16_c01.avi
True: PullUps | Pred: PushUps
-----
Video: /PullUps/v_PullUps_g09_c01.avi
True: PullUps | Pred: Punch
-----
Video: /PullUps/v_PullUps_g17_c01.avi
True: PullUps | Pred: Punch
-----
Video: /PullUps/v_PullUps_g11_c02.avi
True: PullUps | Pred: Punch
-----
Video: /PullUps/v_PullUps_g09_c03.avi
True: PullUps | Pred: Punch
-----
Video: /PullUps/v_PullUps_g06_c04.avi
True: PullUps | Pred: Punch
-----
Video: /Punch/v_Punch_g07_c05.avi
True: Punch | Pred: PushUps
-----
Video: /Punch/v_Punch_g12_c05.avi
True: Punch | Pred: PullUps
-----
Video: /Punch/v_Punch_g08_c07.avi
True: Punch | Pred: PullUps
-----
Video: /Punch/v_Punch_g05_c02.avi
True: Punch | Pred: PushUps
-----
Video: /Punch/v_Punch_g08_c06.avi
True: Punch | Pred: PullUps
-----
Video: /Punch/v_Punch_g12_c07.avi
True: Punch | Pred: PullUps
-----
Video: /PushUps/v_PushUps_g18_c03.avi
True: PushUps | Pred: Punch
-----
Video: /PushUps/v_PushUps_g07_c04.avi
True: PushUps | Pred: Punch
-----
Video: /PushUps/v_PushUps_g10_c04.avi
True: PushUps | Pred: Punch
-----
Video: /PushUps/v_PushUps_g09_c03.avi
True: PushUps | Pred: PullUps
-----
Video: /PushUps/v_PushUps_g17_c04.avi
True: PushUps | Pred: Punch
-----
Video: /PushUps/v_PushUps_g03_c01.avi
True: PushUps | Pred: PullUps
-----
Video: /PushUps/v_PushUps_g16_c03.avi
True: PushUps | Pred: Punch
-----
Video: /PushUps/v_PushUps_g10_c02.avi
True: PushUps | Pred: Punch
-----
Video: /PushUps/v_PushUps_g05_c02.avi
True: PushUps | Pred: Punch
-----

```

3D CNN: File size on disk

```

In [31]: model_path = MODEL_3D_PATH
file_size_mb_3d = os.path.getsize(model_path) / (1024 * 1024)
np.save("../results/stats_deep_learning/model_size_3d.npy", file_size_mb_3d)
print("3D CNN Saved model size: {:.2f} MB".format(file_size_mb_3d))

```

3D CNN: Memory Usage

```
In [32]: if torch.cuda.is_available():
    print("GPU memory allocated:",
          torch.cuda.memory_allocated() / (1024**2), "MB")
    print("GPU memory reserved:",
          torch.cuda.memory_reserved() / (1024**2), "MB")
else:
    print("GPU not available. Running on CPU.")

process = psutil.Process(os.getpid())
ram_mb = process.memory_info().rss / (1024 * 1024)

print("Current CPU RAM usage: {:.2f} MB".format(ram_mb))
```

GPU not available. Running on CPU.

Current CPU RAM usage: 3276.68 MB

3D CNN: Saving the results for comparative analysis

```
In [33]: acc3d = accuracy_score(all_labels_3d, all_preds_3d)
p3d, r3d, f13d, _ = precision_recall_fscore_support(all_labels_3d, all_preds_3d, average="macro")

stats_3d = {
    "accuracy": acc3d,
    "precision": p3d,
    "recall": r3d,
    "f1": f13d,
    "inference_time": inf_time_3d,
    "params": total_params_3d,
    "model_size_mb": file_size_mb_3d
}

with open("../results/stats_deep_learning/stats_3d.json", "w") as f:
    json.dump(stats_3d, f, indent=4)
```

```
In [34]: np.save("../results/stats_deep_learning/preds_2d.npy", all_preds_2d)
np.save("../results/stats_deep_learning/labels_2d.npy", all_labels_2d)

np.save("../results/stats_deep_learning/preds_3d.npy", all_preds_3d)
np.save("../results/stats_deep_learning/labels_3d.npy", all_labels_3d)
```