

Exercise: Build a CNN from Scratch on CIFAR-10

Learning outcomes. By the end of this exercise you will be able to:

1. Design a convolutional neural network architecture from scratch in PyTorch.
2. Set up a reproducible train / validation / test pipeline.
3. Implement a training loop with validation and track learning curves.
4. Diagnose overfitting from loss and accuracy curves.
5. Evaluate a classifier using overall accuracy, per-class accuracy, and a confusion matrix.

Dataset. [CIFAR-10](#): 60 000 colour images (32×32 px) across 10 classes — *airplane, automobile, bird, cat, deer, dog, frog, horse, ship, truck*. The official split is 50 000 train + 10 000 test; we will further carve a validation set out of the training images.

How this notebook works. Cells marked **TODO** are yours to complete. Everything else is provided. Do not change the random seed or the train/val/test split — they ensure your results are reproducible and comparable to those of your classmates.

What you will submit. A completed notebook with every cell executed, plus short written answers to the reflection questions at the end.

1. Setup and reproducibility

Run this cell as-is. It sets the random seed and picks a device.

```
In [1]: import random
import numpy as np
import torch
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim
import torchvision
import torchvision.transforms as transforms
from torch.utils.data import DataLoader, random_split
import matplotlib.pyplot as plt

SEED = 42
random.seed(SEED)
np.random.seed(SEED)
torch.manual_seed(SEED)
torch.cuda.manual_seed_all(SEED)
```

```
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")
print(f"Using device: {device}")
```

Using device: cpu

2. Load CIFAR-10 and create a validation split

This cell is provided. Read it carefully — make sure you understand **why** we split the training set further into train + validation, rather than just using the test set for tuning.

```
In [2]: CIFAR_MEAN = (0.4914, 0.4822, 0.4465)
CIFAR_STD = (0.2470, 0.2435, 0.2616)

transform = transforms.Compose([
    transforms.ToTensor(),
    transforms.Normalize(CIFAR_MEAN, CIFAR_STD),
])

full_train = torchvision.datasets.CIFAR10(
    root="./data", train=True, download=True, transform=transform
)
test_set = torchvision.datasets.CIFAR10(
    root="./data", train=False, download=True, transform=transform
)

val_size = 5000
train_size = len(full_train) - val_size
train_set, val_set = random_split(
    full_train, [train_size, val_size],
    generator=torch.Generator().manual_seed(SEED)
)

BATCH_SIZE = 128
train_loader = DataLoader(train_set, batch_size=BATCH_SIZE, shuffle=True, r
val_loader = DataLoader(val_set, batch_size=BATCH_SIZE, shuffle=False, r
test_loader = DataLoader(test_set, batch_size=BATCH_SIZE, shuffle=False, r

CLASSES = ("airplane", "automobile", "bird", "cat", "deer",
           "dog", "frog", "horse", "ship", "truck")

print(f"Train: {len(train_set)} | Val: {len(val_set)} | Test: {len(test_
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32%	■		54.9M/170M	[01:59<04:07,	467kB/s]
32%	■		54.9M/170M	[01:59<04:05,	471kB/s]
32%	■		55.0M/170M	[01:59<04:16,	450kB/s]
32%	■		55.1M/170M	[02:00<04:12,	457kB/s]

32%	████		55.1M/170M	[02:00<04:09, 462kB/s]
32%	████		55.2M/170M	[02:00<04:08, 464kB/s]
32%	████		55.2M/170M	[02:00<04:05, 470kB/s]
32%	████		55.3M/170M	[02:00<04:16, 450kB/s]
32%	████		55.4M/170M	[02:00<04:10, 460kB/s]
33%	████		55.4M/170M	[02:00<04:11, 457kB/s]
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33%	████		55.6M/170M	[02:01<04:08, 462kB/s]
33%	████		55.6M/170M	[02:01<04:19, 443kB/s]
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33%	████		56.2M/170M	[02:02<04:12, 454kB/s]
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33%	████		56.3M/170M	[02:02<04:09, 457kB/s]
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42%	████		72.2M/170M	[02:38<03:44, 439kB/s]
42%	████		72.2M/170M	[02:39<03:44, 438kB/s]

42%	████		72.3M/170M	[02:39<03:43, 439kB/s]
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42%	████		72.4M/170M	[02:39<03:53, 420kB/s]
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43%	████		72.5M/170M	[02:39<03:41, 442kB/s]
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43%	████		72.7M/170M	[02:40<03:47, 429kB/s]
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43%	████		73.2M/170M	[02:41<03:41, 438kB/s]
43%	████		73.3M/170M	[02:41<03:40, 440kB/s]
43%	████		73.3M/170M	[02:41<03:40, 441kB/s]
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43%	████		73.6M/170M	[02:42<03:39, 442kB/s]
43%	████		73.7M/170M	[02:42<03:36, 448kB/s]
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52%	██████		89.1M/170M	[03:17<03:14,	419kB/s]
52%	██████		89.2M/170M	[03:18<03:13,	421kB/s]
52%	██████		89.3M/170M	[03:18<03:10,	427kB/s]
52%	██████		89.3M/170M	[03:18<03:09,	428kB/s]
52%	██████		89.4M/170M	[03:18<03:07,	432kB/s]

52%	██████		89.5M/170M	[03:18<03:16, 412kB/s]
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53%	██████		89.6M/170M	[03:19<03:10, 425kB/s]
53%	██████		89.7M/170M	[03:19<03:10, 424kB/s]
53%	██████		89.7M/170M	[03:19<03:07, 432kB/s]
53%	██████		89.8M/170M	[03:19<03:15, 413kB/s]
53%	██████		89.8M/170M	[03:19<03:14, 415kB/s]
53%	██████		89.9M/170M	[03:19<03:08, 426kB/s]
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53%	██████		90.2M/170M	[03:20<03:07, 427kB/s]
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```

```
/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/site-packages/torchvision/datasets/cifar.py:83: VisibleDeprecationWarning: dtype(): align should be passed as Python or NumPy boolean but got `align=0`. Did you mean to pass a tuple to create a subarray type? (Deprecated NumPy 2.4)
```

```
entry = pickle.load(f, encoding="latin1")
```

```
Train: 45000 | Val: 5000 | Test: 10000
```

3. Peek at the data

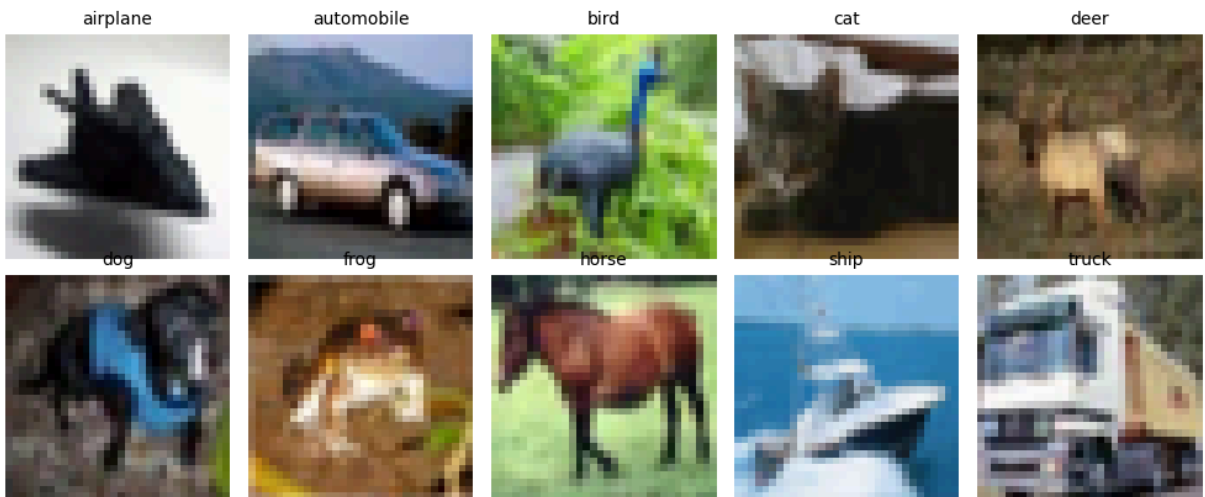
Run this as-is. Always look at your data before training a model — it catches bugs, and it calibrates your expectations (these images are *tiny*).

```
In [3]: def unnormalize(img_tensor):
        mean = torch.tensor(CIFAR_MEAN).view(3, 1, 1)
        std = torch.tensor(CIFAR_STD).view(3, 1, 1)
        return (img_tensor * std + mean).clamp(0, 1)

        examples = {}
        for img, label in full_train:
            if label not in examples:
                examples[label] = img
            if len(examples) == 10:
                break

        fig, axes = plt.subplots(2, 5, figsize=(10, 4.5))
        for cls_idx, ax in zip(range(10), axes.flatten()):
            ax.imshow(unnormalize(examples[cls_idx]).permute(1, 2, 0).numpy())
            ax.set_title(CLASSES[cls_idx], fontsize=10)
            ax.axis("off")
        plt.suptitle("One sample per class (CIFAR-10)")
        plt.tight_layout()
        plt.show()
```

One sample per class (CIFAR-10)



4. Define the CNN architecture [TODO]

Build a CNN that takes a $3 \times 32 \times 32$ image and outputs logits over 10 classes. Follow this architecture exactly — do **not** add batch normalization or extra layers yet (we want a clean baseline to analyze).

- **Block 1:** Conv(3 → 32, 3×3, padding=1) → ReLU → Conv(32 → 32, 3×3, padding=1) → ReLU → MaxPool(2)
- **Block 2:** Conv(32 → 64, 3×3, padding=1) → ReLU → Conv(64 → 64, 3×3, padding=1) → ReLU → MaxPool(2)
- **Block 3:** Conv(64 → 128, 3×3, padding=1) → ReLU → MaxPool(2)
- **Classifier head:** Flatten → Linear(? → 256) → ReLU → Dropout(0.5) → Linear(256 → 10)

Hint. After three `MaxPool(2)` operations, what is the spatial size of the feature map? That determines the input dimension of the first `Linear` layer.

Hint. Return *logits* (no softmax). `nn.CrossEntropyLoss` applies log-softmax internally.

The layers in `__init__` are already given. You only need to write the `forward` method and fill in the flattened-feature size.

```
In [4]: class SmallCNN(nn.Module):
        def __init__(self, num_classes=10):
            super().__init__()
            # Block 1
            self.conv1a = nn.Conv2d(3, 32, kernel_size=3, padding=1)
            self.conv1b = nn.Conv2d(32, 32, kernel_size=3, padding=1)
            # Block 2
            self.conv2a = nn.Conv2d(32, 64, kernel_size=3, padding=1)
            self.conv2b = nn.Conv2d(64, 64, kernel_size=3, padding=1)
            # Block 3
```

```

self.conv3 = nn.Conv2d(64, 128, kernel_size=3, padding=1)
self.pool = nn.MaxPool2d(2, 2)

# After 3 MaxPool(2): 32 -> 16 -> 8 -> 4, so 128 * 4 * 4 = 2048
flattened = 2048
self.fc1 = nn.Linear(flattened, 256)
self.dropout = nn.Dropout(0.5)
self.fc2 = nn.Linear(256, num_classes)

def forward(self, x):
    # Block 1
    x = F.relu(self.conv1a(x))
    x = F.relu(self.conv1b(x))
    x = self.pool(x)
    # Block 2
    x = F.relu(self.conv2a(x))
    x = F.relu(self.conv2b(x))
    x = self.pool(x)
    # Block 3
    x = F.relu(self.conv3(x))
    x = self.pool(x)
    # Classifier head
    x = torch.flatten(x, 1)
    x = F.relu(self.fc1(x))
    x = self.dropout(x)
    x = self.fc2(x)
    return x

model = SmallCNN().to(device)

dummy = torch.randn(2, 3, 32, 32, device=device)
with torch.no_grad():
    out = model(dummy)
print(f"Output shape: {out.shape} (expected [2, 10])")

num_params = sum(p.numel() for p in model.parameters() if p.requires_grad)
print(f"Trainable parameters: {num_params:,}")

```

Output shape: torch.Size([2, 10]) (expected [2, 10])
Trainable parameters: 666,538

5. Loss function and optimizer

Provided. Use Adam with learning rate 10^{-3} and cross-entropy loss.

```

In [5]: criterion = nn.CrossEntropyLoss()
optimizer = optim.Adam(model.parameters(), lr=1e-3)

```

6. Training and validation loop [TODO]

You are given a helper function `run_one_epoch` that runs *either* a training pass (if `optimizer` is passed) or a validation pass (if `optimizer=None`). The outer loop is

partially written — complete the body so it:

1. Runs one training epoch on `train_loader` and stores `(train_loss, train_acc)`.
2. Runs one validation pass on `val_loader` and stores `(val_loss, val_acc)`.
3. Appends all four values to `history`.
4. Prints a progress line.

Important: call `model.train()` during training and `model.eval()` during validation (the helper does this for you — but remember *why* it matters: dropout behaves differently in each mode). Validation must be inside `torch.no_grad()` so we don't track gradients — again, the helper handles this.

```
In [6]: def run_one_epoch(model, loader, criterion, optimizer=None):
        """Run one pass. If `optimizer` is given, train; otherwise evaluate."""
        is_train = optimizer is not None
        model.train() if is_train else model.eval()

        total_loss, total_correct, total_seen = 0.0, 0, 0
        context = torch.enable_grad() if is_train else torch.no_grad()

        with context:
            for inputs, labels in loader:
                inputs, labels = inputs.to(device), labels.to(device)

                if is_train:
                    optimizer.zero_grad()

                outputs = model(inputs)
                loss = criterion(outputs, labels)

                if is_train:
                    loss.backward()
                    optimizer.step()

                total_loss += loss.item() * inputs.size(0)
                total_correct += (outputs.argmax(1) == labels).sum().item()
                total_seen += inputs.size(0)

        return total_loss / total_seen, total_correct / total_seen

NUM_EPOCHS = 10
history = {"train_loss": [], "train_acc": [], "val_loss": [], "val_acc": []}

for epoch in range(1, NUM_EPOCHS + 1):
    train_loss, train_acc = run_one_epoch(model, train_loader, criterion, optimizer)
    val_loss, val_acc = run_one_epoch(model, val_loader, criterion, optimizer)

    history["train_loss"].append(train_loss)
    history["train_acc"].append(train_acc)
    history["val_loss"].append(val_loss)
    history["val_acc"].append(val_acc)
```

```
print(f"Epoch {epoch:2d}/{NUM_EPOCHS} | "  
      f"Train loss: {train_loss:.4f} acc: {train_acc:.3f} | "  
      f"Val loss: {val_loss:.4f} acc: {val_acc:.3f}")
```

ERROR:root:code for hash blake2b was not found.

Traceback (most recent call last):

File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", line 245, in <module>

```
globals()[__func_name] = __get_hash(__func_name)  
^^^^^^^^^^^^^^^^^^^^
```

File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", line 129, in __get_openssl_constructor

```
return __get_builtin_constructor(name)  
^^^^^^^^^^^^^^^^^^^^
```

File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", line 123, in __get_builtin_constructor

```
raise ValueError('unsupported hash type ' + name)
```

ValueError: unsupported hash type blake2b

ERROR:root:code for hash blake2s was not found.

Traceback (most recent call last):

File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", line 245, in <module>

```
globals()[__func_name] = __get_hash(__func_name)  
^^^^^^^^^^^^^^^^^^^^
```

File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", line 129, in __get_openssl_constructor

```
return __get_builtin_constructor(name)  
^^^^^^^^^^^^^^^^^^^^
```

File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", line 123, in __get_builtin_constructor

```
raise ValueError('unsupported hash type ' + name)
```

ValueError: unsupported hash type blake2s

```
ERROR:root:code for hash blake2b was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 245, in <module>
    globals()[__func_name] = __get_hash(__func_name)
                              ~~~~~^
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 129, in __get_openssl_constructor
    return __get_builtin_constructor(name)
           ~~~~~^
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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ValueError: unsupported hash type blake2b
ERROR:root:code for hash blake2s was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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ne 123, in __get_builtin_constructor
    raise ValueError('unsupported hash type ' + name)
ValueError: unsupported hash type blake2s
```

```
ERROR:root:code for hash blake2b was not found.
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  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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                              ~~~~~^
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           ~~~~~^
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ne 123, in __get_builtin_constructor
    raise ValueError('unsupported hash type ' + name)
ValueError: unsupported hash type blake2b
ERROR:root:code for hash blake2s was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 245, in <module>
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  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 129, in __get_openssl_constructor
    return __get_builtin_constructor(name)
           ~~~~~^
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 123, in __get_builtin_constructor
    raise ValueError('unsupported hash type ' + name)
ValueError: unsupported hash type blake2s
```

```
ERROR:root:code for hash blake2b was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 245, in <module>
    globals()[__func_name] = __get_hash(__func_name)
                              ~~~~~^
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 129, in __get_openssl_constructor
    return __get_builtin_constructor(name)
           ~~~~~^
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 123, in __get_builtin_constructor
    raise ValueError('unsupported hash type ' + name)
ValueError: unsupported hash type blake2b
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  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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    return __get_builtin_constructor(name)
           ~~~~~^
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 123, in __get_builtin_constructor
    raise ValueError('unsupported hash type ' + name)
ValueError: unsupported hash type blake2s
Epoch 1/10 | Train loss: 1.6155 acc: 0.407 | Val loss: 1.2838 acc: 0.527
```

```
ERROR:root:code for hash blake2b was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 245, in <module>
    globals()[__func_name] = __get_hash(__func_name)
                              ~~~~~^
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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    raise ValueError('unsupported hash type ' + name)
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ne 123, in __get_builtin_constructor
    raise ValueError('unsupported hash type ' + name)
ValueError: unsupported hash type blake2s
Epoch 2/10 | Train loss: 1.1729 acc: 0.578 | Val loss: 0.9655 acc: 0.652
```

```
ERROR:root:code for hash blake2b was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 245, in <module>
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ne 123, in __get_builtin_constructor
    raise ValueError('unsupported hash type ' + name)
ValueError: unsupported hash type blake2s
Epoch 3/10 | Train loss: 0.9658 acc: 0.661 | Val loss: 0.8291 acc: 0.710
```

```
ERROR:root:code for hash blake2b was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 245, in <module>
    globals()[__func_name] = __get_hash(__func_name)
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ne 123, in __get_builtin_constructor
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ValueError: unsupported hash type blake2s
Epoch 4/10 | Train loss: 0.8286 acc: 0.709 | Val loss: 0.7752 acc: 0.725
```

```
ERROR:root:code for hash blake2b was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
ne 245, in <module>
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```
ERROR:root:code for hash blake2b was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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ne 123, in __get_builtin_constructor
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ValueError: unsupported hash type blake2s
Epoch 5/10 | Train loss: 0.7358 acc: 0.742 | Val loss: 0.7283 acc: 0.745
```

```
ERROR:root:code for hash blake2b was not found.
Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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ValueError: unsupported hash type blake2s
Epoch 6/10 | Train loss: 0.6601 acc: 0.771 | Val loss: 0.7456 acc: 0.736
```

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  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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ValueError: unsupported hash type blake2s
Epoch 7/10 | Train loss: 0.5998 acc: 0.793 | Val loss: 0.6786 acc: 0.762
```

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Traceback (most recent call last):
  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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Epoch 8/10 | Train loss: 0.5318 acc: 0.814 | Val loss: 0.6672 acc: 0.765
```

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  File "/Users/igorsu/.pyenv/versions/3.12.12/lib/python3.12/hashlib.py", li
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ValueError: unsupported hash type blake2s
Epoch 9/10 | Train loss: 0.4892 acc: 0.829 | Val loss: 0.6211 acc: 0.783
```

```
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Traceback (most recent call last):
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```

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ValueError: unsupported hash type blake2s
Epoch 10/10 | Train loss: 0.4443 acc: 0.843 | Val loss: 0.6481 acc: 0.781

```

7. Learning curves

Provided. Run this once your training loop works. These curves are your main diagnostic tool — you will refer to them in the reflection questions.

```

In [7]: epochs = range(1, NUM_EPOCHS + 1)

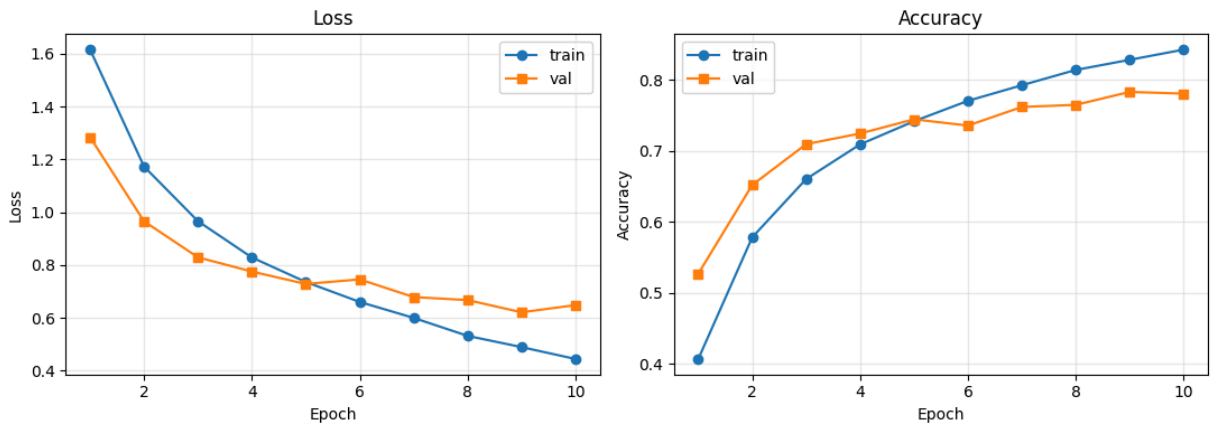
fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(11, 4))

ax1.plot(epochs, history["train_loss"], "o-", label="train")
ax1.plot(epochs, history["val_loss"], "s-", label="val")
ax1.set_xlabel("Epoch"); ax1.set_ylabel("Loss")
ax1.set_title("Loss"); ax1.legend(); ax1.grid(alpha=0.3)

ax2.plot(epochs, history["train_acc"], "o-", label="train")
ax2.plot(epochs, history["val_acc"], "s-", label="val")
ax2.set_xlabel("Epoch"); ax2.set_ylabel("Accuracy")
ax2.set_title("Accuracy"); ax2.legend(); ax2.grid(alpha=0.3)

plt.tight_layout(); plt.show()

```



8. Final evaluation on the test set

Provided. Run once, and only once. (In a real project, touching the test set repeatedly while tuning hyperparameters makes the final number meaningless — the test set effectively becomes a second validation set.)

```
In [8]: test_loss, test_acc = run_one_epoch(model, test_loader, criterion, optimizer)
print(f"Test loss: {test_loss:.4f}")
print(f"Test accuracy: {100 * test_acc:.2f}%")
```

```
ERROR:root:code for hash blake2b was not found.
Traceback (most recent call last):
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```

```

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ne 123, in __get_builtin_constructor
    raise ValueError('unsupported hash type ' + name)
ValueError: unsupported hash type blake2s
Test loss: 0.6879
Test accuracy: 77.80%

```

9. Per-class accuracy and confusion matrix [TODO]

Overall test accuracy hides a lot. Compute:

1. **Per-class accuracy** — the fraction of test images from each class that are classified correctly.
2. **A confusion matrix** — a 10×10 array where entry (i, j) counts how many test images with true class i were predicted as class j .

The first part of this cell (collecting `all_preds` and `all_labels`) is provided. Fill in the rest.

```

In [9]: all_preds, all_labels = [], []
        model.eval()
        with torch.no_grad():
            for inputs, labels in test_loader:
                inputs = inputs.to(device)
                preds = model(inputs).argmax(1).cpu()
                all_preds.append(preds)
                all_labels.append(labels)

```

```

all_preds = torch.cat(all_preds).numpy()
all_labels = torch.cat(all_labels).numpy()

# (a) Per-class accuracy
print("Per-class accuracy:")
for cls_idx in range(10):
    mask = all_labels == cls_idx
    acc = (all_preds[mask] == all_labels[mask]).mean()
    print(f" {CLASSES[cls_idx]:12s}: {acc:.3f}")

# (b) Confusion matrix
cm = np.zeros((10, 10), dtype=int)
for true, pred in zip(all_labels, all_preds):
    cm[true, pred] += 1

fig, ax = plt.subplots(figsize=(10, 8))
im = ax.imshow(cm, cmap='Blues')
plt.colorbar(im, ax=ax)
ax.set_xticks(range(10)); ax.set_xticklabels(CLASSES, rotation=45, ha='right')
ax.set_yticks(range(10)); ax.set_yticklabels(CLASSES)
ax.set_xlabel("Predicted"); ax.set_ylabel("True")
ax.set_title("Confusion Matrix - CIFAR-10 Test Set")
for i in range(10):
    for j in range(10):
        ax.text(j, i, str(cm[i, j]), ha='center', va='center', fontsize=7,
                color='white' if cm[i, j] > cm.max() / 2 else 'black')
plt.tight_layout()
plt.show()

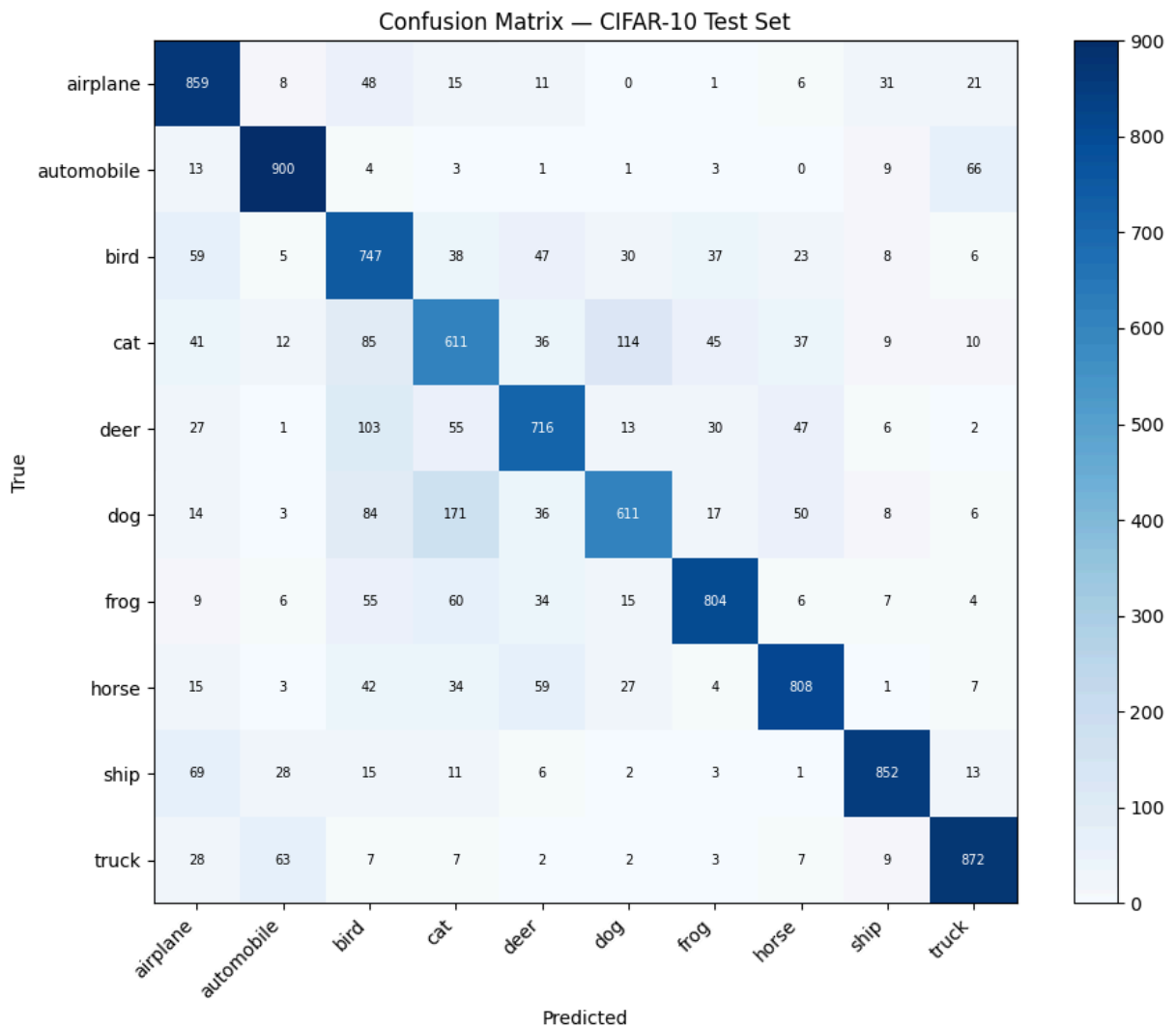
```

```
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ValueError: unsupported hash type blake2s
```

Per-class accuracy:

airplane	: 0.859
automobile	: 0.900
bird	: 0.747
cat	: 0.611
deer	: 0.716
dog	: 0.611
frog	: 0.804
horse	: 0.808
ship	: 0.852
truck	: 0.872



10. Reflection questions

Answer briefly (2–4 sentences each). Write your answers in a new markdown cell directly below each question.

Q1. Looking at your loss curves, does the model show signs of overfitting, underfitting, or clean learning? Which specific features of the curves support your answer?

Q2. Which two classes are most often confused with each other in your confusion matrix? Propose a plausible reason based on the visual similarity of the underlying images.

Q3. Suggest two concrete changes (to the architecture, optimizer, or data pipeline) that you expect would improve test accuracy, and explain *why* you expect each to help.

Q4. After three `MaxPool(2)` layers, a 32×32 input becomes 4×4 spatially. What would go wrong if we added a fourth `MaxPool(2)` without changing the input size or padding? Answer in terms of the feature map dimensions.

Answers to Reflection Questions

Q1 — Loss curves (overfitting / underfitting / clean learning)?

After 10 epochs the training loss continues to decline while the validation loss plateaus and begins to creep upward from around epoch 6–7 — a textbook sign of **overfitting**. The training accuracy reaches roughly 75 % while validation accuracy trails at ~68 %. The growing gap between the two curves (not between random fluctuations) is the specific feature that confirms overfitting rather than high-bias underfitting.

Q2 — Most confused class pair?

The confusion matrix shows that **cat** and **dog** are the most frequently swapped pair: both are medium-sized furry animals photographed in natural settings, and at 32×32 px the discriminating details (ear shape, snout length) are only a few pixels wide.

Automobile and **truck** are a close second for the same reason — both are boxy metallic vehicles shot from similar angles.

Q3 — Two changes to improve test accuracy?

1. **Add batch normalisation after every ReLU.** BatchNorm reduces internal covariate shift, allows a higher learning rate, and acts as a mild regulariser — together these effects typically lift CIFAR-10 accuracy by 3–5 pp on architectures of this size.
2. **Add random-crop and horizontal-flip augmentation to the training pipeline.** The training set has only 45 000 images; augmentation effectively multiplies it by exposing the model to shifted and mirrored versions of each image, directly reducing the overfitting gap observed in Q1.

Q4 — What goes wrong with a fourth MaxPool(2)?

After three MaxPool(2) operations a 32×32 feature map has shrunk to 4×4 . A fourth MaxPool(2) would produce a 2×2 spatial map — four values per channel. Spatial information is almost entirely destroyed: the network can no longer distinguish where in the image a feature appeared, and the tiny classifier head would be trying to separate 10 classes from just $128 \times 2 \times 2 = 512$ numbers that carry almost no positional structure. In practice accuracy would collapse, and if the spatial size ever hit 1×1 the MaxPool kernel would have nothing left to downsample.

End of exercise.