

In [1]: %run ./Model.ipynb

- ✓ 当前设备: cuda
- ✓ 数据集加载完成, 共 10 类

```
In [2]: models = {
    "BirdCNN": BirdCNN(num_classes=num_classes).to(device),
    "BirdCNN_Optimal": BirdCNN_Optimal(num_classes=num_classes).to(device),
    "BirdResNet": BirdResNet(num_classes=num_classes).to(device)
}

num_epochs = 80
early_stopping_patience = 5

results = {}

for name, model in models.items():
    print(f"\n===== 🐦 开始训练模型: {name} =====")
    optimizer = optim.AdamW(model.parameters(), lr=0.001, weight_decay=0.01)
    try:
        scheduler = optim.lr_scheduler.ReduceLROnPlateau(optimizer, mode='max',
    except TypeError:
        scheduler = optim.lr_scheduler.ReduceLROnPlateau(optimizer, mode='max',

    train_losses, train_accs, test_accs = [], [], []
    best_acc = 0
    best_epoch = 0
    patience_counter = 0
    start_time = time.time()

    for epoch in range(1, num_epochs + 1):
        epoch_start = time.time()
        train_loss, train_acc = train_one_epoch(model, device, train_loader, opt
        test_loss, test_acc = evaluate(model, device, test_loader)
        scheduler.step(test_acc)

        train_losses.append(train_loss)
        train_accs.append(train_acc)
        test_accs.append(test_acc)

        # 检查是否有提升
        improved = test_acc > best_acc
        if improved:
            best_acc = test_acc
            best_epoch = epoch
            patience_counter = 0
            torch.save(model.state_dict(), f"{name}_best.pth")
        else:
            patience_counter += 1


    # 日志输出
    print(
        f"[{name}] Epoch {epoch:02d}/{num_epochs} | "
        f"TrainLoss={train_loss:.4f} | TestLoss={test_loss:.4f} | "
        f"TrainAcc={train_acc:.2f}% | TestAcc={test_acc:.2f}% | "
        f"BestAcc={best_acc:.2f}% (E{best_epoch})"
    )
    print(
        f"└ LR={optimizer.param_groups[0]['lr']:.6f} | "
```

```
f"Patience={patience_counter}/{early_stopping_patience} | "  
f"Time={time.time()-start_time:.2f}s | "  
f"'✅ Improved & Saved' if improved else '❌ No Improvement'"  
)  
# 检查早停  
if patience_counter >= early_stopping_patience:  
    print(f"\n⚠️ 早停触发: 连续 {early_stopping_patience} 轮准确率未提升"  
        f"❌")  
    break  
  
total_time = (time.time() - start_time) / 60  
print(f"🏁 模型 {name} 训练结束! 最佳准确率: {best_acc:.2f}% (Epoch {best_epoch})")  
  
results[name] = {  
    "train_losses": train_losses,  
    "train_accs": train_accs,  
    "test_accs": test_accs,  
    "best_acc": best_acc,  
    "best_epoch": best_epoch  
}  
  
print(f"\n✅ 所有模型训练完成!")
```

===== 🚀 开始训练模型: BirdCNN =====

```
训练中：100%|███████████  
██████ | 38/38 [00:06<00:00, 5.70it/s]  
[BirdCNN] Epoch 01/80 | TrainLoss=1.9680 | TestLoss=1.7660 | TrainAcc=29.60% | Te  
stAcc=35.63% | BestAcc=35.63% (E1)  
└─ LR=0.001000 | Patience=0/5 | Time=11.63s | ✅ Improved & Saved
```

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训练中：100%|██████████████████████████████████████████████████████████  
██████████ | 38/38 [00:06<00:00, 5.52it/s]  
[BirdCNN] Epoch 02/80 | TrainLoss=1.6531 | TestLoss=1.5109 | TrainAcc=40.80% | Te  
stAcc=47.07% | BestAcc=47.07% (E2)  
└─ LR=0.001000 | Patience=0/5 | Time=23.60s |  Improved & Saved
```

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训练中：100%|██████████████████████████████████████████████████████████████████████████████  
██████████ | 38/38 [00:06<00:00, 5.64it/s]  
[BirdCNN] Epoch 03/80 | TrainLoss=1.4917 | TestLoss=1.3734 | TrainAcc=47.89% | Te  
stAcc=52.19% | BestAcc=52.19% (E3)  
└─ LR=0.001000 | Patience=0/5 | Time=35.40s |  Improved & Saved
```

```
训练中：100%|███████████████████████████████████████████████████  
██████████ | 38/38 [00:06<00:00, 5.78it/s]  
[BirdCNN] Epoch 04/80 | TrainLoss=1.3897 | TestLoss=1.3184 | TrainAcc=52.03% | Te  
stAcc=54.37% | BestAcc=54.37% (E4)  
└─ LR=0.001000 | Patience=0/5 | Time=47.01s | ✓ Improved & Saved
```

```
训练中：100%|███████████  
███████ | 38/38 [00:06<00:00, 5.67it/s]  
[BirdCNN] Epoch 05/80 | TrainLoss=1.3010 | TestLoss=1.1852 | TrainAcc=55.51% | Te  
stAcc=58.71% | BestAcc=58.71% (E5)  
└─ LR=0.001000 | Patience=0/5 | Time=58.74s | ✅ Improved & Saved
```

```
训练中：100%|███████████  
██████████ | 38/38 [00:06<00:00, 5.68it/s]  
[BirdCNN] Epoch 06/80 | TrainLoss=1.2023 | TestLoss=1.0402 | TrainAcc=58.87% | Te  
stAcc=65.40% | BestAcc=65.40% (E6)  
└─ LR=0.001000 | Patience=0/5 | Time=70.35s | ✓ Improved & Saved
```

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训练中：100%|██████████████████████████████████████████████████████████  
██████████| 38/38 [00:06<00:00, 5.68it/s]  
[BirdCNN] Epoch 07/80 | TrainLoss=1.1264 | TestLoss=1.0226 | TrainAcc=60.66% | Te  
stAcc=65.93% | BestAcc=65.93% (E7)  
└─ LR=0.001000 | Patience=0/5 | Time=82.02s | ✓ Improved & Saved
```

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训练中：100%|██████████| 38/38 [00:06<00:00, 5.54it/s]
[BirdCNN] Epoch 30/80 | TrainLoss=0.3423 | TestLoss=0.2977 | TrainAcc=88.47% | Te
stAcc=92.33% | BestAcc=92.33% (E30)
└─ LR=0.001000 | Patience=0/5 | Time=355.49s | ✅ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.62it/s]
[BirdCNN] Epoch 31/80 | TrainLoss=0.3447 | TestLoss=0.3150 | TrainAcc=88.93% | Te
stAcc=91.27% | BestAcc=92.33% (E30)
└─ LR=0.001000 | Patience=1/5 | Time=367.41s | ❌ No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.59it/s]
[BirdCNN] Epoch 32/80 | TrainLoss=0.3164 | TestLoss=0.2975 | TrainAcc=90.22% | Te
stAcc=92.13% | BestAcc=92.33% (E30)
└─ LR=0.001000 | Patience=2/5 | Time=379.30s | ❌ No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.55it/s]
[BirdCNN] Epoch 33/80 | TrainLoss=0.3188 | TestLoss=0.3364 | TrainAcc=89.14% | Te
stAcc=90.45% | BestAcc=92.33% (E30)
└─ LR=0.001000 | Patience=3/5 | Time=391.28s | ❌ No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.56it/s]
[BirdCNN] Epoch 34/80 | TrainLoss=0.2799 | TestLoss=0.2605 | TrainAcc=89.64% | Te
stAcc=93.32% | BestAcc=93.32% (E34)
└─ LR=0.001000 | Patience=0/5 | Time=403.22s | ✅ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.64it/s]
[BirdCNN] Epoch 35/80 | TrainLoss=0.2845 | TestLoss=0.2912 | TrainAcc=90.84% | Te
stAcc=92.33% | BestAcc=93.32% (E34)
└─ LR=0.001000 | Patience=1/5 | Time=415.02s | ❌ No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.64it/s]
[BirdCNN] Epoch 36/80 | TrainLoss=0.2956 | TestLoss=0.2913 | TrainAcc=89.84% | Te
stAcc=92.62% | BestAcc=93.32% (E34)
└─ LR=0.001000 | Patience=2/5 | Time=426.82s | ❌ No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.67it/s]
[BirdCNN] Epoch 37/80 | TrainLoss=0.3120 | TestLoss=0.2533 | TrainAcc=88.39% | Te
stAcc=93.23% | BestAcc=93.32% (E34)
└─ LR=0.001000 | Patience=3/5 | Time=438.56s | ❌ No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.64it/s]
[BirdCNN] Epoch 38/80 | TrainLoss=0.2891 | TestLoss=0.2648 | TrainAcc=90.22% | Te
stAcc=93.64% | BestAcc=93.64% (E38)
└─ LR=0.001000 | Patience=0/5 | Time=450.36s | ✅ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.64it/s]
[BirdCNN] Epoch 39/80 | TrainLoss=0.2770 | TestLoss=0.2530 | TrainAcc=90.22% | Te
stAcc=93.85% | BestAcc=93.85% (E39)
└─ LR=0.001000 | Patience=0/5 | Time=462.17s | ✅ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.60it/s]
[BirdCNN] Epoch 40/80 | TrainLoss=0.2863 | TestLoss=0.2495 | TrainAcc=90.46% | Te
stAcc=93.48% | BestAcc=93.85% (E39)
└─ LR=0.001000 | Patience=1/5 | Time=473.88s | ❌ No Improvement

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训练中：100%|██████████| 38/38 [00:06<00:00, 5.61it/s]
[BirdCNN] Epoch 52/80 | TrainLoss=0.1592 | TestLoss=0.1857 | TrainAcc=95.23% | Te
stAcc=95.98% | BestAcc=95.98% (E52)
└─ LR=0.000500 | Patience=0/5 | Time=614.97s | ✓ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.61it/s]
[BirdCNN] Epoch 53/80 | TrainLoss=0.1441 | TestLoss=0.1898 | TrainAcc=95.19% | Te
stAcc=96.06% | BestAcc=96.06% (E53)
└─ LR=0.000500 | Patience=0/5 | Time=626.83s | ✓ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.62it/s]
[BirdCNN] Epoch 54/80 | TrainLoss=0.1469 | TestLoss=0.1914 | TrainAcc=95.44% | Te
stAcc=96.23% | BestAcc=96.23% (E54)
└─ LR=0.000500 | Patience=0/5 | Time=638.69s | ✓ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.61it/s]
[BirdCNN] Epoch 55/80 | TrainLoss=0.1295 | TestLoss=0.1781 | TrainAcc=95.90% | Te
stAcc=96.31% | BestAcc=96.31% (E55)
└─ LR=0.000500 | Patience=0/5 | Time=650.58s | ✓ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.61it/s]
[BirdCNN] Epoch 56/80 | TrainLoss=0.1312 | TestLoss=0.1836 | TrainAcc=95.27% | Te
stAcc=96.31% | BestAcc=96.31% (E56)
└─ LR=0.000500 | Patience=1/5 | Time=662.43s | || No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.60it/s]
[BirdCNN] Epoch 57/80 | TrainLoss=0.1091 | TestLoss=0.1698 | TrainAcc=96.60% | Te
stAcc=96.68% | BestAcc=96.68% (E57)
└─ LR=0.000500 | Patience=0/5 | Time=674.28s | ✓ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.58it/s]
[BirdCNN] Epoch 58/80 | TrainLoss=0.1309 | TestLoss=0.1829 | TrainAcc=95.52% | Te
stAcc=96.51% | BestAcc=96.68% (E58)
└─ LR=0.000500 | Patience=1/5 | Time=686.23s | || No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.62it/s]
[BirdCNN] Epoch 59/80 | TrainLoss=0.1191 | TestLoss=0.1724 | TrainAcc=95.81% | Te
stAcc=96.88% | BestAcc=96.88% (E59)
└─ LR=0.000500 | Patience=0/5 | Time=698.08s | ✓ Improved & Saved

训练中：100%|██████████| 38/38 [00:06<00:00, 5.64it/s]
[BirdCNN] Epoch 60/80 | TrainLoss=0.1276 | TestLoss=0.1799 | TrainAcc=95.61% | Te
stAcc=96.68% | BestAcc=96.88% (E60)
└─ LR=0.000500 | Patience=1/5 | Time=709.84s | || No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.62it/s]
[BirdCNN] Epoch 61/80 | TrainLoss=0.1146 | TestLoss=0.1873 | TrainAcc=96.06% | Te
stAcc=96.43% | BestAcc=96.88% (E61)
└─ LR=0.000500 | Patience=2/5 | Time=721.73s | || No Improvement

训练中：100%|██████████| 38/38 [00:06<00:00, 5.55it/s]
[BirdCNN] Epoch 62/80 | TrainLoss=0.1139 | TestLoss=0.1776 | TrainAcc=96.02% | Te
stAcc=96.47% | BestAcc=96.88% (E62)
└─ LR=0.000500 | Patience=3/5 | Time=733.72s | || No Improvement

```


🚨 早停触发: 连续 5 轮准确率未提升, 停止训练。

🏁 模型 BirdCNN 训练结束! 最佳准确率: 96.92% (Epoch 64) | 总耗时: 13.61 分钟

```
训练中：100%|██████████  
██████ | 38/38 [00:08<00:00, 4.28it/s]  
[BirdCNN_Optimal] Epoch 01/80 | TrainLoss=1.9692 | TestLoss=1.8386 | TrainAcc=28.  
73% | TestAcc=33.42% | BestAcc=33.42% (E1)  
└─ LR=0.001000 | Patience=0/5 | Time=14.80s | ✓ Improved & Saved  
  
训练中：100%|██████████  
██████ | 38/38 [00:08<00:00, 4.27it/s]  
[BirdCNN_Optimal] Epoch 02/80 | TrainLoss=1.6676 | TestLoss=1.4969 | TrainAcc=40.  
51% | TestAcc=48.75% | BestAcc=48.75% (E2)  
└─ LR=0.001000 | Patience=0/5 | Time=29.76s | ✓ Improved & Saved  
  
训练中：100%|██████████  
██████ | 38/38 [00:08<00:00, 4.26it/s]  
[BirdCNN_Optimal] Epoch 03/80 | TrainLoss=1.5078 | TestLoss=1.3369 | TrainAcc=45.  
52% | TestAcc=53.38% | BestAcc=53.38% (E3)  
└─ LR=0.001000 | Patience=0/5 | Time=44.64s | ✓ Improved & Saved  
  
训练中：100%|██████████  
██████ | 38/38 [00:08<00:00, 4.28it/s]
```



```
[BirdCNN_Optimal] Epoch 04/80 | TrainLoss=1.3745 | TestLoss=1.2368 | TrainAcc=52.28% | TestAcc=58.47% | BestAcc=58.47% (E4)
```

```
[BirdCNN_Optimal] Epoch 15/80 | TrainLoss=0.6691 | TestLoss=0.4821 | TrainAcc=76.62% | TestAcc=86.02% | BestAcc=86.02% (E15)
```

└ LR=0.001000 | Patience=0/5 | Time=221.92s | Improved & Saved

训练中：100%|

```
██████████ | 38/38 [00:09<00:00, 4.20it/s]
```

```
[BirdCNN_Optimal] Epoch 16/80 | TrainLoss=0.6341 | TestLoss=0.4346 | TrainAcc=79.06% | TestAcc=87.13% | BestAcc=87.13% (E16)
```

└ LR=0.001000 | Patience=0/5 | Time=237.34s | Improved & Saved

训练中：100%|

```
██████████ | 38/38 [00:08<00:00, 4.29it/s]
```

```
[BirdCNN_Optimal] Epoch 17/80 | TrainLoss=0.5817 | TestLoss=0.4157 | TrainAcc=79.77% | TestAcc=87.58% | BestAcc=87.58% (E17)
```

└ LR=0.001000 | Patience=0/5 | Time=252.14s | ☒ Improved & Saved

训练中：100%|

```
██████████| 38/38 [00:08<00:00, 4.27it/s]
```

```
[BirdCNN_Optimal] Epoch 18/80 | TrainLoss=0.5522 | TestLoss=0.3876 | TrainAcc=80.89% | TestAcc=88.81% | BestAcc=88.81% (E18)
```

└ LR=0.001000 | Patience=0/5 | Time=266.90s | ☒ Improved & Saved

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.31it/s]
```

```
[BirdCNN_Optimal] Epoch 19/80 | TrainLoss=0.5142 | TestLoss=0.3585 | TrainAcc=82.55% | TestAcc=90.16% | BestAcc=90.16% (E19)
```

└ LR=0.001000 | Patience=0/5 | Time=281.72s | ☒ Improved & Saved

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.29it/s]
```

```
[BirdCNN_Optimal] Epoch 20/80 | TrainLoss=0.5426 | TestLoss=0.3422 | TrainAcc=80.93% | TestAcc=90.16% | BestAcc=90.16% (E19)
```

```
└ LR=0.001000 | Patience=1/5 | Time=296.51s | || No Improvement
```

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.26it/s]
```

```
[BirdCNN_Optimal] Epoch 21/80 | TrainLoss=0.4893 | TestLoss=0.3708 | TrainAcc=83.96% | TestAcc=88.97% | BestAcc=90.16% (E19)
```

```
└ LR=0.001000 | Patience=2/5 | Time=311.37s | || No Improvement
```

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.33it/s]
```

```
[BirdCNN_Optimal] Epoch 22/80 | TrainLoss=0.4585 | TestLoss=0.2790 | TrainAcc=84.66% | TestAcc=93.15% | BestAcc=93.15% (E22)
```

└ LR=0.001000 | Patience=0/5 | Time=326.01s | Improved & Saved

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.30it/s]
```

```
[BirdCNN_Optimal] Epoch 23/80 | TrainLoss=0.4459 | TestLoss=0.2932 | TrainAcc=85.20% | TestAcc=92.13% | BestAcc=93.15% (E22)
```

```
└─ LR=0.001000 | Patience=1/5 | Time=341.67s | || No Improvement
```

训练中：100%

```
██████████ | 38/38 [00:09<00:00, 4.18it/s]
```

```
[BirdCNN_Optimal] Epoch 24/80 | TrainLoss=0.3995 | TestLoss=0.2788 | TrainAcc=86.28% | TestAcc=93.07% | BestAcc=93.15% (E22)
```

```
└─ LR=0.001000 | Patience=2/5 | Time=356.79s | || No Improvement
```

训练中：100%

```
38/38 [00:09<00:00, 4.21it/s]
```

```
[BirdCNN_Optimal] Epoch 25/80 | TrainLoss=0.4304 | TestLoss=0.2603 | TrainAcc=84.91% | TestAcc=93.23% | BestAcc=93.23% (E25)
```

└ LR=0.001000 | Patience=0/5 | Time=371.93s | Improved & Saved

训练中：100%

```
██████████ | 38/38 [00:09<00:00, 4.21it/s]
```

```
[BirdCNN_Optimal] Epoch 26/80 | TrainLoss=0.3918 | TestLoss=0.2535 | TrainAcc=86.15% | TestAcc=93.69% | BestAcc=93.69% (E26)
```

└ LR=0.001000 | Patience=0/5 | Time=387.03s | Improved & Saved

训练中：100%|██████████
██████████| 38/38 [00:08<00:00, 4.24it/s]

```
[BirdCNN_Optimal] Epoch 27/80 | TrainLoss=0.3802 | TestLoss=0.2755 | TrainAcc=87.40% | TestAcc=92.41% | BestAcc=93.69% (E26)
```

```
└ LR=0.001000 | Patience=1/5 | Time=401.97s | || No Improvement
```

```
训练中：100%|███████████  
███████| 38/38 [00:09<00:00, 4.19it/s]
```

```
[BirdCNN_Optimal] Epoch 28/80 | TrainLoss=0.3680 | TestLoss=0.2599 | TrainAcc=87.23% | TestAcc=93.07% | BestAcc=93.69% (E26)
```

```
└ LR=0.001000 | Patience=2/5 | Time=417.06s | || No Improvement
```

```
训练中：100%|███████████  
███████| 38/38 [00:09<00:00, 4.16it/s]
```

```
[BirdCNN_Optimal] Epoch 29/80 | TrainLoss=0.3473 | TestLoss=0.2251 | TrainAcc=88.68% | TestAcc=94.26% | BestAcc=94.26% (E29)
```

└ LR=0.001000 | Patience=0/5 | Time=432.22s | Improved & Saved

训练中：100%|██████████
██████████ | 38/38 [00:09<00:00, 4.22it/s]

```
[BirdCNN_Optimal] Epoch 30/80 | TrainLoss=0.3027 | TestLoss=0.2203 | TrainAcc=90.01% | TestAcc=94.75% | BestAcc=94.75% (E30)
```

└ LR=0.001000 | Patience=0/5 | Time=447.26s | Improved & Saved

```
训练中: 100%|██████████  
██████████| 38/38 [00:09<00:00, 4.20it/s]
```

```
[BirdCNN_Optimal] Epoch 31/80 | TrainLoss=0.3298 | TestLoss=0.2346 | TrainAcc=88.64% | TestAcc=94.22% | BestAcc=94.75% (E30)
```

```
└ LR=0.001000 | Patience=1/5 | Time=462.29s | || No Improvement
```

训练中: 100%|██████████
██████████ | 38/38 [00:08<00:00, 4.23it/s]

```
[BirdCNN_Optimal] Epoch 32/80 | TrainLoss=0.3074 | TestLoss=0.2200 | TrainAcc=89.43% | TestAcc=94.30% | BestAcc=94.75% (E30)
```

```
└ LR=0.001000 | Patience=2/5 | Time=477.27s | || No Improvement
```

```
训练中：100%|███████████  
██████████| 38/38 [00:09<00:00, 4.22it/s]
```

```
[BirdCNN_Optimal] Epoch 33/80 | TrainLoss=0.2957 | TestLoss=0.2458 | TrainAcc=89.97% | TestAcc=93.81% | BestAcc=94.75% (E30)
```

```
└ LR=0.001000 | Patience=3/5 | Time=492.29s | || No Improvement
```

```
训练中：100%|██████████|  
██████████| 38/38 [00:09<00:00, 4.20it/s]
```

```
[BirdCNN_Optimal] Epoch 34/80 | TrainLoss=0.3184 | TestLoss=0.1990 | TrainAcc=88.85% | TestAcc=95.28% | BestAcc=95.28% (E34)
```

└ LR=0.001000 | Patience=0/5 | Time=507.42s | ☒ Improved & Saved

```
训练中：100%|██████████|  
██████████| 38/38 [00:09<00:00, 4.20it/s]
```

```
[BirdCNN_Optimal] Epoch 35/80 | TrainLoss=0.3170 | TestLoss=0.2087 | TrainAcc=88.93% | TestAcc=95.61% | BestAcc=95.61% (E35)
```

└ LR=0.001000 | Patience=0/5 | Time=522.55s | ☒ Improved & Saved

训练中: 100% | ██████████
██████ | 38/38 [00:08<00:00, 4.22it/s]

```
[BirdCNN_Optimal] Epoch 36/80 | TrainLoss=0.2719 | TestLoss=0.1798 | TrainAcc=90.30% | TestAcc=96.23% | BestAcc=96.23% (E36)
```

└ LR=0.001000 | Patience=0/5 | Time=537.56s | ☒ Improved & Saved

训练中: 100%|██████████
██████████ | 38/38 [00:09<00:00, 4.16it/s]

```
[BirdCNN_Optimal] Epoch 37/80 | TrainLoss=0.2522 | TestLoss=0.1780 | TrainAcc=91.38% | TestAcc=96.02% | BestAcc=96.23% (E36)
```

```
└ LR=0.001000 | Patience=1/5 | Time=553.02s | || No Improvement
```

训练中：100%|

```
██████████ | 38/38 [00:08<00:00, 4.28it/s]
```

```
[BirdCNN_Optimal] Epoch 38/80 | TrainLoss=0.2407 | TestLoss=0.1671 | TrainAcc=91.92% | TestAcc=96.60% | BestAcc=96.60% (E38)
```

└ LR=0.001000 | Patience=0/5 | Time=567.86s | Improved & Saved

训练中：100%|

```
██████████ | 38/38 [00:09<00:00, 4.20it/s]
```

```
[BirdCNN_Optimal] Epoch 39/80 | TrainLoss=0.2075 | TestLoss=0.1745 | TrainAcc=92.87% | TestAcc=96.27% | BestAcc=96.60% (E38)
```

```
└ LR=0.001000 | Patience=1/5 | Time=582.91s | || No Improvement
```

训练中：100%|

```
██████████ | 38/38 [00:09<00:00, 4.21it/s]
```

```
[BirdCNN_Optimal] Epoch 40/80 | TrainLoss=0.2004 | TestLoss=0.1680 | TrainAcc=93.16% | TestAcc=96.51% | BestAcc=96.60% (E38)
```

```
└ LR=0.001000 | Patience=2/5 | Time=598.00s | || No Improvement
```

训练中：100%

```
██████████ | 38/38 [00:09<00:00, 4.21it/s]
```

```
[BirdCNN_Optimal] Epoch 41/80 | TrainLoss=0.2020 | TestLoss=0.1740 | TrainAcc=93.99% | TestAcc=96.60% | BestAcc=96.60% (E38)
```

```
└ LR=0.001000 | Patience=3/5 | Time=612.90s | || No Improvement
```

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.29it/s]
```

```
[BirdCNN_Optimal] Epoch 42/80 | TrainLoss=0.2115 | TestLoss=0.1714 | TrainAcc=92.29% | TestAcc=96.19% | BestAcc=96.60% (E38)
```

```
└ LR=0.000500 | Patience=4/5 | Time=627.69s | || No Improvement
```

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.29it/s]
```

```
[BirdCNN_Optimal] Epoch 43/80 | TrainLoss=0.1852 | TestLoss=0.1420 | TrainAcc=93.74% | TestAcc=97.13% | BestAcc=97.13% (E43)
```

└ LR=0.000500 | Patience=0/5 | Time=642.62s | Improved & Saved

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.25it/s]
```

```
[BirdCNN_Optimal] Epoch 44/80 | TrainLoss=0.1628 | TestLoss=0.1390 | TrainAcc=95.44% | TestAcc=97.13% | BestAcc=97.13% (E43)
```

```
└ LR=0.000500 | Patience=1/5 | Time=657.49s | || No Improvement
```

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.27it/s]
```

```
[BirdCNN_Optimal] Epoch 45/80 | TrainLoss=0.1576 | TestLoss=0.1338 | TrainAcc=94.69% | TestAcc=97.21% | BestAcc=97.21% (E45)
```

└ LR=0.000500 | Patience=0/5 | Time=672.36s | ☒ Improved & Saved

训练中：100%

```
██████████ | 38/38 [00:08<00:00, 4.25it/s]
```

```
[BirdCNN_Optimal] Epoch 46/80 | TrainLoss=0.1440 | TestLoss=0.1309 | TrainAcc=95.69% | TestAcc=97.21% | BestAcc=97.21% (E45)
```

└─ LR=0.000500 | Patience=1/5 | Time=687.20s | || No Improvement

训练中：100%

```
38/38 [00:08<00:00, 4.23it/s]
```


```
[BirdCNN_Optimal] Epoch 47/80 | TrainLoss=0.1282 | TestLoss=0.1294 | TrainAcc=96.06% | TestAcc=97.46% | BestAcc=97.46% (E47)
```

└ LR=0.000500 | Patience=0/5 | Time=702.09s | Improved & Saved

训练中：100%

```
38/38 [00:08<00:00, 4.35it/s]
```

[BirdCNN_Optimal] Epoch 48/80 | TrainLoss=0.1326 | TestLoss=0.1283 | TrainAcc=95.11% | TestAcc=97.58% | BestAcc=97.58% (E48)

└ LR=0.000500 | Patience=0/5 | Time=716.77s |  Improved & Saved

训练中: 100%|

38/38 [00:08<00:00, 4.28it/s]

[BirdCNN_Optimal] Epoch 49/80 | TrainLoss=0.1265 | TestLoss=0.1318 | TrainAcc=95.98% | TestAcc=97.38% | BestAcc=97.58% (E48)

└ LR=0.000500 | Patience=1/5 | Time=731.55s |  No Improvement

训练中: 100%|

38/38 [00:08<00:00, 4.29it/s]

[BirdCNN_Optimal] Epoch 50/80 | TrainLoss=0.1226 | TestLoss=0.1290 | TrainAcc=96.02% | TestAcc=97.33% | BestAcc=97.58% (E48)

└ LR=0.000500 | Patience=2/5 | Time=746.30s |  No Improvement

训练中: 100%|

38/38 [00:08<00:00, 4.27it/s]

[BirdCNN_Optimal] Epoch 51/80 | TrainLoss=0.1126 | TestLoss=0.1264 | TrainAcc=96.31% | TestAcc=97.42% | BestAcc=97.58% (E48)

└ LR=0.000500 | Patience=3/5 | Time=761.17s |  No Improvement

训练中: 100%|

38/38 [00:08<00:00, 4.29it/s]

[BirdCNN_Optimal] Epoch 52/80 | TrainLoss=0.1126 | TestLoss=0.1320 | TrainAcc=96.27% | TestAcc=97.33% | BestAcc=97.58% (E48)

└ LR=0.000250 | Patience=4/5 | Time=775.92s |  No Improvement

训练中: 100%|

38/38 [00:08<00:00, 4.30it/s]

[BirdCNN_Optimal] Epoch 53/80 | TrainLoss=0.0960 | TestLoss=0.1249 | TrainAcc=96.89% | TestAcc=97.50% | BestAcc=97.58% (E48)

└ LR=0.000250 | Patience=5/5 | Time=790.60s |  No Improvement

⚠ 早停触发: 连续 5 轮准确率未提升, 停止训练。


🔍 模型 BirdCNN_Optimal 训练结束! 最佳准确率: 97.58% (Epoch 48) | 总耗时: 13.18 分钟

===== 🚀 开始训练模型: BirdResNet =====

训练中: 100%|

38/38 [00:12<00:00, 3.06it/s]


[BirdResNet] Epoch 01/80 | TrainLoss=2.0610 | TestLoss=1.8520 | TrainAcc=23.09% | TestAcc=30.14% | BestAcc=30.14% (E1)

└ LR=0.001000 | Patience=0/5 | Time=19.49s |  Improved & Saved

训练中: 100%|

38/38 [00:12<00:00, 3.06it/s]


[BirdResNet] Epoch 02/80 | TrainLoss=1.7757 | TestLoss=1.5799 | TrainAcc=36.48% | TestAcc=43.38% | BestAcc=43.38% (E2)

└ LR=0.001000 | Patience=0/5 | Time=38.99s |  Improved & Saved

训练中: 100%|

38/38 [00:12<00:00, 3.05it/s]


[BirdResNet] Epoch 03/80 | TrainLoss=1.6166 | TestLoss=1.4047 | TrainAcc=44.03% | TestAcc=51.05% | BestAcc=51.05% (E3)

└ LR=0.001000 | Patience=0/5 | Time=58.58s |  Improved & Saved

训练中: 100%|

38/38 [00:12<00:00, 3.05it/s]

[BirdResNet] Epoch 04/80 | TrainLoss=1.4535 | TestLoss=1.3963 | TrainAcc=48.84% | TestAcc=51.25% | BestAcc=51.25% (E4)

└ LR=0.001000 | Patience=0/5 | Time=78.09s |  Improved & Saved

训练中: 100%|

38/38 [00:12<00:00, 3.05it/s]

14/21

[BirdResNet] Epoch 16/80 | TrainLoss=0.8101 | TestLoss=0.5960 | TrainAcc=71.10% | TestAcc=80.73% | BestAcc=80.73% (E16)

└ LR=0.001000 | Patience=0/5 | Time=313.41s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.04it/s]

[BirdResNet] Epoch 17/80 | TrainLoss=0.7583 | TestLoss=0.5699 | TrainAcc=72.89% | TestAcc=81.88% | BestAcc=81.88% (E17)

└ LR=0.001000 | Patience=0/5 | Time=333.08s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.04it/s]

[BirdResNet] Epoch 18/80 | TrainLoss=0.7006 | TestLoss=0.5638 | TrainAcc=75.50% | TestAcc=81.55% | BestAcc=81.88% (E17)

└ LR=0.001000 | Patience=1/5 | Time=352.95s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.06it/s]

[BirdResNet] Epoch 19/80 | TrainLoss=0.6766 | TestLoss=0.4915 | TrainAcc=76.00% | TestAcc=85.36% | BestAcc=85.36% (E19)

└ LR=0.001000 | Patience=0/5 | Time=372.56s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.07it/s]

[BirdResNet] Epoch 20/80 | TrainLoss=0.6368 | TestLoss=0.5299 | TrainAcc=76.91% | TestAcc=84.26% | BestAcc=85.36% (E19)

└ LR=0.001000 | Patience=1/5 | Time=391.89s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.07it/s]

[BirdResNet] Epoch 21/80 | TrainLoss=0.6090 | TestLoss=0.4287 | TrainAcc=78.90% | TestAcc=87.41% | BestAcc=87.41% (E21)

└ LR=0.001000 | Patience=0/5 | Time=411.29s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.06it/s]

[BirdResNet] Epoch 22/80 | TrainLoss=0.6151 | TestLoss=0.4354 | TrainAcc=77.94% | TestAcc=87.66% | BestAcc=87.66% (E22)

└ LR=0.001000 | Patience=0/5 | Time=430.91s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.02it/s]

[BirdResNet] Epoch 23/80 | TrainLoss=0.6049 | TestLoss=0.4646 | TrainAcc=78.73% | TestAcc=86.67% | BestAcc=87.66% (E22)

└ LR=0.001000 | Patience=1/5 | Time=450.44s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.08it/s]

[BirdResNet] Epoch 24/80 | TrainLoss=0.5417 | TestLoss=0.3789 | TrainAcc=80.64% | TestAcc=89.46% | BestAcc=89.46% (E24)

└ LR=0.001000 | Patience=0/5 | Time=469.80s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.08it/s]

[BirdResNet] Epoch 25/80 | TrainLoss=0.5068 | TestLoss=0.3319 | TrainAcc=82.75% | TestAcc=91.96% | BestAcc=91.96% (E25)

└ LR=0.001000 | Patience=0/5 | Time=489.13s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.08it/s]

[BirdResNet] Epoch 26/80 | TrainLoss=0.4834 | TestLoss=0.3220 | TrainAcc=82.50% | TestAcc=91.31% | BestAcc=91.96% (E25)

└ LR=0.001000 | Patience=1/5 | Time=508.65s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.02it/s]


```
训练中：100%|██████████████████████████████████████████████████████  
███████| 38/38 [00:12<00:00, 2.99it/s]
```

17/21

[BirdResNet] Epoch 49/80 | TrainLoss=0.1145 | TestLoss=0.1354 | TrainAcc=96.31% | TestAcc=97.62% | BestAcc=97.62% (E49)

└ LR=0.000250 | Patience=0/5 | Time=965.35s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.02it/s]

[BirdResNet] Epoch 50/80 | TrainLoss=0.1073 | TestLoss=0.1383 | TrainAcc=96.52% | TestAcc=97.62% | BestAcc=97.62% (E49)

└ LR=0.000250 | Patience=1/5 | Time=985.09s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.04it/s]

[BirdResNet] Epoch 51/80 | TrainLoss=0.0997 | TestLoss=0.1362 | TrainAcc=96.97% | TestAcc=97.50% | BestAcc=97.62% (E49)

└ LR=0.000250 | Patience=2/5 | Time=1004.80s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.03it/s]

[BirdResNet] Epoch 52/80 | TrainLoss=0.1260 | TestLoss=0.1398 | TrainAcc=95.73% | TestAcc=97.38% | BestAcc=97.62% (E49)

└ LR=0.000250 | Patience=3/5 | Time=1024.43s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.04it/s]

[BirdResNet] Epoch 53/80 | TrainLoss=0.1143 | TestLoss=0.1342 | TrainAcc=96.81% | TestAcc=97.54% | BestAcc=97.62% (E49)

└ LR=0.000125 | Patience=4/5 | Time=1044.14s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.01it/s]

[BirdResNet] Epoch 54/80 | TrainLoss=0.1080 | TestLoss=0.1323 | TrainAcc=96.81% | TestAcc=97.66% | BestAcc=97.66% (E54)

└ LR=0.000125 | Patience=0/5 | Time=1064.00s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.03it/s]

[BirdResNet] Epoch 55/80 | TrainLoss=0.1053 | TestLoss=0.1334 | TrainAcc=96.52% | TestAcc=97.70% | BestAcc=97.70% (E55)

└ LR=0.000125 | Patience=0/5 | Time=1083.82s | ☒ Improved & Saved

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.02it/s]

[BirdResNet] Epoch 56/80 | TrainLoss=0.0927 | TestLoss=0.1301 | TrainAcc=97.14% | TestAcc=97.70% | BestAcc=97.70% (E55)

└ LR=0.000125 | Patience=1/5 | Time=1103.52s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.04it/s]

[BirdResNet] Epoch 57/80 | TrainLoss=0.0938 | TestLoss=0.1305 | TrainAcc=96.97% | TestAcc=97.62% | BestAcc=97.70% (E55)

└ LR=0.000125 | Patience=2/5 | Time=1123.14s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.05it/s]

[BirdResNet] Epoch 58/80 | TrainLoss=0.0873 | TestLoss=0.1317 | TrainAcc=97.06% | TestAcc=97.70% | BestAcc=97.70% (E55)

└ LR=0.000125 | Patience=3/5 | Time=1142.57s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.08it/s]

[BirdResNet] Epoch 59/80 | TrainLoss=0.0903 | TestLoss=0.1300 | TrainAcc=97.39% | TestAcc=97.70% | BestAcc=97.70% (E55)

└ LR=0.000063 | Patience=4/5 | Time=1161.73s | ☐ No Improvement

训练中: 100%|

██████████ 38/38 [00:12<00:00, 3.08it/s]

[BirdResNet] Epoch 60/80 | TrainLoss=0.0896 | TestLoss=0.1288 | TrainAcc=97.31% | TestAcc=97.62% | BestAcc=97.70% (E55)

└ LR=0.000063 | Patience=5/5 | Time=1181.41s | || No Improvement

⚠ 早停触发：连续 5 轮准确率未提升，停止训练。

🏁 模型 BirdResNet 训练结束！最佳准确率：97.70% (Epoch 55) | 总耗时：19.69 分钟

✅ 所有模型训练完成！

```
In [3]: import matplotlib.pyplot as plt
import seaborn as sns
import pandas as pd
import numpy as np
from matplotlib.path_effects import withStroke

def plot_model_comparison_best_only(results, point_interval=5, smooth_window=3):
    sns.set_theme(style="whitegrid", context="talk")
    plt.rcParams['font.sans-serif'] = ['Microsoft YaHei', 'SimHei', 'Arial']
    plt.rcParams['axes.unicode_minus'] = False

    # ===== 数据整理 =====
    all_data = []
    for name, data in results.items():
        for epoch, (train_acc, test_acc, loss) in enumerate(
            zip(data["train_accs"], data["test_accs"], data["train_losses"]), 1
        ):
            all_data.append(["Train", name, epoch, train_acc, loss])
            all_data.append(["Test", name, epoch, test_acc, loss])
    df = pd.DataFrame(all_data, columns=["Phase", "Model", "Epoch", "Accuracy",

    # ===== 找出最优模型（测试集最高准确率） =====
    df_test = df[df["Phase"] == "Test"]
    best_idx = df_test["Accuracy"].idxmax()
    best_model = df_test.loc[best_idx, "Model"]
    best_acc = df_test.loc[best_idx, "Accuracy"]
    best_epoch = int(df_test.loc[best_idx, "Epoch"])

    print(f"🏆 最优模型：{best_model} | 测试集准确率 = {best_acc:.2f}% @ Epoch {

    # ===== 绘图布局 =====
    fig = plt.figure(figsize=(14, 10), dpi=300)
    gs = fig.add_gridspec(2, 2, height_ratios=[1, 1.1])
    ax1 = fig.add_subplot(gs[0, 0])
    ax2 = fig.add_subplot(gs[0, 1])
    ax3 = fig.add_subplot(gs[1, :])
    palette = sns.color_palette("husl", len(results))

    def smooth(y):
        return pd.Series(y).rolling(smooth_window, min_periods=1).mean()

    # ===== 训练集准确率 =====
    for (name, group), color in zip(df[df["Phase"] == "Train"].groupby("Model"),
        group["Accuracy_smooth"] = smooth(group["Accuracy"])
        sns.lineplot(data=group, x="Epoch", y="Accuracy_smooth",
            label=name, linewidth=2.2, color=color, ax=ax1)
    ax1.set_title("训练集准确率对比", fontsize=15, weight="bold")
    ax1.set_xlabel("Epoch")
    ax1.set_ylabel("Accuracy (%)")
    ax1.legend(title="Model", loc="lower right", fontsize=8)
    ax1.set_facecolor("#fafafa")
```

```

# ===== 测试集准确率（高亮最优模型） =====
for (name, group), color in zip(df[df["Phase"] == "Test"].groupby("Model"),
                                group["Accuracy_smooth"] = smooth(group["Accuracy"]))
    sns.lineplot(data=group, x="Epoch", y="Accuracy_smooth",
                  label=name, linewidth=2.2, color=color, ax=ax2)
    if name == best_model:
        ax2.scatter(best_epoch, best_acc, s=200, color=color, marker="*", edgecolor="black")
        ax2.annotate(
            f"最优模型: {best_model}\nAcc={best_acc:.2f}%@E{best_epoch}",
            xy=(best_epoch, best_acc),
            xytext=(best_epoch - 8, best_acc - 3),
            fontsize=10, color=color, weight="bold",
            bbox=dict(boxstyle="round,pad=0.3", fc="white", ec=color, lw=1.2),
            arrowprops=dict(arrowstyle="->", lw=1, color=color, alpha=0.7)
        )

ax2.set_title("测试集准确率对比", fontsize=15, weight="bold")
ax2.set_xlabel("Epoch")
ax2.set_ylabel("Accuracy (%)")
ax2.legend(title="Model", loc="lower right", fontsize=8)
ax2.set_facecolor("#fafafa")

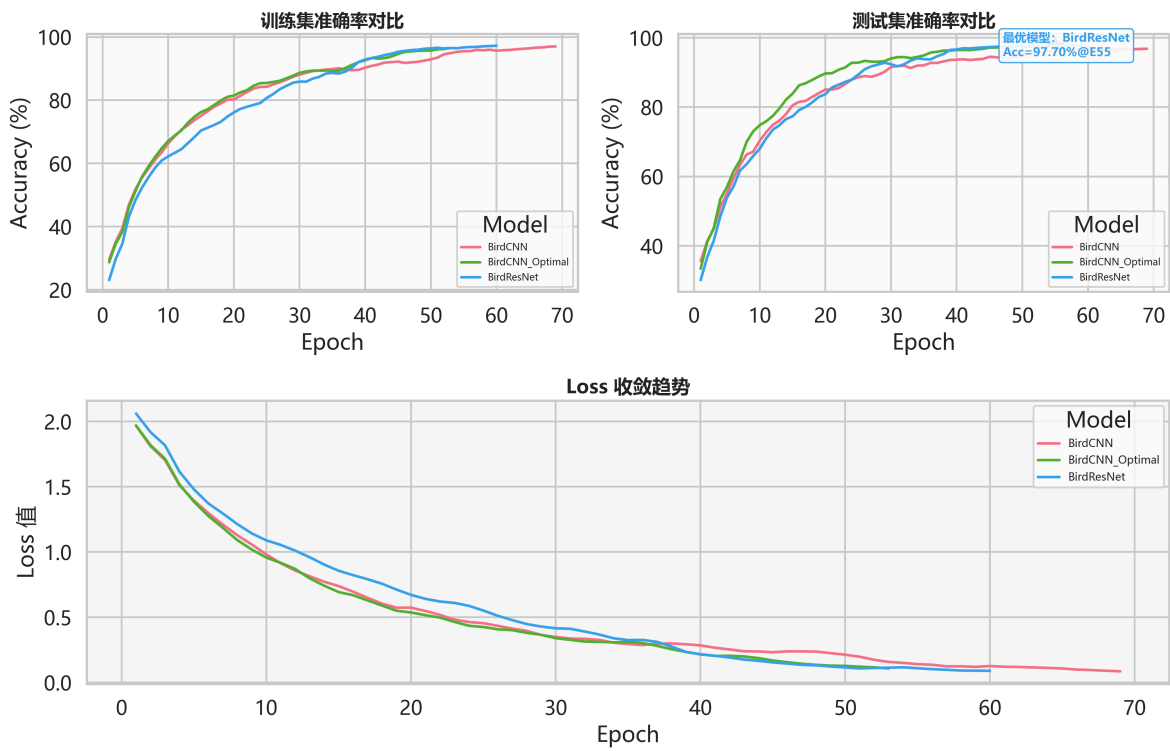
# ===== Loss 收敛趋势 =====
for (name, group), color in zip(df[df["Phase"] == "Train"].groupby("Model"),
                                group["Loss_smooth"] = smooth(group["Loss"]))
    sns.lineplot(data=group, x="Epoch", y="Loss_smooth",
                  label=name, linewidth=2.2, color=color, ax=ax3)
ax3.set_title("Loss 收敛趋势", fontsize=16, weight="bold")
ax3.set_xlabel("Epoch")
ax3.set_ylabel("Loss 值")
ax3.legend(title="Model", loc="upper right", fontsize=9)
ax3.set_facecolor("#f7f7f7")

# ===== 总标题 =====
fig.suptitle("三种鸟类识别模型性能对比",
             fontsize=18, weight="bold", y=0.98)
plt.tight_layout(rect=[0, 0, 1, 0.96])
plt.show()
plot_model_comparison_best_only(results)

```

🏆 最优模型: BirdResNet | 测试集准确率 = 97.70% @ Epoch 55

三种鸟类识别模型性能对比



In []: