哈尔滨工业大学

模式识别与深度学习

实验二: 卷积神经网络实现

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提交日期: 2023.5.9

摘要

本次深度学习实验为模式识别与深度学习课程的实验二: 即卷积神经网络的实现,实验的主要任务是基于 Python 的 PyTorch 库工具来实现 AlexNet 卷积神经 网络结构,并且在 CalTech 101 数据集上进行模型验证。在本次实验中,我复现并且改进了 AlexNet 的卷积神经网络结构,同时还使用 Tensorboard 图形显示工具进行训练得到的数据可视化,最终在数据集上达到了 78.7%一个较为不错的准确率。

关键词: 模式识别与深度学习, AlexNet, TensorBoard, CalTech101 数据集

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一、深度学习框架与实验环境

本次实验采用的深度学习框架是 Python 中强大的深度学习库 Pytorch,整个实验是在 Visual Studio + Pip 环境下完成的。Pip 是一个开源的 Python 发行版本,可以很方便地安装许多深度学习所需要的模块包,而 Visual Studio 则是一个功能强大的 IDE,可以在其中完成 python 代码编写深度学习过程、进行训练测试等深度学习环节。由于我在大二时参加过美赛有接触到一些深度学习相关的工具知识,因此在本次实验中的配置环境过程相对得心应手。配置环境的具体流程比较繁琐,查看系统 Pytorch 库以及 cuda 版本如下图 1 所示(英伟达表示 cuda 可升级到的最高版本):

```
C:\Users\刘天瑞>python
Python 3.9.7 (tags/v3.9.7:1016ef3, Aug 30 2021, 20:19:38) [MSC v.1929 64 bit (AMD64)] on win32
Type "help", "copyright", "credits" or "license" for more information.
>>> import torch
>>> print(torch.__version__)
2.0.0+cu118
>>> ^Z
```

>>> import torch
>>> print(torch.backends.cudnn.version())
8700

		瑞>nvidi 3:24:48 2						
NVID	IA-SMI	531.41			Driver	Version: 531.41	CUDA Versio	on: 12.1
GPU Fan	Name Temp	Perf			C/WDDM age/Cap	Bus-Id Disp. Memory-Usag		Uncorr. ECC Compute M. MIG M.
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Θ	N/A	N/A	11620	C+G	5n1	lh2txyewy\ShellExperi	enceHost.exe	N/A
0	N/A	N/A	13316	C+G		yewy\StartMenuExperi		N/A
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Θ	N/A	N/A	17748	C+G	GeF	orce Experience\NVID	IA Share.exe	N/A
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0	N/A	N/A	25060	C+G	403	36\office6\promecefpl	uginhost.exe	N/A
0	N/A	N/A	25076	C+G	8	3wekyb3d8bbwe\Windows	Terminal.exe	N/A
0	N/A	N/A	25856	C+G	si\	/eControlPanel\System	Settings.exe	N/A
0	N/A	N/A	26908	С	Pro	grams\Python\Python3	9\python.exe	N/A
0	N/A	N/A	26948	C+G	8	3wekyb3d8bbwe\Windows	Terminal.exe	N/A
0	N/A	N/A	30532	C+G	22\	Community\Common7\ID	E\devenv.exe	N/A
0	N/A	N/A	31092	C+G	ft	Office\root\Office16	\WINWORD.EXE	N/A
Θ	N/A	N/A	31864	C+G	403	36\office6\promecefpl	uginhost.exe	N/A

二、 主要研究内容以及实验背景知识

2.1 AlexNet 网络模型简介

Alexnet 网络模型是由 5 个卷积层, 3 个池化层以及 3 个全连接层所构成的。同时 AlexNet 是 LeNet 神经网络的进一步发展, 其中包含了许多新的亮点如下所示:

- 1. AlexNet 网络模型引入了数据增广技术,可以对图像进行颜色变换、裁剪、翻转等操作;
- 2. AlexNet 网络模型采用了 ReLU()激活函数来代替 Sigmoid()函数,从而提升了训练速度,并且在一定规模数据上的性能表现超过了使用 Sigmoid()函数的网络模型;
- 3. AlexNet 网络模型引入了 Dropout 参数用于解决模型训练过程中容易出现过拟合的问题。

AlexNet 模型的网络结构如下图 2 所示:

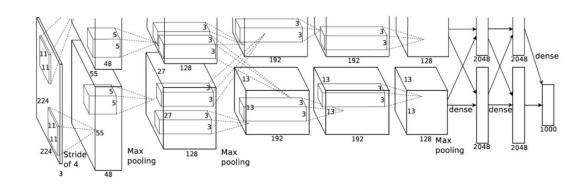


图 2

2.2 CalTech 101 数据集介绍

Caltech 101 数据集是图像识别分类领域常用的数据集。其总共包含有 9146 张图像,这些图像被分为 101 个不同类别(例如 face, piano, ant 等等)和背景类别。而与图像一起被提供的还有一组注释,其用来描述每个图像的准确轮廓。 在本次深度学习实验中,我按照实验的具体要求忽略去掉了 Caltech 101 数据集中的 文件夹内容: BACKGROUND Google 类,再用剩下的数据来完成接下来的

三、实验详细过程

3.1 加载构建并读取数据集

由于 Caltech 101 数据集不能够通过 Pytorch 直接进行导入,所以我需要自己编写数据集类,以便在训练数据时使用。在本次实验中,数据集类我将其保存在了 caltech101.py 程序代码中。完成的主要工作是对__init___,__getitem__以及__len__ 三个方法的重写。值得注意的是,在__getitem__方法中,需要利用到 PIL 库来读入图片,并且将图片转换 RGB 格式,从而方便后续进一步处理。在完成上述步骤以后,便可以在主函数 main()中调用该数据集了。

3.2 搭建 AlexNet 网络结构

AlexNet 网络模型的原始论文中采用了两块 GPU 进行运算后再拼接向量(如上图 2 所示),而由于设备所限,我只实现了其中一块 GPU 对应的网络结构。

具体而言,我搭建的网络结构可以分为 features 与 classifier 两部分。features 部分负责提取图片中的特征,而 classifier 部分则负责具体的图片分类。

features 部分的网络结构如下所示:

• 卷积层 1:

输入: 224 × 224 × 3 的图像; 卷积核数量: 48 (对应单片的 GPU); 卷积核大小: 11 × 11 × 3; stride = 4 (步长为 4); padding = 2 (表示扩充边缘两行两列); 完成卷积后,接入一层 ReLU 并进行 max pooling (最大池化处理)。 max pooling 的参数为 kernal size = 3, stride = 2, padding = 0;

输出: 55 × 55 × 48 的 feature。

• 卷积层 2:

输入: 55×55×48 的 feature (上一层的输出); 卷积核数量: 128; 卷积核大小: 5×5×48; stride = 1; padding = 2; 完成卷积后,同样接入 ReLU 并进行 max pooling 处理 (max pooling 的参数同之前一样);

输出: 27 ×27 ×128 的 feature。

• 卷积层 3:

输入:上一层的输出;卷积核数量: 192;卷积核大小: $3 \times 3 \times 128$; stride = 1;

padding = 1; 完成卷积后,接入 ReLU,但此时不进行 max pooling 处理;

输出: 13 ×13 ×192 的 feature。

• 卷积层 4:

输入: 上一层的输出; 卷积核数量: 192; 卷积核大小: 3 × 3 × 192; stride = 1; padding = 1; 完成卷积后,接入 ReLU,但此时不进行 max pooling 处理;

输出: 13 ×13 ×192 的 feature。

• 卷积层 5:

输入:上一层的输出;卷积核数量: 128;卷积核大小: 3×3×192; stride = 1; padding = 2; 完成卷积后,接入 ReLU 并进行 max pooling 处理 (max pooling 参数同之前一样);

输出: 27 ×27 ×128 的 feature。

完成上述步骤后,我们可以得到大小为 13×13×128 的特征,并且将其通过 flatten 方法展平后输入至 classifier 部分,该部分的网络结构如下所示:

• 全连接层 1:

输入: $128 \times 6 \times 6$ 的图像; 在进入该层前,设置 dropout 参数为 0.5; 完成后,接入一层 ReLU;

输出:长度为2048的一维向量。

• 全连接层 2:

输入:长度为 2048 的一维向量(上一层的输出);在进入该层前,设置 dropout 参数为 0.5;完成后,接入一层 ReLU;

输出: 仍为长度为 2048 的一维向量。

• 全连接层 3:

输入: 上一层的输出:

输出:长度为 num class 的一维向量(在本次实验中,对应了 101 个类)。

3.3 定义并且设置模型参数

3.3.1 损失函数与优化器

为了取得相对较好的训练效果,我继续采用了交叉熵损失与 Adam 优化器。 其具体参数如下图 3 所示:

```
# 定义损失函数和优化器
loss_func = torch.nn.CrossEntropyLoss().cuda()
optimizer = torch.optim.Adam(params = model.parameters(), lr = 0.0003)# 学习率设置为0.0003
```

图 3

3.3.2 超参数

超参数的设定值如下图 4 所示:

超参数设置 batch_size = 64 epoch = 80

图 4

3.4 引入 Tensorboard 图形显示工具

通过 Pip 命令行指令来安装 Tensorboard。在训练相关代码执行前,需要实例 化一个 SummaryWriter 来保存相关信息。在训练过程中,需要将网络结构,本轮训练损失以及本轮训练的准确率等信息加入到 SummaryWriter 实例中,在训练结束后即可查询。

在本次实验中,我还将损失函数值,精确度值以及网络结构这三个数据写入到了 SummaryWriter 中,在训练结束之后就可以在 Tensorboard 线上网页上查看到。

四、实验结果与分析

在我这台计算机的 GPU 为 Nvidia GeForce RTX 3060 的环境下,训练 1 轮 epoch 大致需要 10s。而训练完 80 轮 epoch 后, AlexNet 网络模型在该数据集上取得了 78.7%的准确率,得到的实验命令行运行结果如下图 5 所示:

Epoch:2 Train Loss: 4.1867 Epoch:2 Train Loss: 3.6879 Epoch:3 Train Loss: 3.2419 Epoch:5 Train Loss: 3.2419 Epoch:6 Train Loss: 2.9719 Epoch:7 Train Loss: 2.8158 Epoch:8 Train Loss: 2.7132 Epoch:9 Train Loss: 2.7132 Epoch:10 Train Loss: 2.5243 Epoch:11 Train Loss: 2.5243 Epoch:12 Train Loss: 2.2695 Epoch:14 Train Loss: 2.2695 Epoch:15 Train Loss: 2.1805 Epoch:16 Train Loss: 2.1805 Epoch:17 Train Loss: 2.1805 Epoch:18 Train Loss: 2.1805 Epoch:19 Train Loss: 1.9906 Epoch:19 Train Loss: 1.9906 Epoch:20 Train Loss: 1.9906 Epoch:21 Train Loss: 1.7671 Epoch:21 Train Loss: 1.5725 Epoch:22 Train Loss: 1.5725 Epoch:23 Train Loss: 1.6459 Epoch:24 Train Loss: 1.6459 Epoch:25 Train Loss: 1.6459 Epoch:26 Train Loss: 1.5450 Epoch:27 Train Loss: 1.5229 Epoch:28 Train Loss: 1.1906 Epoch:30 Train Loss: 1.2919 Epoch:31 Train Loss: 1.2919 Epoch:31 Train Loss: 1.2919 Epoch:32 Train Loss: 1.2919 Epoch:33 Train Loss: 1.2919 Epoch:34 Train Loss: 1.2919 Epoch:35 Train Loss: 1.2919 Epoch:36 Train Loss: 1.2919 Epoch:37 Train Loss: 1.2919 Epoch:38 Train Loss: 1.2919 Epoch:39 Train Loss: 1.1906 Epoch:40 Train Loss: 1.2919 Epoch:30 Train Loss: 1.2919 Epoch:31 Train Loss: 1.2919 Epoch:32 Train Loss: 1.2919 Epoch:33 Train Loss: 1.2919 Epoch:34 Train Loss: 1.2919 Epoch:35 Train Loss: 1.2919 Epoch:36 Train Loss: 1.2919 Epoch:37 Train Loss: 1.2919 Epoch:40 Train Loss: 1.2919 Epoch:41 Train Loss: 1.2919 Epoch:42 Train Loss: 1.2919 Epoch:43 Train Loss: 0.9504 Epoch:44 Train Loss: 0.9504 Epoch:55 Train Loss: 0.9504 Epoch:56 Train Loss: 0.9504 Epoch:57 Train Loss: 0.9504 Epoch:58 Train Loss: 0.9504 Epoch:59 Train Loss: 0.9504 Epoch:50 Train Loss: 0.9504 Epoch:51 Train Loss: 0.9504 Epoch:52 Train Loss: 0.9504 Epoch:53 Train Loss: 0.9504 Epoch:64 Train Loss: 0.9504 Epoch:65 Train Loss: 0.9504 Epoch:66 Train Loss: 0.9504 Epoch:67 Train Loss: 0.9504 Epoch:68 Train Loss: 0.9504 Epoch:69 Train Loss: 0.9504 Epoch:60 T	C:\Users\刘天瑞\AppData\Loc × + ∨								
Epoch:4	Epoch:1	Train Loss: 4.1867	accuracy:0.1734						
Epoch:4	Epoch:2	Train Loss: 3.6879	accuracy:0.2195						
Epoch:6	Epoch:3	Train Loss: 3.4554	accuracy:0.2569						
Epoch:6	Epoch:4	Train Loss: 3.2419							
Epoch:8									
Epoch:8									
Epoch:9 Train Loss: 2.6215 Epoch:10 Train Loss: 2.5243 Epoch:11 Train Loss: 2.4297 Epoch:12 Train Loss: 2.4297 Epoch:12 Train Loss: 2.3681 Epoch:13 Train Loss: 2.2695 Epoch:14 Train Loss: 2.1805 Epoch:15 Train Loss: 2.1805 Epoch:16 Train Loss: 2.1805 Epoch:17 Train Loss: 2.1939 Epoch:17 Train Loss: 1.9395 Epoch:18 Train Loss: 1.9395 Epoch:19 Train Loss: 1.9395 Epoch:20 Train Loss: 1.9662 Epoch:21 Train Loss: 1.9662 Epoch:22 Train Loss: 1.7671 Epoch:22 Train Loss: 1.7671 Epoch:23 Train Loss: 1.6129 Epoch:24 Train Loss: 1.5725 Epoch:25 Train Loss: 1.5725 Epoch:26 Train Loss: 1.5725 Epoch:27 Train Loss: 1.5725 Epoch:28 Train Loss: 1.4570 Epoch:29 Train Loss: 1.3395 Epoch:29 Train Loss: 1.3395 Epoch:20 Train Loss: 1.3395 Epoch:20 Train Loss: 1.3395 Epoch:21 Train Loss: 1.3395 Epoch:22 Train Loss: 1.3395 Epoch:23 Train Loss: 1.3395 Epoch:24 Train Loss: 1.3395 Epoch:25 Train Loss: 1.3395 Epoch:26 Train Loss: 1.3395 Epoch:27 Train Loss: 1.2919 Epoch:30 Train Loss: 1.2919 Epoch:31 Train Loss: 1.2919 Epoch:32 Train Loss: 1.2950 Epoch:33 Train Loss: 1.2950 Epoch:34 Train Loss: 1.2950 Epoch:35 Train Loss: 1.2950 Epoch:36 Train Loss: 1.2950 Epoch:37 Train Loss: 1.1903 Epoch:38 Train Loss: 1.993 Epoch:39 Train Loss: 1.0668 Epoch:40 Train Loss: 1.0668 Epoch:41 Train Loss: 1.0688 Epoch:42 Train Loss: 1.0689 Epoch:44 Train Loss: 1.0688 Epoch:45 Train Loss: 1.0688 Epoch:40 Train Loss: 1.0688 Epoch:41 Train Loss: 0.9965 Epoch:42 Train Loss: 0.9965 Epoch:44 Train Loss: 0.9965 Epoch:45 Train Loss: 0.9594 Epoch:50 Train Loss: 0.9594 Epoch:50 Train Loss: 0.9594 Epoch:51 Train Loss: 0.9594 Epoch:52 Train Loss: 0.9594 Epoch:55 Train Loss: 0.9594 Epoch:56 Train Loss: 0.8854 Epoch:57 Train Loss: 0.9594 Epoch:58 Train Loss: 0.8854 Epoch:59 Train Loss: 0.9594 Epoch:50 Train Loss: 0.9594 Epoch:50 Train Loss: 0.9594 Epoch:51 Train Loss: 0.9594 Epoch:52 Train Loss: 0.9594 Epoch:53 Train Loss: 0.9594 Epoch:54 Train Loss: 0.9594 Epoch:55 Train Loss: 0.9594 Epoch:66 Train Loss: 0.9695 Epoch:67 Train Loss: 0.9595 Epoch:68 Train Loss: 0.9595 Epoc									
Epoch:10									
Epoch:11 Train Loss: 2.4297 accuracy:0.4499 Epoch:12 Train Loss: 2.3681 accuracy:0.4799 Epoch:13 Train Loss: 2.1805 accuracy:0.4775 Epoch:15 Train Loss: 2.1239 accuracy:0.4775 Epoch:16 Train Loss: 2.0739 accuracy:0.4775 Epoch:17 Train Loss: 1.9396 accuracy:0.5192 Epoch:18 Train Loss: 1.9395 accuracy:0.5192 Epoch:19 Train Loss: 1.9395 accuracy:0.5302 Epoch:19 Train Loss: 1.9395 accuracy:0.5302 Epoch:20 Train Loss: 1.7671 accuracy:0.5214 Epoch:21 Train Loss: 1.7671 accuracy:0.5499 Epoch:22 Train Loss: 1.6129 accuracy:0.5499 Epoch:23 Train Loss: 1.6129 accuracy:0.5499 Epoch:24 Train Loss: 1.5725 accuracy:0.5576 Epoch:25 Train Loss: 1.5725 accuracy:0.5576 Epoch:26 Train Loss: 1.4870 accuracy:0.5785 Epoch:27 Train Loss: 1.3922 accuracy:0.5785 Epoch:27 Train Loss: 1.3392 accuracy:0.5785 Epoch:28 Train Loss: 1.3392 accuracy:0.5785 Epoch:29 Train Loss: 1.3392 accuracy:0.5785 Epoch:29 Train Loss: 1.3395 accuracy:0.5587 Epoch:30 Train Loss: 1.3395 accuracy:0.5587 Epoch:31 Train Loss: 1.3395 accuracy:0.5587 Epoch:32 Train Loss: 1.3395 accuracy:0.5587 Epoch:33 Train Loss: 1.2919 accuracy:0.5840 Epoch:34 Train Loss: 1.2919 accuracy:0.5840 Epoch:34 Train Loss: 1.2919 accuracy:0.5840 Epoch:35 Train Loss: 1.1903 accuracy:0.5966 Epoch:40 Train Loss: 1.1903 accuracy:0.5966 Epoch:40 Train Loss: 1.9399 accuracy:0.5966 Epoch:40 Train Loss: 1.0389 accuracy:0.5966 Epoch:41 Train Loss: 1.0389 accuracy:0.5966 Epoch:42 Train Loss: 1.0389 accuracy:0.5968 Epoch:43 Train Loss: 1.0389 accuracy:0.5968 Epoch:44 Train Loss: 0.9529 accuracy:0.5959 Epoch:45 Train Loss: 0.9529 accuracy:0.5959 Epoch:40 Train Loss: 0.9529 Epoch:40 Train Loss: 0.9529 Epoch:40 Train Loss: 0.9529 Epoch:40 Train Loss: 0.9529 Epoch:50 Train Loss: 0.9534 accuracy:0.5996 Epoch:50 Train Loss: 0.8428 accuracy:0.5996 Epoch:51 Train Loss: 0.8964 accuracy:0.5996 Epoch:52 Train Loss: 0.87621 accuracy:0.5997 Epoch:55 Train Loss: 0.7821 accuracy:0.5997 Epoch:56 Train Loss: 0.7821 accuracy:0.5997 Epoch:57 Train Loss: 0.7821 accuracy:0.5997 Epoch:60 Train Loss: 0.7563 accuracy:0.59			-						
Epoch:12									
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Epoch:68 Train Loss: 0.6929 accuracy:0.6092									
Epoch. 07 ITAIN 2033. 0.044/ accuracy. 0.0233	Epoch:69	Train Loss: 0.6447	accuracy:0.6235						

```
Epoch:70
           Train Loss: 0.6676
                                 accuracy:0.6136
                                 accuracy:0.5895
Epoch:71
           Train Loss: 0.6667
           Train Loss: 0.6559
Epoch:72
                                 accuracy:0.5818
Epoch:73
           Train Loss: 0.6380
                                 accuracy:0.5741
Epoch:74
           Train Loss: 0.6349
                                 accuracy:0.6125
Epoch:75
            Train Loss: 0.6513
                                 accuracy:0.6037
                                 accuracy:0.5928
Epoch:76
           Train Loss: 0.6031
Epoch:77
            Train Loss:
                        0.6120
                                 accuracy: 0.5906
Epoch: 78
           Train Loss: 0.6107
                                 accuracy:0.5917
                                 accuracy:0.6026
Epoch: 79
           Train Loss: 0.5969
Epoch:80
           Train Loss: 0.5987
                                 accuracy:0.5950
Finished
Test Set accuracy:0.5914
Press any key to continue .
```

图 5

模型在测试集上的表现如下图 6 所示:

```
Load model | Accuracy:0.7870
Press any key to continue . . .
```

图 6

最后在程序的根目录下 Python 终端里运行如下所示命令,其中主机端口 localhost port 为 6006:

tensorboard – logdir Runs

便可以在 Tensorboard 相关网页中查看到 train_loss、learning rate 与 Accuracy 的相关结果如下图 7 所示:

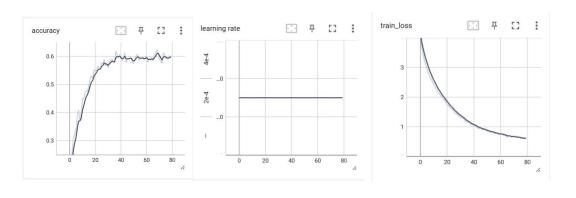


图 9

损失也在一定数量的 epoch 迭代轮次后保持在了 1.00 以下,并没有出现过 拟合的现象。

最后我说明一下模型和数据文档归类。在实验的当前文件夹中,alexnet.py是程序文件,即我自己实现的 AlexNet 网络模型类。train.py则为训练程序文件。./Data 中是从网站上下载下来的保存 Caltech 101 数据集(提交时已删除),

而./Model 中则保存着已经训练好的模型(即本次实验中我仅保留的最优模型)。./Runs 文件夹保存了 Tensorboard 的日志文件。load_img_data.py 程序文件保存了训练程序中所用到的功能函数(数据集读取,划分,载入等等)。

程序运行方法如下所示:在 train.py 的 main 函数中如果只保留着 train_model()函数,运行 python train.py -mode train,就会重新训练模型(需要助教重新下载数据集到./Data 文件夹路径下),则可以进行对 AlexNet 网络模型的训练过程,最后训练完成后的最佳模型就会保存在./Model/Best_AlexNet.ckpt 路径文件中;而如果只保留 load_model()函数,运行 python train.py -mode test,就会载入保存好的最优模型进行测试并且打印测试结果,同时在测试集上验证其效果。

源代码以及注释见附件。