Investigating popular datasets and DNN architectures

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Introduction

This paper is a continuation of "A Survey on Deep Neural Network Security in an Embedded Context". In this paper, we will be investigating some of the datasets and models described in survey. This paper will cover environment setup, dataset preparation, model training, and model evaluation.

Environment Setup

Hardware

The following table describes the hardware used for this paper.

Component	Specification
CPU	Ryzen 5 5600
GPU	NVIDIA GeForce RTX 3070
RAM	32 GB

Software

The following table describes the relevant software used for this paper.

Component	Specification
OS	Windows 11
Python	3.8.5
PyTorch	1.8.1
CUDA	11.1

Setting up the Environment

Python was installed from the official Python website. PyTorch was installed using the following command (found on the PyTorch website):

```
pip3 install torch torchvision torchaudio --extra-index-url
https://download.pytorch.org/whl/cu116
```

To confirm successful installation, the following commands were run:

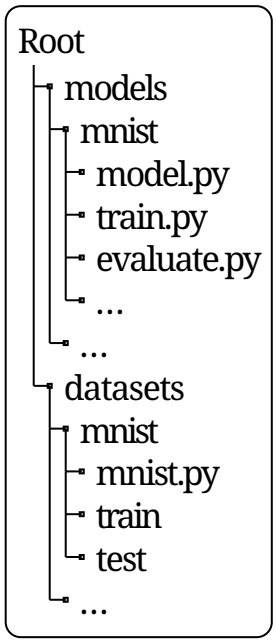
```
python3
>>> import torch
>>> torch.cuda.is_available()
```

```
True
```

Project Structure

The source code for this paper can be found on Github. The directory structure is split into two parts: the 'models' directory and the 'datasets' directory. The 'models' directory contains the source code for the models that will be trained and evaluated. The 'datasets' directory contains the different datasets used.

For example, the following shows files relevant to MNIST and the CNN-2-2 model.



Datasets and Models

The following table describes the datasets and models that will be investigated in this paper.

Dataset	Model
MNIST	CNN with 2 convolutional layers and 2 fully connected layers (CNN-2-2)
CIFAR-10	ResNet-18
GTSRB	ResNet-18

These datasets and models were chosen because they were described in the survey paper and were the most common amongst the works discussed in the survey.

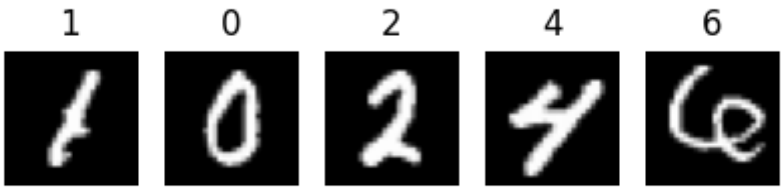
MNIST

The relevant files for MNIST can be found in the 'models/mnist/' and 'datasets/mnist/' directory.

Dataset

The MNIST dataset is a dataset of 60,000 28x28 grayscale images of the 10 digits, along with a test set of 10,000 images. The dataset is available from the MNIST section of the PyTorch documentation. The MNIST dataset is a popular dataset for testing image classification models and is often used as a "Hello World" example for image classification.

The following is a random sample of 5 images from the MNIST training dataset (these can be obtained by running the 'datasets/mnist/mnist.py' script).



Model

The model used for MNIST is a CNN with 2 convolutional layers and 2 fully connected layers (CNN-2-2). The model is defined in the 'models/mnist/model.py' file. A summary of the model is shown below (this can be obtained by running the 'models/mnist/model.py' script).

```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1          [-1, 32, 24, 24]             832
            Conv2d-2            [-1, 64, 8, 8]          51,264
            Linear-3                [-1, 1024]       1,049,600
            Linear-4                  [-1, 10]          10,250
================================================================
Total params: 1,111,946
Trainable params: 1,111,946
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.00
Forward/backward pass size (MB): 0.18
Params size (MB): 4.24
Estimated Total Size (MB): 4.42
----------------------------------------------------------------
```

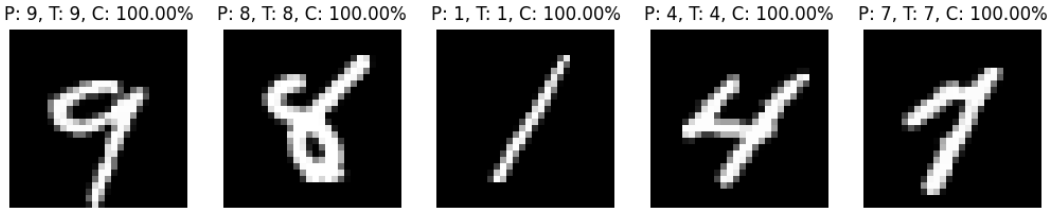
Training

The model was trained using the 'models/mnist/train.py' script. The following table describes the training parameters used.

Parameter	Value
Batch Size	100
Learning Rate	0.001
Epochs	50
Optimizer	Adam
Loss Function	Cross Entropy

Evaluation

The model was evaluated using the 'models/mnist/evaluate.py' script. A final accuracy of 99.21% was achieved on the test set. The following is a random sample of 5 images from the MNIST test dataset along with the model's prediction, true value, and confidence (these can be obtained by running the 'models/mnist/evaluate.py' script).



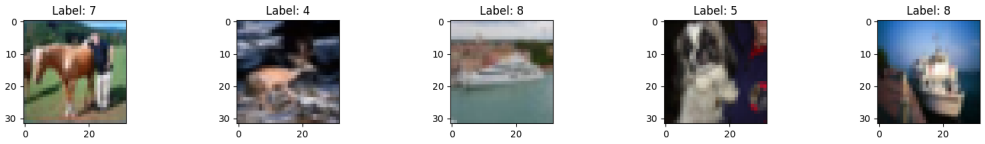
CIFAR-10

The relevant files for CIFAR-10 can be found in the 'models/cifar10/' and 'datasets/cifar10/' directory.

Dataset

The CIFAR-10 dataset is a dataset of 50,000 32x32 color images in 10 classes, along with a test set of 10,000 images. The dataset is available from the CIFAR section of the PyTorch documentation. The CIFAR-10 dataset is a subset of the CIFAR-100 dataset. The CIFAR-10 dataset is a popular dataset for testing image classification models.

The following is a random sample of 5 images from the CIFAR-10 training dataset (these can be obtained by running the 'datasets/cifar10/cifar10.py' script).



Model

The model used for CIFAR-10 is a ResNet-18 model. The model is defined in the 'models/cifar10/model.py' file. A summary of the model is shown below (this can be obtained by running the 'models/cifar10/model.py' script).

```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1          [-1, 64, 16, 16]           9,408
       BatchNorm2d-2          [-1, 64, 16, 16]             128
              ReLU-3          [-1, 64, 16, 16]               0
         MaxPool2d-4            [-1, 64, 8, 8]               0
            Conv2d-5            [-1, 64, 8, 8]          36,864
       BatchNorm2d-6            [-1, 64, 8, 8]             128
              ReLU-7            [-1, 64, 8, 8]               0
            Conv2d-8            [-1, 64, 8, 8]          36,864
       BatchNorm2d-9            [-1, 64, 8, 8]             128
             ReLU-10            [-1, 64, 8, 8]               0
       BasicBlock-11            [-1, 64, 8, 8]               0
           Conv2d-12            [-1, 64, 8, 8]          36,864
      BatchNorm2d-13            [-1, 64, 8, 8]             128
             ReLU-14            [-1, 64, 8, 8]               0
           Conv2d-15            [-1, 64, 8, 8]          36,864
      BatchNorm2d-16            [-1, 64, 8, 8]             128
             ReLU-17            [-1, 64, 8, 8]               0
       BasicBlock-18            [-1, 64, 8, 8]               0
           Conv2d-19           [-1, 128, 4, 4]          73,728
      BatchNorm2d-20           [-1, 128, 4, 4]             256
             ReLU-21           [-1, 128, 4, 4]               0
           Conv2d-22           [-1, 128, 4, 4]         147,456
      BatchNorm2d-23           [-1, 128, 4, 4]             256
           Conv2d-24           [-1, 128, 4, 4]           8,192
      BatchNorm2d-25           [-1, 128, 4, 4]             256
             ReLU-26           [-1, 128, 4, 4]               0
       BasicBlock-27           [-1, 128, 4, 4]               0
           Conv2d-28           [-1, 128, 4, 4]         147,456
      BatchNorm2d-29           [-1, 128, 4, 4]             256
             ReLU-30           [-1, 128, 4, 4]               0
           Conv2d-31           [-1, 128, 4, 4]         147,456
      BatchNorm2d-32           [-1, 128, 4, 4]             256
             ReLU-33           [-1, 128, 4, 4]               0
       BasicBlock-34           [-1, 128, 4, 4]               0
           Conv2d-35           [-1, 256, 2, 2]         294,912
      BatchNorm2d-36           [-1, 256, 2, 2]             512
```

```
              ReLU-37            [-1, 256, 2, 2]               0
            Conv2d-38            [-1, 256, 2, 2]         589,824
       BatchNorm2d-39            [-1, 256, 2, 2]             512
            Conv2d-40            [-1, 256, 2, 2]          32,768
       BatchNorm2d-41            [-1, 256, 2, 2]             512
              ReLU-42            [-1, 256, 2, 2]               0
        BasicBlock-43            [-1, 256, 2, 2]               0
            Conv2d-44            [-1, 256, 2, 2]         589,824
       BatchNorm2d-45            [-1, 256, 2, 2]             512
              ReLU-46            [-1, 256, 2, 2]               0
            Conv2d-47            [-1, 256, 2, 2]         589,824
       BatchNorm2d-48            [-1, 256, 2, 2]             512
              ReLU-49            [-1, 256, 2, 2]               0
        BasicBlock-50            [-1, 256, 2, 2]               0
            Conv2d-51            [-1, 512, 1, 1]       1,179,648
       BatchNorm2d-52            [-1, 512, 1, 1]           1,024
              ReLU-53            [-1, 512, 1, 1]               0
            Conv2d-54            [-1, 512, 1, 1]       2,359,296
       BatchNorm2d-55            [-1, 512, 1, 1]           1,024
            Conv2d-56            [-1, 512, 1, 1]         131,072
       BatchNorm2d-57            [-1, 512, 1, 1]           1,024
              ReLU-58            [-1, 512, 1, 1]               0
        BasicBlock-59            [-1, 512, 1, 1]               0
            Conv2d-60            [-1, 512, 1, 1]       2,359,296
       BatchNorm2d-61            [-1, 512, 1, 1]           1,024
              ReLU-62            [-1, 512, 1, 1]               0
            Conv2d-63            [-1, 512, 1, 1]       2,359,296
       BatchNorm2d-64            [-1, 512, 1, 1]           1,024
              ReLU-65            [-1, 512, 1, 1]               0
        BasicBlock-66            [-1, 512, 1, 1]               0
AdaptiveAvgPool2d-67            [-1, 512, 1, 1]               0
            Linear-68                 [-1, 1000]         513,000
================================================================
Total params: 11,689,512
Trainable params: 11,689,512
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.01
Forward/backward pass size (MB): 1.29
Params size (MB): 44.59
Estimated Total Size (MB): 45.90
----------------------------------------------------------------
```

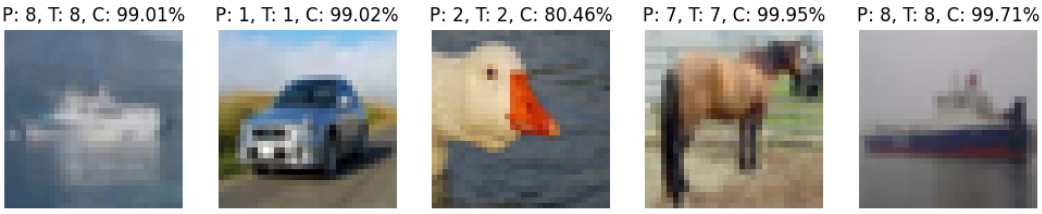
Training

The training script is defined in the 'models/cifar10/train.py' file. The following table describes the training parameters used.

Parameter	Value
Batch Size	128
Learning Rate	0.1
Weight Decay	5e-4
Momentum	0.9
Epochs	200
Optimizer	SGD
Loss Function	Cross Entropy

Evaluation

The model was evaluated using the 'models/cifar10/evaluate.py' script. A final accuracy of 74.66% was achieved on the test set. The following is a random sample of 5 images from the CIFAR-10 test dataset along with the model's prediction, true value, and confidence (these can be obtained by running the 'models/cifar10/evaluate.py' script).



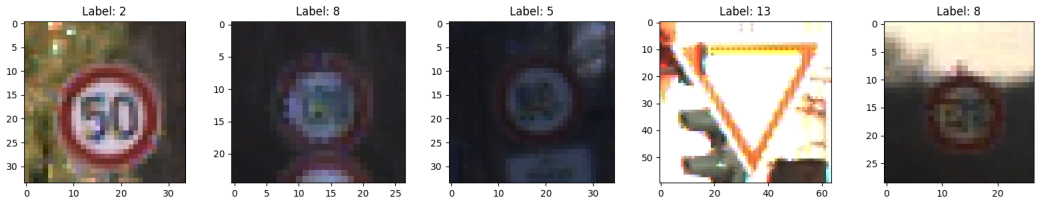
GTSRB

The relevant files for GTSRB can be found in the 'models/gtsrb/' and 'datasets/gtsrb/' directory.

Dataset

The German Traffic Sign Recognition Benchmark (GTSRB) is a multi-class, single-image classification challenge held at the International Joint Conference on Neural Networks (IJCNN) 2011. The dataset consists of 43 classes of traffic signs. The images are 30x30 RGB images. The dataset is available from the GTSRB section of the PyTorch documentation.

The following is a random sample of 5 images from the GTSRB dataset.



Model

The model used for GTSRB is a ResNet-18 model. The model is defined in the 'models/gtsrb/model.py' file. A summary of the model is shown below (this can be obtained by running the 'models/gtsrb/model.py' script).

```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1          [-1, 64, 16, 16]           9,408
       BatchNorm2d-2          [-1, 64, 16, 16]             128
              ReLU-3          [-1, 64, 16, 16]               0
         MaxPool2d-4            [-1, 64, 8, 8]               0
            Conv2d-5            [-1, 64, 8, 8]          36,864
       BatchNorm2d-6            [-1, 64, 8, 8]             128
              ReLU-7            [-1, 64, 8, 8]               0
            Conv2d-8            [-1, 64, 8, 8]          36,864
       BatchNorm2d-9            [-1, 64, 8, 8]             128
             ReLU-10            [-1, 64, 8, 8]               0
       BasicBlock-11            [-1, 64, 8, 8]               0
           Conv2d-12            [-1, 64, 8, 8]          36,864
      BatchNorm2d-13            [-1, 64, 8, 8]             128
             ReLU-14            [-1, 64, 8, 8]               0
           Conv2d-15            [-1, 64, 8, 8]          36,864
      BatchNorm2d-16            [-1, 64, 8, 8]             128
             ReLU-17            [-1, 64, 8, 8]               0
       BasicBlock-18            [-1, 64, 8, 8]               0
           Conv2d-19           [-1, 128, 4, 4]          73,728
      BatchNorm2d-20           [-1, 128, 4, 4]             256
             ReLU-21           [-1, 128, 4, 4]               0
           Conv2d-22           [-1, 128, 4, 4]         147,456
      BatchNorm2d-23           [-1, 128, 4, 4]             256
           Conv2d-24           [-1, 128, 4, 4]           8,192
      BatchNorm2d-25           [-1, 128, 4, 4]             256
             ReLU-26           [-1, 128, 4, 4]               0
       BasicBlock-27           [-1, 128, 4, 4]               0
           Conv2d-28           [-1, 128, 4, 4]         147,456
      BatchNorm2d-29           [-1, 128, 4, 4]             256
             ReLU-30           [-1, 128, 4, 4]               0
           Conv2d-31           [-1, 128, 4, 4]         147,456
      BatchNorm2d-32           [-1, 128, 4, 4]             256
             ReLU-33           [-1, 128, 4, 4]               0
       BasicBlock-34           [-1, 128, 4, 4]               0
           Conv2d-35           [-1, 256, 2, 2]         294,912
      BatchNorm2d-36           [-1, 256, 2, 2]             512
             ReLU-37           [-1, 256, 2, 2]               0
           Conv2d-38           [-1, 256, 2, 2]         589,824
      BatchNorm2d-39           [-1, 256, 2, 2]             512
           Conv2d-40           [-1, 256, 2, 2]          32,768
      BatchNorm2d-41           [-1, 256, 2, 2]             512
```

```
              ReLU-42            [-1, 256, 2, 2]               0
        BasicBlock-43            [-1, 256, 2, 2]               0
            Conv2d-44            [-1, 256, 2, 2]         589,824
       BatchNorm2d-45            [-1, 256, 2, 2]             512
              ReLU-46            [-1, 256, 2, 2]               0
            Conv2d-47            [-1, 256, 2, 2]         589,824
       BatchNorm2d-48            [-1, 256, 2, 2]             512
              ReLU-49            [-1, 256, 2, 2]               0
        BasicBlock-50            [-1, 256, 2, 2]               0
            Conv2d-51            [-1, 512, 1, 1]       1,179,648
       BatchNorm2d-52            [-1, 512, 1, 1]           1,024
              ReLU-53            [-1, 512, 1, 1]               0
            Conv2d-54            [-1, 512, 1, 1]       2,359,296
       BatchNorm2d-55            [-1, 512, 1, 1]           1,024
            Conv2d-56            [-1, 512, 1, 1]         131,072
       BatchNorm2d-57            [-1, 512, 1, 1]           1,024
              ReLU-58            [-1, 512, 1, 1]               0
        BasicBlock-59            [-1, 512, 1, 1]               0
            Conv2d-60            [-1, 512, 1, 1]       2,359,296
       BatchNorm2d-61            [-1, 512, 1, 1]           1,024
              ReLU-62            [-1, 512, 1, 1]               0
            Conv2d-63            [-1, 512, 1, 1]       2,359,296
       BatchNorm2d-64            [-1, 512, 1, 1]           1,024
              ReLU-65            [-1, 512, 1, 1]               0
        BasicBlock-66            [-1, 512, 1, 1]               0
AdaptiveAvgPool2d-67            [-1, 512, 1, 1]               0
            Linear-68                 [-1, 1000]         513,000
================================================================
Total params: 11,689,512
Trainable params: 11,689,512
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.01
Forward/backward pass size (MB): 1.29
Params size (MB): 44.59
Estimated Total Size (MB): 45.90
----------------------------------------------------------------
```

Training

The training script is defined in the 'models/gtsrb/train.py' file. The training script uses the 'models/gtsrb/model.py' file to define the model. The training script uses the 'models/gtsrb/dataset.py' file to define the dataset. The following table describes the training parameters used.

Parameter	**Value**
Batch Size	256
Learning Rate	0.0001

Parameter	Value
Scheduler	ReduceLROnPlateau
Scheduler Parameters	patience=5, factor=0.1, mode='min'
Epochs	18
Optimizer	Adam
Loss Function	Cross Entropy

Evaluation

The evaluation script is defined in the 'models/gtsrb/evaluate.py' file. A final accuracy of 73.11% was achieved on the test set. The following is a random sample of 5 images from the GTSRB test dataset along with the model's prediction, true value, and confidence (these can be obtained by running the 'models/gtsrb/evaluate.py' script).