Deploying a Caffe Model on OpenMV using CMSIS-NN

Version 1.0

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Release Information

Document History

Version	Date	Confidentiality	Change
1.0	15 October 2018	Non-Confidential	First release

Non-Confidential Proprietary Notice

Confidentiality Status

Product Status

The information in this document is Final, that is for a developed product.

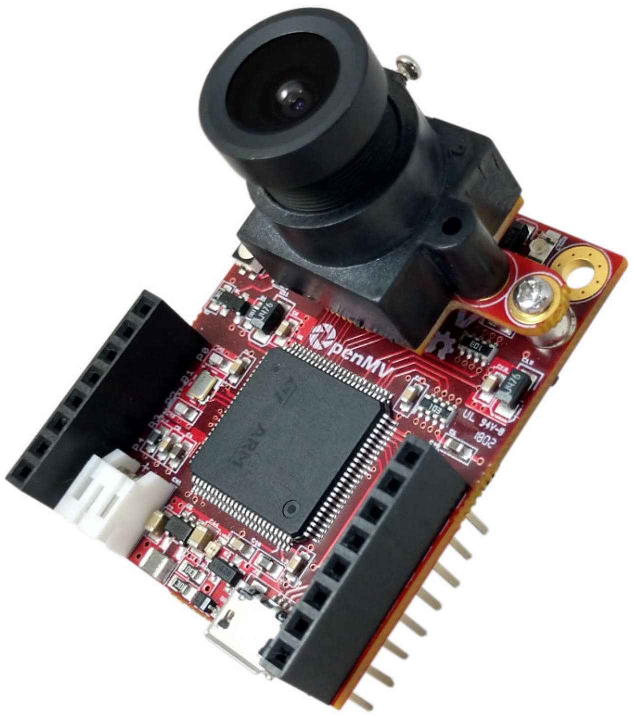
Web Address

http://www.arm.com

Contents

1 Overview

This guide will walk you through the deployment of a Caffe model to an ultra-low-cost and low-power Arm Cortex-M based processor. For this guide we will be using the OpenMV board, developed by two Arm Innovators, Ibrahim Abdalkader and Kwabena W. Agyeman.



In this guide, you will work through the following steps:

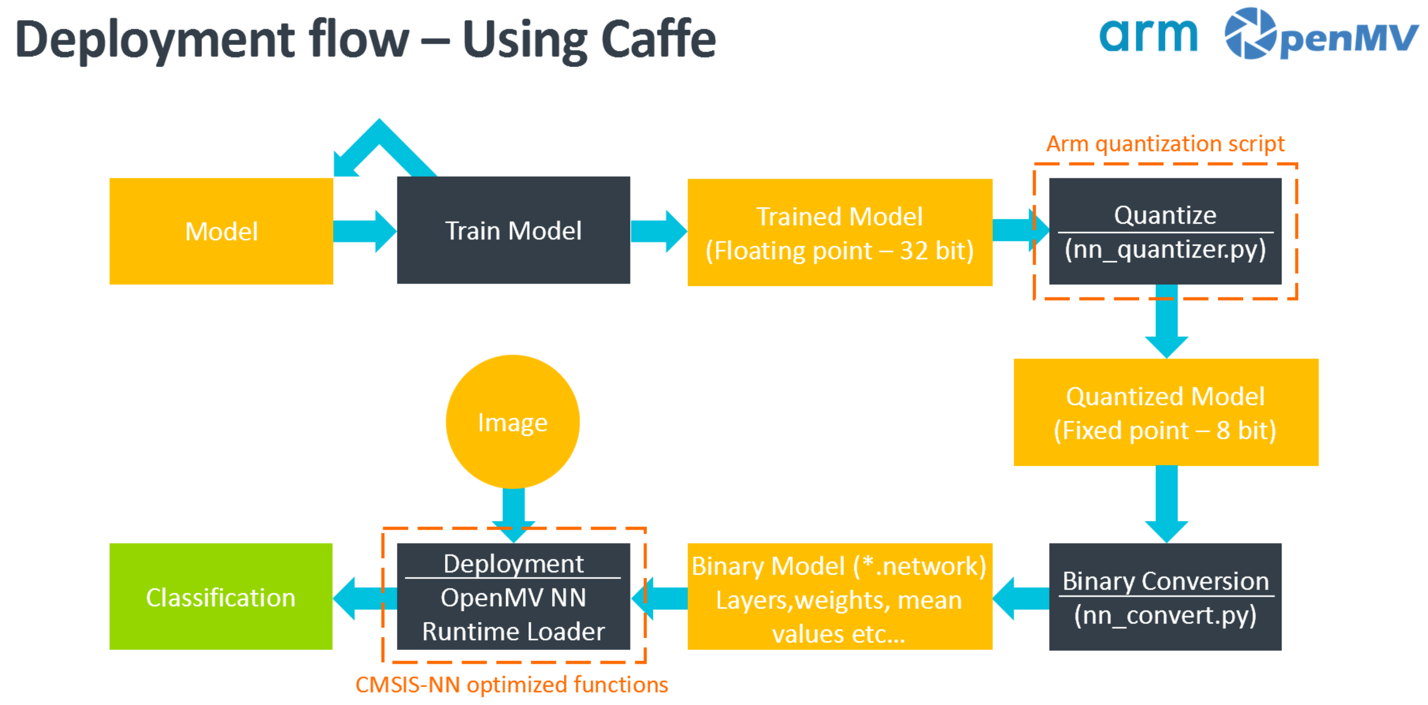
1. Set up Environment
2. Training the Neural Network Model
    - Define the model.
    - Prepare the dataset.
    - Train the model in Caffe.

Note: Training the Neural Network Model is provided for completeness, and is not required to be performed for this guide.

3. Deploy the Model on Arm Cortex-M
    - Quantize the model.
    - Convert model to binary.
    - Deploy on OpenMV.
    - Run smile detection.

At the end of this guide, you will be able to deploy an Arm NN model aimed at recognizing smiling faces on an Arm Cortex-M7 processor.

The following image summarizes the deployment flow that you will go through: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2 Set up Environment

Linux machine setup

Set up your Linux environment by installing a virtual machine as described below. For completeness, we illustrate all the steps to follow to set up your own environment.

With Virtual Machine

Note: Installation with Virtual Machine is the recommended option. Installation with Linux will take longer.

1. Install Virtual Box.
    - Install Virtual Box from the USB provided or from this link.
2. Download Image.
    - Download the Virtual Box image using the USB provided or from this link.
3. Import image. Follow this guide.
4. Log into machine.

    Username: Embedded
    Password: embedded

or

Linux

If required, follow the steps here.

OpenMV setup

In the VirtualBox, start the OpenMV IDE from the terminal:

```
./openmvide/bin/openmvide.sh &
```

Note: If not preinstalled, do the following

Install the OpenmMV IDE on the guest OS (the Linux virtual machine). View the full guide here.

Connect board:

1. Connect OpenMV to laptop with USB.
2. To setup the USB connection to the OpenMV board on the virtual machine follow this USB VM Setup Guide.
3. Update firmware if necessary.

Test:

1. Click on the connection icon on the bottom left of the IDE or CTRL+E.
2. Start the program by selecting the play icon on the bottom left of the IDE or CTRL+R.
3. The program should run and display images on the top right without any errors.

Now that the setup is done, we will deploy the chosen model on the Arm Cortex-M7 OpenMV board.

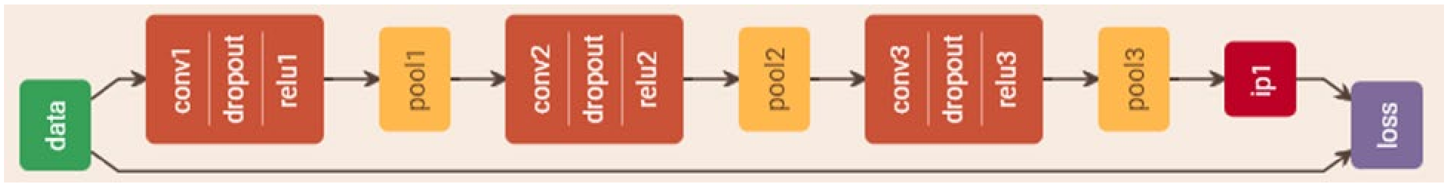
Read the following document for a full OpenMV guide.

3 Define the model

Note: You are not asked to do anything in this section. It is only here for completeness.

There are different ways to implement image classification, but recent work in artificial intelligence has shown that a certain type of neural network, called a Convolutional Neural Network (CNN), is particularly good at classifying images. For an introduction to CNNs read this article.

To recognize smiling faces, we will use the Smile model as defined by OpenMV. The network is a three-layer CNN as shown in the figure below:



The network is composed of the following layers:

- Convolution layer - responsible for extracting features from the image.
- Dropout layer - responsible for avoiding overfitting by ignoring random nodes during the training phase. For more information read this dropout article.

- Rectified Linear Unit (ReLU) - the activation function responsible for introducing non-linearity in the model. The function returns 0 if it receives any negative input, but for any positive value x it returns that value back. Read this ReLU article for a more thorough explanation.
- Pooling layer - responsible to progressively reduce the spatial size of the model reducing the number of parameters and the amount of computation in the network, and hence also controlling overfitting. Read more here.
- Inner product (Inp) or fully connected layer.

The above image has been generated using this online tool.

4 Prepare the dataset

The smile dataset that we will use can be found on GitHub.

We will use dataset in
`repos/SMILEsmileD/SMILEs/`:

- `negatives`
- `positives`

Check number of images in the two sets:

```
ls repos/SMILEsmileD/SMILEs/negatives/negatives7/. -1 | wc -l
ls repos/SMILEsmileD/SMILEs/positives/positives7/. -1 | wc -l
```

The dataset consists of ~3000 positive images and ~9000 negative images. To avoid generating a biased model, we would like to have the same number of positive and negative images.

To fix this, we can augment the dataset by using this augmentation script on the positive images. Using this script will increase the number of positive examples by 3x:

Create folder, if it is not already present:

```
mkdir repos/SMILEsmileD/SMILEs/positives/positives_aug/
```

Augment data set:

```
python2 repos/openmv/tools/augment_images.py --input repos/SMILEsmileD/SMILEs/positives/positives7/
--output repos/SMILEsmileD/SMILEs/positives/positives_aug/ --count 3
```

5 Train the model

Note: Due to time constraints, we won't train the neural network in this guide.. This material is only here for completeness.

Currently, support for translating a Caffe model to CMSIS-NN functions is provided. Support for other frameworks (TensorFlow, PyTorch, etc.) will come in the future.

For this guide, the model has been pretrained and can be found here. For a full guide on how to train a model with Caffe, see this tutorial.

The trained model also needs to be converted into an lmdb database. The converted files should be in

```
repos/openmv/ml/cmsisnn/models/smile/smile_database/
```

6 Quantize the model

Once we have a train mode we need to shrink it to a reasonable size. To do this we use the quantization script from Arm to convert the Caffe model weights and activations from 32-bit floating point to an 8-bit and fixed point format. This will not only reduce the size of the network, but also avoid floating point computations.

The NN quantizer script works by testing the network and figuring out the best format for the dynamic fixed-point representation. The output of this script is a serialized Python (.pkl) file which includes the network's model, quantized weights and activations, and the quantization format of each layer. Running the following command generates the quantized model:

```
python2 repos/ML-examples/cmsisnn-cifar10/nn_quantizer.py --model
repos/openmv/ml/cmsisnn/models/smile/smile_train_test.prototxt --weights
repos/openmv/ml/cmsisnn/models/smile/smile_iter_*.caffemodel --save
repos/openmv/ml/cmsisnn/models/smile/smile.pkl
```

If you want to learn more about quantization read this blog.

7 Convert model to binary

The final step is to use the OpenMV NN converter script to convert the model into a binary format, runnable by the OpenMV Cam. The converter script outputs a code for each layer type, followed by the layer's dimensions and weights (if any).

On the OpenMV Cam, the firmware reads the binary file and builds the network in memory using a linked list data structure.

Running this command generates the binary model:

```
python2 repos/openmv/ml/cmsisnn/nn_convert.py --model
repos/openmv/ml/cmsisnn/models/smile/smile.pkl --mean
/home/embedded/repos/openmv/ml/cmsisnn/models/smile/smile_database/mean.binaryproto --output
repos/openmv/ml/cmsisnn/models/smile/smile.network
```

8 Deploy the model on the OpenMV

Download the smile.network directly to the Arm Cortex-M7, on the OpenMV board. To do this use the USB connection.

Note: If the device is not visible on the virtual machine, follow this USB VM Setup Guide.

In this step, you will make use of CMSIS-NN, an open source collection of efficient neural network kernels developed to maximize the performance and minimize the memory footprint of neural networks on Arm Cortex-M processor cores. Neural network inference based on CMSIS-NN kernels achieves 4.6X improvement in runtime/throughput and 4.9X improvement in energy efficiency.

9 Run smile detection

Run the following program on the smile detection Python example on the OpenMV IDE.

```
Select Files -> Examples -> 25-Machine-Learning -> nn_haar_smile_detection.py
```

The program enables to identify a person smiling by braking the problem down in two distinct phases:

1. Identify a face in an image using a Haar Cascade classifier.
2. Identify whether the identified face is smiling or not.
3. Display a yellow happy or sad face on the image on the top right.

Optional task: modify the python example

1. Play around with the size of the rectangle used to limit the smile detection area.
2. Add terminal output when a smile is detected.

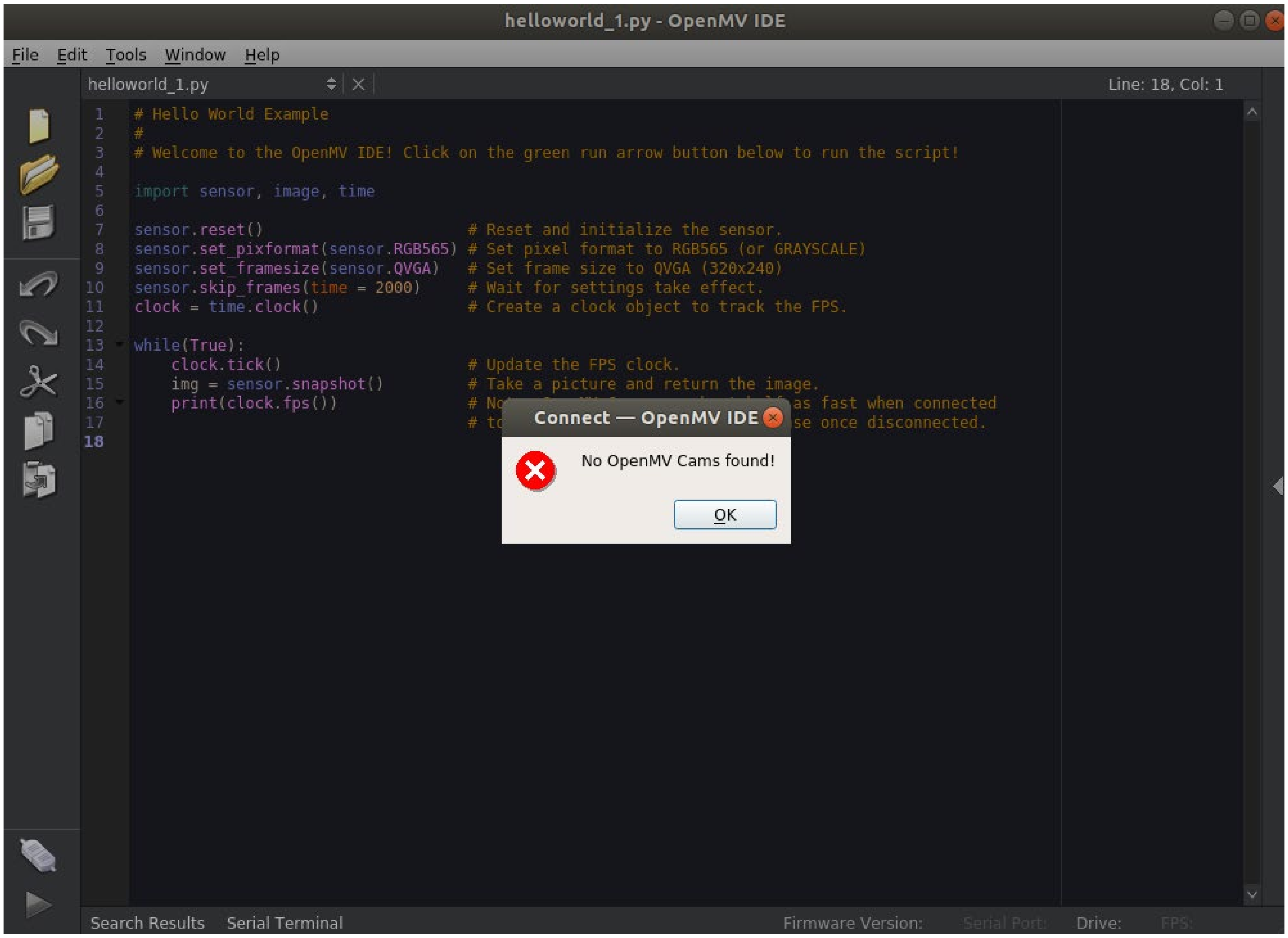
Optional: final deployable model
Note: This step is not required if the previous steps have been executed successfully.

The final pre-trained and pre-converted models can be found on GitHub here.

10 Troubleshooting

If you get the following errors:

No OpenMV Cams found


helloworld_1.py - OpenMV IDE
File Edit Tools Window Help
helloworld_1.py
Line: 18, Col: 1
Search Results Serial Terminal
Firmware Version: Serial Port: Drive: FPS:

```
# Hello World Example
#
# Welcome to the OpenMV IDE! Click on the green run arrow button below to run the script!

import sensor, image, time

sensor.reset()                      # Reset and initialize the sensor.
sensor.set_pixformat(sensor.RGB565) # Set pixel format to RGB565 (or GRAYSCALE)
sensor.set_framesize(sensor.QVGA)   # Set frame size to QVGA (320x240)
sensor.skip_frames(time = 2000)     # Wait for settings take effect.
clock = time.clock()                # Create a clock object to track the FPS.

while(True):
    clock.tick()                    # Update the FPS clock.
    img = sensor.snapshot()         # Take a picture and return the image.
    print(clock.fps())              # No                          as fast when connected
                                    # to                          se once disconnected.
```

Connect — OpenMV IDE

No OpenMV Cams found!

OK

This means that the OpenMV is either not connected to the computer or not recognized by the OS:

1. Check that the OpenMV board is connected to the computer via USB.
2. If running on Linux please follow this USB VM Setup Guide.

No module named caffe

```
ImportError: No module named caffe
```

Check if it has been appended in pythonpath properly by typing

```
python >>> import sys >>> sys.path ['', '/home/embedded/caffe/python', '/usr/lib/python2.7',
'/usr/lib/python2.7/plat-x86_64-linux-gnu', '/usr/lib/python2.7/lib-tk', '/usr/lib/python2.7/lib-
old', '/usr/lib/python2.7/lib-dynload', '/home/embedded/.local/lib/python2.7/site-packages',
'/usr/local/lib/python2.7/dist-packages', '/usr/lib/python2.7/dist-packages']
```

if `/home/embedded/caffe/python` is not there

```
>>> exit() export PYTHONPATH=~/caffe/python
```

Check failed: mdb_status == 0 (2 vs. 0) No such file or directory

```
Check failed: mdb_status == 0 (2 vs. 0) No such file or directory
```

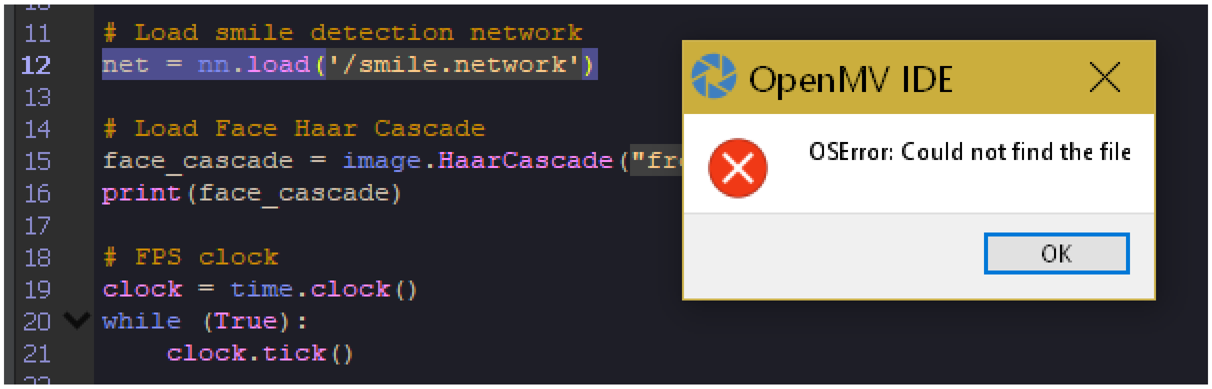
Open the file:

```
repos/openmv/ml/cmsisnn/models/smile/smile_train_test.prototxt
```

and check that the `mean_file` and source are pointing to the files in

```
repos/openmv/ml/cmsisnn/models/smile/smile_database/
```

OSError: Could not find the file



```
# Load smile detection network
net = nn.load('/smile.network')

# Load Face Haar Cascade
face_cascade = image.HaarCascade("fr
print(face_cascade)

# FPS clock
clock = time.clock()
while (True):
    clock.tick()
```

OSError: Could not find the file

Make sure to upload the file to the Arm Cortex-M7 on the OpenMV board.

11 Resources

- Read how Arm is changing machine learning experiences: Project Trillium.
- Why is ML moving to the edge.
- Learn how to train and deploy more models on the OpenMV.
- See CMSIS-NN on Github.
- Explore the OpenMV Tutorial: Low Power Deep Learning on the OpenMV Cam.
- Learn more about the Arm Innovator Program.