Training Neural Networks on Embedded Devices

Targeting Embedded Environments

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Master's Thesis

Uppsala University

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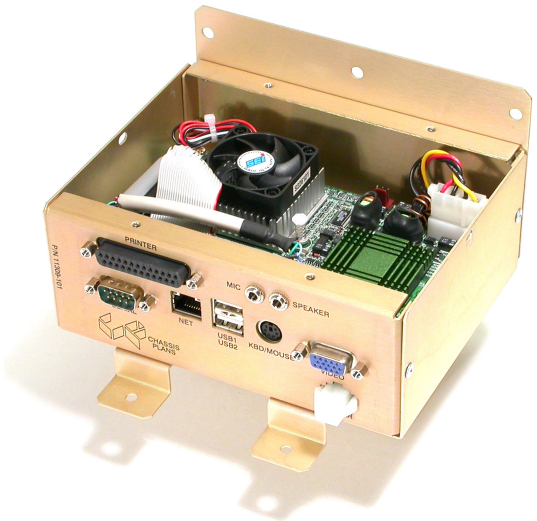
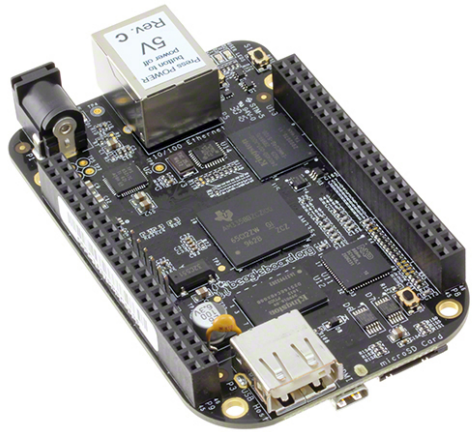
Outline

Neural Network Applications on Embedded Devices

Embedded Devices





Goal : Neural Network training on Scania C300

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Predictive vehicle maintenance using data from a fleet of connected trucks

Why Training on the C300?

- Repurpose existing C300 units to perform neural network related tasks
- Training on devices to reduce network bandwidth usage, ensure data privacy, etc.

Scope *Repurpose Scania C300, train neural network model, assess training performance*

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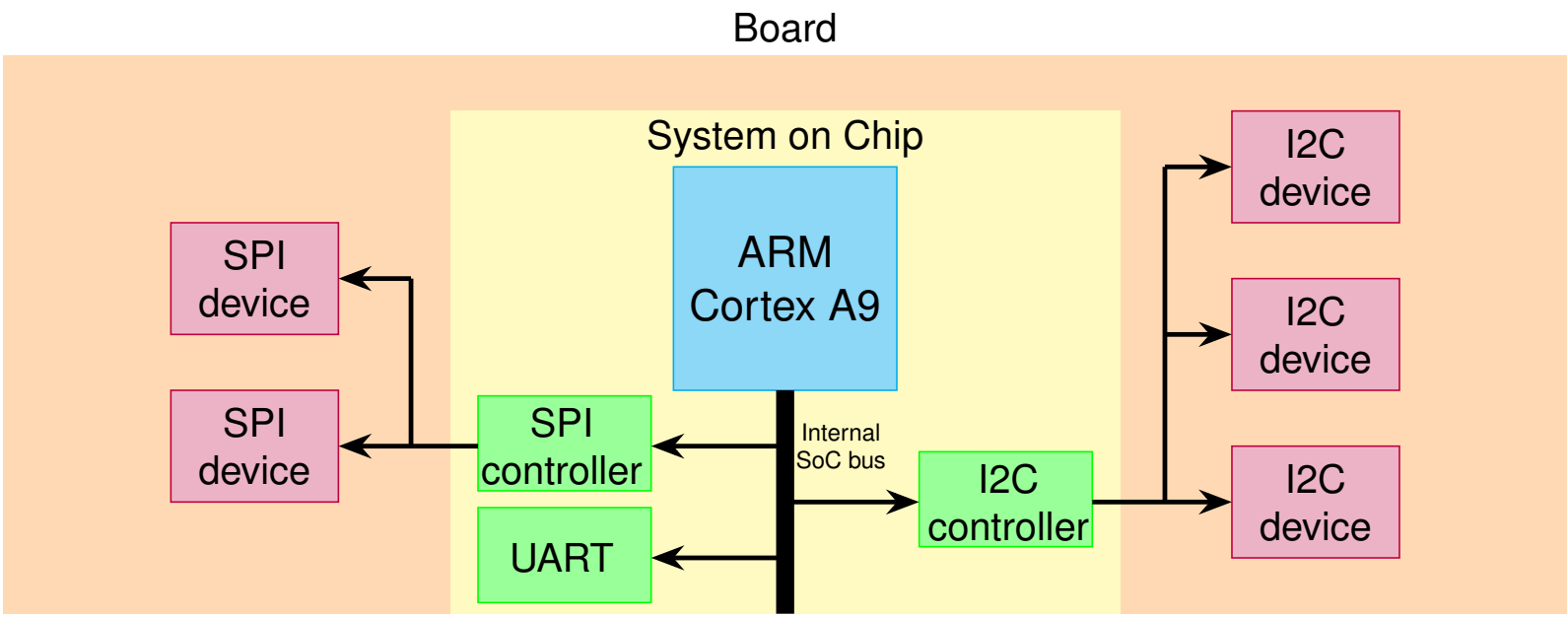
ARM Boards

SoC	Application Domain	Architecture	Processor Core
nRF51822	Ultra low power, BLE	ARM v6-M	ARM Cortex M0
AM2732	Automotive	ARM v7-R	ARM Cortex R5
AM3358	Industrial / IoT	ARM v7-A	ARM Cortex A8
i.MX6S	Multimedia applications	ARM v7-A	ARM Cortex A9
Kryo 240	Smartphones	ARM v8-A	ARM Cortex-A73, A53

ARM Boards

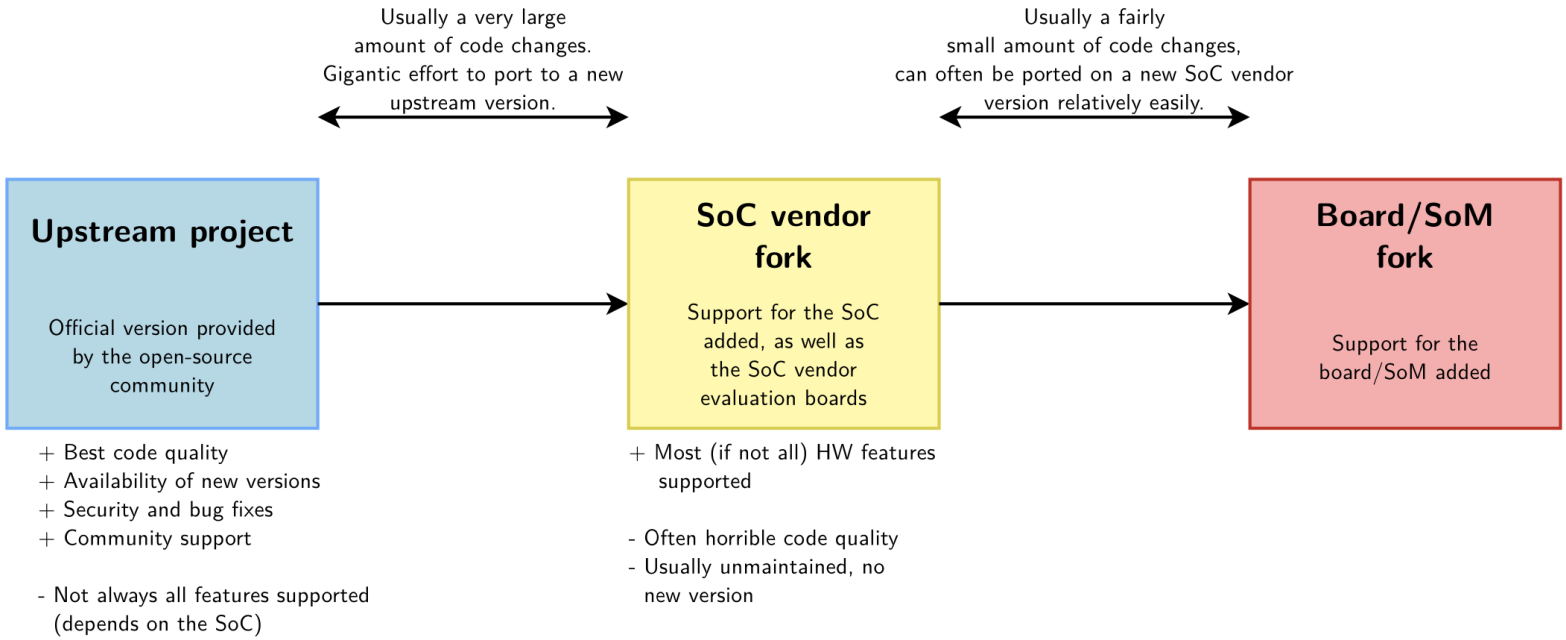

Board
System on Chip
ARM Cortex A9
SPI device
SPI device
SPI controller
UART
Internal SoC bus
I2C controller
I2C device
I2C device
I2C device

Embedded Linux

Operating System for Embedded Devices
- Customized for Specific Hardware

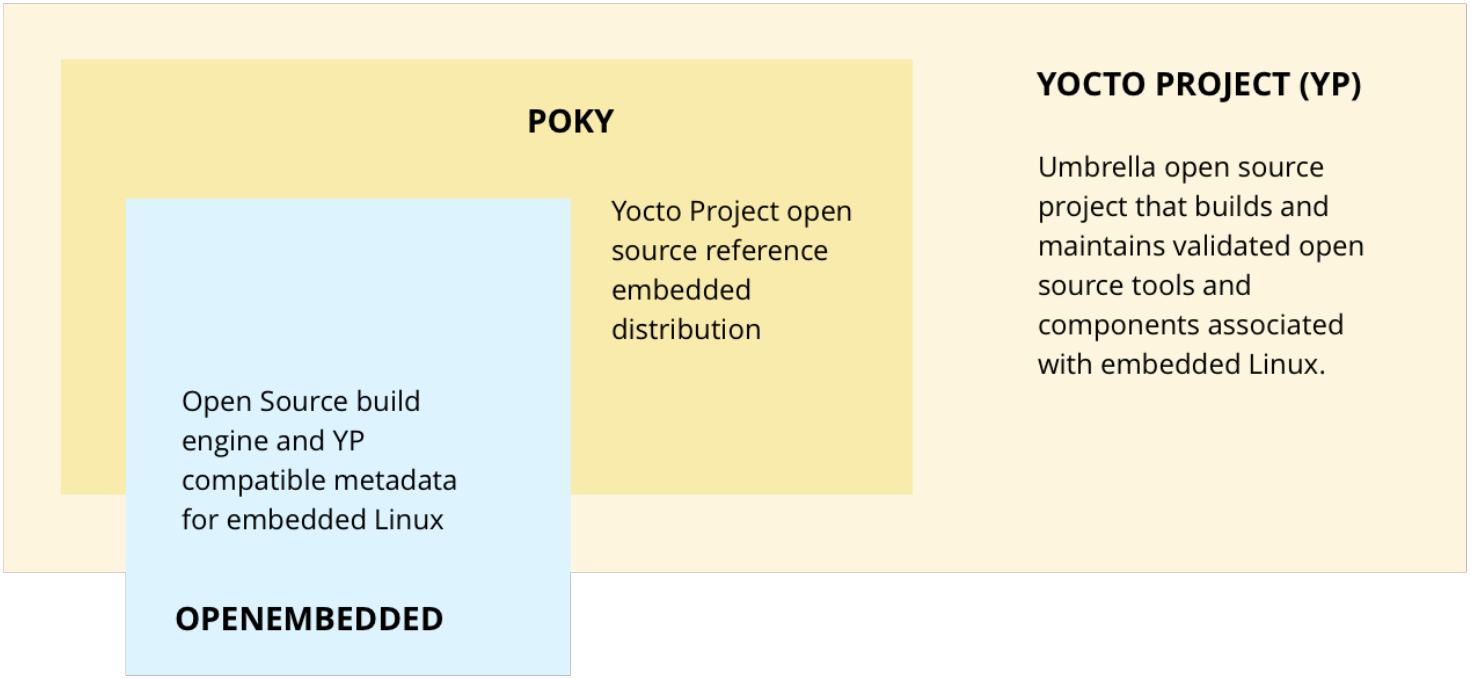
Kernel, Bootloaders, Device Trees
Cross Compilation, Toolchains, Root Filesystems

Software Versions

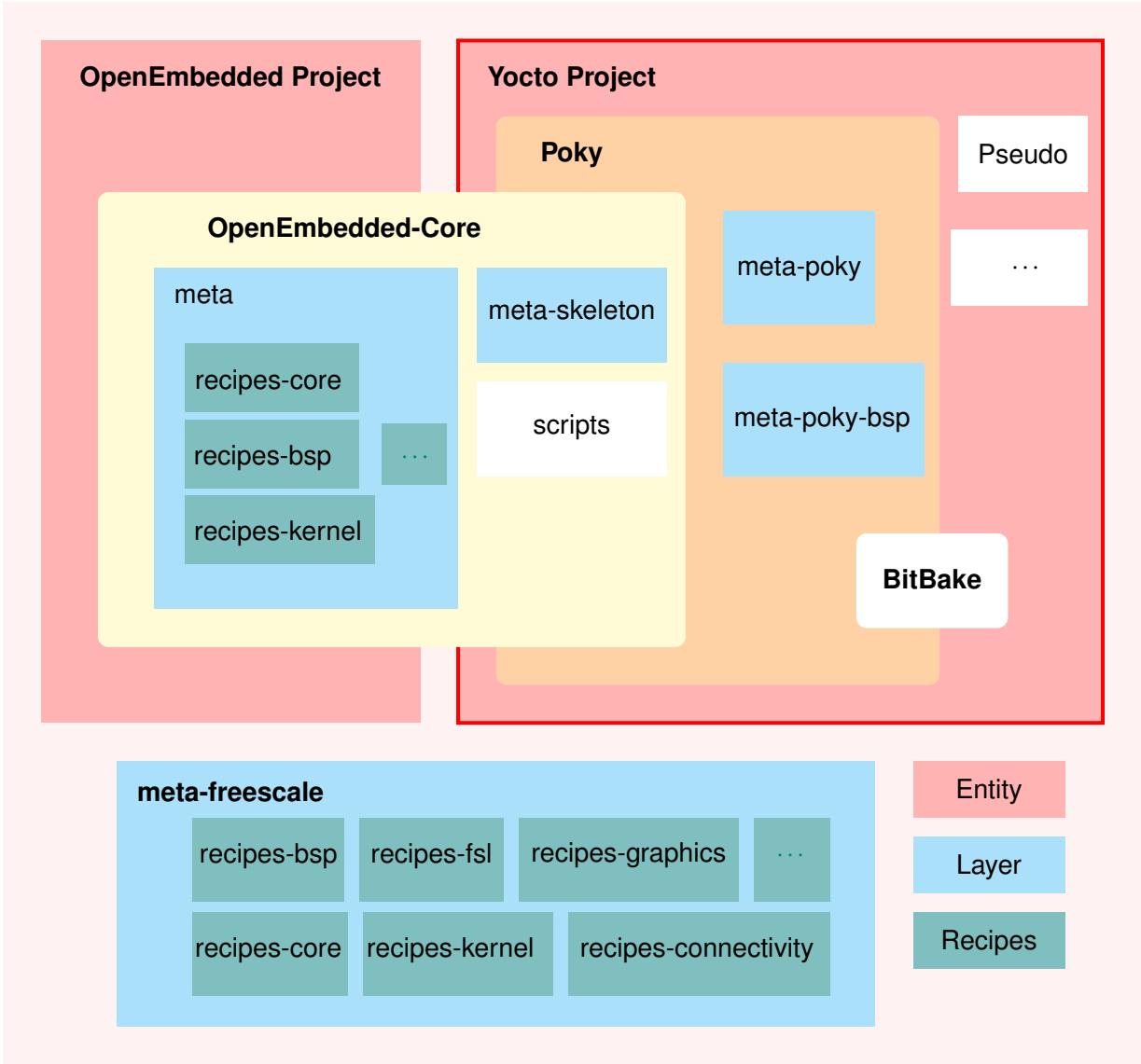


Build Systems

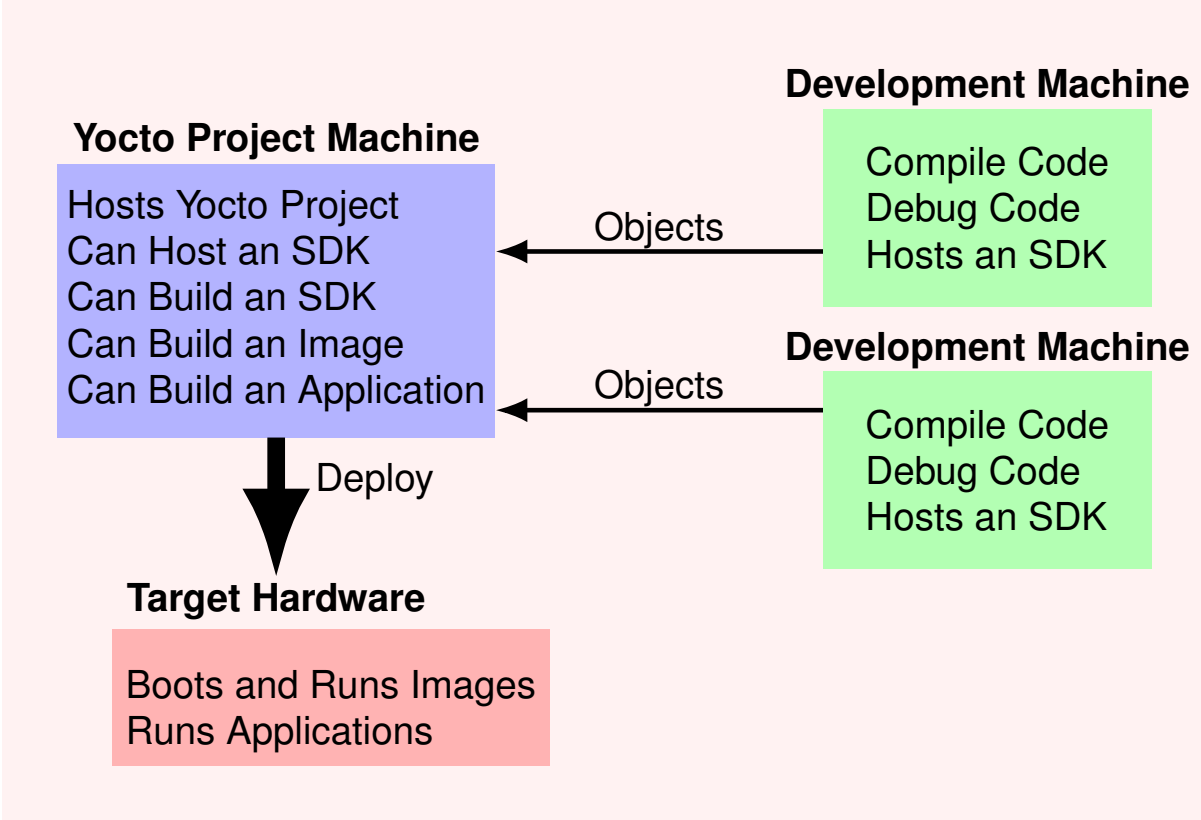
Yocto Project



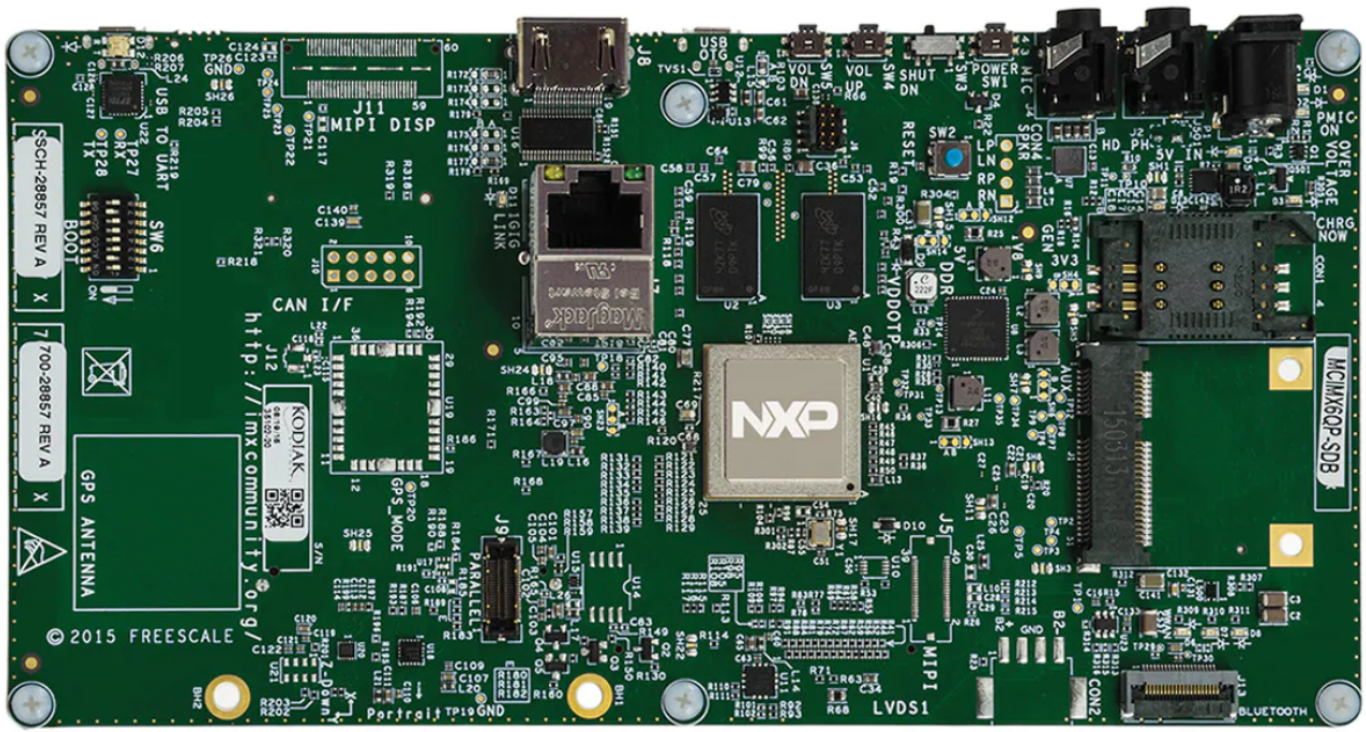
Yocto Project



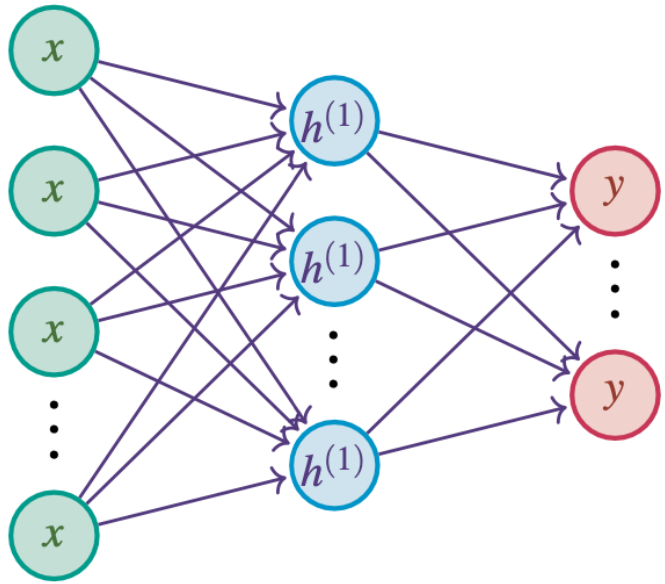
Yocto Project



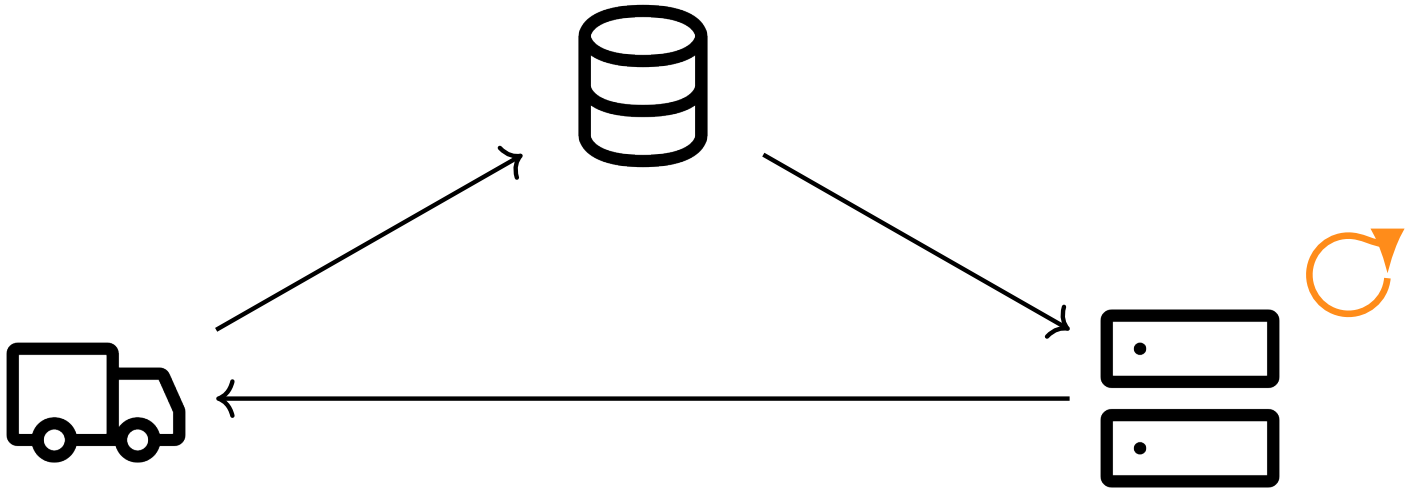
Scania C300 to MCIMX6Q-SDB



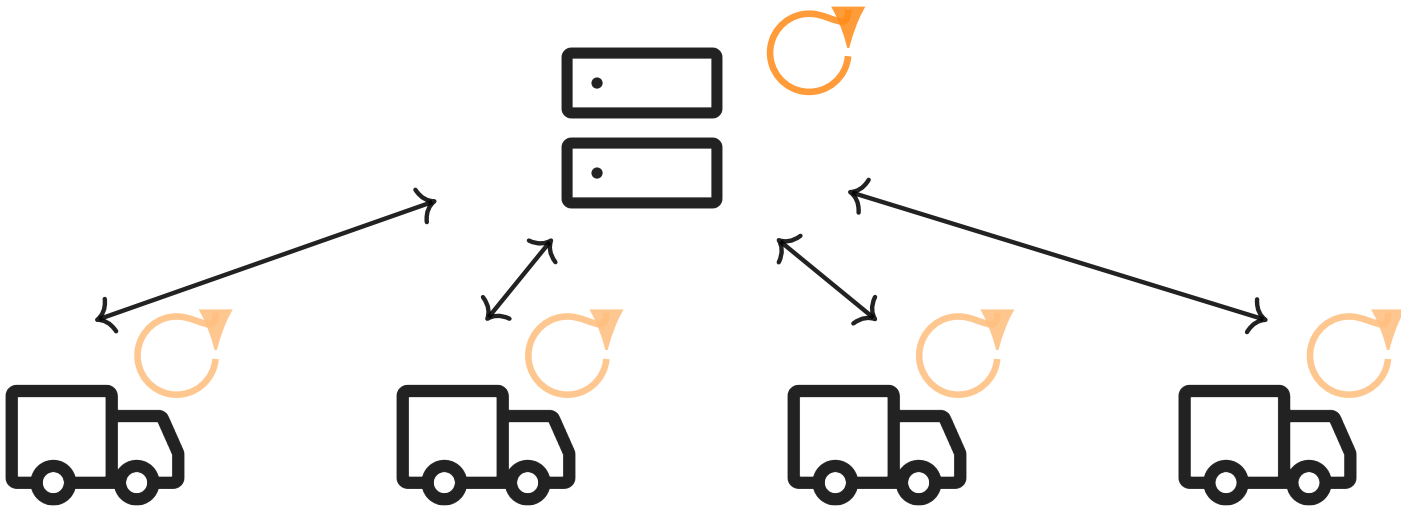
Training and Inference



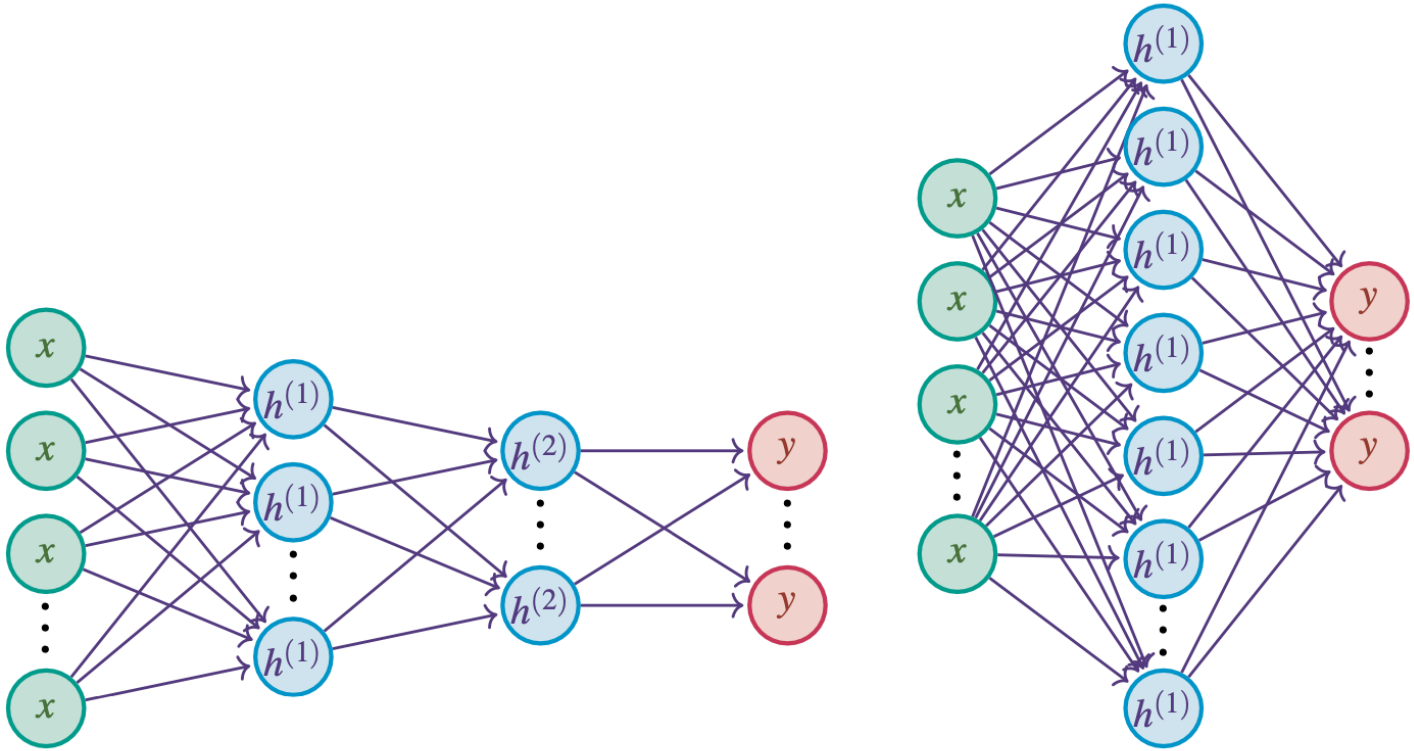
Traditional Paradigm



Federated Learning



Handwritten Digit Recognition Neural Network



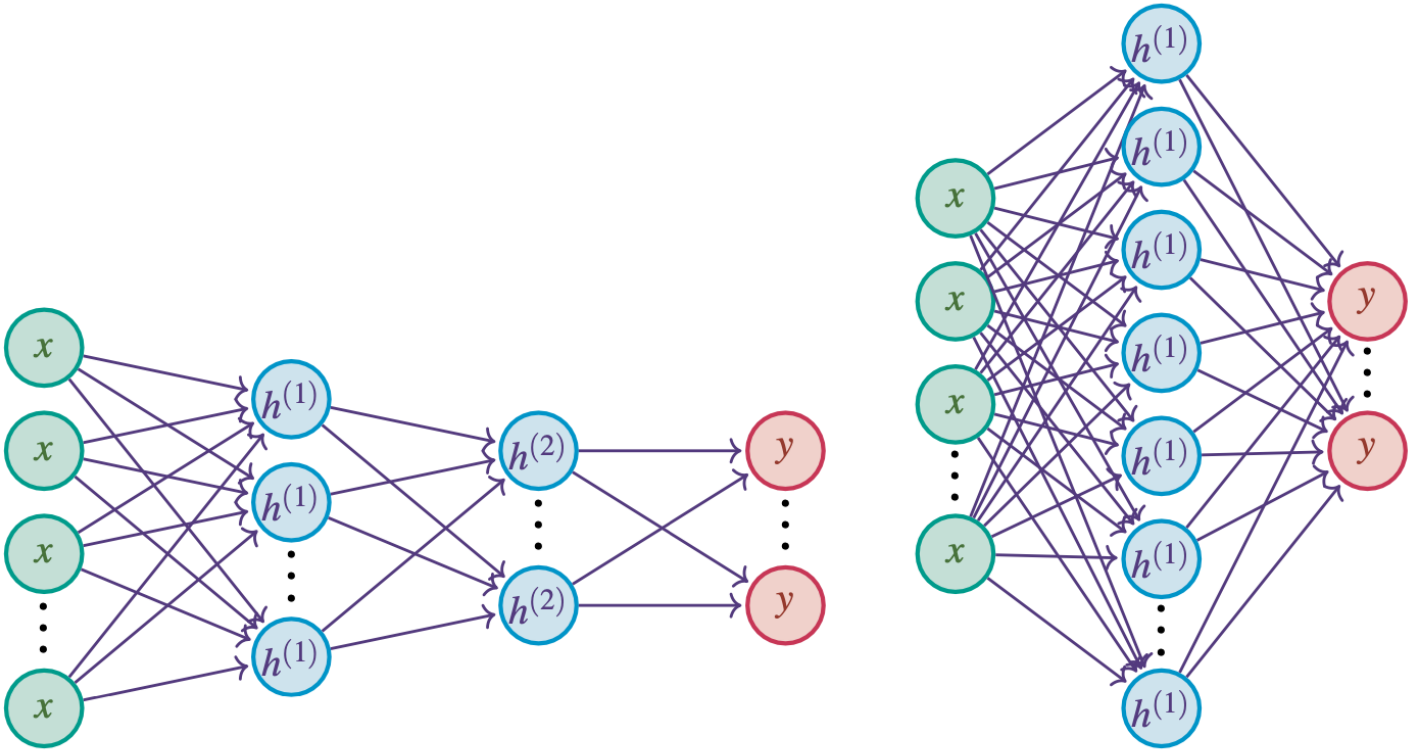
Learning Algorithm

Algorithm 1 Mini Batch Gradient Descent with learning rate η and the Mean Squared Error (MSE) cost function

Require: initial weights $w^{(0)}$, number of epochs E, batch size B, training data with T entries
Ensure: final weights $w^{(E*T)}$

```
for e = 0 → E − 1 do
    for b = 0 → T/B do
        for t = b ∗ B → (b + 1) ∗ B do
            estimate ∇ℒ(w^(t))                    ▷ ℒ here is MSE
            compute Δw^(b) += −∇ℒ(w^(t))
        end for
        w^(e+1) := w^(e) + η Δw^(e)
    end for
end for
return w^(T)
```

HDR-NN configurability



HDR-NN configurability

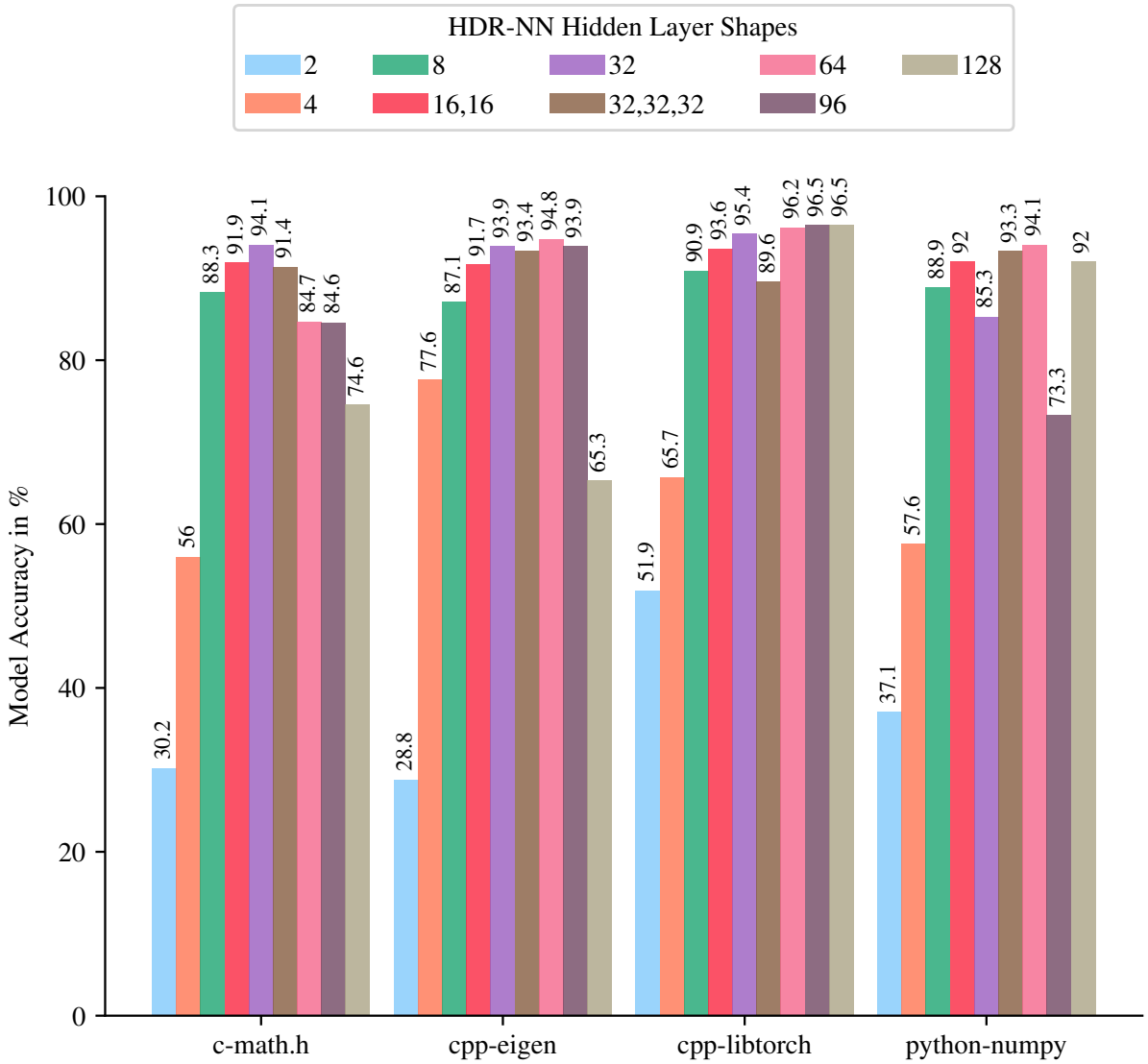
```
→ ./bin/hdrnn
nothing to do
Usage: ./bin/hdrnn

        <command> [<args>]

Commands:
        infer [-i, --image IMAGE_PATH] [-n, --net c-math.nn]
        train [-s, --shape 32] [-e, --epochs 30]
         [-q, --quiet] [-bs, --batch_size=10]
         [-lr, --learning_rate 3] [-n, --net c-math.nn]
```

C based HDR-NN

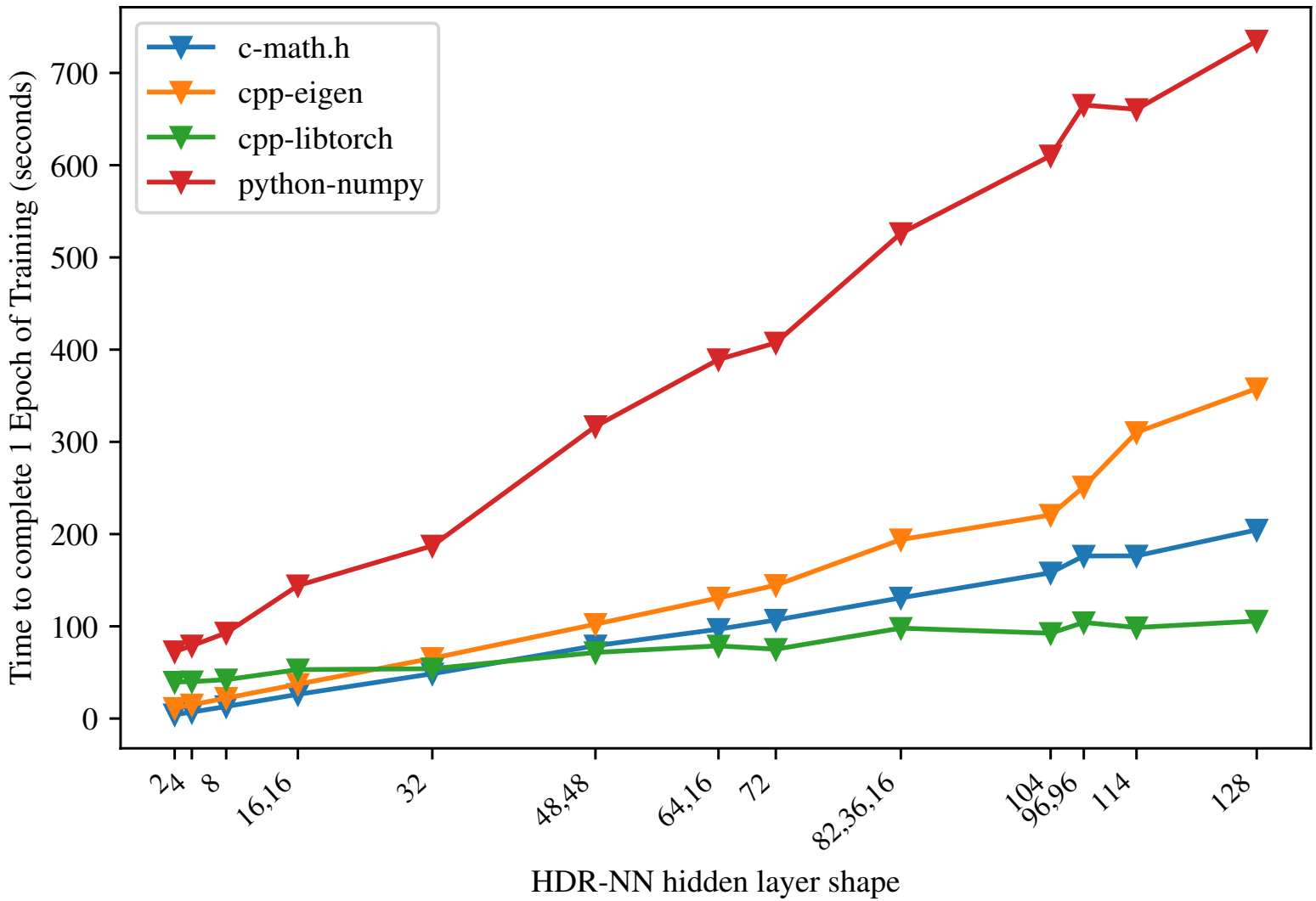
```c
/* HDR Neural Network */
typedef struct
{
    float bias;
    float *weights;
    float *nabla_w;
} Neuron;

typedef struct LayerT
{
    int size;
    int incidents;
    Neuron *neurons;
    float *activations;
    float *z_values;
    float *nabla_b;
    struct LayerT *next;
    struct LayerT *previous;
} Layer; // Network layers except for input

typedef struct
{
    Layer *layers;
    int depth;
} Network; // HDRNN
```

```c
static void feed_forward(Network *network, float *image)
{
    // First layer is the image
    float *activations = image;

    Layer *layer = network->layers;
    while (layer != NULL)
    {
        for (int i = 0; i < layer->size; i++)
        {
            Neuron *neuron = &layer->neurons[i];
            float zvalue = 0;
            for (int j = 0; j < layer->incidents; j++)
            {
                zvalue += neuron->weights[j] * activations[j];
            }
            layer->z_values[i] = zvalue + neuron->bias;
            layer->activations[i] = sigmoid(layer->z_values[i]);
        }
        activations = layer->activations;
        layer = layer->next;
    }
}
```

Accuracy


HDR-NN Hidden Layer Shapes
2
4
8
16,16
32
32,32,32
64
96
128
Model Accuracy in %
0
20
40
60
80
100
30.2
56
88.3
91.9
94.1
91.4
84.7
84.6
74.6
28.8
77.6
87.1
91.7
93.9
93.4
94.8
93.9
65.3
51.9
65.7
90.9
93.6
95.4
89.6
96.2
96.5
96.5
37.1
57.6
88.9
92
85.3
93.3
94.1
73.3
92
c-math.h
cpp-eigen
cpp-libtorch
python-numpy

Training Time



Development Experience

- Implementing back propagation in `C`
- Porting `libtorch` to `armv7hl`

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Future Work

Reverse Engineering Efforts on the C300

Development Experience