QONNX

EDGE ML SCHOOL
23.–27. SEPT. 2024
MARIUS KÖPPEL

ETH zürich

Why ONNX (Open Neural Network Exchange)?

Caffe2

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PyTorch

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TensorFlow

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Keras

Why ONNX (Open Neural Network Exchange)?

Caffe2

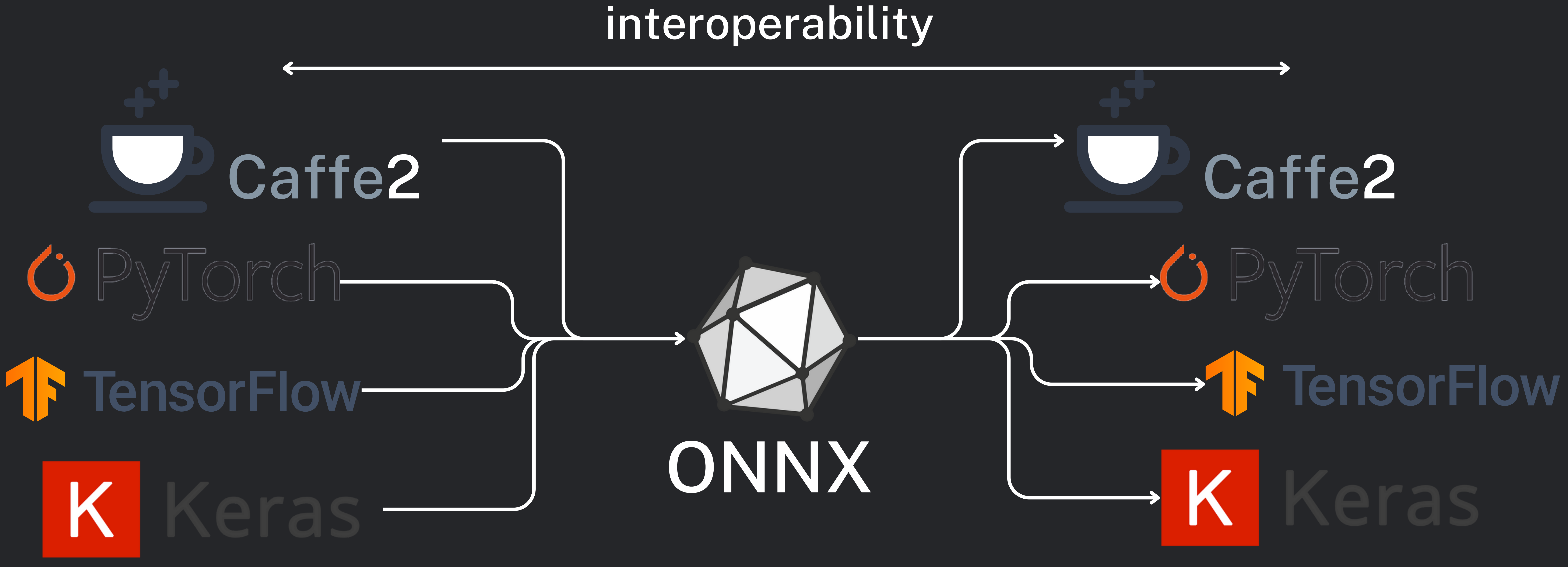
PyTorch

TensorFlow

Keras

And many many more

Why ONNX (Open Neural Network Exchange)?



export to onnx

load from onnx

Basic ONNX Graph

y = x @ a + c

```
def onnx_linear_regressor(x):
    y = onnx.Add(onnx.MatMul(x, a), c)
    return y
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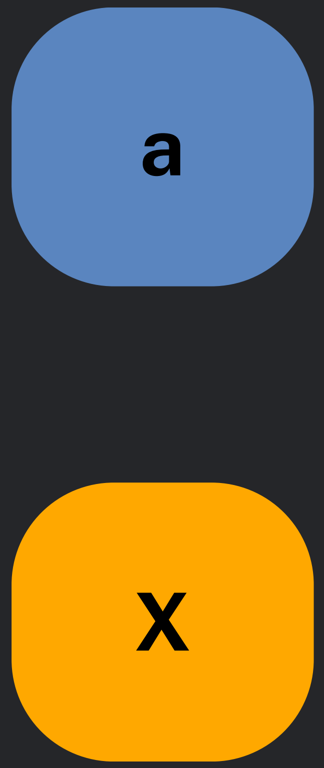

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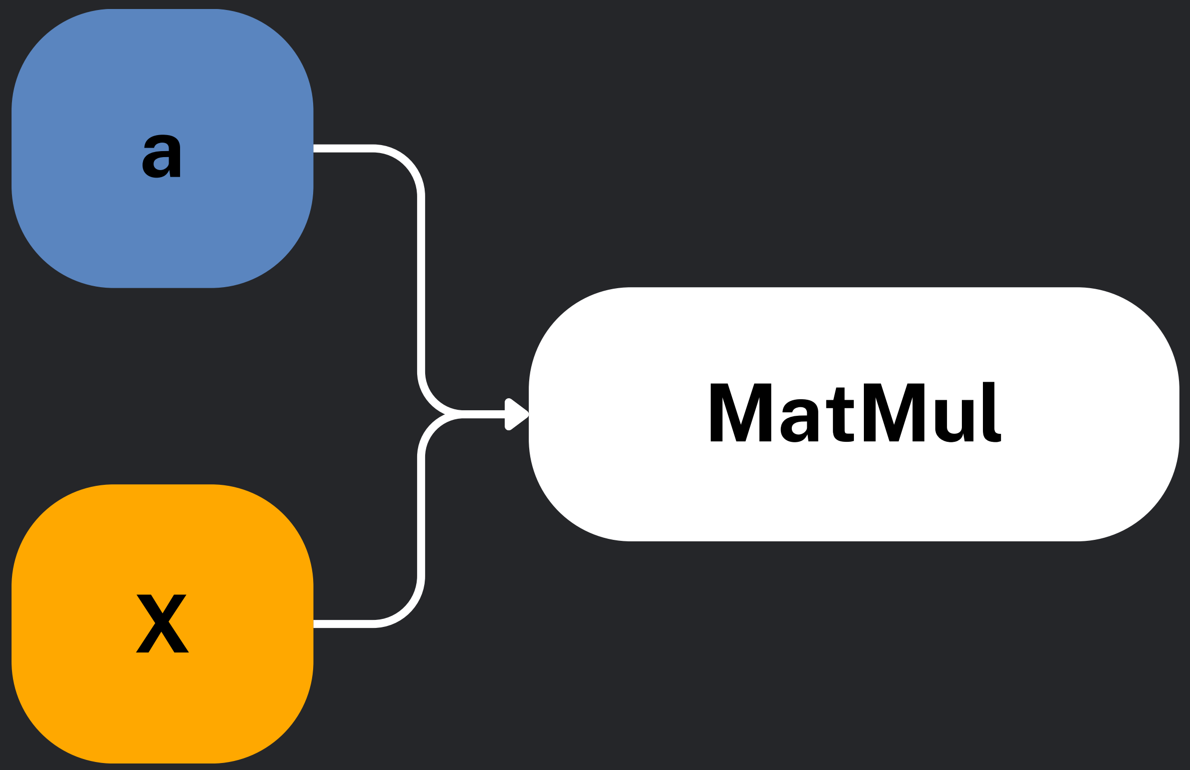

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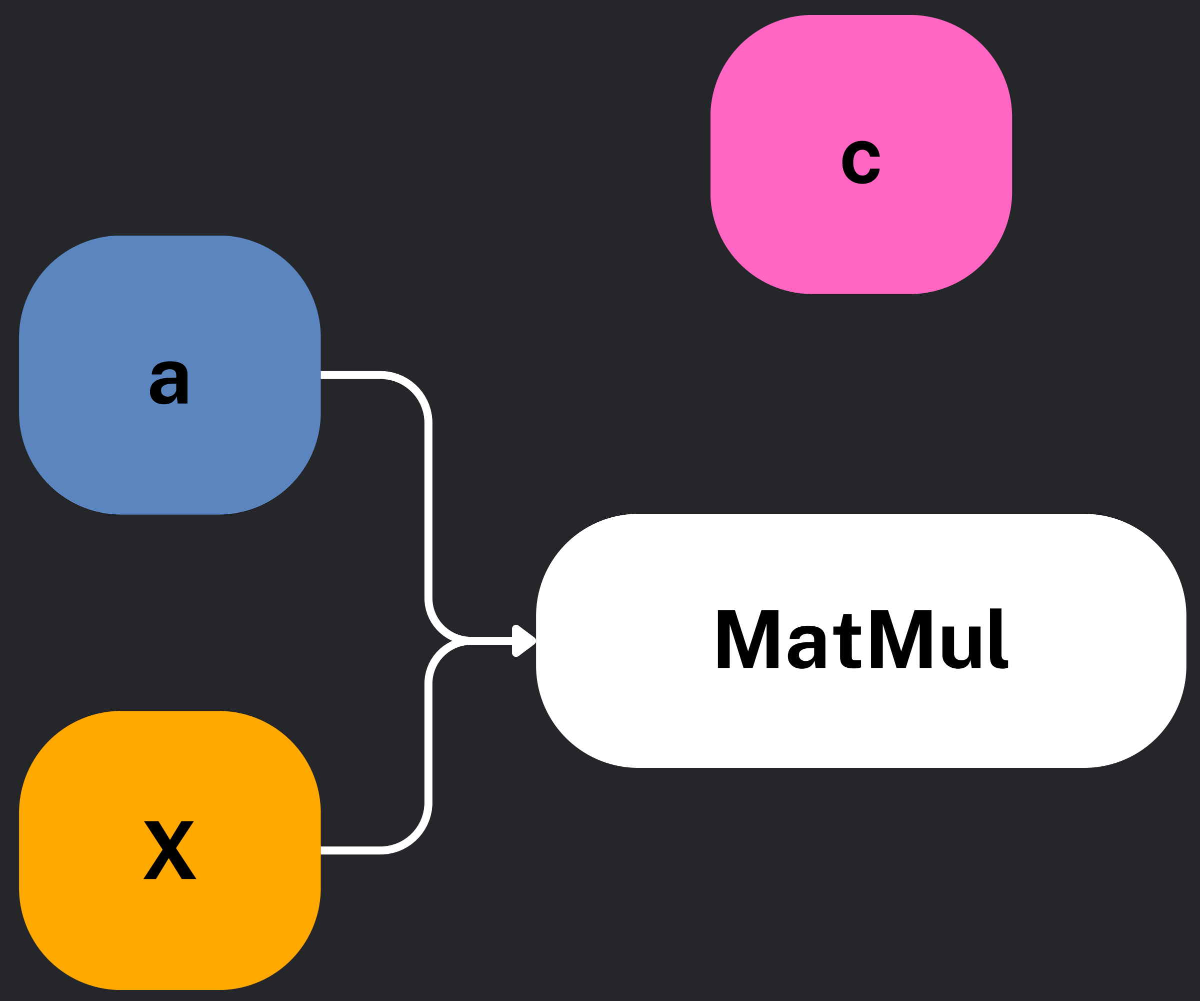

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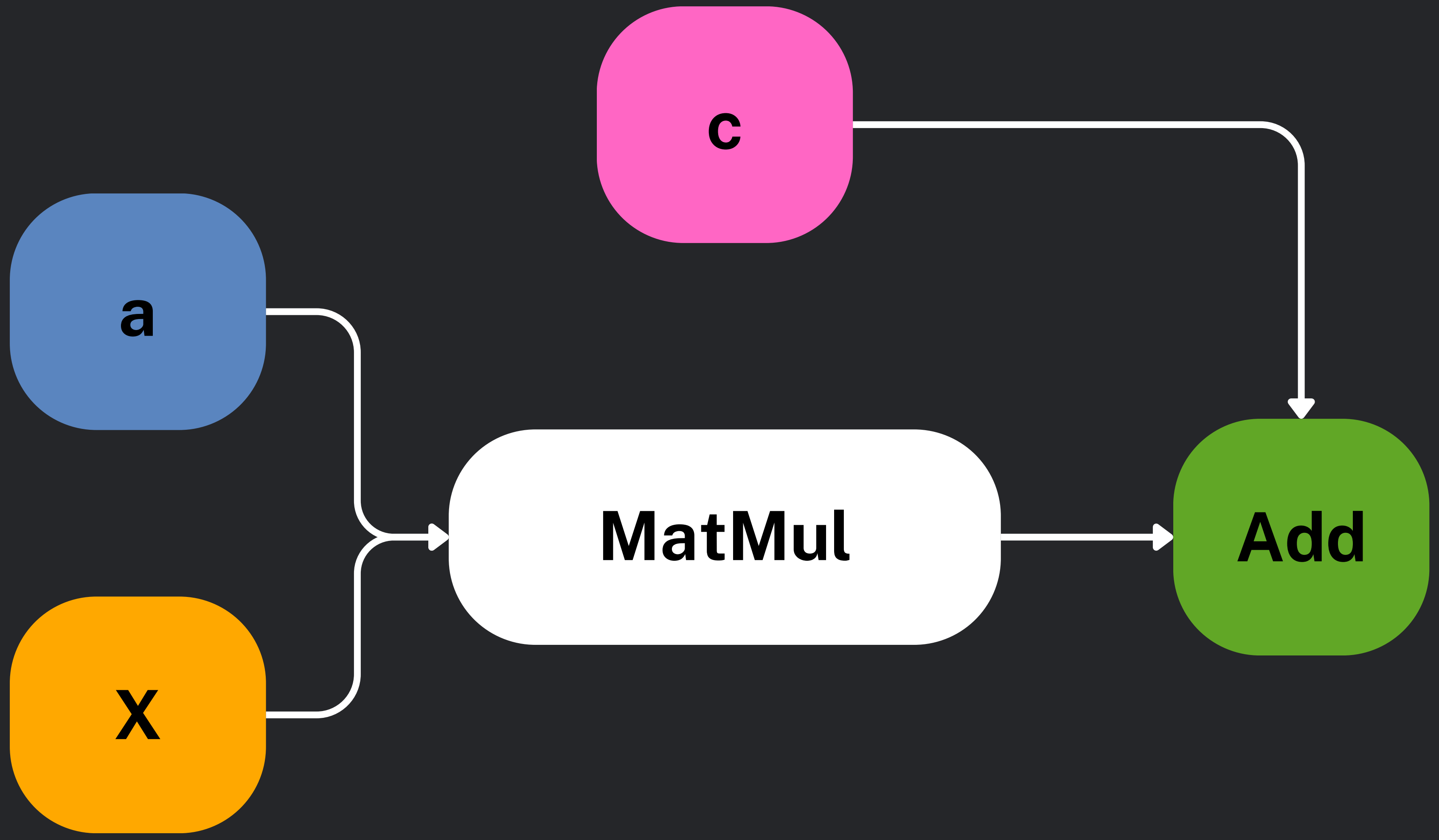

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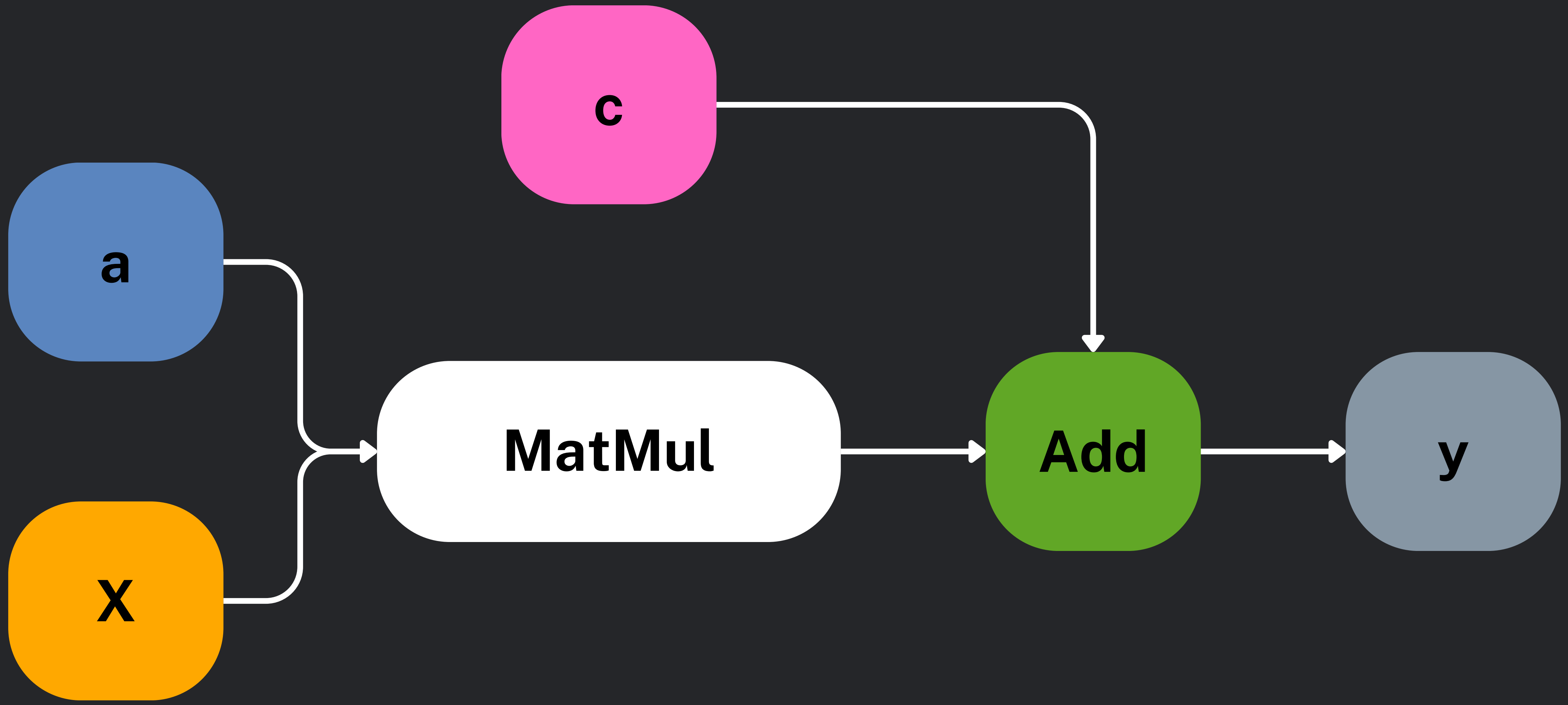
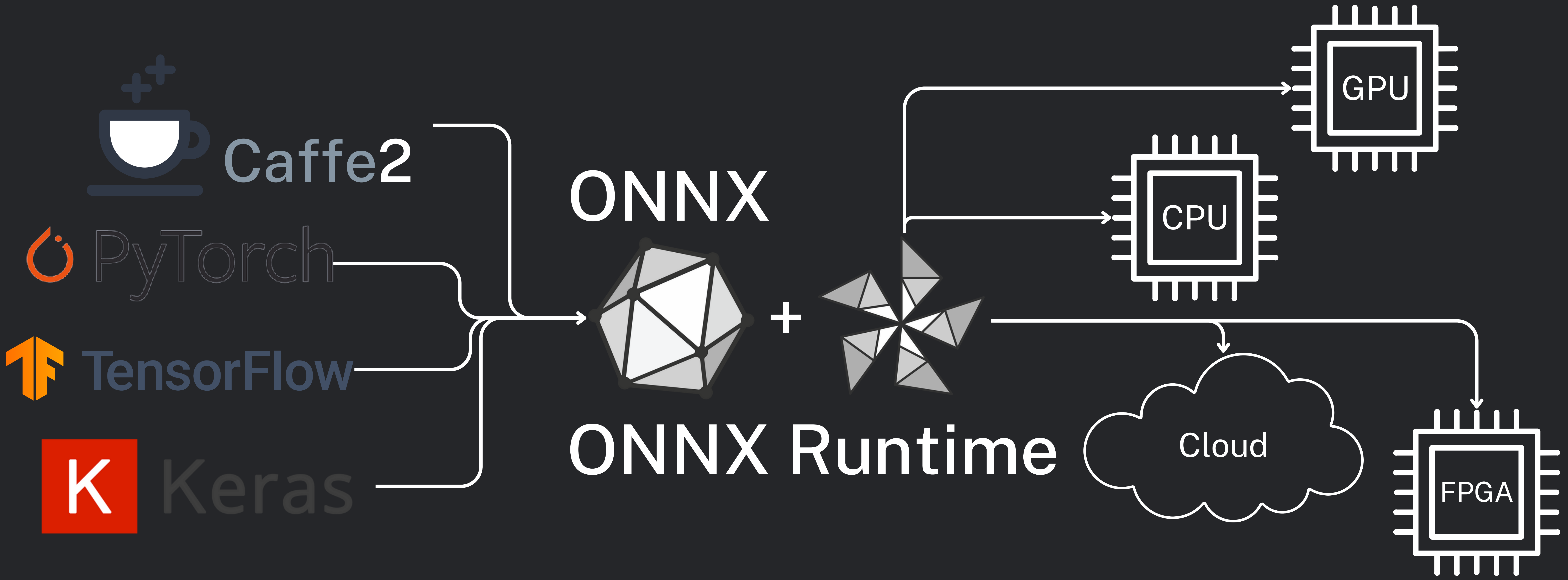


- Common language for any ML framework
- Operators (Add, Mul, Max, Min, etc.)
- ONNX data types (int8, float16, bool, etc.)

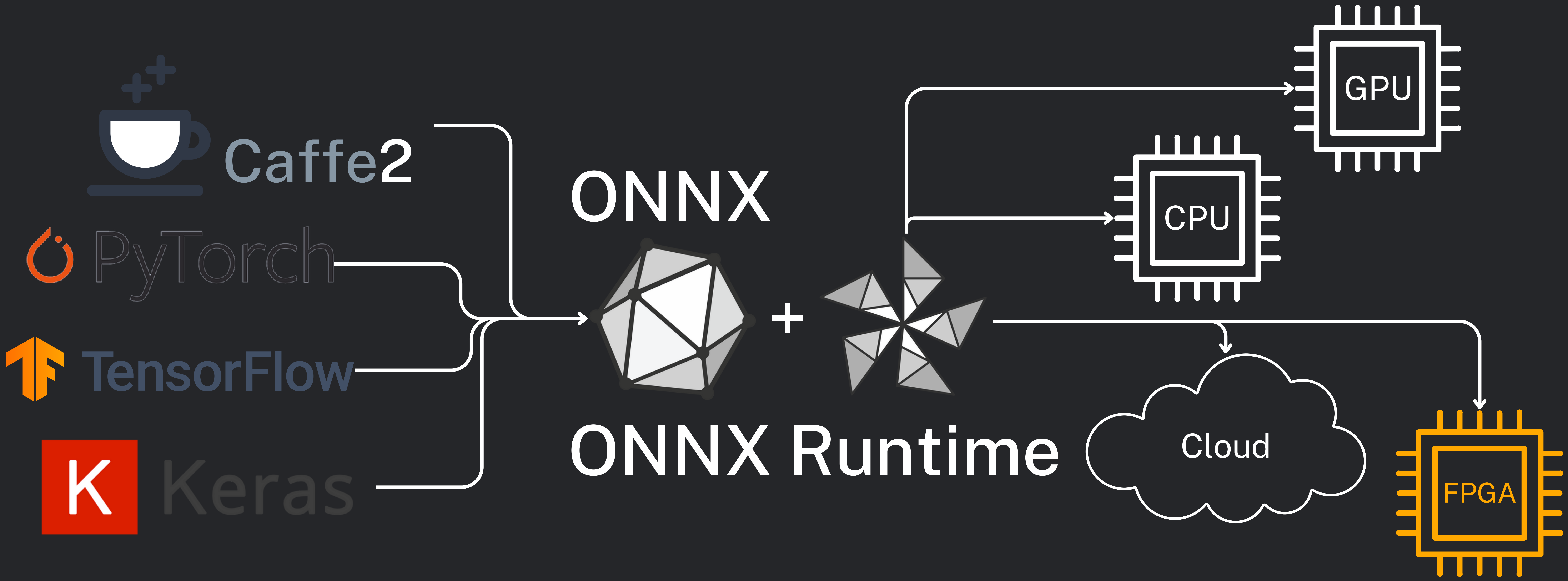
Deployment with ONNX



training

deployment

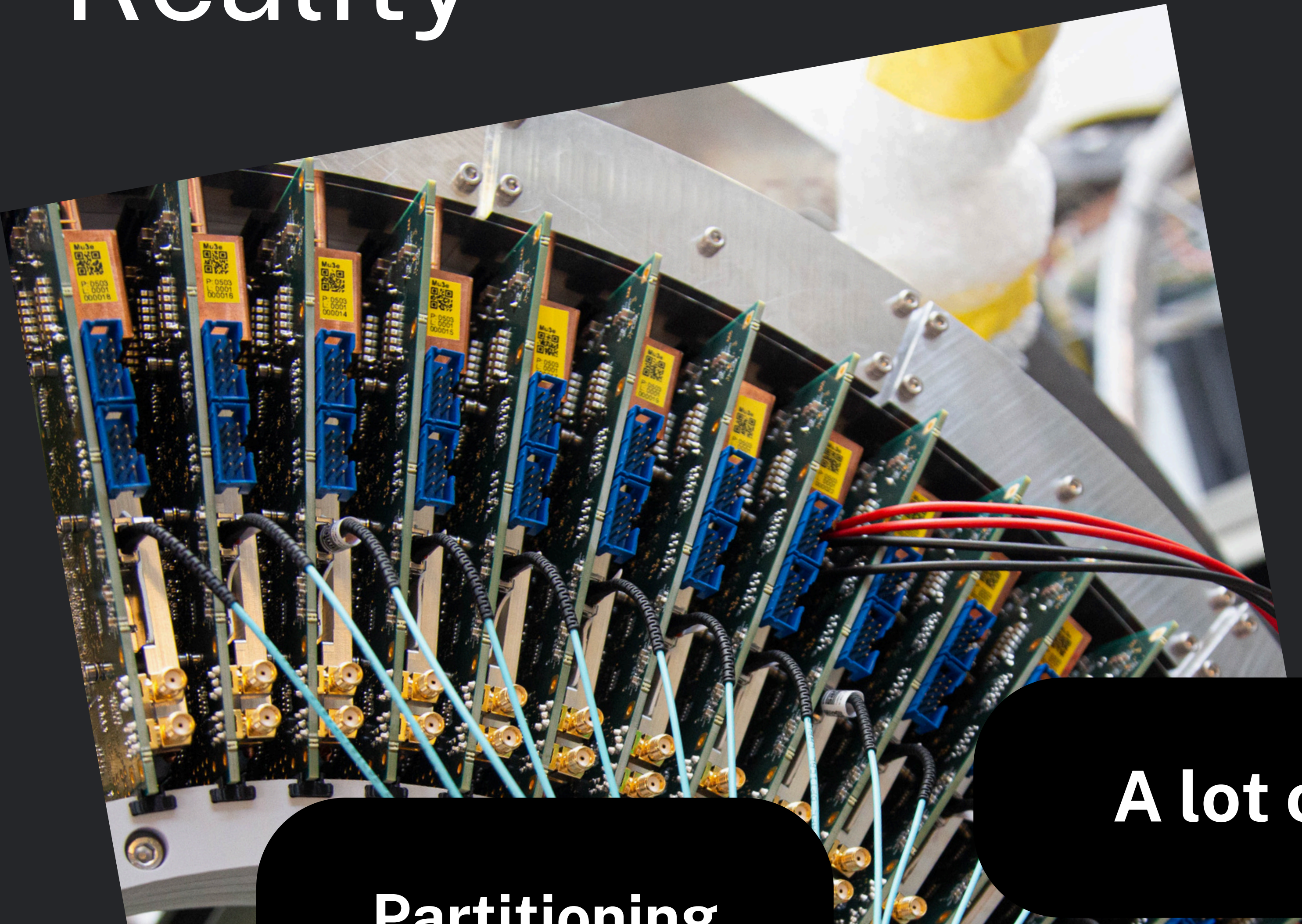
Deployment with ONNX



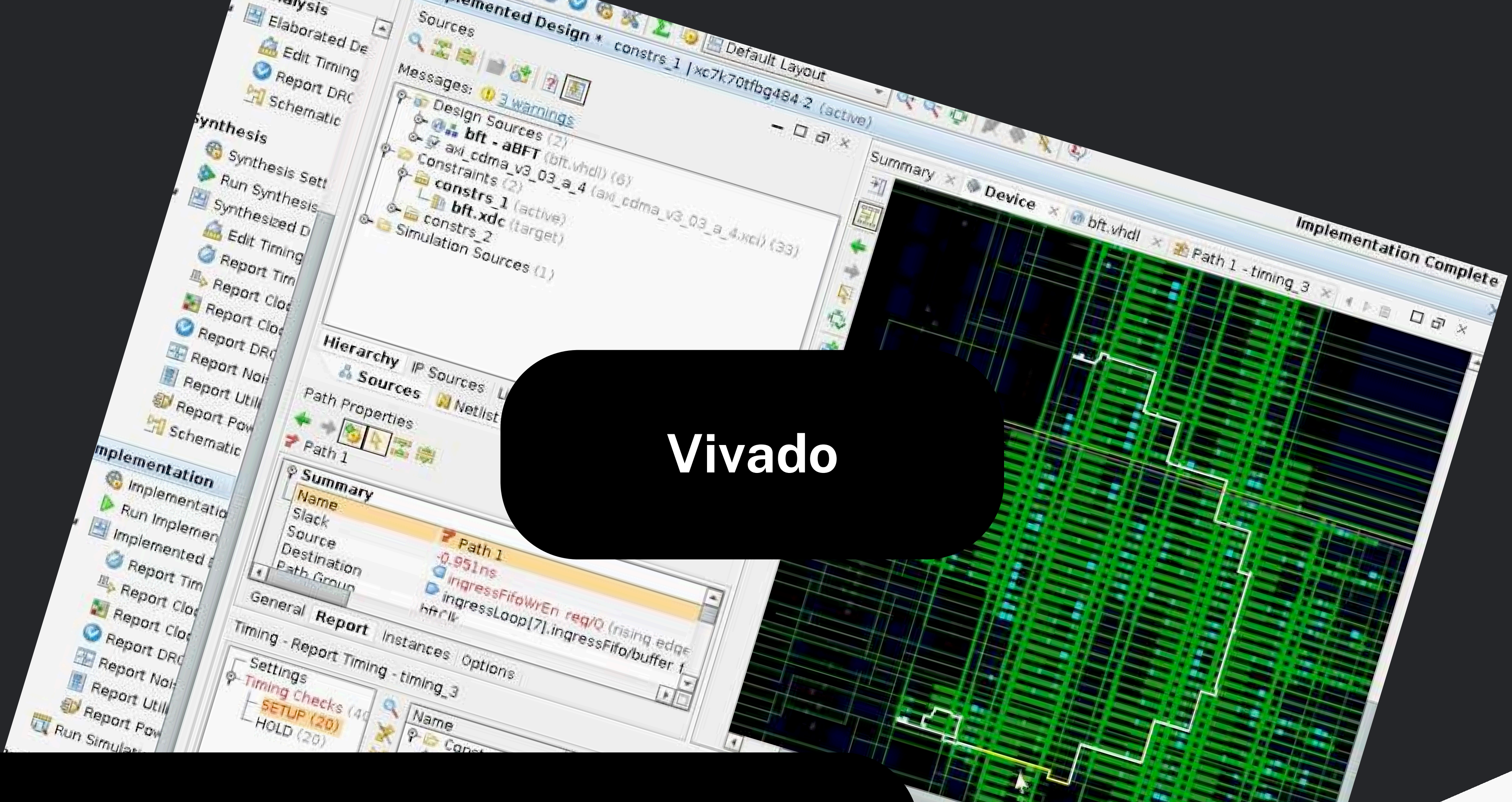
training

deployment

Reality

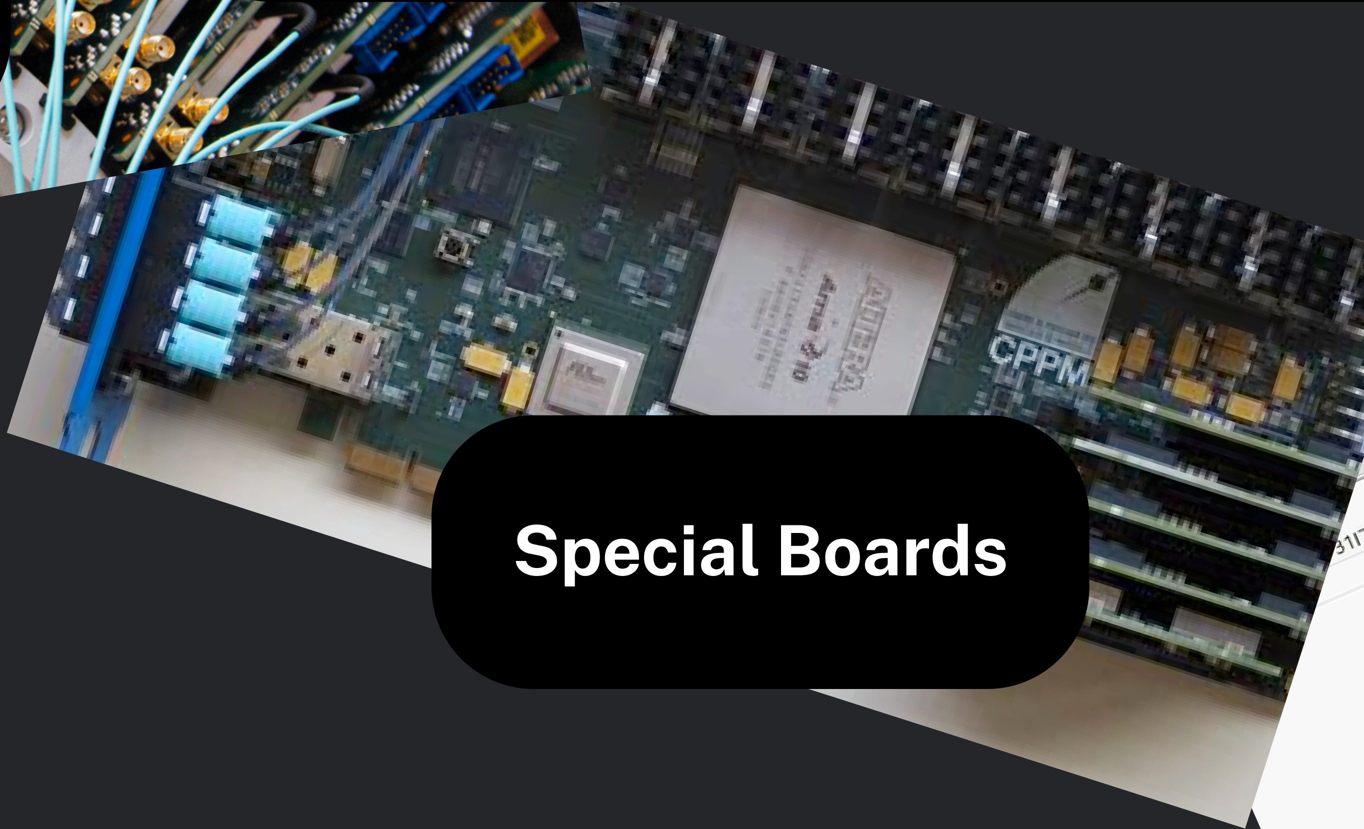


Partitioning

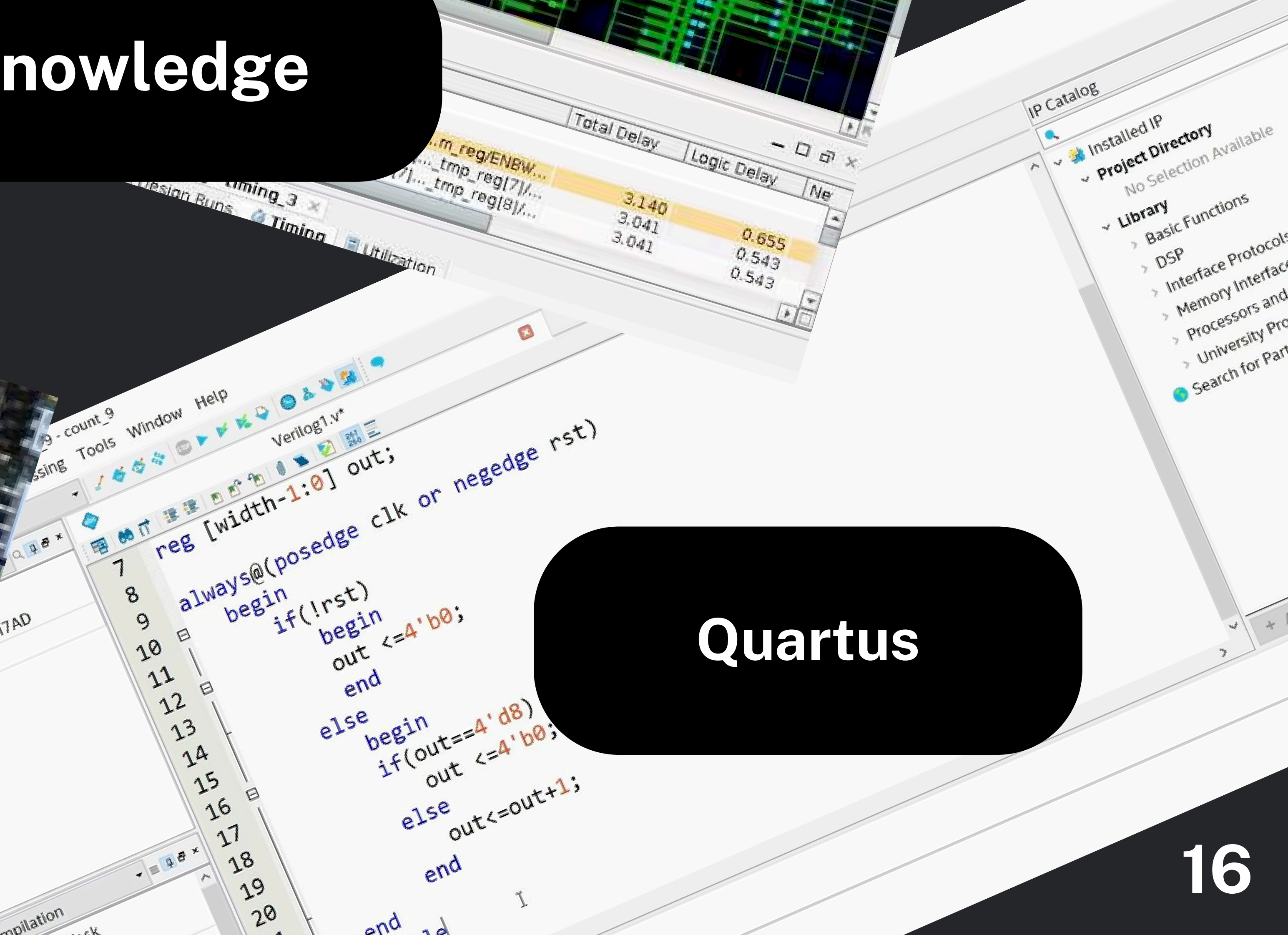


Vivado

A lot of tooling, software, knowledge



Special Boards

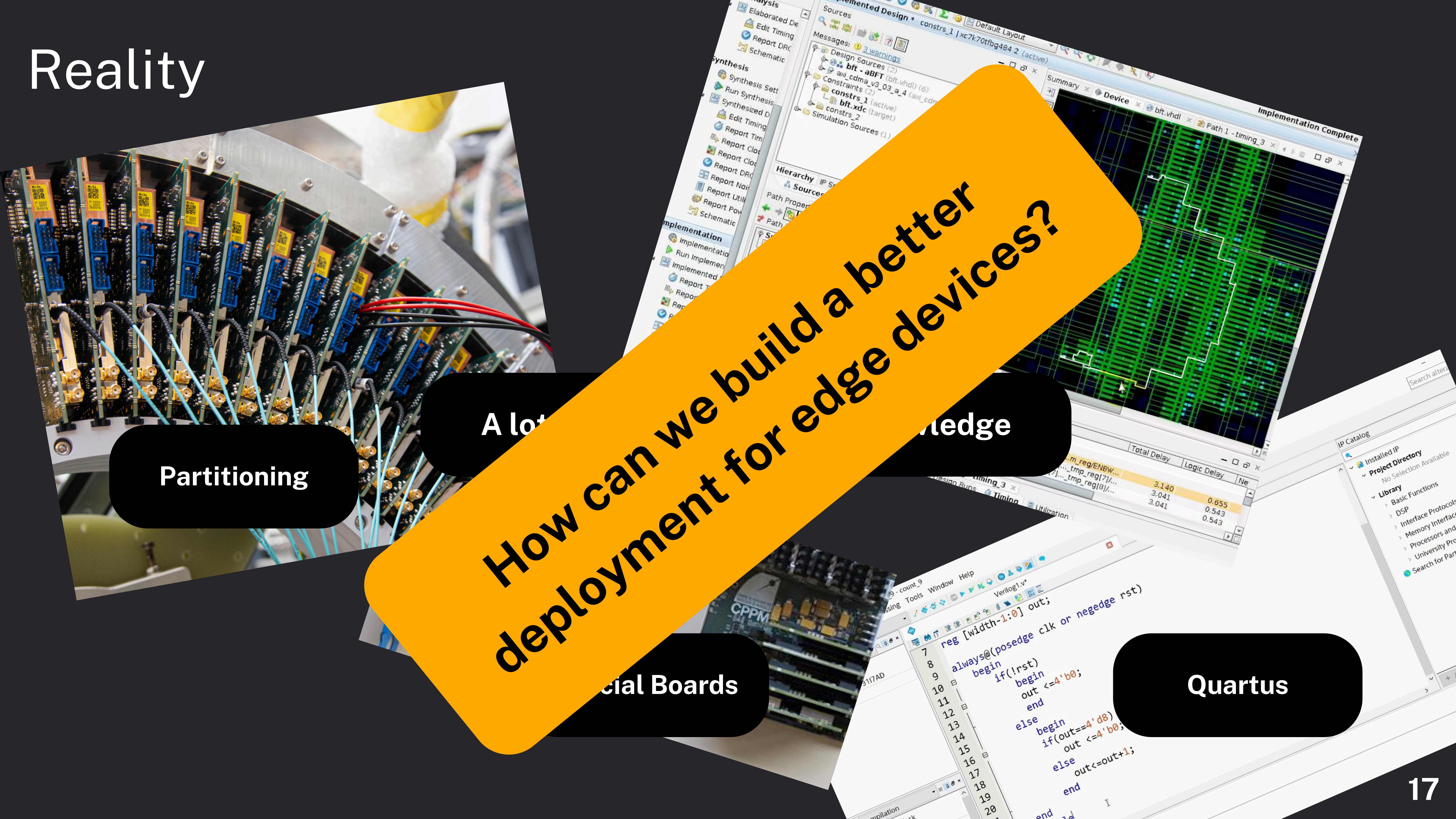


```verilog
reg [width-1:0] out;

always@(posedge clk or negedge rst)
  begin
    if(!rst)
      begin
        out <=4'b0;
      end
    else
      begin
        if(out==4'd8)
          out <=4'b0;
        else
          out<=out+1;
      end
end
```

Quartus

Reality



Partitioning

A lot … ledge

…cial Boards

Quartus

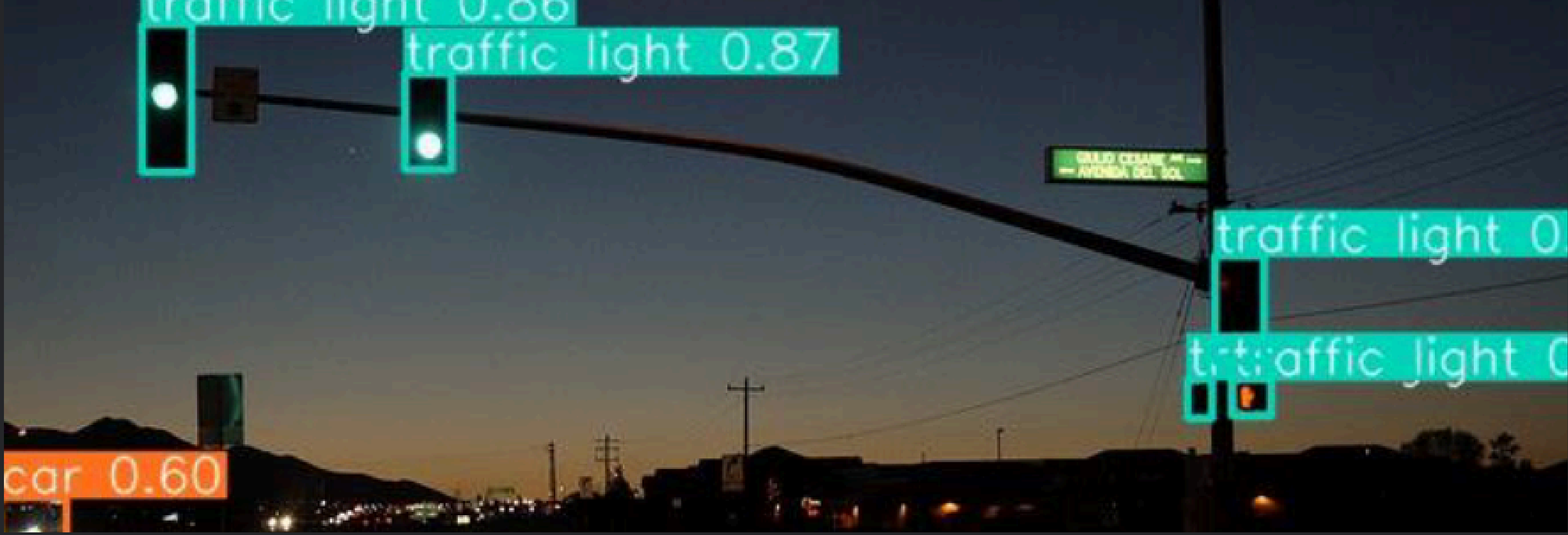
How can we build a better deployment for edge devices?

```
reg [width-1:0] out;

always@(posedge clk or negedge rst)
    begin
        if(!rst)
            begin
                out <=4'b0;
            end
        else
            begin
                if(out==4'd8)
                    out <=4'b0;
                else
                    out<=out+1;
            end
    end
```

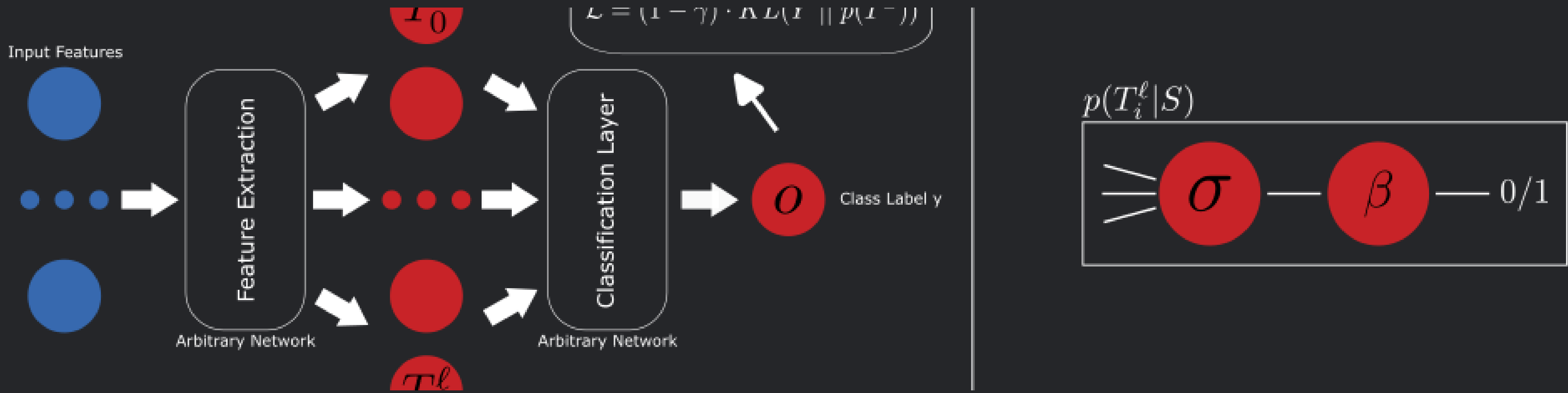
QNNs

- Need highly optimized deployment
- High throughput
- Low latency
- Low power constraints
- Nice mathematical properties
- Interpretability
- On edge devices
- …



YOLOv10 arXiv:2405.14458

AXOL1TL arXiv:2312.10009

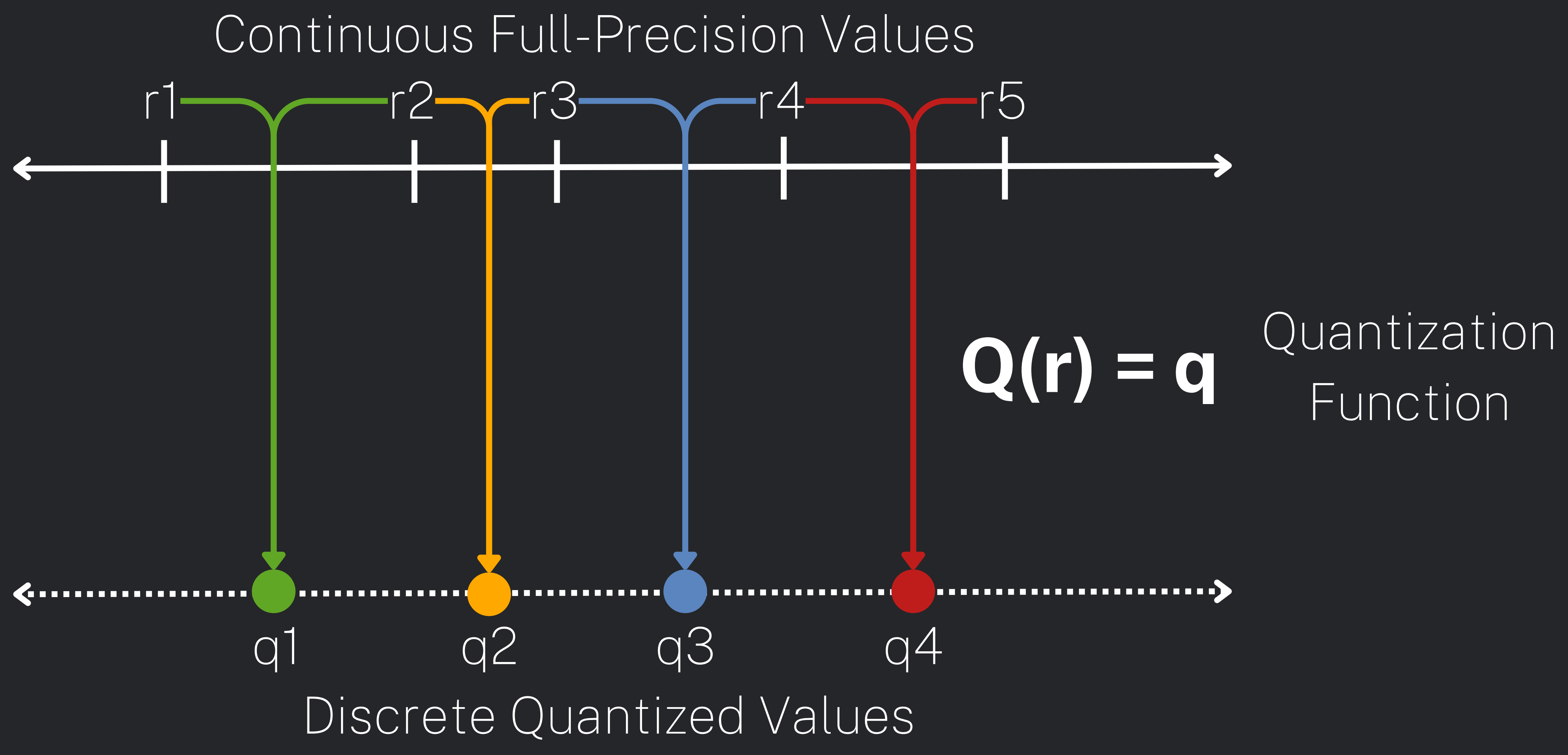


BinaryMI arXiv:2208.02656

Quantization in NNs

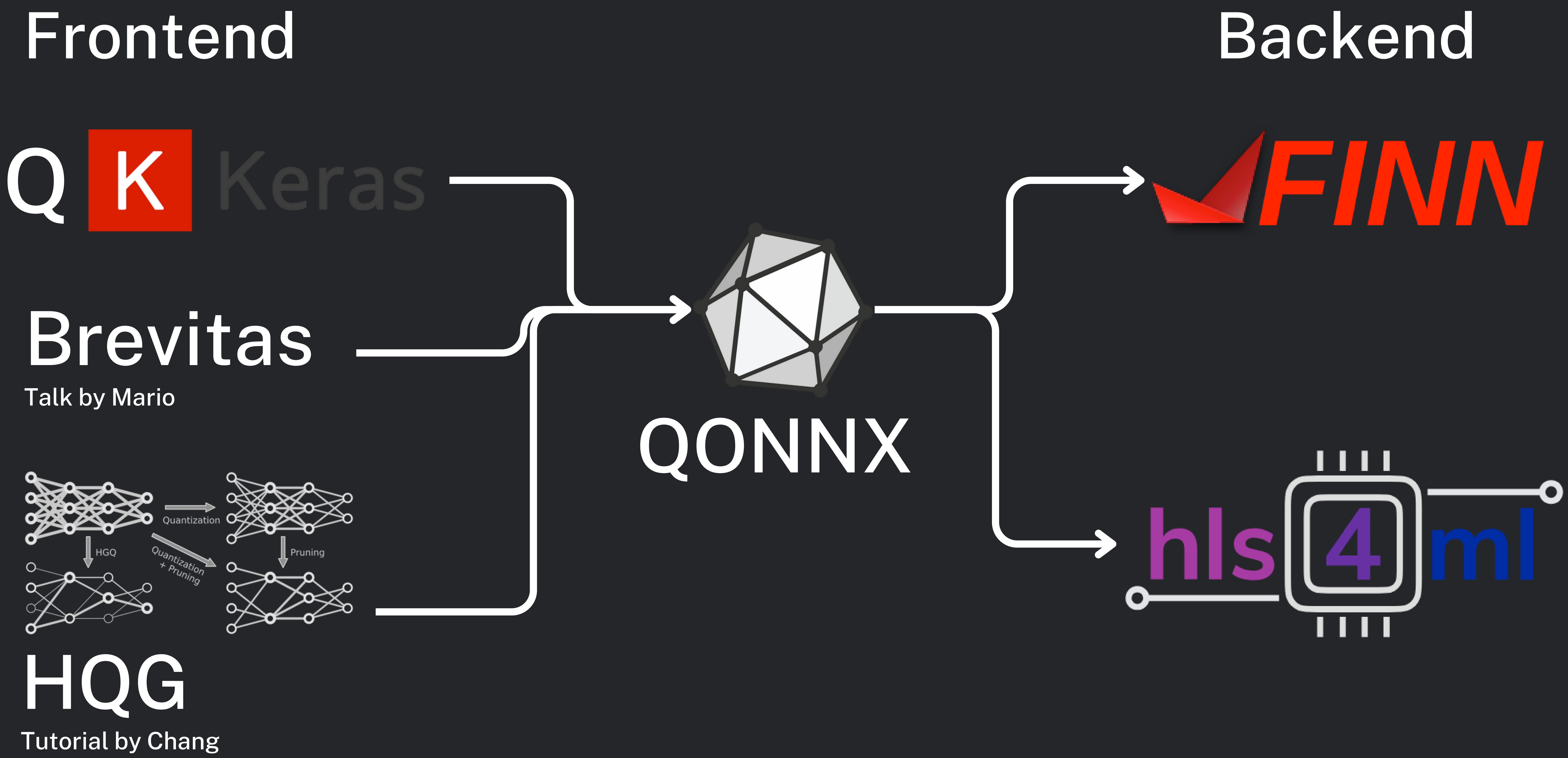
y = x @ a + c

- Each part of the NN can be quantized
- A lot of techniques / strategy out there
  - x-bit instead of floating point
  - Quantization-Aware Training (QAT)
  - Post-Training Quantization (PTQ)
  - Mixed-Precision Quantization
  - …
- Need for a common standard



Note: “everyone” is “ignoring” how to do “proper” backpropagation

Why QONNX?



Frontend

Backend

QKeras

Brevitas

Talk by Mario

HQG

Tutorial by Chang

QONNX

FINN

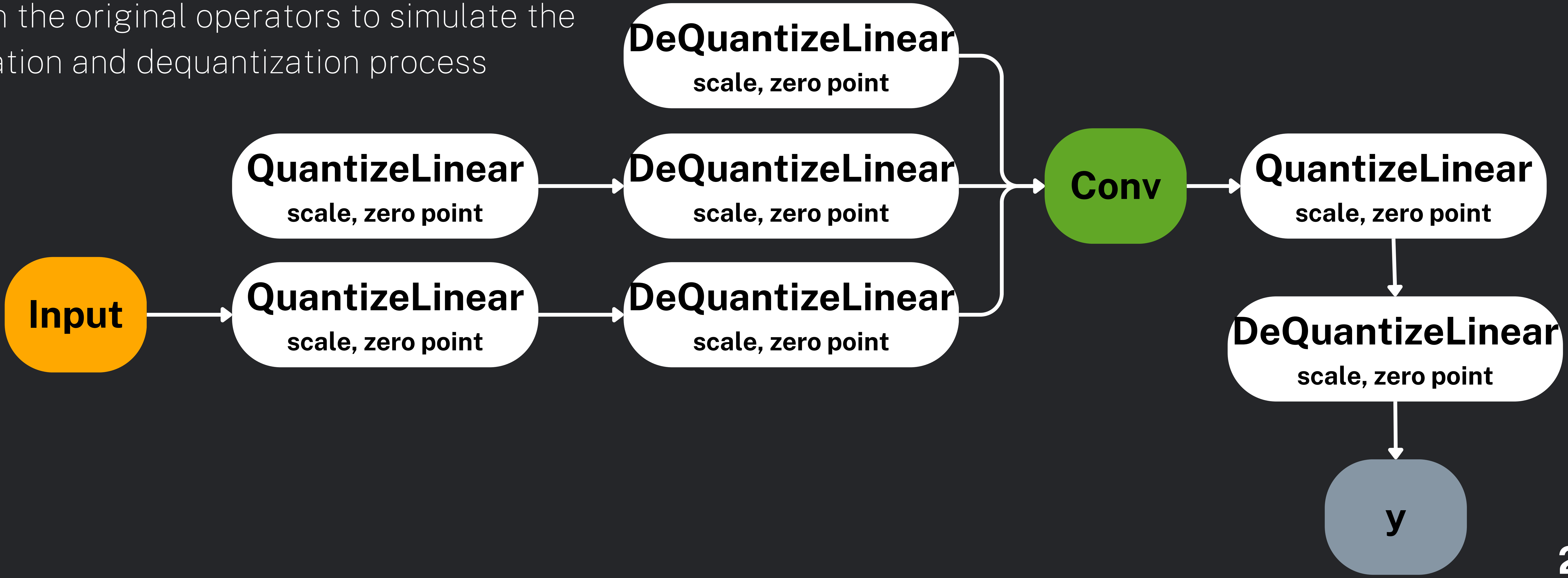
hls4ml

Current quantization formats in ONNX

Tensor-oriented

(QDQ - Quantize and DeQuantize)

- Inserts DeQuantizeLinear(QuantizeLinear(tensor)) between the original operators to simulate the quantization and dequantization process

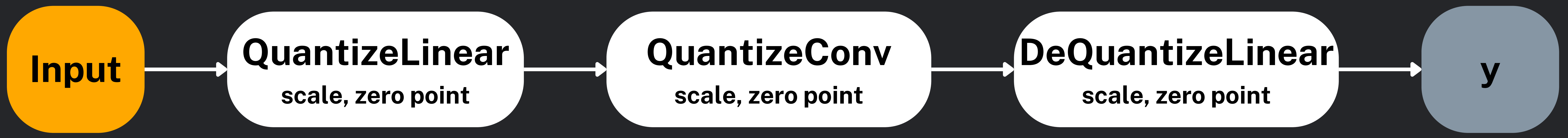


Current quantization formats in ONNX

Operator-oriented

(QOperator)

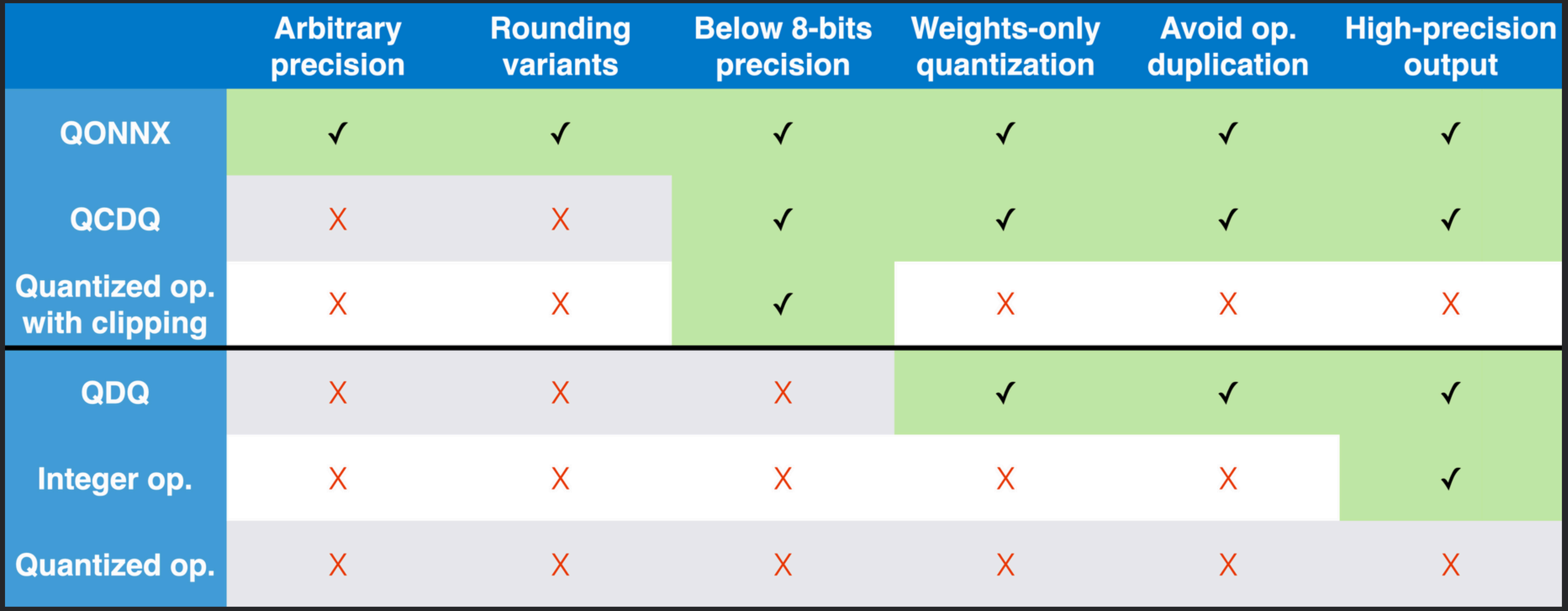
- All quantized operators own ONNX definitions
  - (like QLinearConv, MatMulInteger etc)



QONNX in a Nutshell

QONNX is a collection of specialized ONNX operators

- **Quant:** for 2-to-arbitrary-bit quantization, with scaling and zero-point
- **BipolarQuant:** for 1-bit (bipolar) quantization, with scaling and zero-point
- **Trunc:** for truncating to a specified number of bits, with scaling and zero-point
- **FixedPoint** (Coming soon).

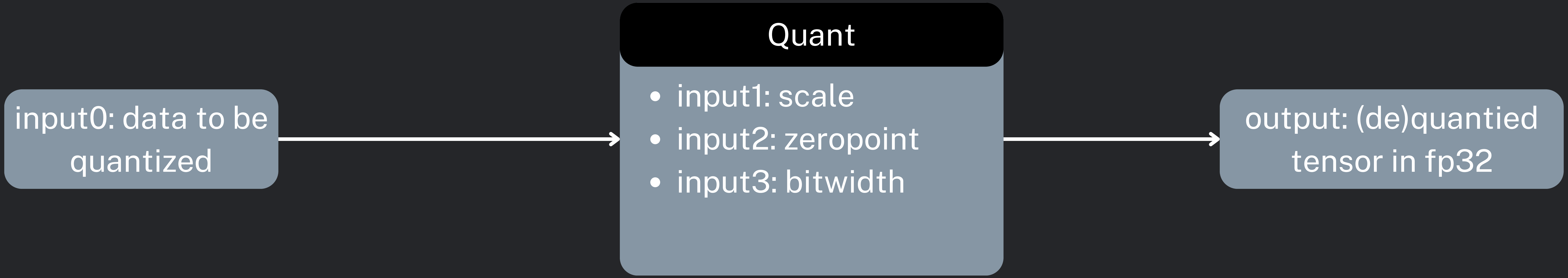


	Arbitrary precision	Rounding variants	Below 8-bits precision	Weights-only quantization	Avoid op. duplication	High-precision output
QONNX	✓	✓	✓	✓	✓	✓
QCDQ	X	X	✓	✓	✓	✓
Quantized op. with clipping	X	X	✓	X	X	X
QDQ	X	X	X	✓	✓	✓
Integer op.	X	X	X	X	X	✓
Quantized op.	X	X	X	X	X	X

Tools

- **Analysis Passes:** nodes statistics, inference cost **(Tutorial)**
- **Transformation Passes:** convert node types (float->int), pruning, etc.

How does the Quant op work?



input0: data to be quantized

Quant

- input1: scale
- input2: zeropoint
- input3: bitwidth

output: (de)quantied tensor in fp32

$$y = \mathrm{quantize}(x) = \mathrm{clamp}(\mathrm{round}(\frac{x}{s} + z), y_{min}, y_{max})$$

$$y_{max} = \begin{cases} 2^{n_b-1} - 1, & \text{if signed} \\ 2^{n_b} - 1 & \text{otherwise} \end{cases} \quad y_{min} = \begin{cases} -2^{n_b-1}, & \text{if signed} \\ 0 & \text{otherwise} \end{cases}$$

Inference cost with QONNX

Bit Operations (BOPs) in QONNX

The BOPs metric is used to assess the computational complexity and performance on NNs deployed to FPGAs and ASICs

$$\mathrm{BOPs} = mn[(1 - f_p)b_a b_w + b_a + b_w + \log_2(n)]$$

- **n/m:** # number of inputs/outputs
- **bw / ba:** bit width of the weights / activations
- **fp:** is the fraction of pruned layer weights
  - fp does account for pruned multiplication operations

more about BOPs arXiv:1804.10969 & arXiv: 2102.11289

```
> qonnx-inference-cost CNV_2W2A.onnx
> Inference cost for CNV_2W2A.onnx
{
# discount Multiply-Accumulate Operations (MAC) counts by layer sparsity (disregard zero-valued MACs and params)
 "discount_sparsity": true,
# mem_o_X: number of outputs with datatype X
 "mem_o_INT32": 142602.0,
# mem_o_X: number weights with datatype X
 "mem_w_INT2": 908033.0,
# op_mac_X_Y: # of MAC operations, datatype X by Y
# scaled integer datatypes have a tensor
# number of scaled int8 x int2 MACs
 "op_mac_SCALEDINT<8>_INT2": 1345500.0,
# number of int2 x int2 MACs
 "op_mac_INT2_INT2": 35615771.0,
# total number of MACs normalized to bit-ops (BOPS)
 "total_bops": 163991084.0,
}
```

Open-Source QONNX Repositories

Checked 23.09.2024

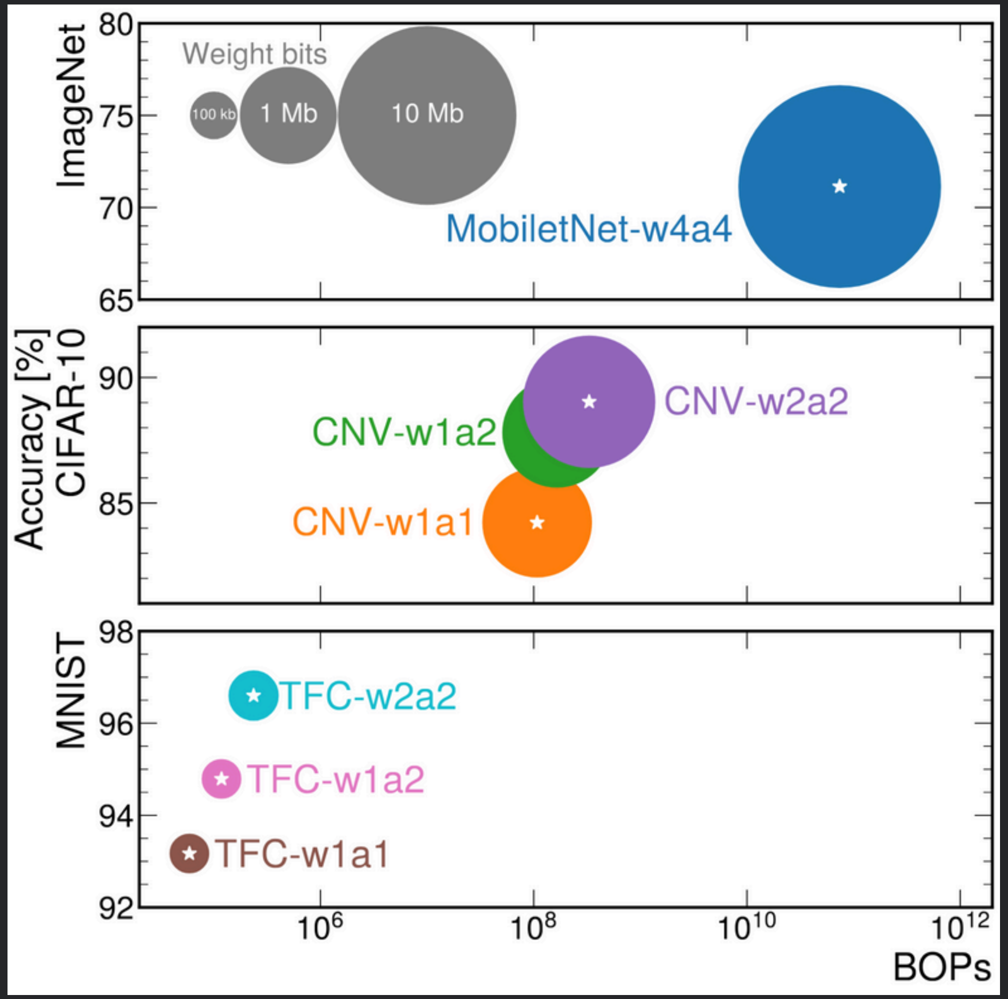
Python Toolkit

github.com/fastmachinelearning/qonnx

- QONNX is a set of specialized ONNX operators
- Execution of custom QONNX nodes
- Getting inference analysis
- Doing model transformation
- Multplie pretrained models available
- …

Model Zoo

github.com/fastmachinelearning/QONNX_model_zoo



Next model trained on physics data?

QONNX Tutorial

https://github.com/makoeppel/Edge-ML-School0924-QONNX