# tinyML® Summit

*Miniature dreams can come true…*

**March 28-30, 2022 | San Francisco Bay Area**

TINY ML

www.tinyML.org

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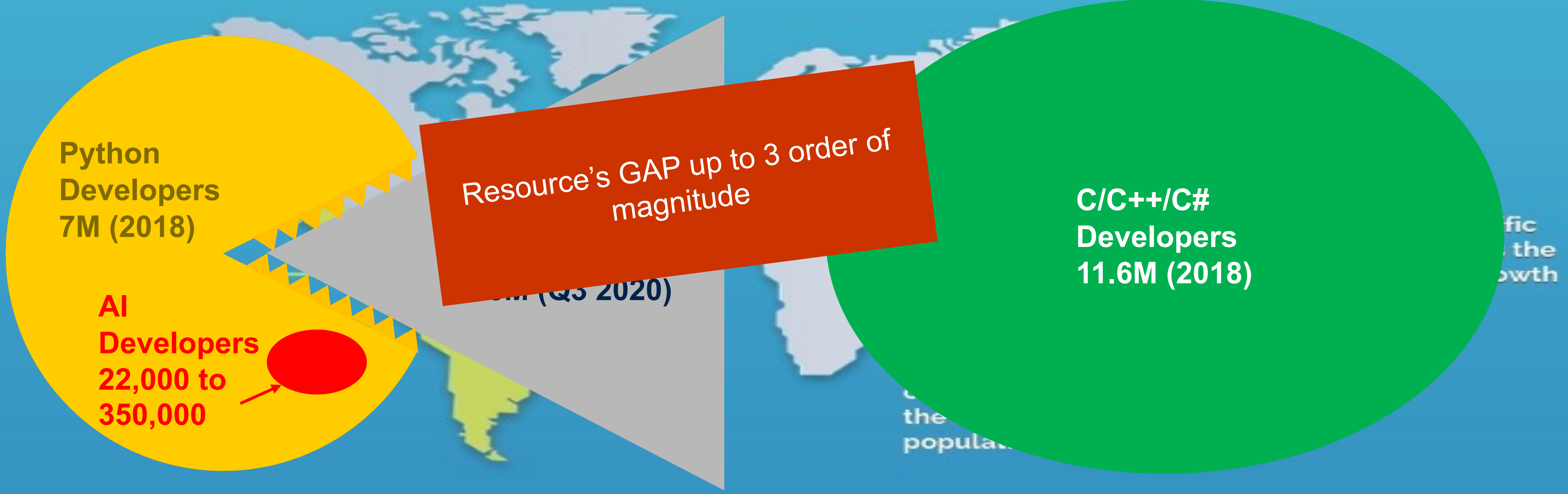
# Ecosystem of tools for better productivity

Danilo PAU, Technical Director, IEEE and ST Fellow, STMicroelectronics

# Global Developer Population and Demographic Study 2019, Vol 1

Source https://www.daxx.com/blog/development-trends/number-software-developers-world
*https://www.stateofai2019.com/chapter-6-the-war-for-talent/#:~:text=Estimates%20of%20the%20number%20of,AI%20originated%20in%20academia.



Python Developers 7M (2018)

AI Developers 22,000 to 350,000

Resource's GAP up to 3 order of magnitude

C/C++/C# Developers 11.6M (2018)

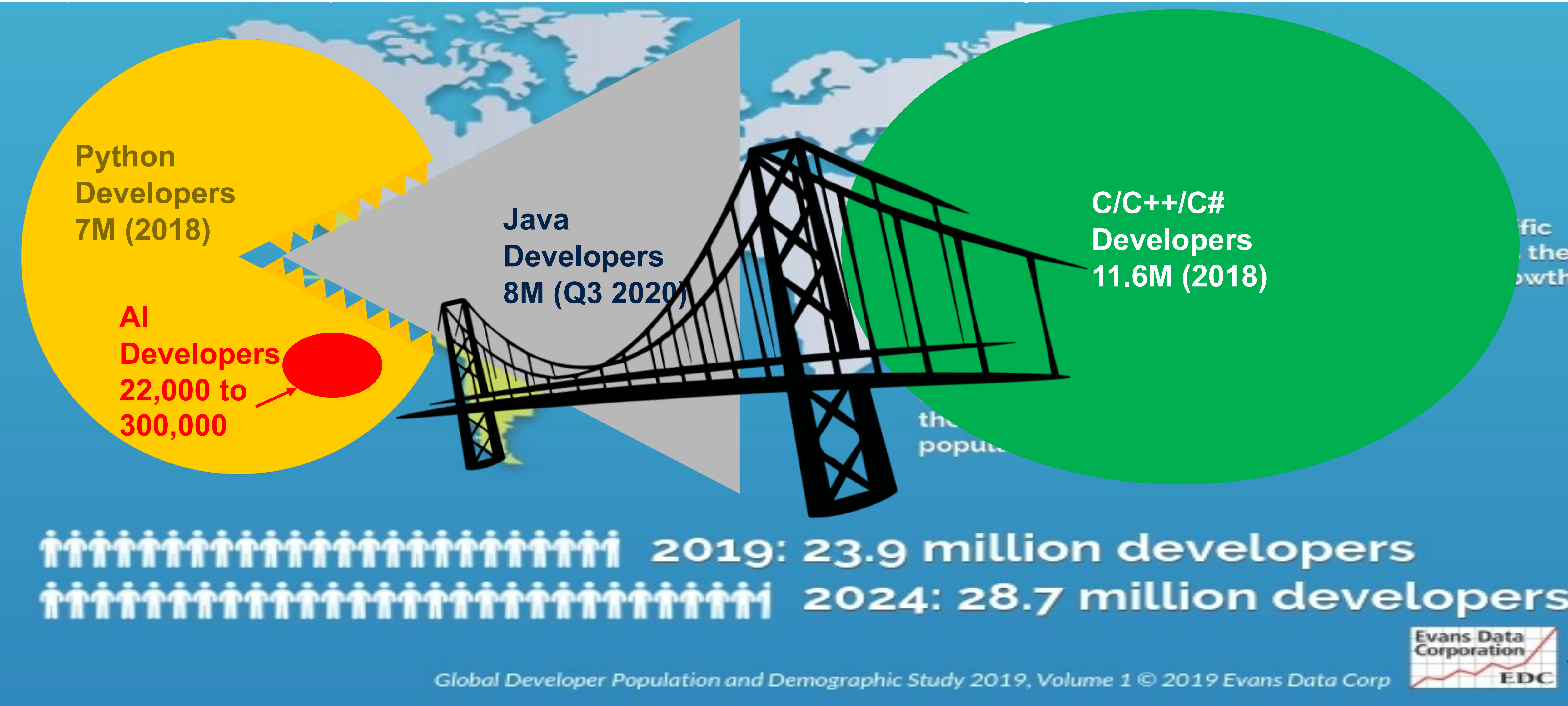
2019: 23.9 million developers

2024: 28.7 million developers

*Global Developer Population and Demographic Study 2019, Volume 1 © 2019 Evans Data Corp*

Evans Data Corporation EDC

# How to bridge the AI and embedded communities?



Python Developers 7M (2018)

AI Developers 22,000 to 300,000

Java Developers 8M (Q3 2020)

C/C++/C# Developers 11.6M (2018)

2019: 23.9 million developers

2024: 28.7 million developers

Global Developer Population and Demographic Study 2019, Volume 1 © 2019 Evans Data Corp

# More FAEs ? How many ? WRONG!

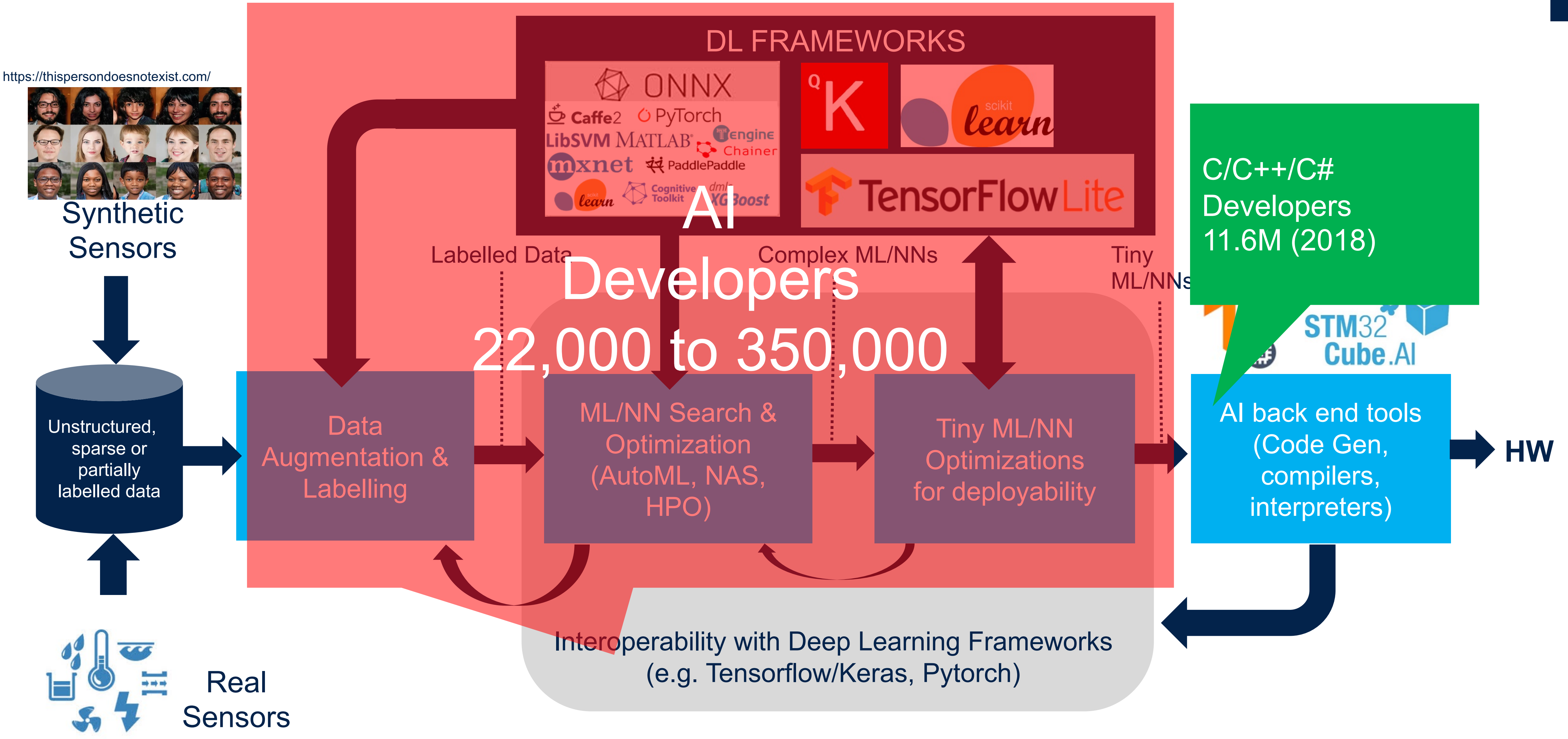
**24.1 billion**
IoT connected devices in 2030 (7.6bn 2019)

**$1.5 trillion**
IoT revenue in 2030 ($465bn 2019)

*Image source: Transforma Insights*

# Listen to their needs

# End-to-end Tools Ecosystem



https://thispersondoesnotexist.com/

Synthetic Sensors

Unstructured, sparse or partially labelled data

Real Sensors

DL FRAMEWORKS

AI Developers 22,000 to 350,000

Labelled Data

Complex ML/NNs

Tiny ML/NNs

Data Augmentation & Labelling

ML/NN Search & Optimization (AutoML, NAS, HPO)

Tiny ML/NN Optimizations for deployability

C/C++/C# Developers 11.6M (2018)

AI back end tools (Code Gen, compilers, interpreters)

HW

Interoperability with Deep Learning Frameworks (e.g. Tensorflow/Keras, Pytorch)

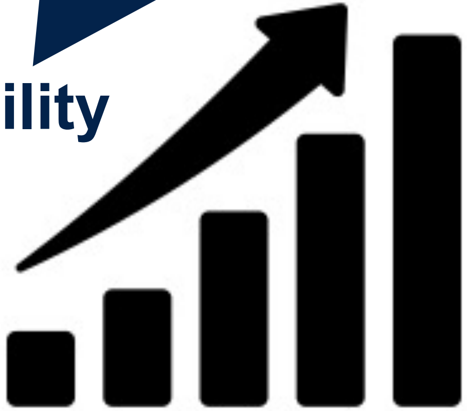
# The needs

## Interoperability

"The documented agreement reached by a group of individuals who recognize the advantage of all doing certain things in an agreed way".
Leonardo Chiariglione

Serving trillions of sensors

## Scalability



## Automation

"everything that can be automated will be automated".
First law
Shoshana ZUBOFF

## Productivity

Keep calm and
hand-craft ML

# Auto tinyML

## March 30 , 2022 – 15:10 to 17:30

**EON Tuner: AutoML for constrained devices**
Jan JONGBOOM, CTO, Edge Impulse

**Optimizing AutoML for the tinyML Future**
Elias FALLON, VP for Machine Learning, Qeexo Co.

**1 kB and not a bit more! The ideal weight for a tinyML model**
Blair NEWMAN, CTO, Neuton

**Model Optimization with QKeras' Quantization-Aware Training and Vizier's Automatic Neural Architecture Search**
Daniele MORO, Software Engineer, Google

**Automated Machine Learning under model's deployability on tiny devices**
Antonio CANDELIERI, Assistant Professor, University of Milano-Bicocca, Italy

**Automating Model Optimization for Efficient Edge AI: from automated solutions to open-source toolkit**
Dave Cheng, Qualcomm, USA

Session moderator: Danilo PAU
Technical Director, IEEE and ST Fellow, STMicroelectronics

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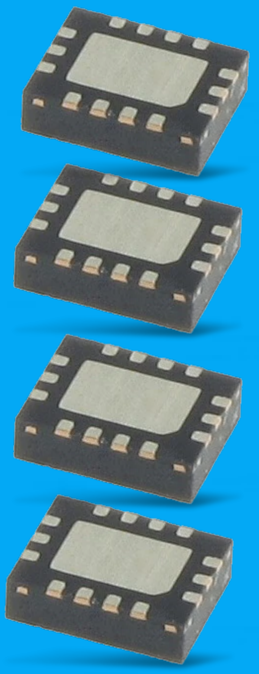
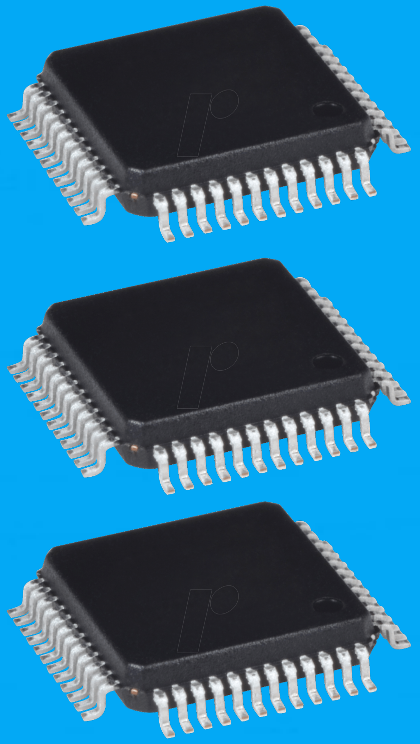
# Further challenges

- A sensor with **a C compiler** !
- **QKeras importer**
- Processor, 5 - 10 MHz
- Binary instructions
- Memory, 40 KiB
- µW energy envelope

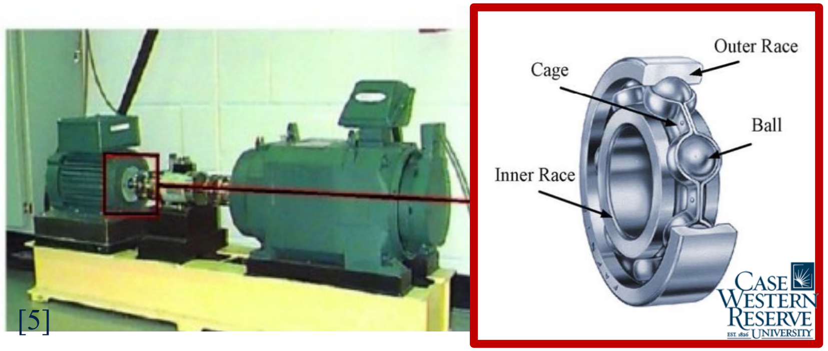


- MCU standard vs custom ISA
- **Code gen, interpreters**
- Different **compilers**
- Processor, 10s - 100s MHz
- Embedded RAM, 10s-100s KiB
- Embedded FLASH, ≤ 2MB
- mW energy envelope

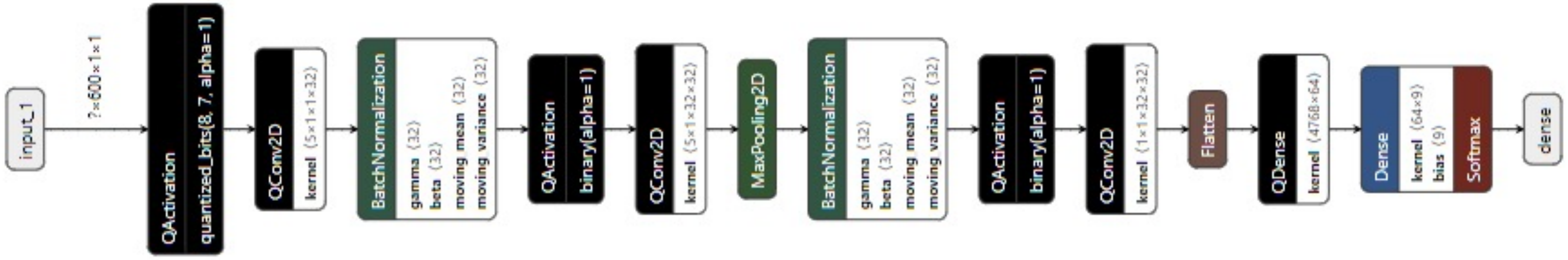


```
!pip install qkeras==0.9.0

# feature extractor
x = x_in = Input(shape)
x = QActivation("quantized_bits(8, 7, alpha=1)", name="act_0")(x)
x = QConv2D(channel_CNN, (kernel_size_CNN, 1),
    kernel_quantizer="quantized_bits(8, 7, alpha=1)",
    use_bias = False,
    name="conv2d_1")(x)
x = BatchNormalization()(x)
x = QActivation("binary(alpha=1)", name="act_1")(x)
x = QConv2D(channel_CNN, (kernel_size_CNN, 1),
    kernel_quantizer="binary(alpha=1)",
    padding="same",
    use_bias = False,
    name="conv2d_2")(x)
x = MaxPooling2D(pool_size=(pool_size_CNN,1))(x)
x = BatchNormalization()(x)
x = QActivation("binary(alpha=1)")(x)
x = QConv2D(32, (1, 1),
    kernel_quantizer="binary(alpha=1)",
    padding="same",
    use_bias = False)(x)
# CNN_Head - classifier
x = Flatten()(x)
x = QDense(64,kernel_quantizer="binary(alpha=1)",use_bias=False)(x)
x = Dense(9,activation="softmax")(x)
```

```
Number of operation types in model:
sfmult_1_32:    305152    (8.5%)
smult_8_8:      95360     (2.6%)
sxor_1_1:       3204096   (89%)

Weight profiling:
conv2d_1_weights :    160 (8-bit unit)
conv2d_2_weights :   5120 (1-bit unit)
q_conv2d_weights :   1024 (1-bit unit)
q_dense_weights : 305152 (1-bit unit)
```



# Anomaly (bearings) classification



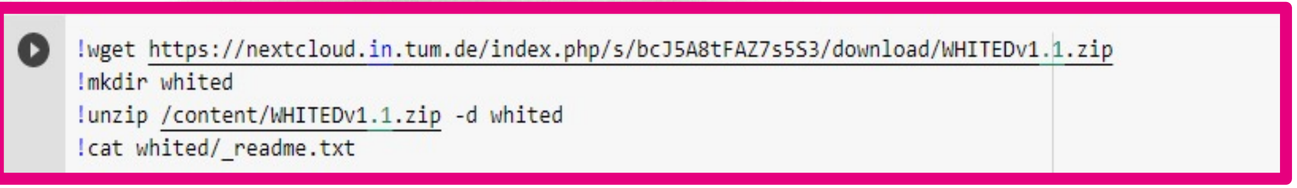
| Model | | Accuracy (average of 10 trials) % | MACC | WEIGHTS KiB | RAM KiB | STM32 inference/s |
|---|---|---|---|---|---|---|
| Keras | FP32 | 98.89 | 3,624,496 | 1218.56 | 75.5 | 19 |
| TFLite | INT8 | 25.96 | 3,634,132 | 305.44 | 24.94 | 34 |
| **QKeras** | **INT1/FP32** | **98.39** | **3,624,432** | **41.32** | **18.88** | **72** |

Note: based on X-CUBE-AI (alpha version) code generation

# Home Appliance classification

- Only current measurements
- 16 KHz sampling rate

```
!pip install qkeras==0.9.0
```



```
!wget https://nextcloud.in.tum.de/index.php/s/bcJ5A8tFAZ7s5S3/download/WHITEDv1.1.zip
!mkdir whited
!unzip /content/WHITEDv1.1.zip -d whited
!cat whited/_readme.txt
```

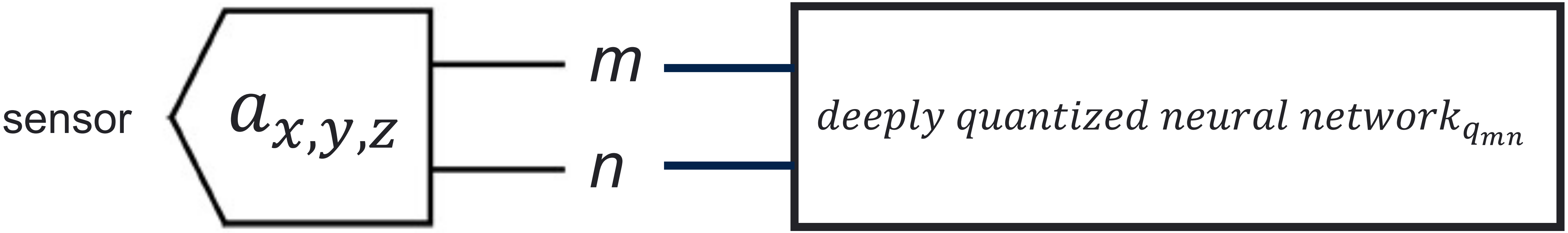
```
Number of operation types in model:
smult_8_8:   276768   (3.4%)
sxor_1_1:   7831008 (96.6%)
```

| Model | | MACC | FLASH KiB | RAM KiB | Accuracy (%) K-fold=5 | Inference/s |
|---|---|---|---|---|---|---|
| Keras | FP32 | 5,864,688 | 108.5 | 87.12 | 99.43 | 12 |
| TFLITE | INT8 | 5,888,972 | 27.68 | 22.81 | 99.39 | 30 |
| **QKeras** | **INT1/FP32** | **8,139,824** | **11.84** | **16** | **98.73** | **105** |

Note: based on X-CUBE-AI (alpha version) code generation

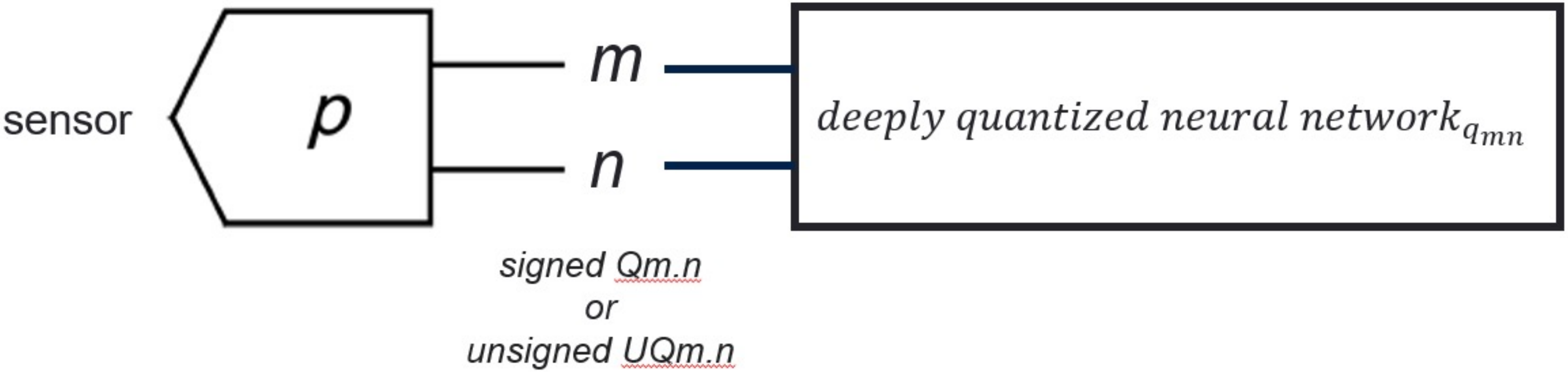
# Generalizing

```
Average Accuracy of AutoEncoder model in 10 (CWRU) trials is: 98.5167

Number of operation types per inference:
    smux_1_16                         : 7200
    sxor_1_1                          : 6080

Weight profiling:
    q_conv2d_2_weights                 : 40     (1-bit unit)
    q_conv2d_3_weights                 : 320    (1-bit unit)
    q_conv2d_4_weights                 : 320    (1-bit unit)
    q_conv2d_5_weights                 : 40     (1-bit unit)
    Total                              : 720     bits

Activations profiling:
    Total allocation                   : 512     bytes
```



*signed Qm.n*
*or*
*unsigned UQm.n*

# How to automate the dqnn design?



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