tinyML® EMEA

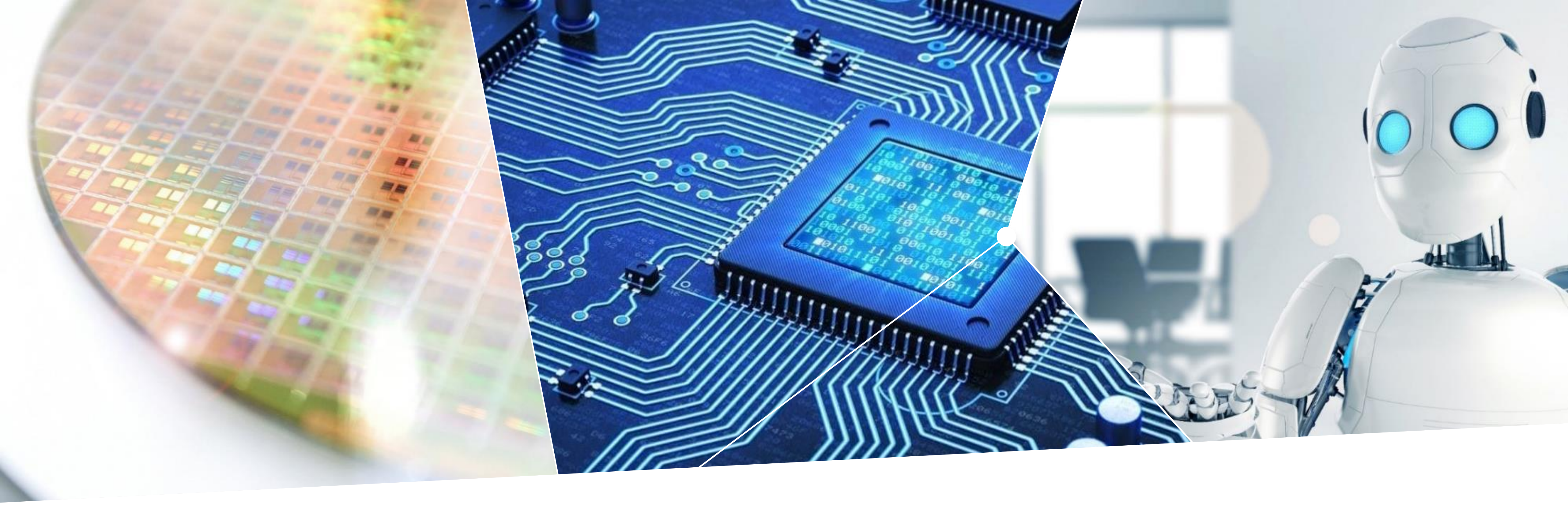
Enabling Ultra-low Power Machine Learning at the Edge

tinyML EMEA Technical Forum 2021 Proceedings

June 7 – 10, 2021

Virtual Event

www.tinyML.org



tinyML beyond Audio and Vision

Wolfgang Furtner
Infineon Technologies AG
June 2021

Overview

1. Sensors beyond audio and vision
2. tinyML applications with this sensors
3. The future of sensors and tinyML

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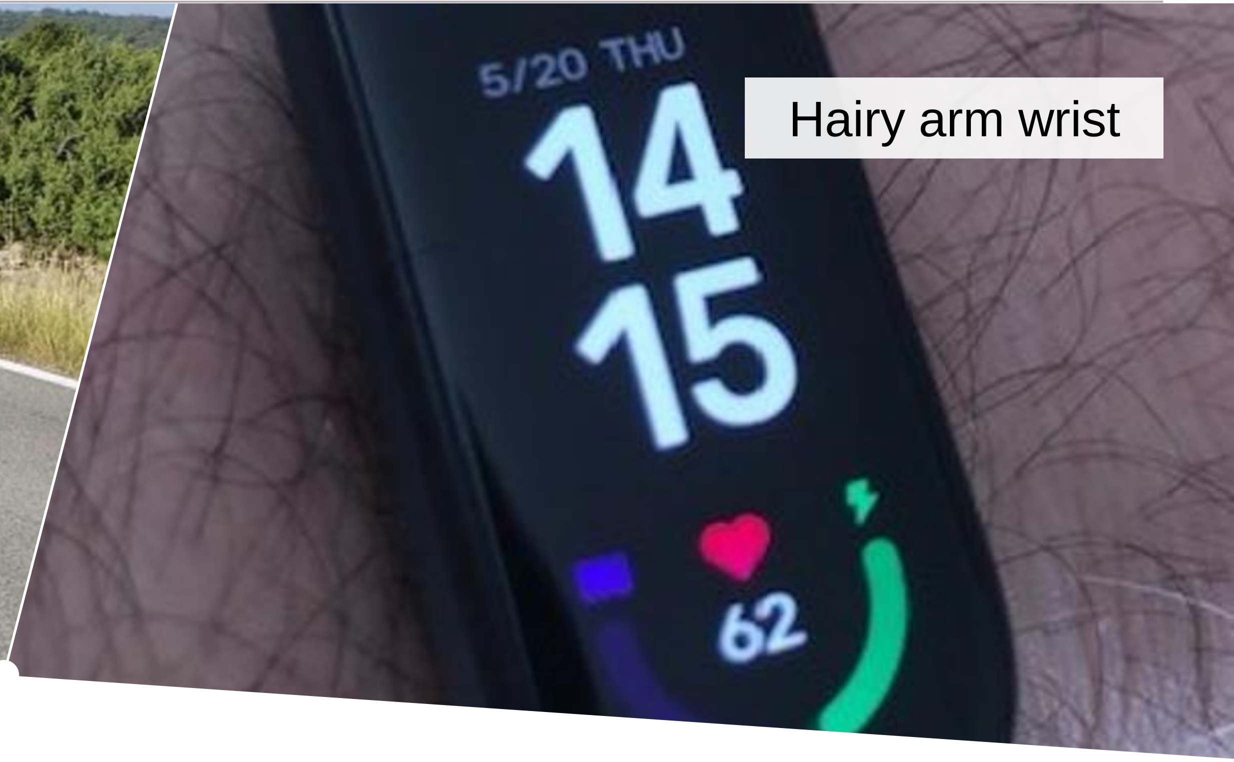
My new fitness tracker …



Sensors + AIML

- Heart rate detection
- Blood oxygen (SpO_2) tracking
- Motion
  - Activity type (sleep, walk, bike, …)
  - Wrist turn for display on

Other features

- Several days of battery life
- BT Connectivity
- Fancy colorful OLED display

Sensors + AIML are enabling new applications

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Where will health monitoring go in the future?

Source: Wikipedia

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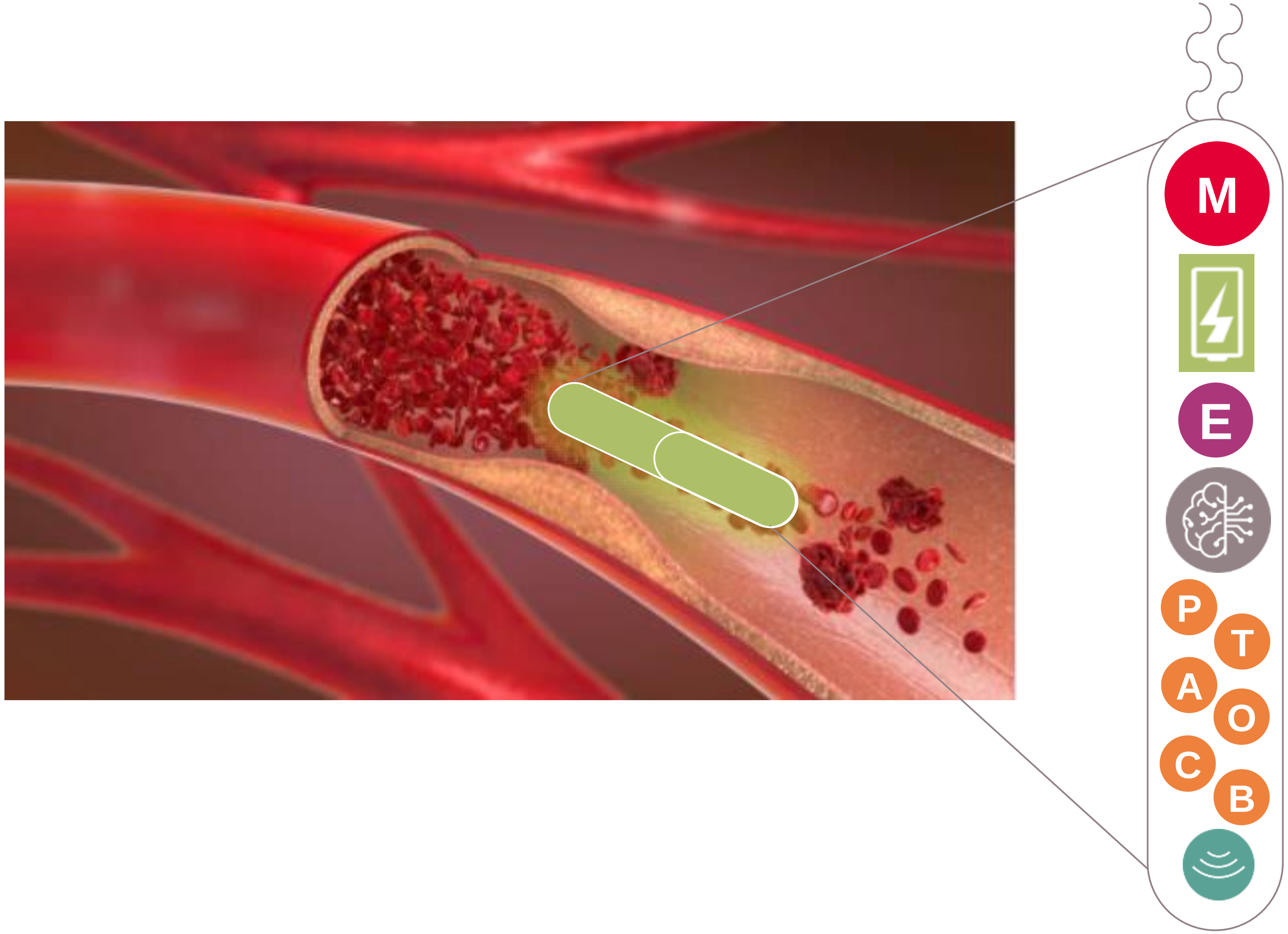
Micro submarine health monitors in your blood vessels



Propulsion Motor

Energy Storage

Energy Harvesting

Neuromorphic "Brain"

Pressure Sensor
Temperature Sensor
Accelerometer
Optical Sensor
Chemical Sensor
Biological Sensor

Wireless Communication
& Radar Navigation

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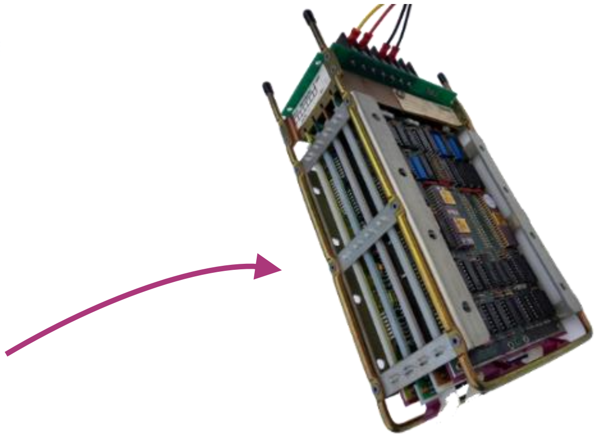
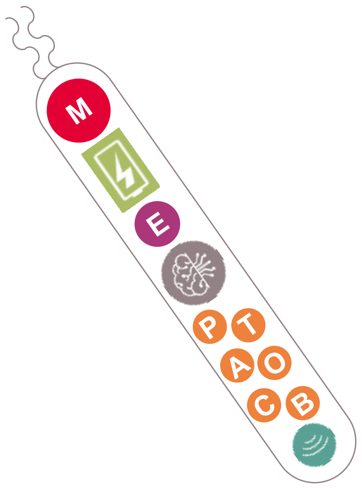
We all know this is possible for computers …

My oldest computer





	PDP11-23	EZ-BLE	Future HT
Make	1979	2019	?
Mac/s	~30 k	600 M	100 T
Size	274x 146x 76 mm^3 ~ 3.05×10^6 mm^3	14x 18.5x 2 mm^3 ~518 mm^3	~0.1 mm^3
Mac/s/mm^3	9.4e-3	1.16e+6 double every ~1.5 yrs	1e+12
Features	CPU only	+ Wireless	+ Sensors + Energy

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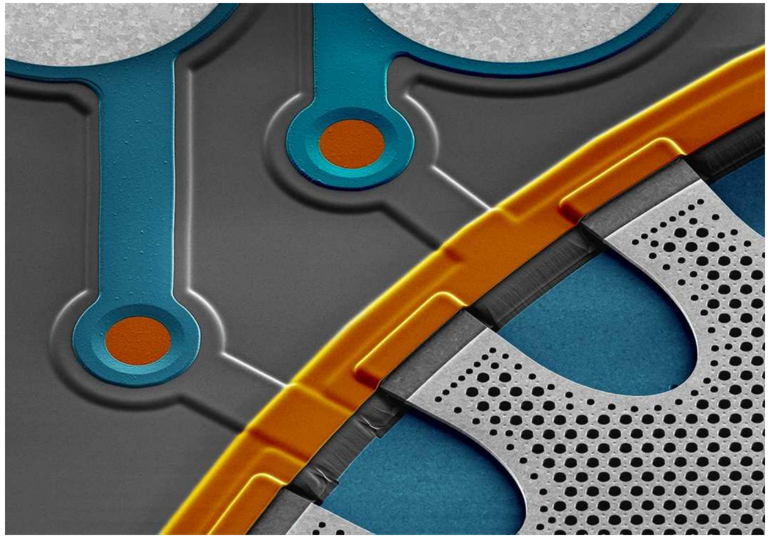
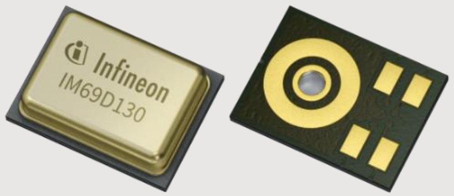
MEMS Technology allow miniaturization of sensors (+ actuators)



Silicon Microphone

- 73 dB(A) signal-to-noise ratio
- 4 x 3 x 1.2 mm3
- 900uA power consumption



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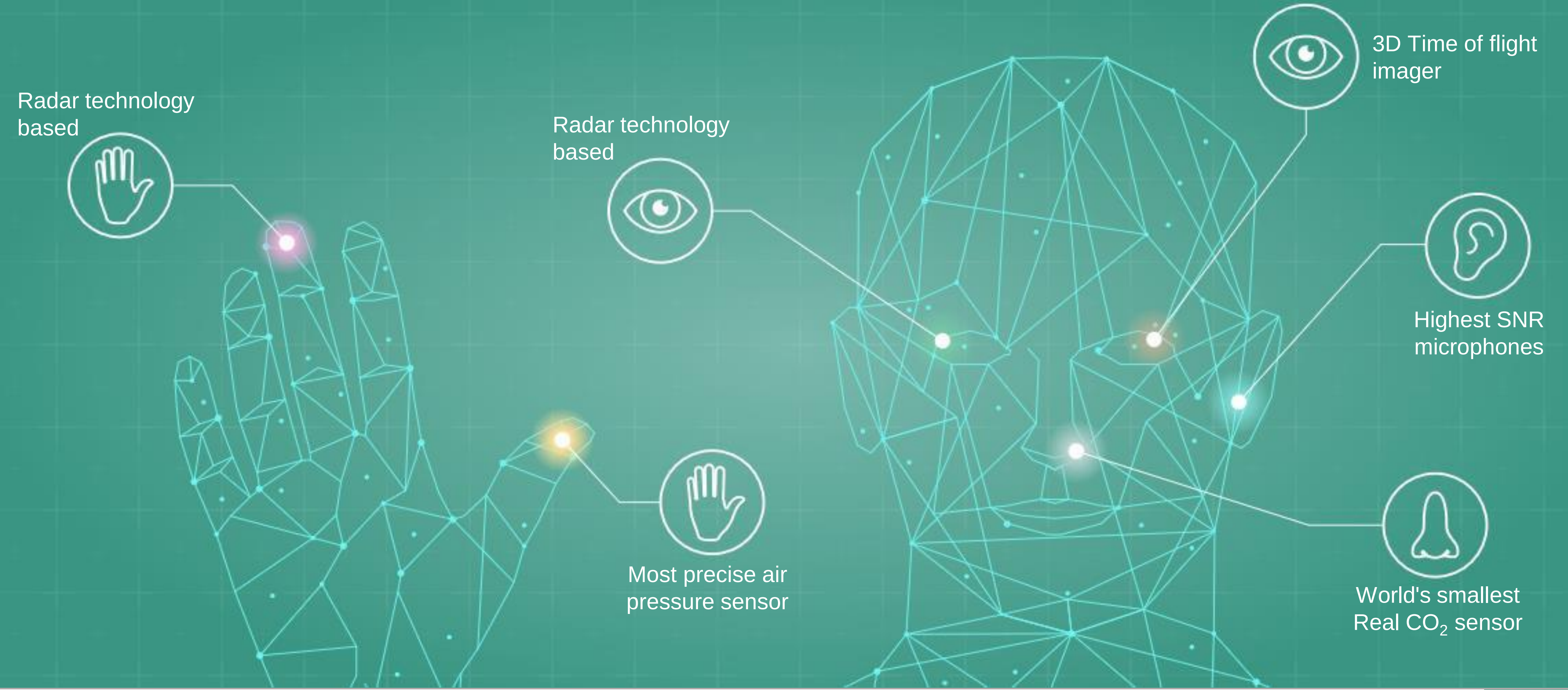
Intuitive Sensors – Giving things the (super-)human senses to make our lifes easier

Infineon **XENSIV™ sensors** are exceptionally precise thanks to industry-leading technologies.
They are the perfect fit for various customer applications in automotive, industrial and consumer markets.



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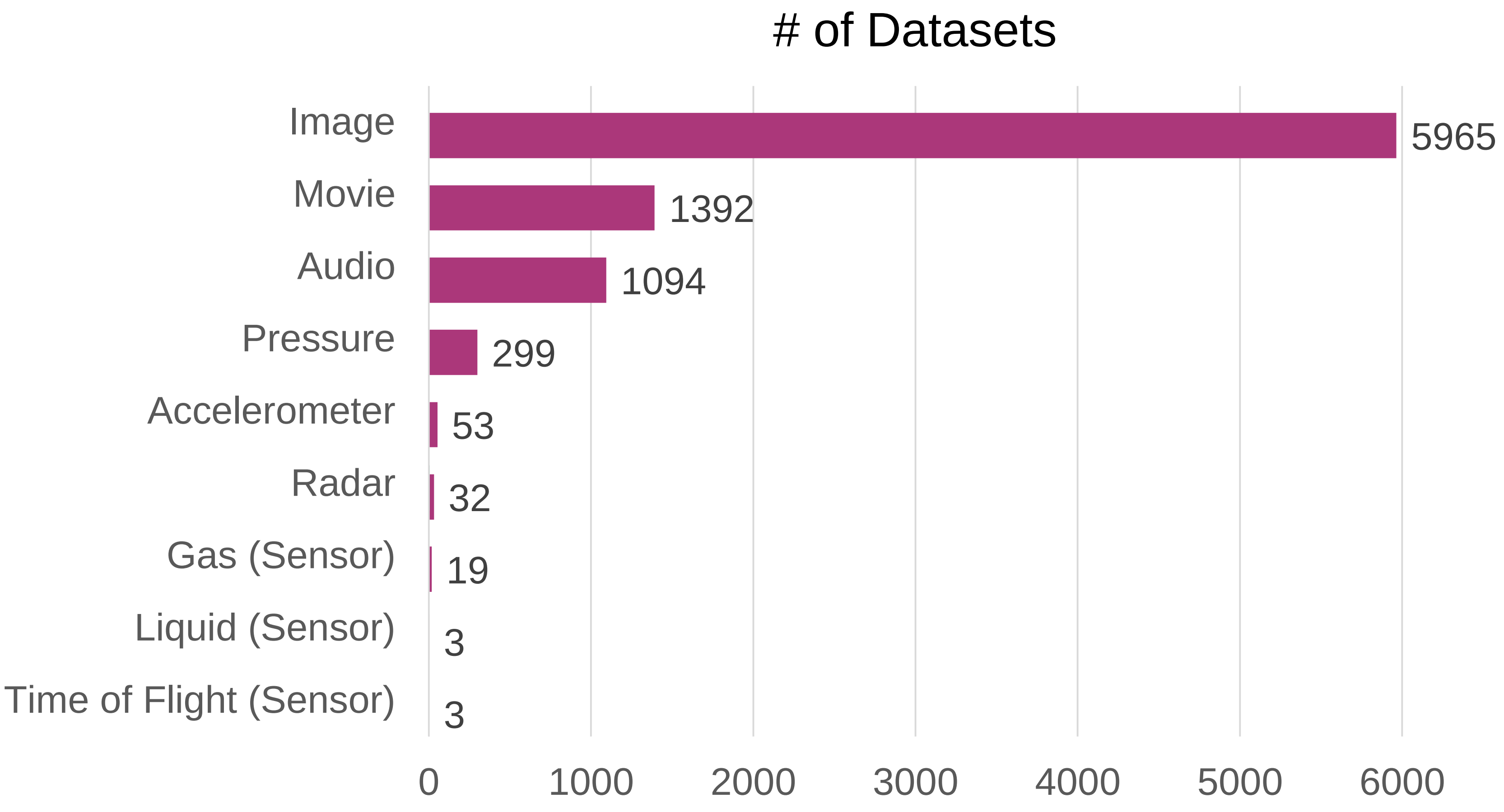
Public data sets beyond audio and vision is sparsely available



Data for new sensors

- Missing Standards
- Sensor specific (e.g. radar antenna configuration)
- Diversified (e.g. many gases and liquid)
- IP protection

Source: Search results kaggle.com

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Overview

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3. The future of sensors and tinyML

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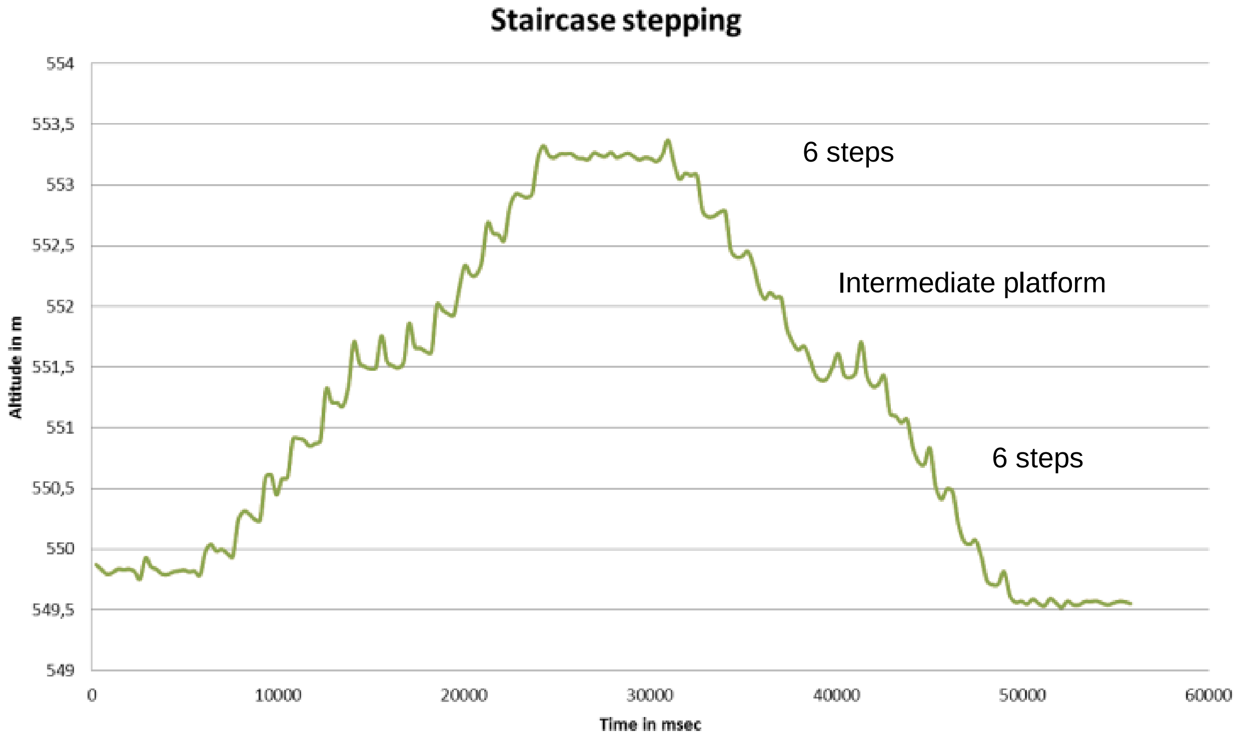
tinyML use Case: Motion Pattern Recognition
Sensor: Barometric Pressure Sensor

IFX pressure sensor detects

- Single steps or gestures
- Motions: Sitting, standing-up, walking, running
- Transient states

DPS310

Precision: ± 0.02 m
Rel. accuracy: ± 0.5 m
Abs. accuracy: ± 8 m



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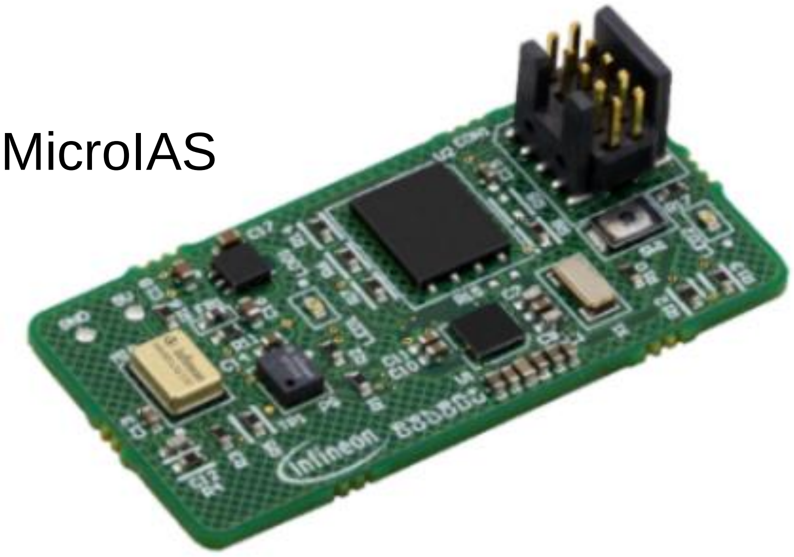
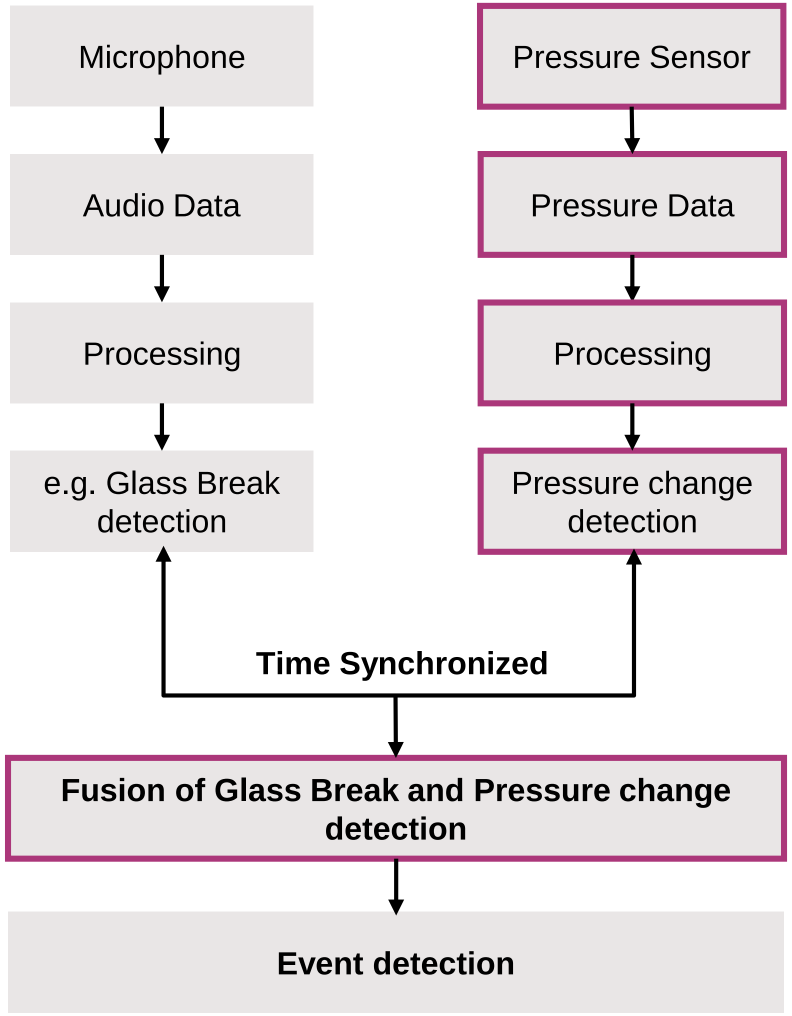
tinyML Use Case: Alarm System
Sensor: Pressure and Microphone

MicroIAS



- ARM Cortex M4-F 80 MHz
- 512 KB SRAM, 8 MB SPI-Flash
- DPS310 – digital pressure sensor
- IM69D130 – digital microphone
- AIML based event detection



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Data Acquisition
Sensor: Pressure and Microphone

- Glass break audio data is available but no pressure data
- Data obtained destructive experiment and manual labeling
- This becomes expensive …

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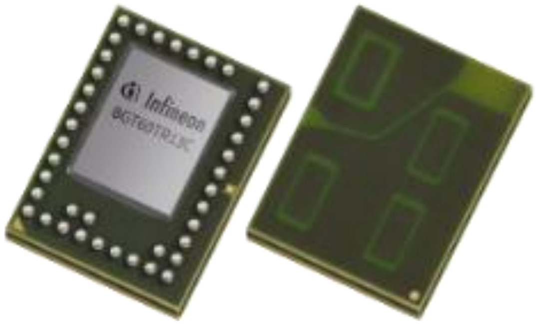
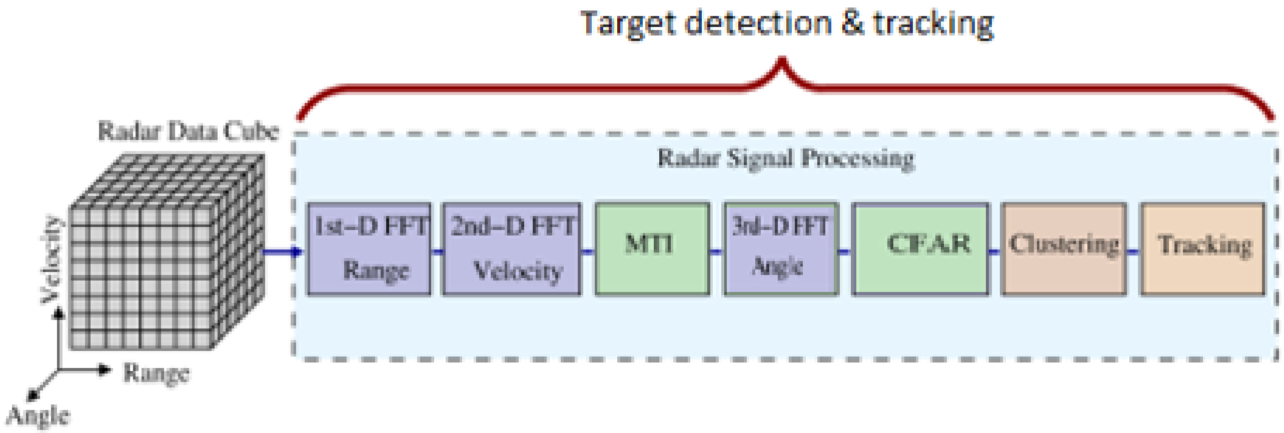
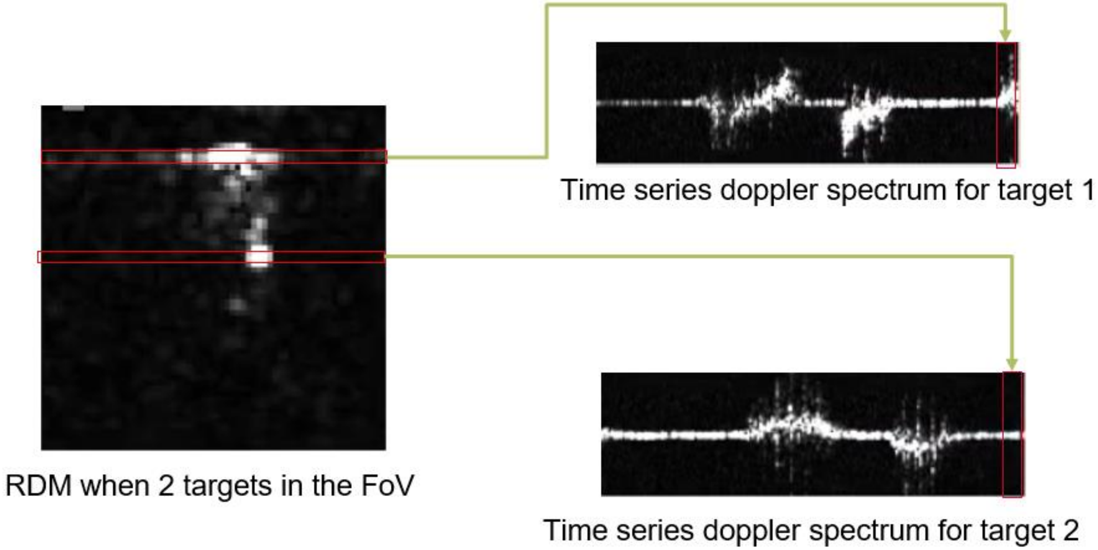
Sensor: 60 GHz Radar





BGT60TR13C

- Antennas: 1x Tx, 3x Rx (integrated)
- Size: 5x6.5 mm2
- Power Consumption: <5 mW (duty cycled)
- Bandwidth: >5 GHz, Range resolution ~3 cm
- SNR: Can detect people up to 15 m
- Ramp speed: 800 MHz/µs



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tinyML Use Case: Gesture Recognition
Sensor: 60 GHz Radar

- Detect and classify three different gestures
  - Right swipe
  - Left swipe
  - Waving pattern
- Reject unknown gestures
- Signal the detected gesture using a LED on the board

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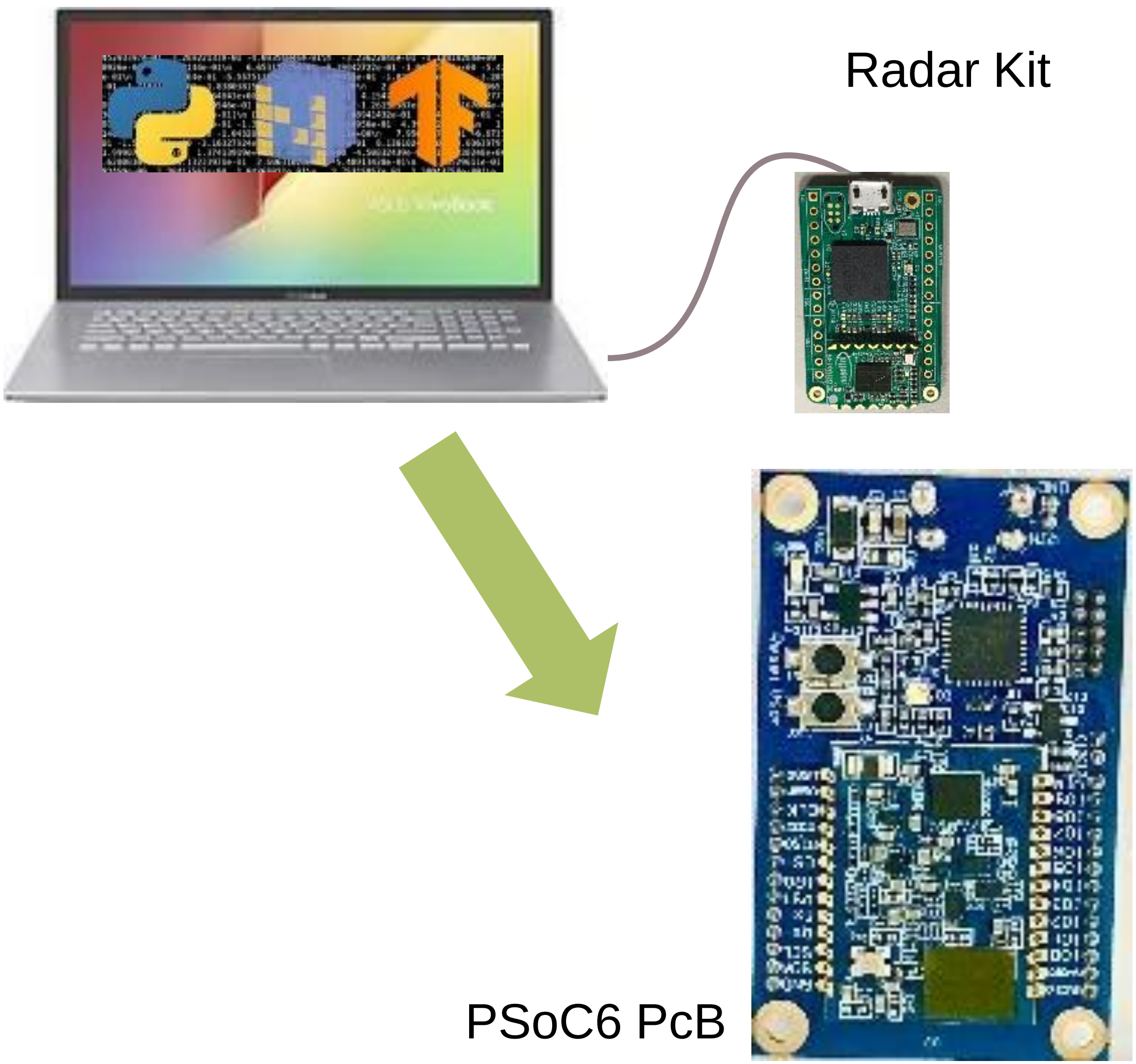
tinyML Use Case: Gesture Recognition
Sensor: 60 GHz Radar

Unconstrained implementation:

- Standard Laptop
- 60 GHz Radar Demo Kit
- Python based application code
- Tensorflow Model
- Using a total RAM footprint of ~1 GByte

Standalone embedded implementation:

- Formfactor PCB
- Soli C Radar Sensor, 1xTx, 3xRx
- Uses Tensorflow Lite / Micro
- IFX-Cypress PSoC6 MCU
  - Arm M4 Processor running @150 MHz
  - and a total RAM footprint of 288 kByte



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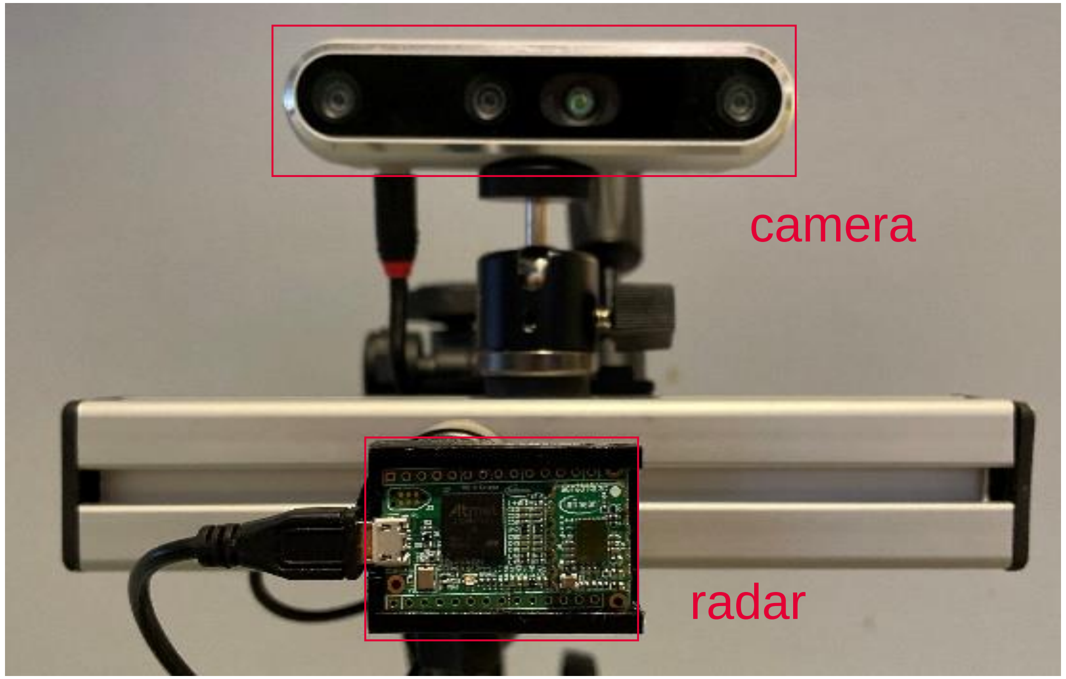
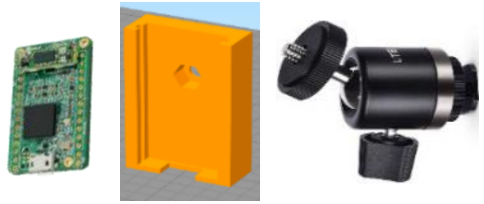
Data Acquisition
Sensor: 60 GHz Radar

DAQ Kit for Radar

- Single depth camera for ground truth generation
- Highly portable & minimum setup effort
- Flexible assembly on base frame
- Python package for data acquisition





Radar board
3d printed radar housing

+

RealSense

+

Base frame

+

Tripod

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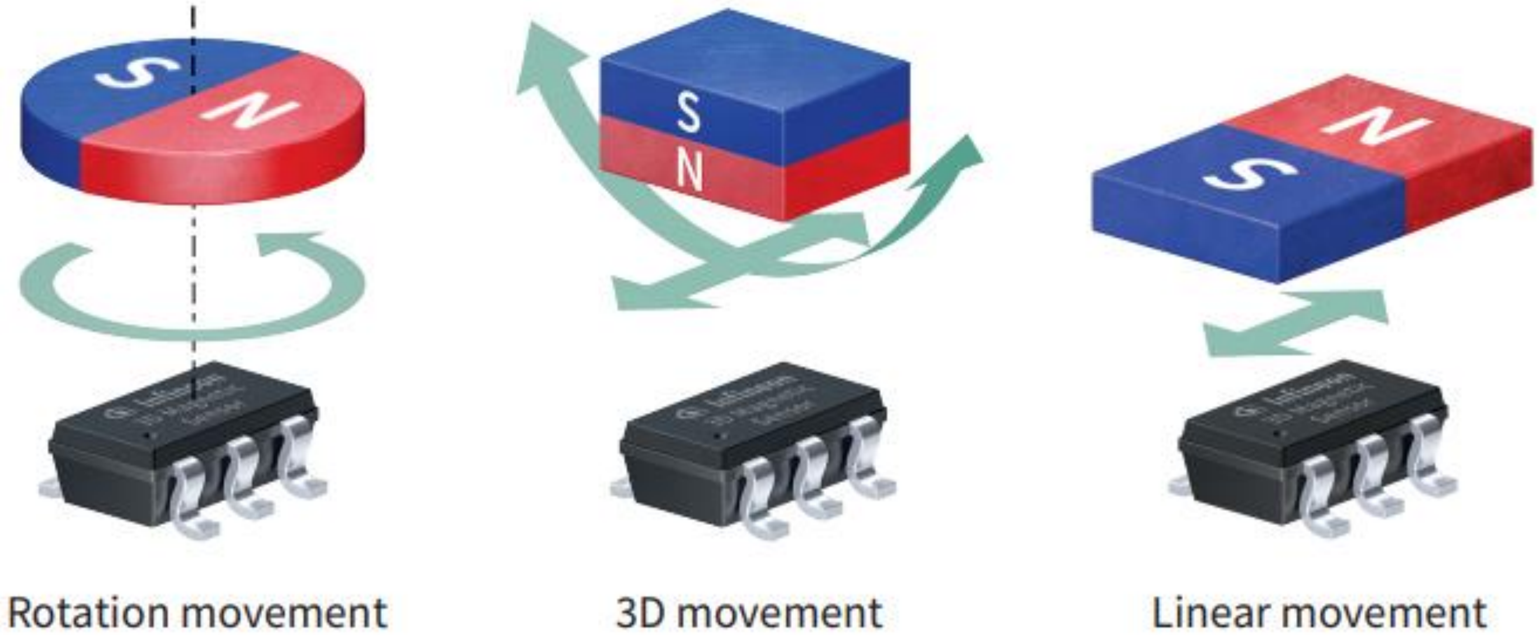
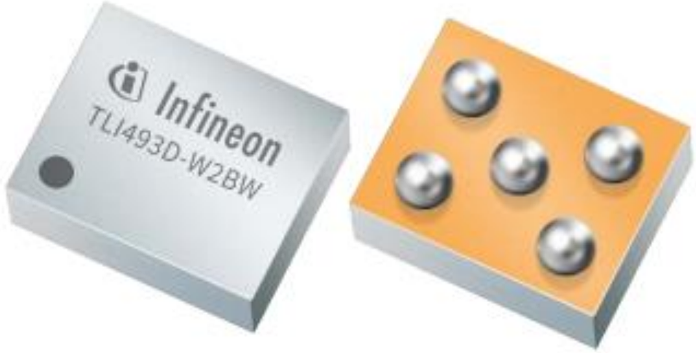
Sensor: 3D Magnetic Hall Sensor



TLI493D



- Bx, By and Bz linear magnetic field measurement up to ±160 mT
- 12-bit data resolution for each measurement direction
- Sensitivity 7.7 to 30.8 LSB12/mT
- Sample rate 0.05 ... 7.8 kHz

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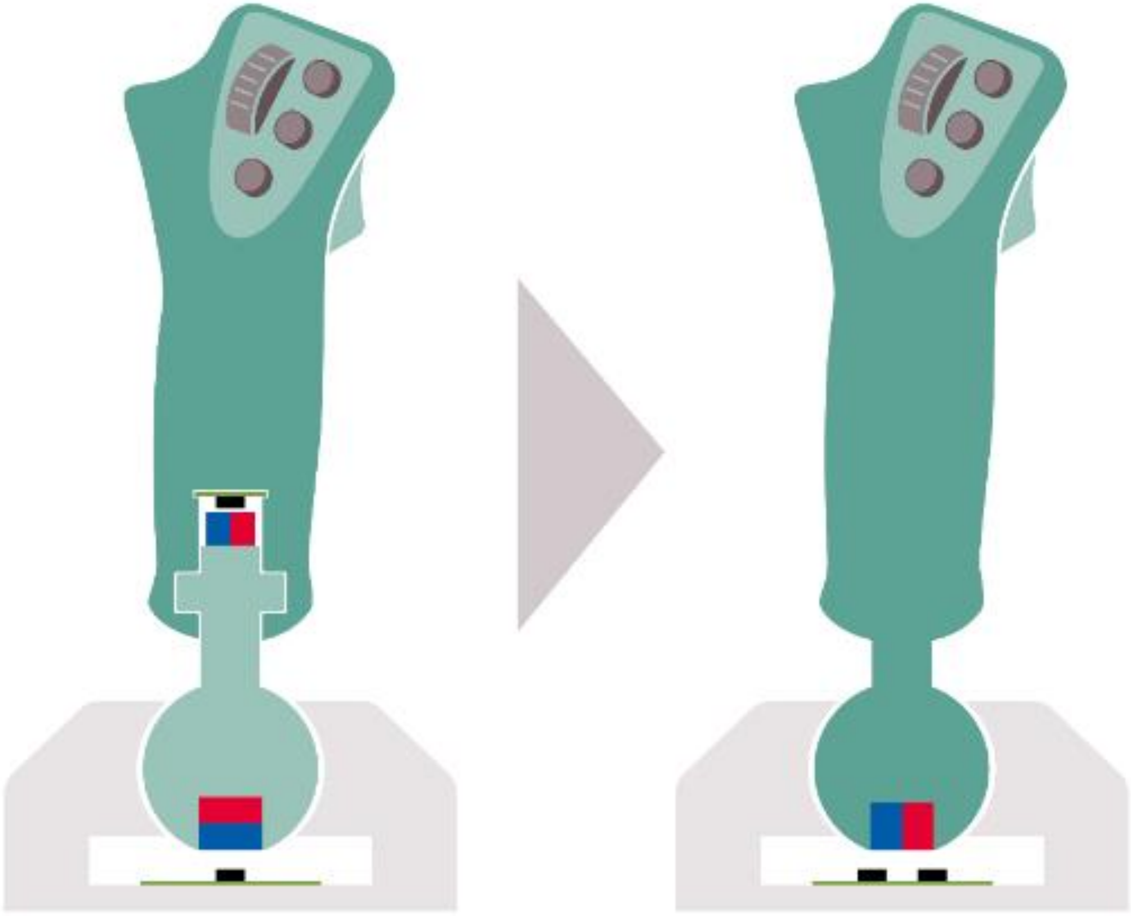
tinyML Use Case: Rotatable Joystick
Sensor: 3D Magnetic Hall Sensor

Simplified system 3-axis joystick

- Two 3D magnetic hall sensors
- Only one magnet
- Complex field geometry simulated in Python
- Sensor raw data:
  Bx, By and Bz from two magnetic field sensors
- Desired output:
  - X and y tilt
  - Rotation angle



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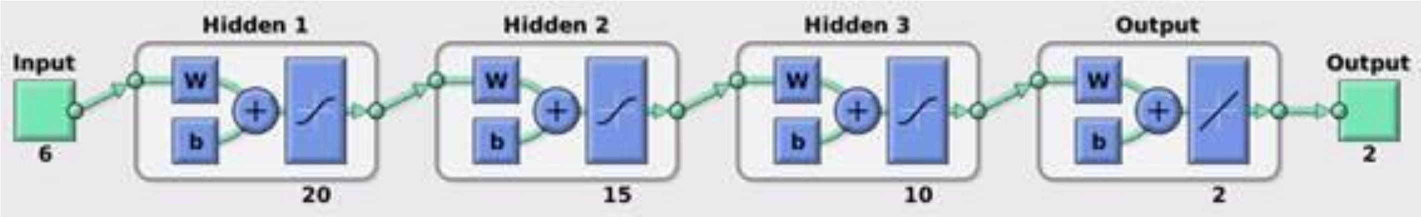
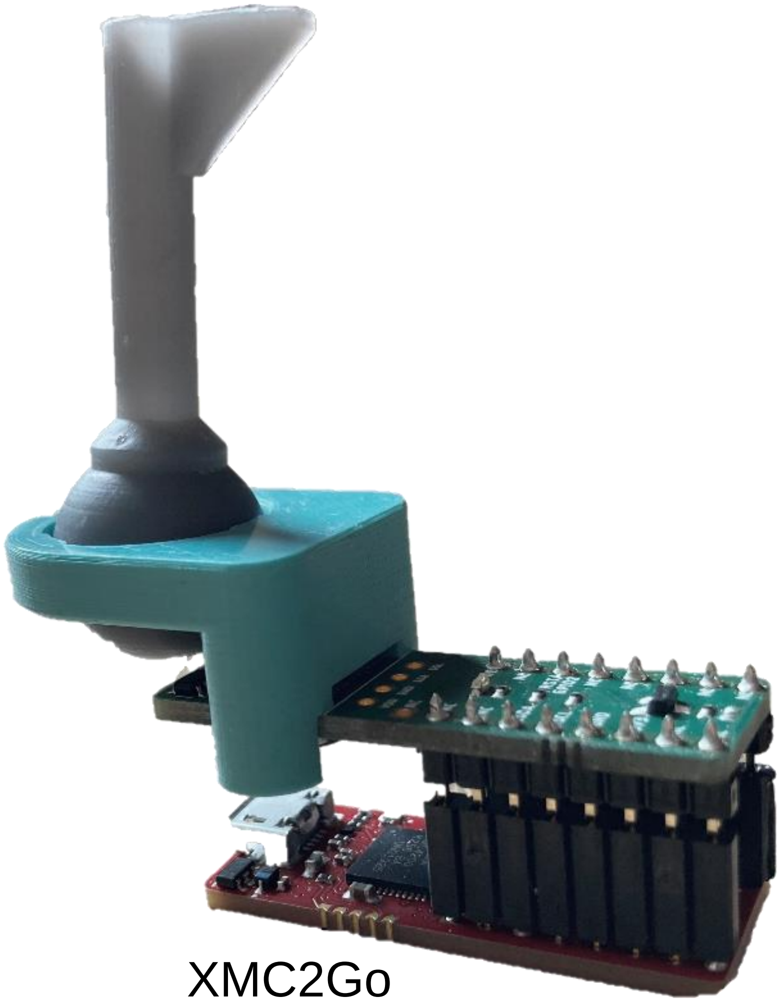
tinyML Use Case: Rotatable Joystick Sensor: 3D Magnetic Hall Sensor

Network architecture
- 1x FFNN for x/y tilt
- 1 x FFNN for rotation angle sine and cosine
- Both FFNN 3 hidden layers, 637 parameters each
- Position algo trained to NN with MathWorks Deep Learning Toolbox



Implementation
- IFX XMC2Go board with ARM M0 processor
- Code generation with MATLAB Coder
- Quantization to INT16, no retraining
- NN inference time: 23 ms
- Embedded code size: 19 KB (incl. pre-/post-processing)
- Free for application: 45 KB



XMC2Go

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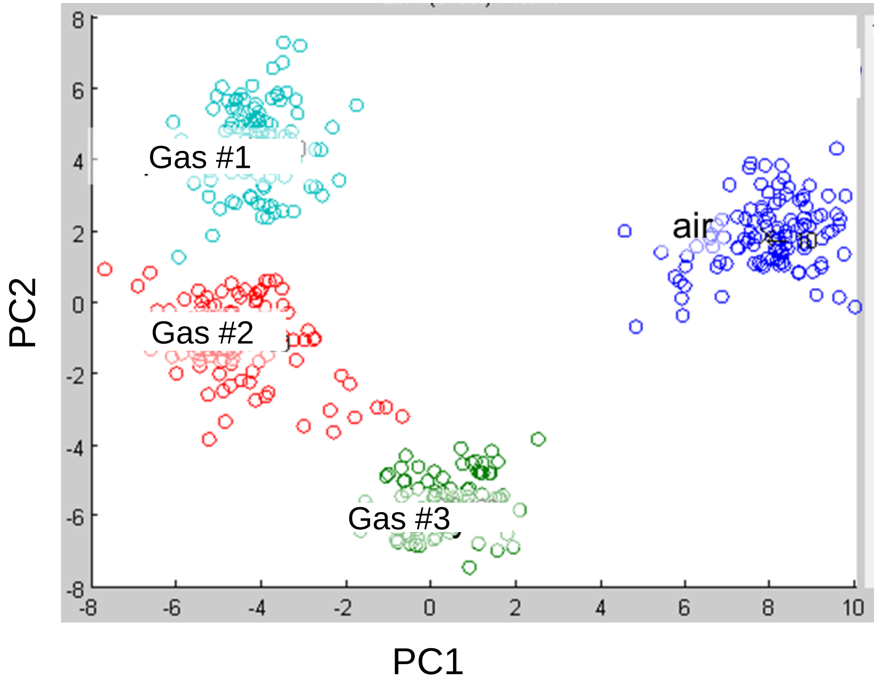
Sensor: Gas (e.g. CO2)



XENSIV™ PAS CO2

- Photoacoustic Spectroscopy based
- Small form factor (14 x 13.8 x 7.5 mm3)
- High accuracy (±30 ppm ±3% of reading)

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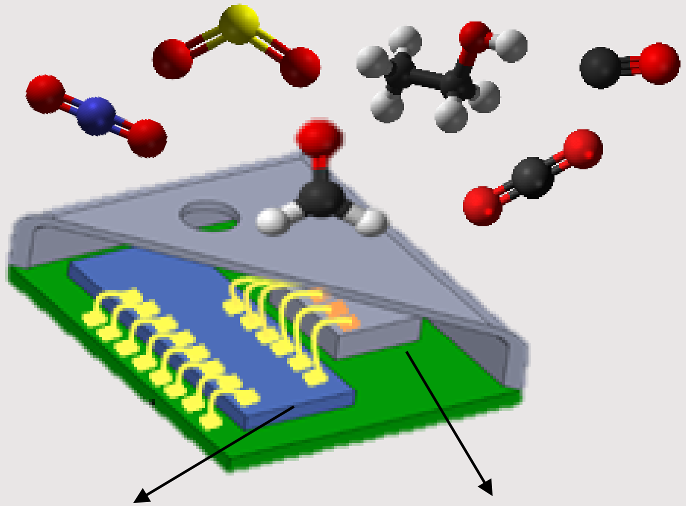
tinyML Use Case: Air Quality Monitoring
Sensor: Gas (CO2, CO, NOx, O3, …)

Smart Sensor

- Embedded Sensor Processing with RNN
- Gas concentration deliverd in PPM
- I2C and SPI interface
- Embedded Flash 32 kB
- Embedded SRAM: 4 kB

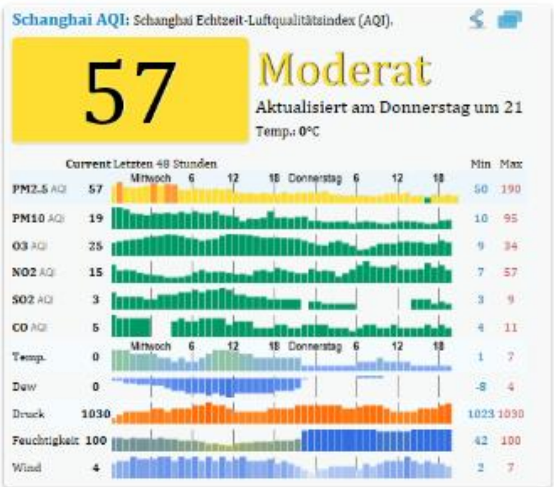


PSoC® Analog Coprocessor (Arm® Cortex®-M0+)

Sensor MEMS

Indoor Air Quality

Outdoor Air Quality



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Overview

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3 The future of sensors and tinyML

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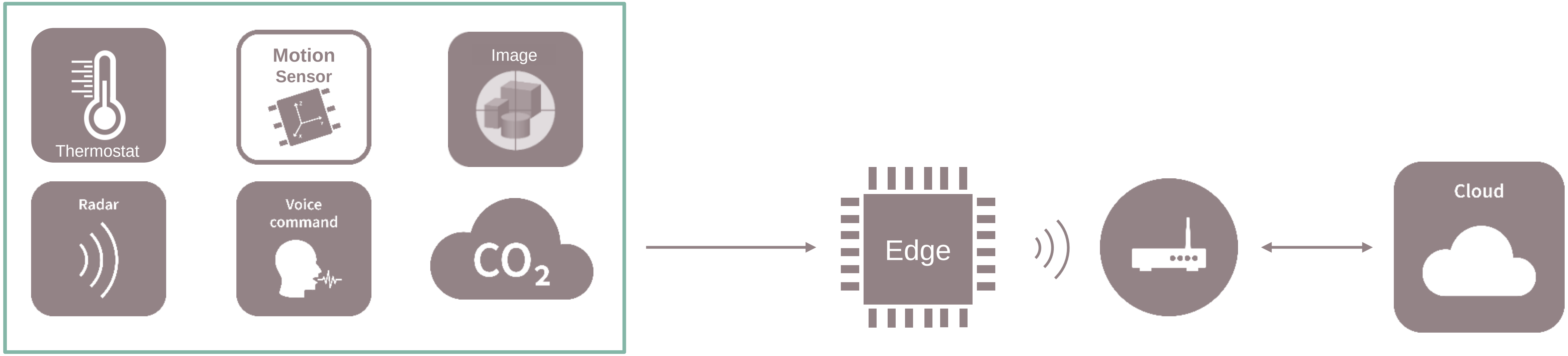
Unlocking the value of Edge AI



- **Processing** – Meet application performance requirements with confluence of light weight ML accelerators AND reduction in software footprint (tinyML)
- **Sensing & data** – Provide miniaturized low power sensors with training data
- **Security** – Deliver data privacy to latest, ever increasing, standards – starting with root of trust
- **Ecosystem** – Provide development system, lifecycle management, connectivity, could services

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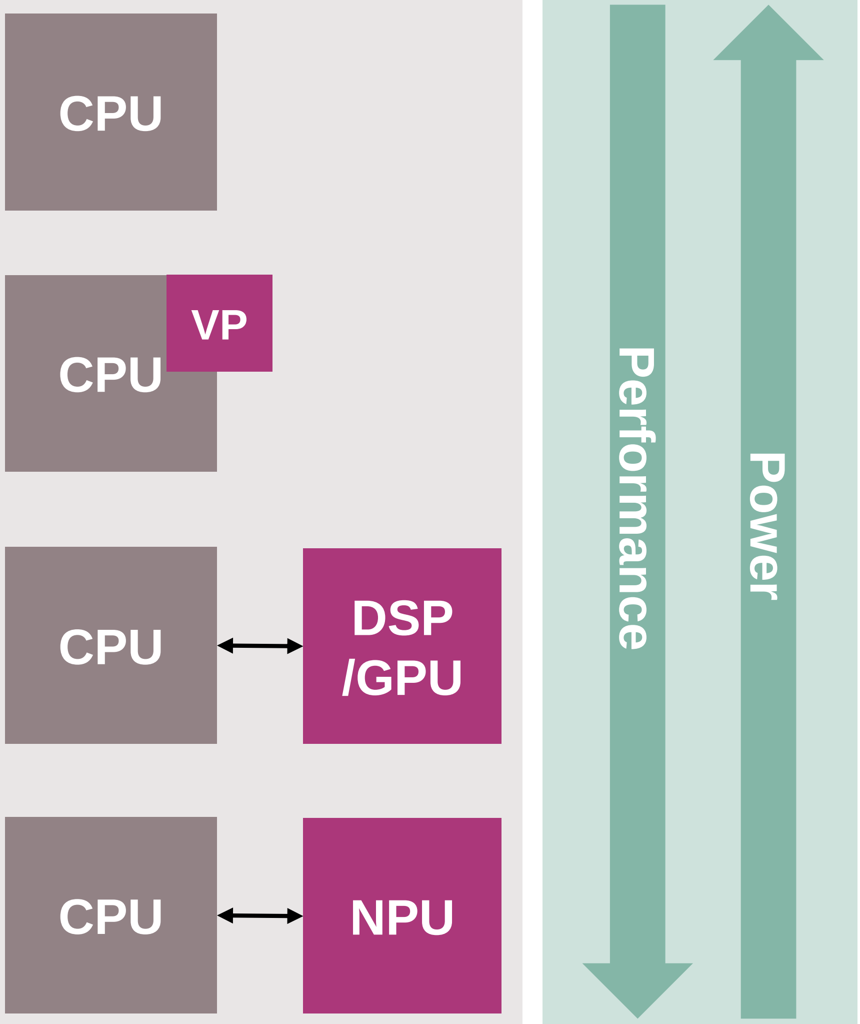
There are several ways to accelerate neural networks in silicon and they can be chosen according to the respective field of application

CPU only
- AI in software

CPU with extensions
- Vector processing extensions

CPU + DSP/GPU
- Digital Signal Processor
- Graphics Processing Unit

CPU + NPU
- Specialized Neural Processing Unit



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Benchmarking of ARM Cortex-M4 / M7 / M55 and Ethos-U55-xy

Modell: MobileNet_v1_ 1.0 _224_quant ***	**Standard MC**		**MC + Vector Ext.**	**AI Accelerators (NPU)**			
	M4 (Cypress PSoC6)	**M7**	**M55**	**U55-32**	**U55-64**	**U55-128**	**U55-256**
Cycle count	2,903,927,184	2,770,050,574	504,600,758	20,418,884	10,500,041	5,741,145	3,338,857
Inference time @ 250 Mhz in ms	**11,615.70**	**11,080.20**	**2,018.40**	**81.86**	**42.00**	**22.96**	**13.36**
Relative to M4	100%	95.4%	17.4%	0.7%	0.4%	0.2%	0.1%
Max. Frame Rage in Hz	0.09	0.09	0.50	12.22	23.81	43.55	74.85

Data obtained by Infineon

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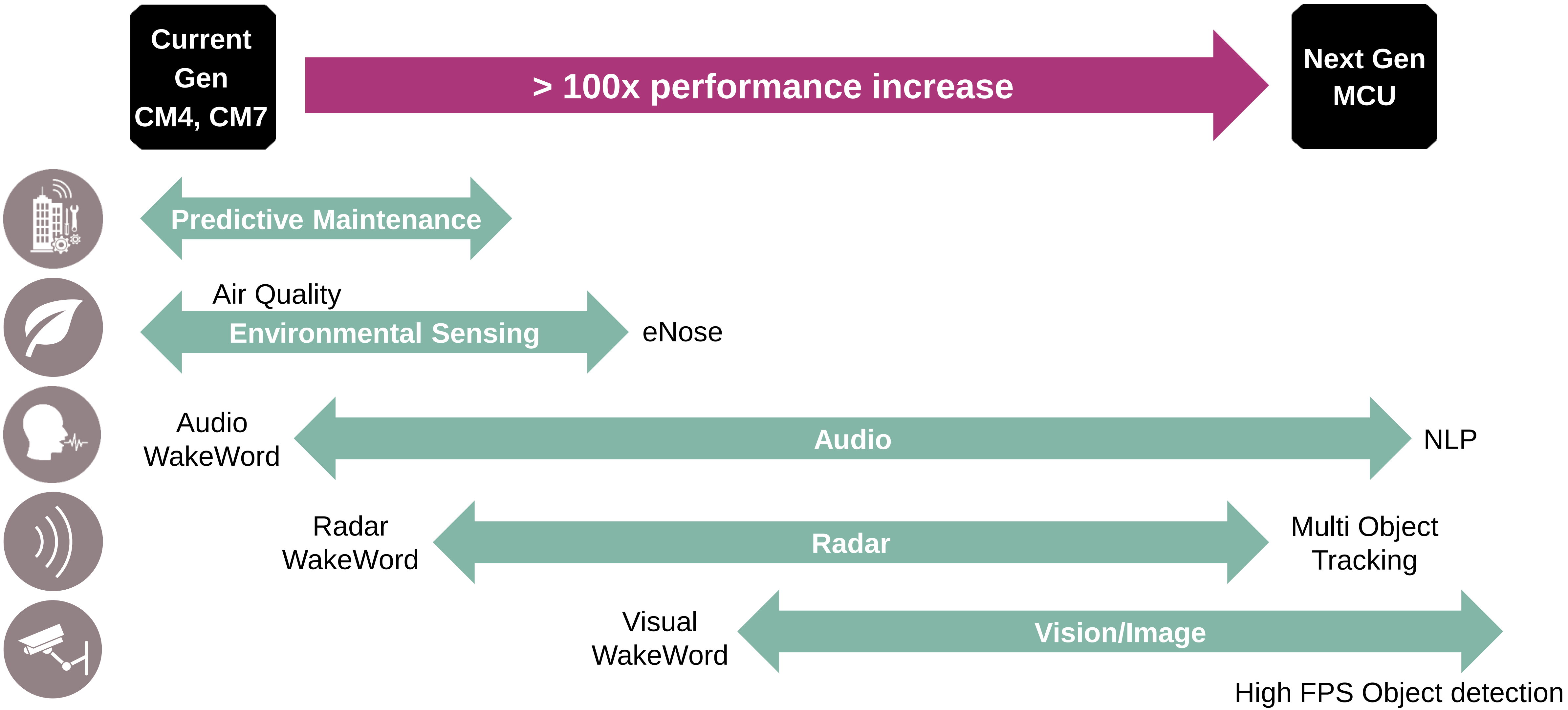
The next generation of MCUs will enable new applications at the Edge



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Securing the edge is essential to run trusted, distribute AI

Fake devices !

› Secured storage of device identity and device authentication protocols

Data poisioning !

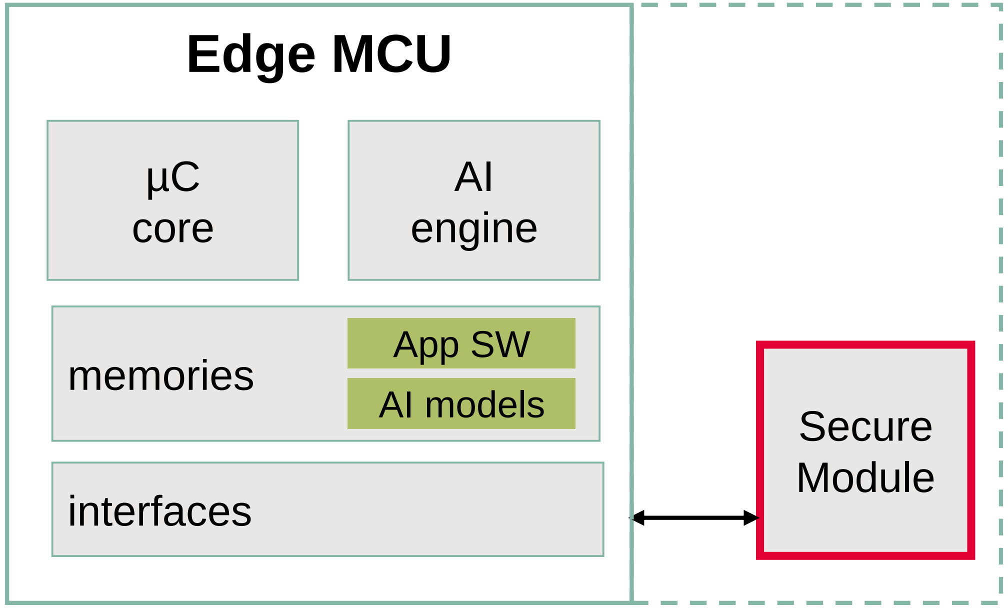
› Secured communication protocols

Malware !

› Secured update of firmware and AI models

IP Loss !

› Secured storage and encryption



tinyML for Security

› Biometric authentication (e.g. fingerprint)

› Anomaly detection (e.g. intrusion detection)

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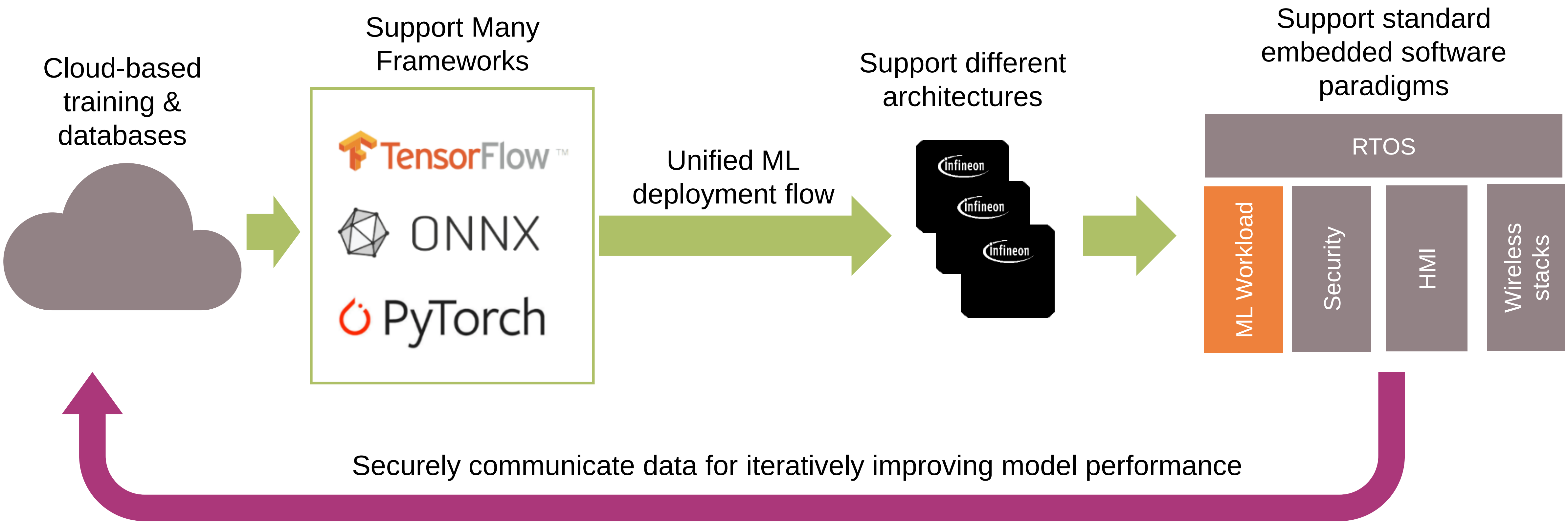
ML on the Edge – MCU Software Requirements



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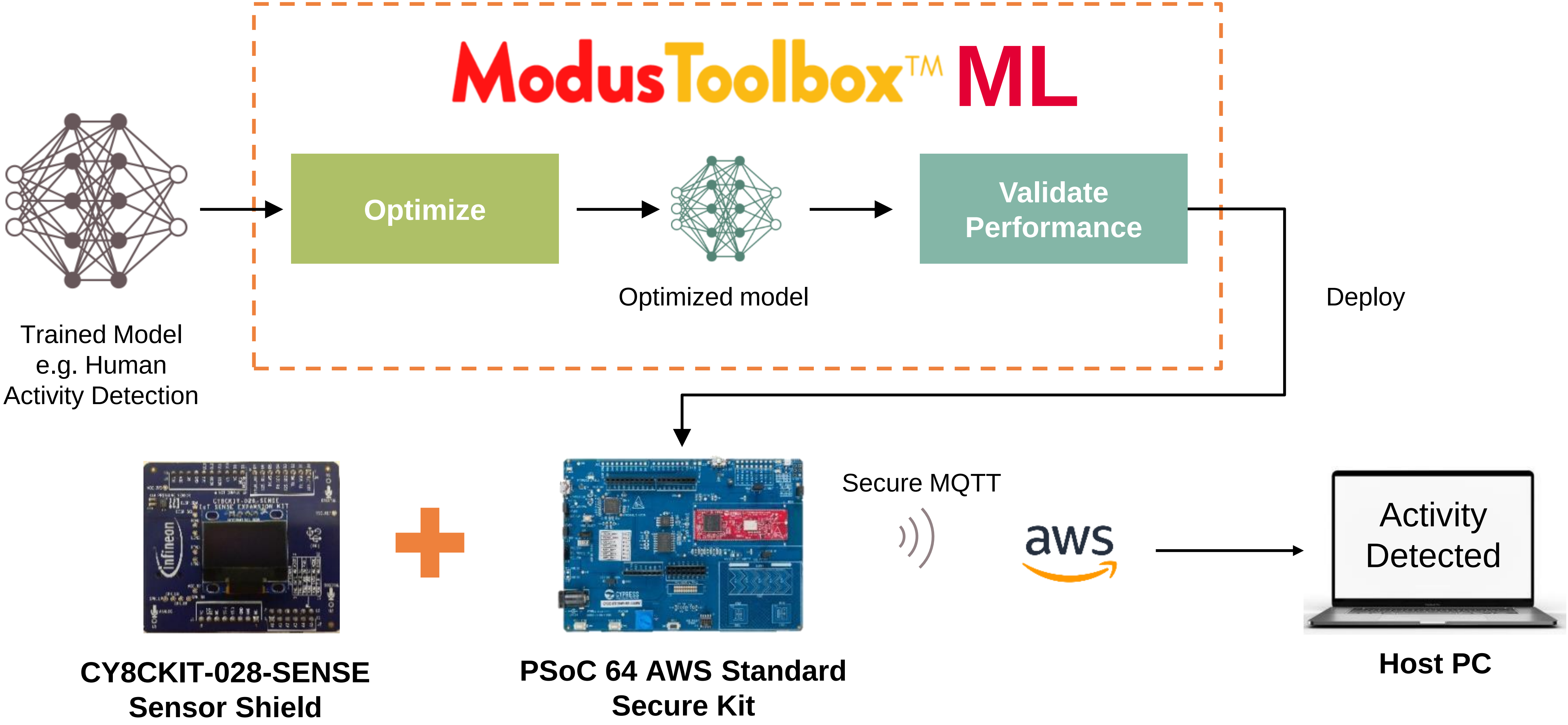
Evaluate and Deploy Models with Modus Toolbox ML



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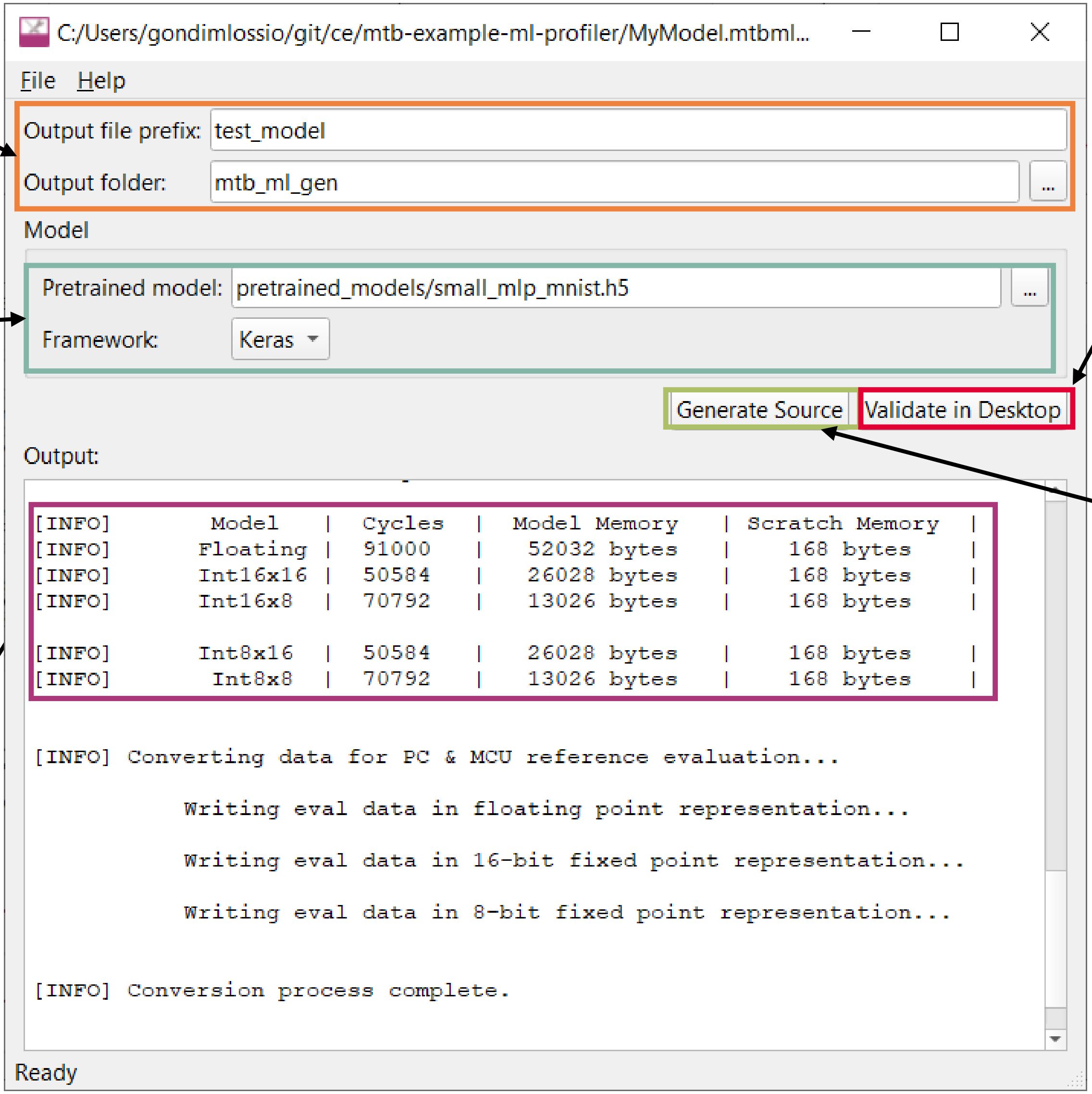
MTB-ML Configurator Tool – Model Conversion

Define the model prefix name and the output folder

Import your Model into the MTB-ML Configurator

Tool Provides information on
- Size of model(Flash)
- Memory needed(RAM)
- Approximate Computational complexity(cycles)



Open a new window to validate the model in the Desktop

Convert the model into optimized embedded variants

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MTB-ML Configurator Tool – Model Validation

Select either randomly generated validation data (or) specify test data

Run test data into the original model (reference) on the selected quantization

Tabular data of Maximum Absolute Error of each test set for all quantization

Print test results for each of the quantization

Plot of data in a specific test data set

Validation - ML Configurator 1.0

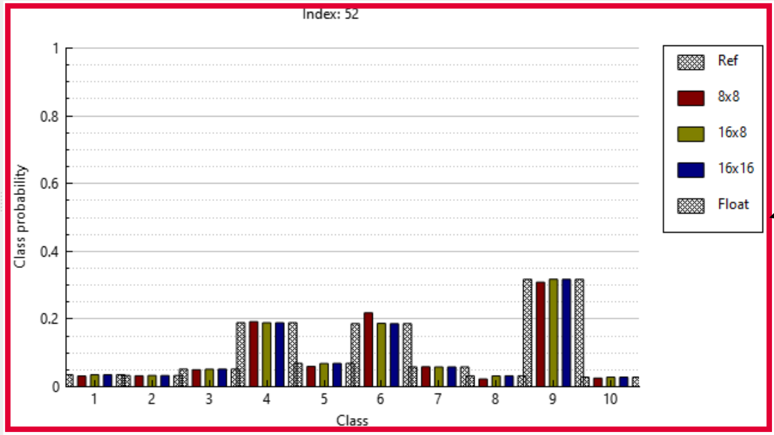
Dataset structure: Random

Sample count: 100

Quantization: ☑ 8x8 ☑ 16x8 ☑ 16x16 ☑ Float

Validate

Index	MAE 8x8	Index	MAE 16x8	Index	MAE 16x16	Index
52	0.0072	61	0.0004	3	0.0001	83
83	0.0062	3	0.0004	64	0.0001	15
54	0.0055	64	0.0004	0	0.0001	24
2	0.0050	96	0.0003	17	0.0001	14
48	0.0047	12	0.0003	8	0.0001	70
27	0.0042	33	0.0003	60	0.0001	82
96	0.0039	65	0.0003	6	0.0001	51
47	0.0039	62	0.0003	55	0.0001	86
20	0.0039	37	0.0003	54	0.0001	25
33	0.0038	49	0.0003	33	0.0001	71
16	0.0034	27	0.0003	1	0.0001	68




```
[INFO]: Expecting log files: ['test_model_log.txt', 'log_flt.txt']
[INFO] Model passed float relative accuracy verification
[INFO] Model passed float mismatch error verification
[INFO] Model passed float scratch memory verification
[INFO] Saving Cross-domain verification outputs for float to cdv_results...
[INFO] Cross-domain verification outputs for float saved to cdv_results


[INFO] Overall CDV Results
-------------------------

Float32 model: PASS
Int16x16 model: PASS
Int16x8 model: PASS
Int8x8 model: PASS
```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Useful Links/Resources

- New ModusToolbox Software and Tools Page
- Overview Landing Page for the MTB-ML
- PSoC® 64 Standard Secure - AWS Wi-Fi BT Pioneer Kit (CY8CKIT-064S0S2-4343W)
- IoT Sense Expansion Kit for MTB-ML for PSoC 6 Pioneer Kit (CY8CKIT-028-SENSE)
- MTB-ML Code Examples (mtb-example-ml-*) on GitHub Repository

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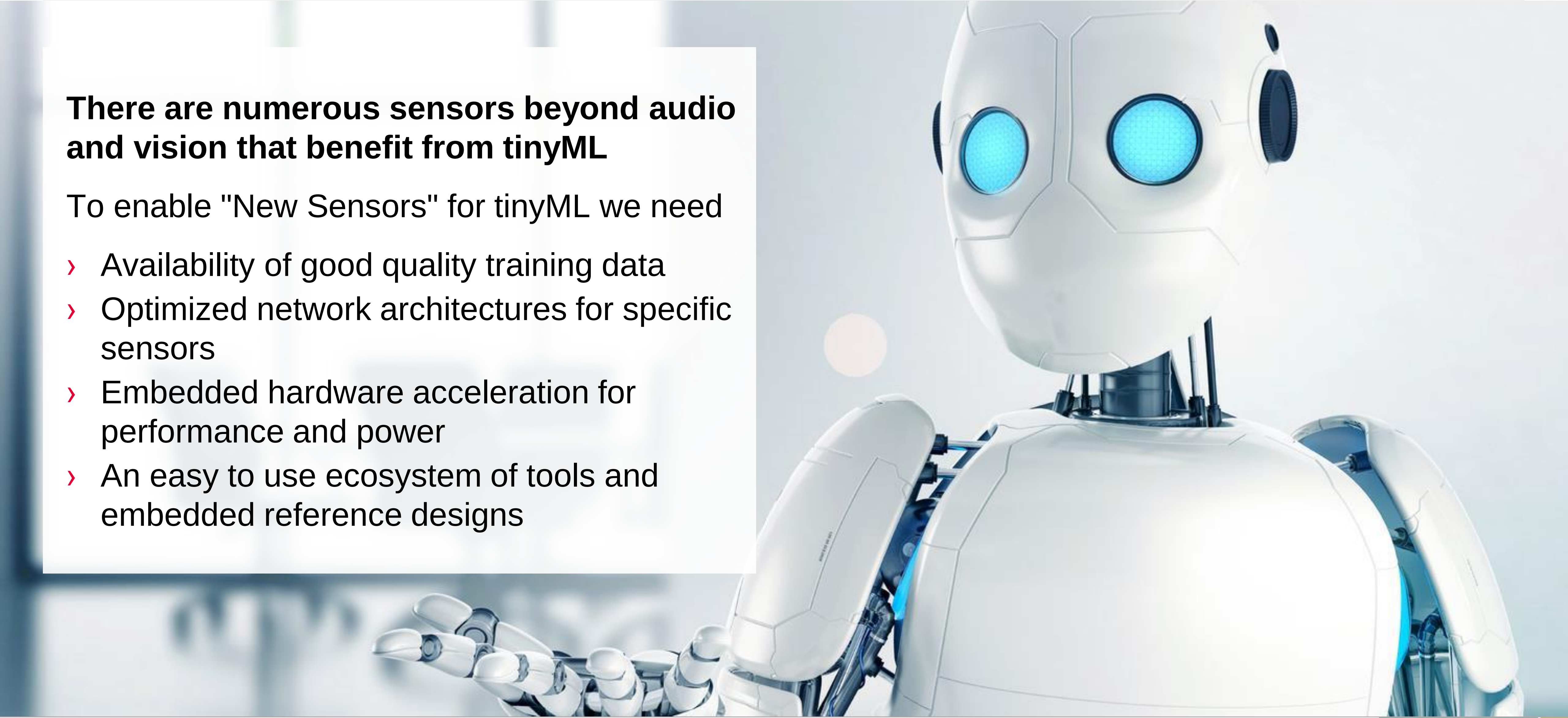
Conclusion

There are numerous sensors beyond audio and vision that benefit from tinyML

To enable "New Sensors" for tinyML we need

- Availability of good quality training data
- Optimized network architectures for specific sensors
- Embedded hardware acceleration for performance and power
- An easy to use ecosystem of tools and embedded reference designs



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Zero-code SaaS solution

Create tiny models, ready for embedding, in just a few clicks!

Compare the benchmarks of our compact models to those of TensorFlow and other leading neural network frameworks.

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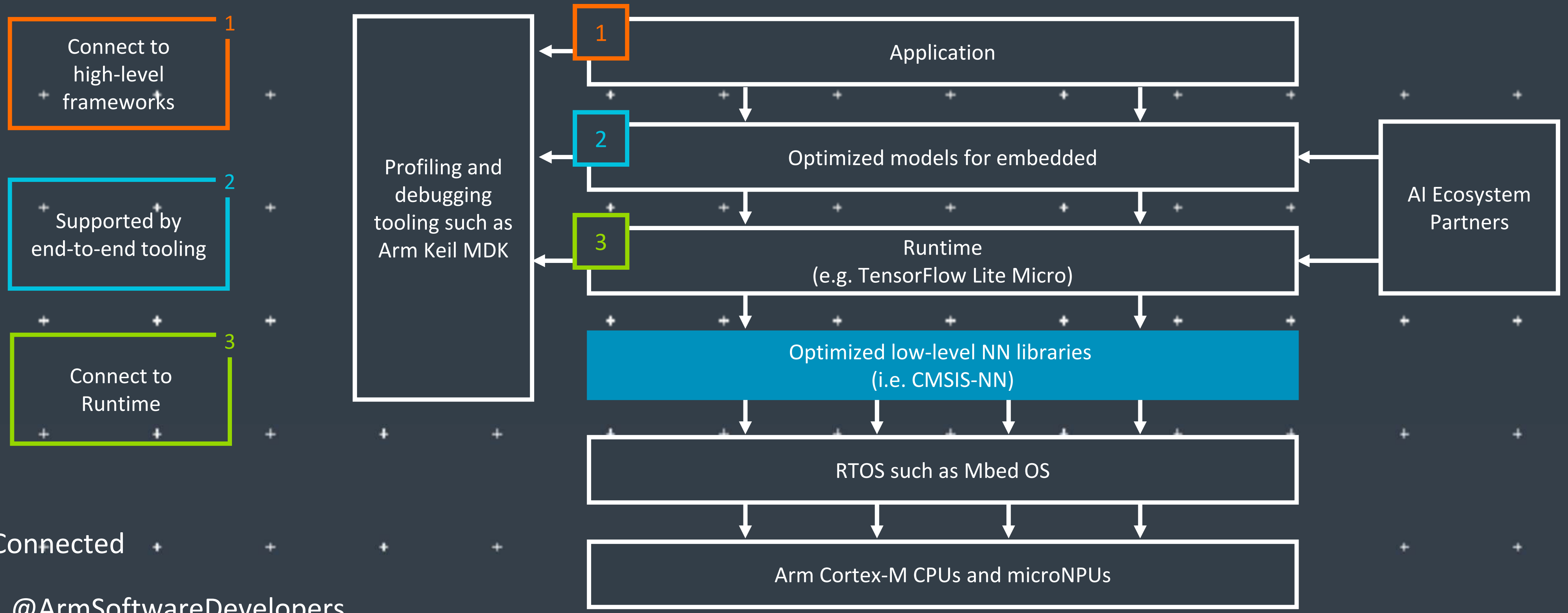
Arm: The Software and Hardware Foundation for tinyML



Stay Connected

@ArmSoftwareDevelopers

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Resources: developer.arm.com/solutions/machine-learning-on-arm

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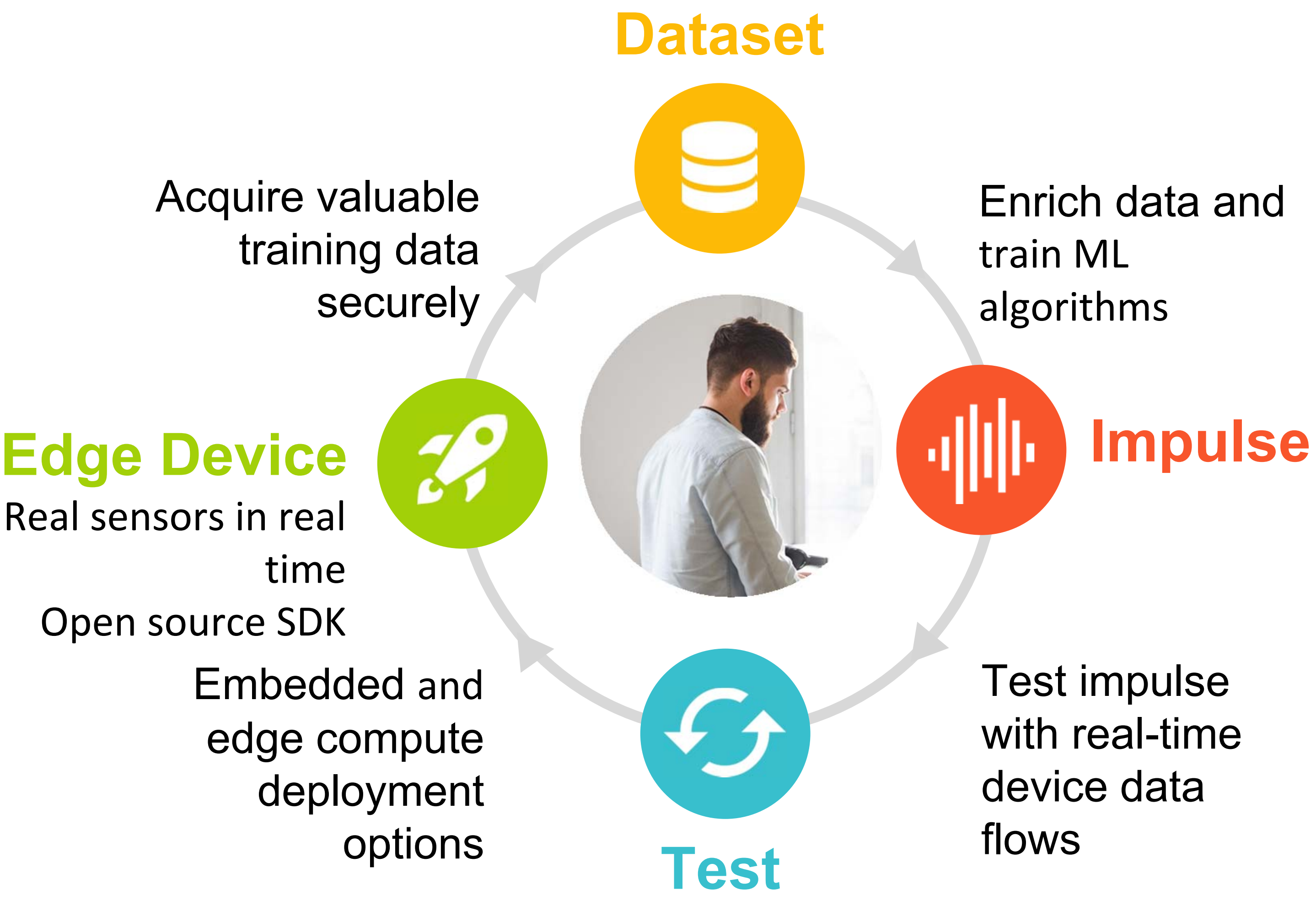
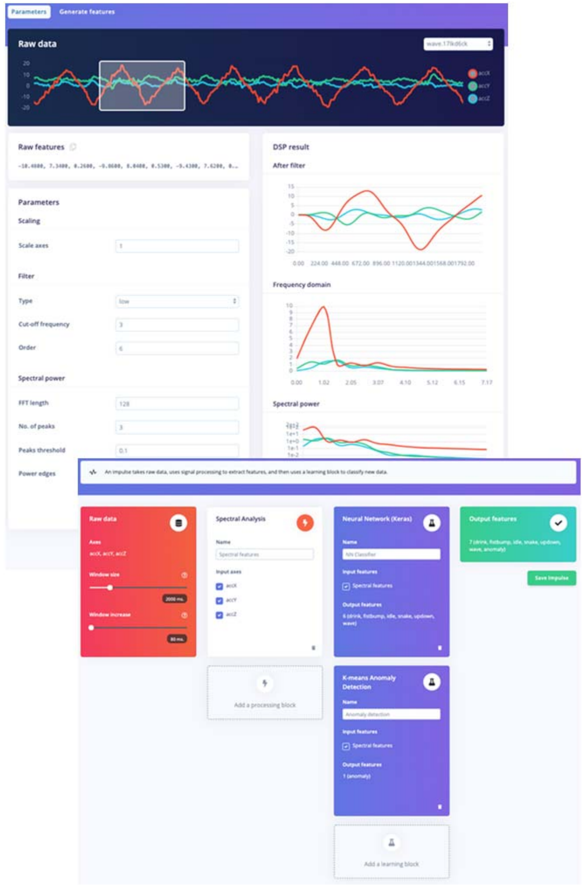
TinyML for all developers

C++ library

Arduino library

WebAssembly





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Qualcomm
AI research

Advancing AI research to make efficient AI ubiquitous

Power efficiency

Model design, compression, quantization, algorithms, efficient hardware, software tool

Personalization

Continuous learning, contextual, always-on, privacy-preserved, distributed learning

Efficient learning

Robust learning through minimal data, unsupervised learning, on-device learning

A platform to scale AI across the industry

Perception

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Action

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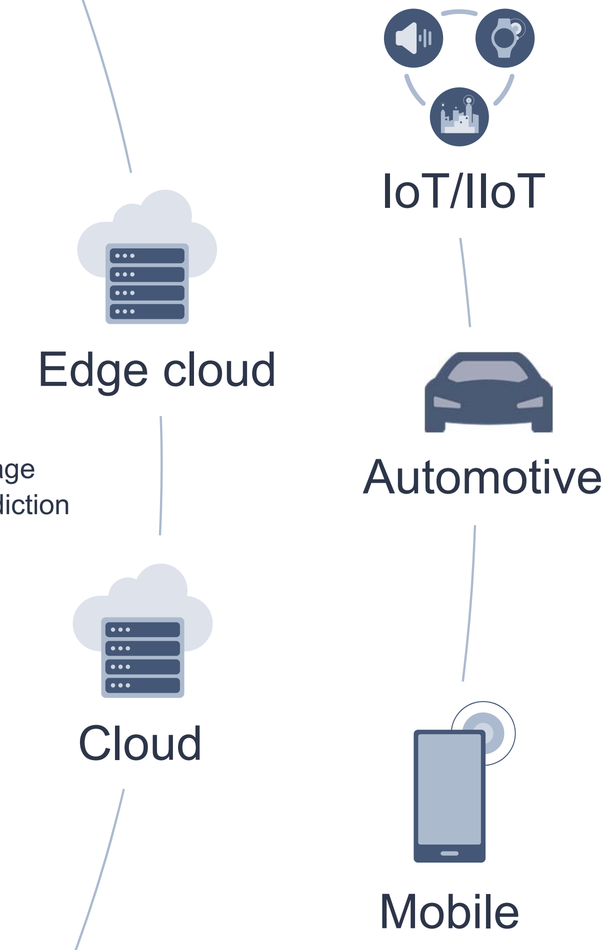

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Founded in 2017 and headquartered in Irvine, California, the company is backed by Amazon, Applied Materials, Atlantic Bridge Capital, Bosch, Intel Capital, Microsoft, Motorola, and others. Syntiant was recently named a CES® 2021 Best of Innovation Awards Honoree, shipped over 10M units worldwide, and unveiled the NDP120 part of the NDP10x family of inference engines for low-power applications.

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