tinyML® Summit

Miniature dreams can come true...

March 28-30, 2022 | San Francisco Bay Area

www.tinyML.org

TinyML
March 23, 2022

Sensing Applications as a Driver for TinyML Solutions

PD Dr. Victor Pankratius

Bosch Sensortec
Head of Global Software Engineering

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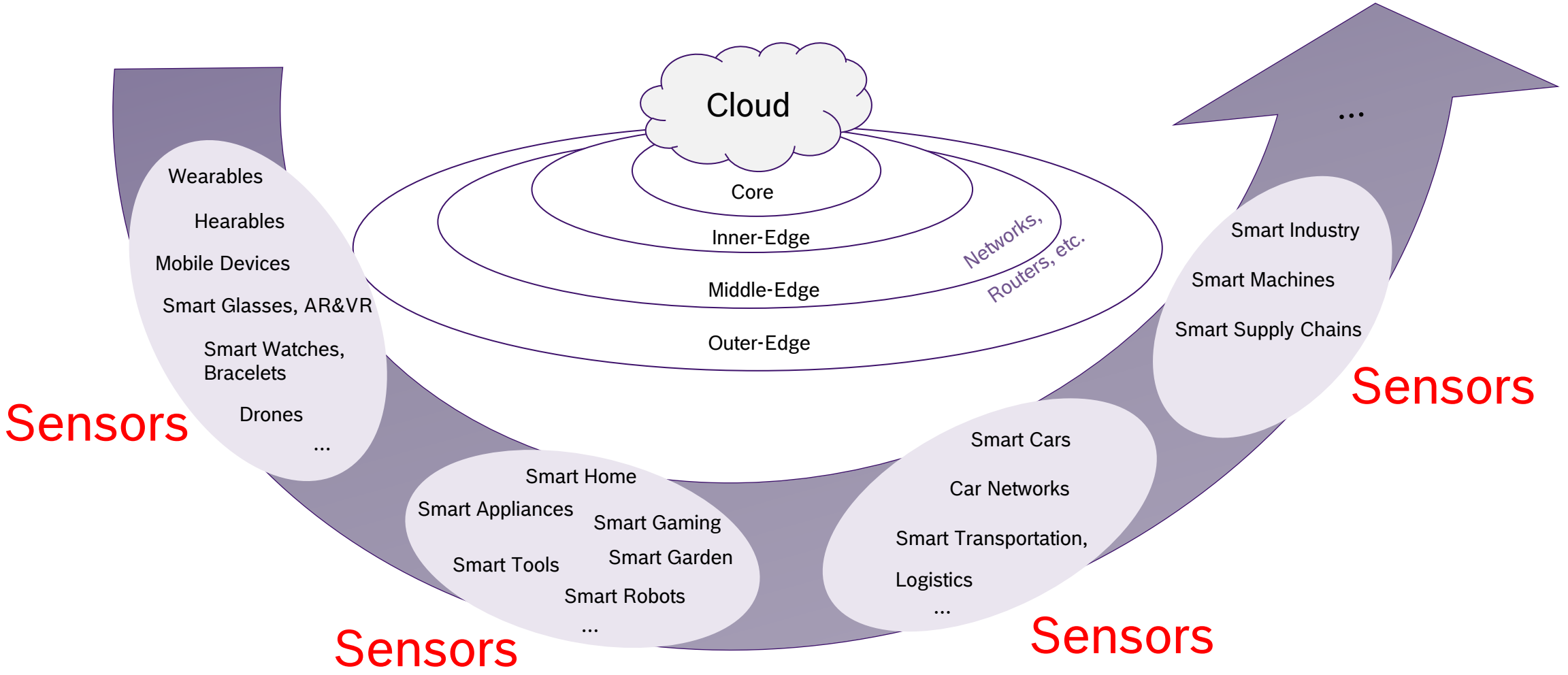
Trends



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Sources: Pankratius lecture &

Based on: https://media.wiley.com/product_data/excerpt/89/11195249/1119524989-14.pdf

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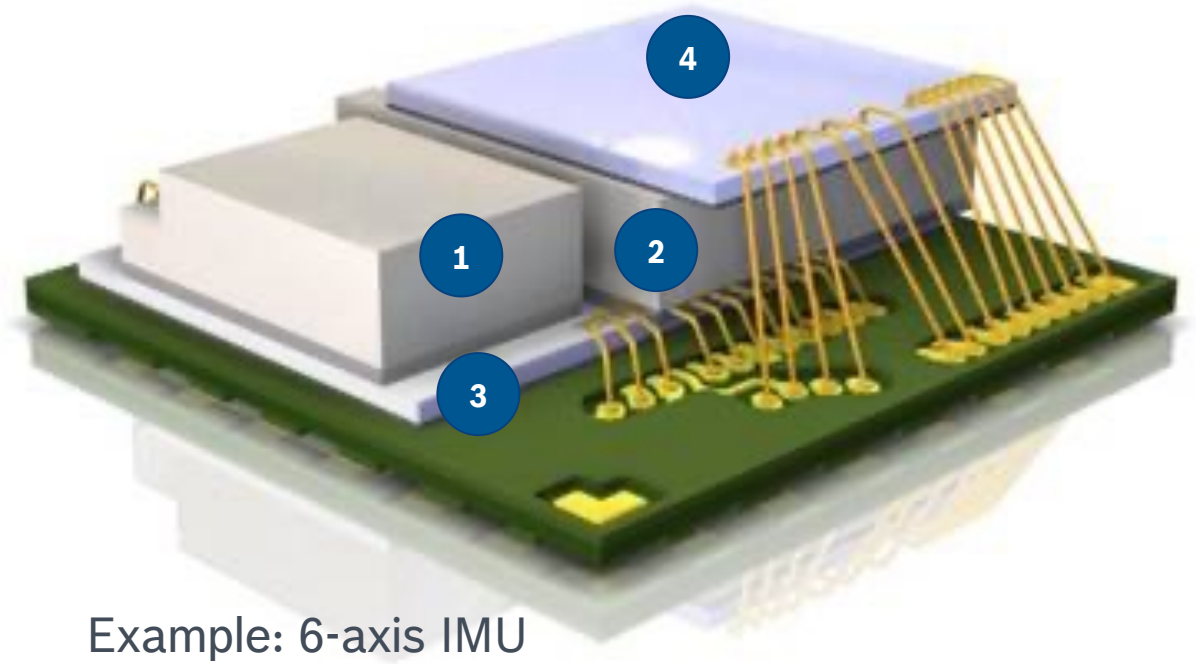
The Edge needs sensors that are



Example: 6-axis IMU

+ microcontroller

+ embedded software

smart, compact, all-inclusive

1. MEMS accelerometer
2. MEMS gyroscope
3. ASIC
4. Microcontroller

Hardware & software in one package enable

TinyML on sensors

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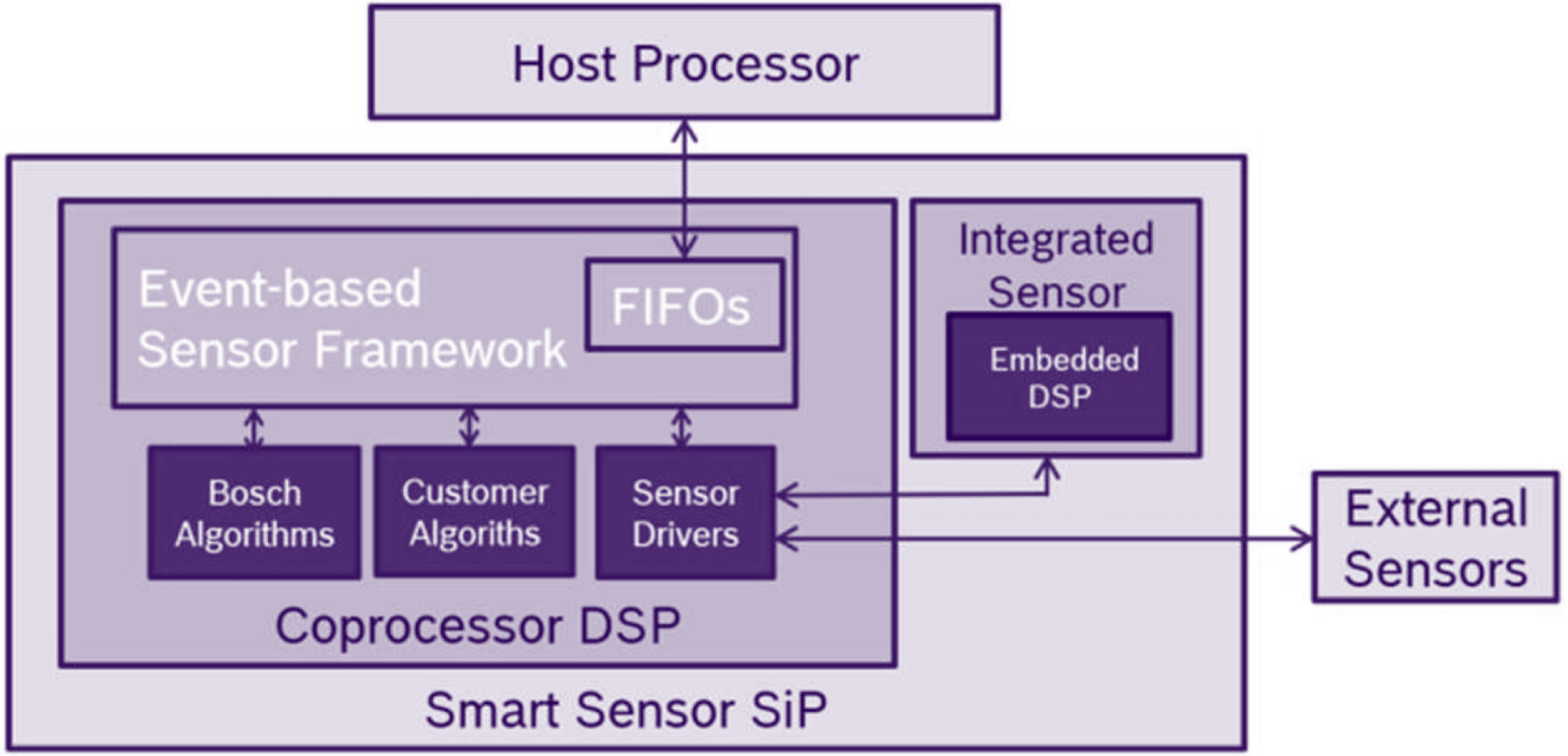
Architecture of a Smart Sensor System-in-Package



Lammel et al., Smart System Architecture for Sensors with Integrated Signal Processing and AI, Smart Systems Integration, 2021

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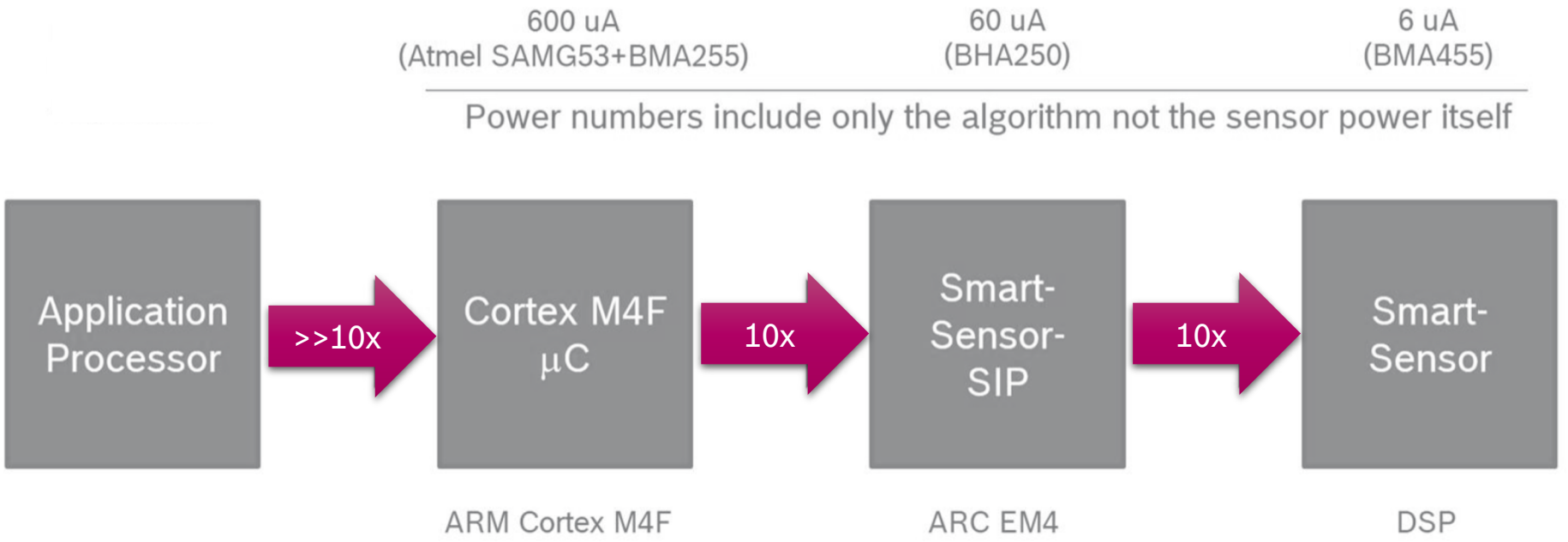
Pushing Algos to Sensor Reduces Power Consumption

Example: Bosch Sensortec Step Counter



~10x power reduction per hierarchy level in sensor subsystem

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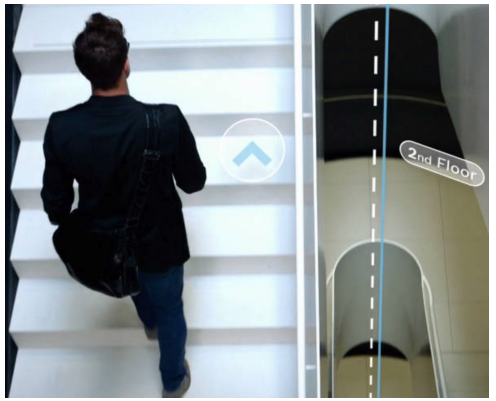
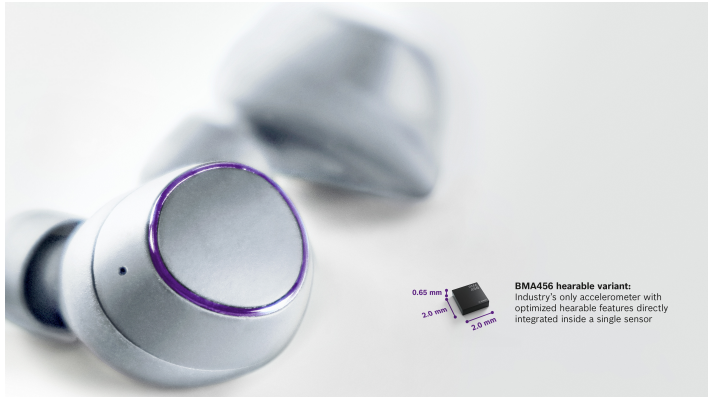
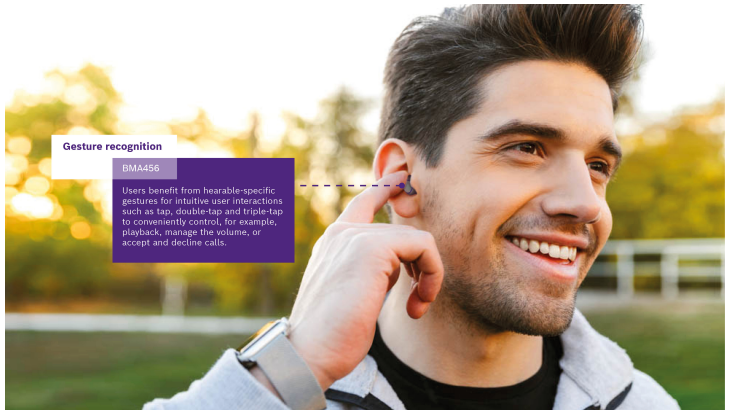
Example Applications: Gestures, Indoor Navigation, HCI

https://www.bosch-presse.de/pressportal/de/en/bosch-announces-industrys-first-position-tracking-smart-sensor-bhi160bp-for-wearables-175104.html



https://www.bosch-presse.de/pressportal/de/en/accurate-indoor-localization-can-save-thousands-of-lives-%E2%80%93-enabled-by-pressure-sensing-solution-210368.html





https://www.bosch-presse.de/pressportal/de/en/hearables-bosch-brings-smart-features-to-your-ear-192128.html

https://www.bosch-presse.de/pressportal/de/en/more-than-meets-the-eye-bosch-enables-the-next-generation-of-smartglasses-204480.html

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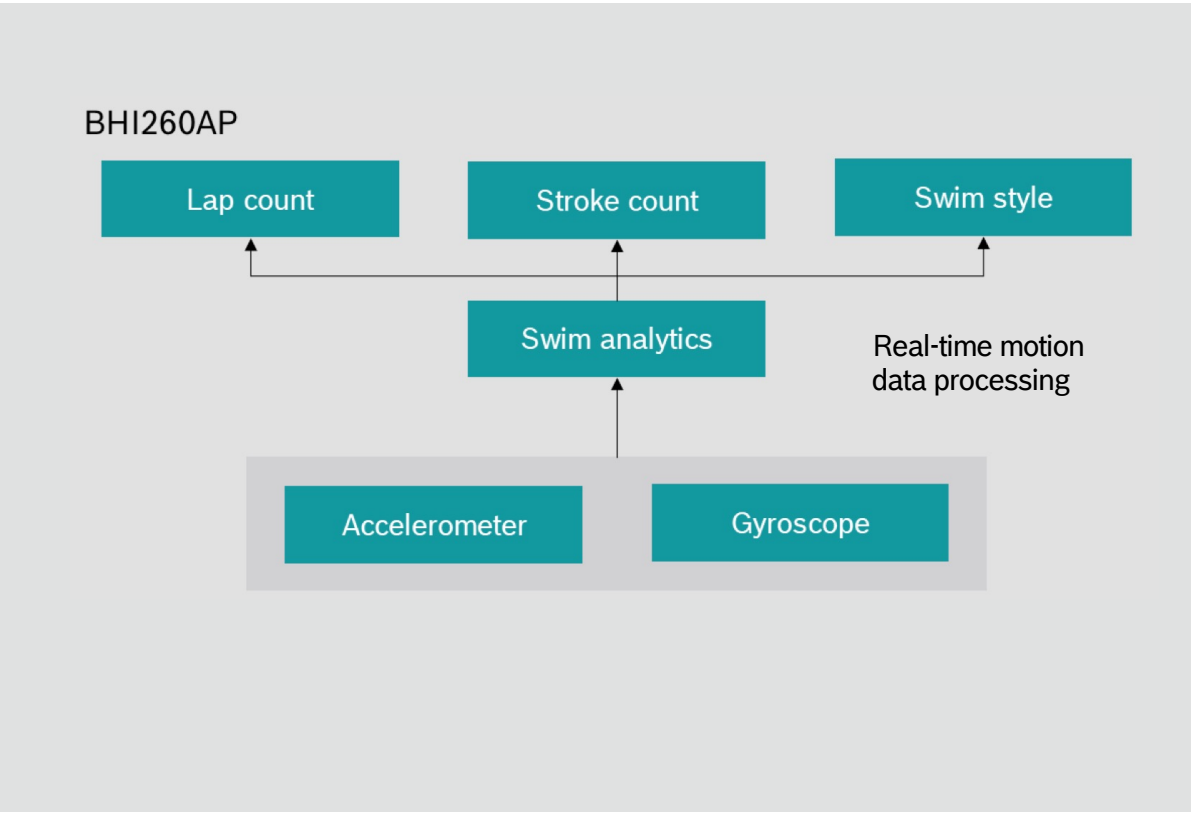
Example Applications: Sports Analytics

Swimming

- Speed, distance, technique
- Classification: start swimming, backstroke, freestyle, breast stroke, butterfly
- How many strokes, laps, breaks



https://www.bosch-sensortec.com/white-paper-swimming.html

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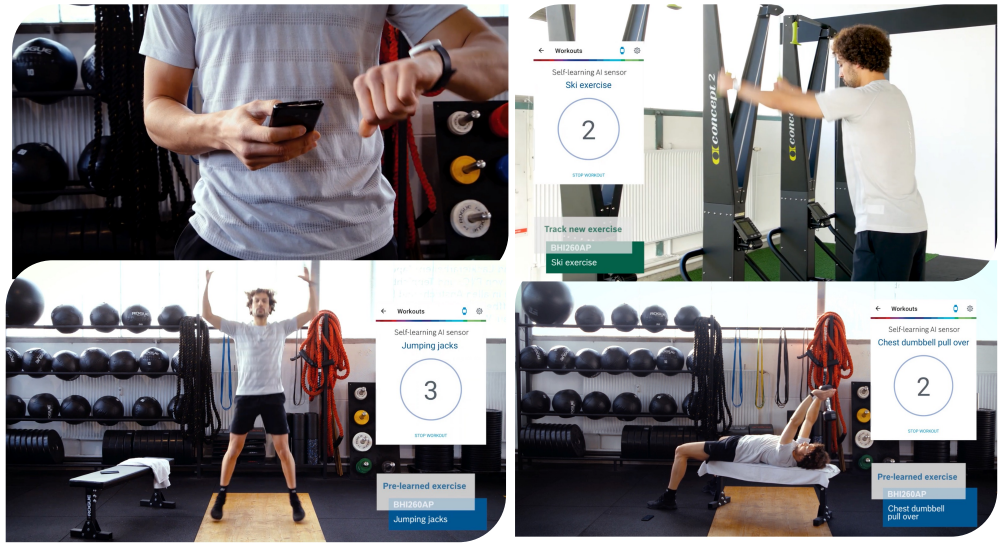
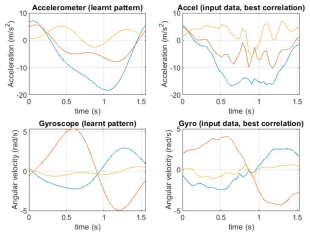
Example Applications: Sports Analytics

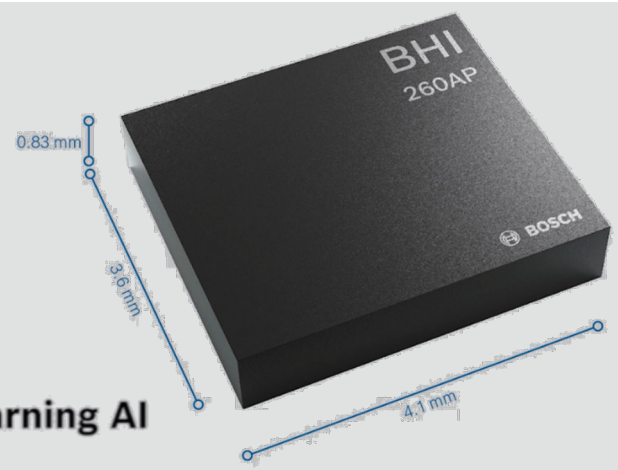


Personalized Workout

Example:



→ Kettlebell Swing



Benefits of the self-learning AI sensor BHI260AP:

- World's first self-learning AI sensor
- Personalized and automatic activity counting
- Easy-to-extend with new activities, directly on-the-edge (typ. 50 activities)

Source: Bosch Sensortec, https://youtu.be/wxV2Ght7zKA
https://www.bosch-sensortec.com/white-paper-fitness.html
Lammel et al, SSI2021

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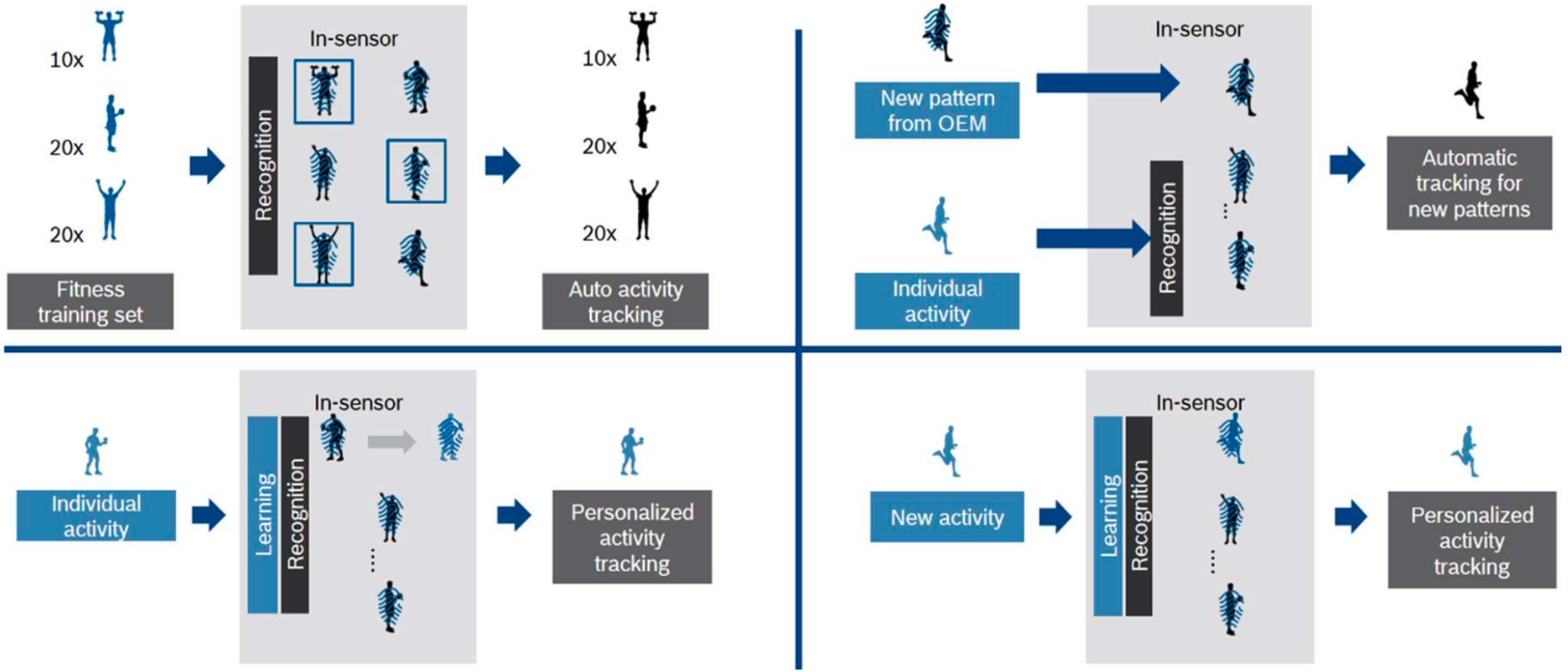
Example Applications: Sports Analytics



Lammel et al., Smart System Architecture for Sensors with Integrated Signal Processing and AI, Smart Systems Integration, 2021

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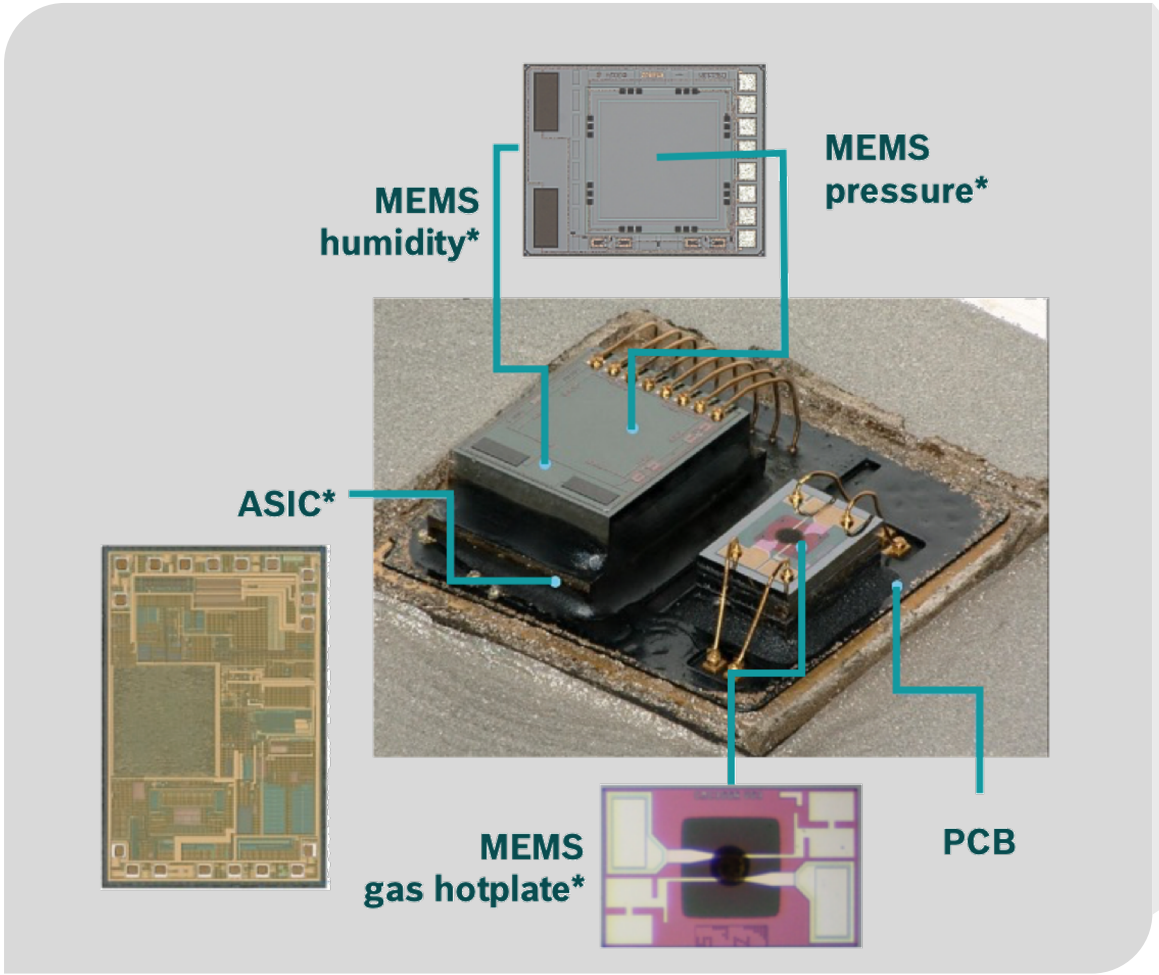
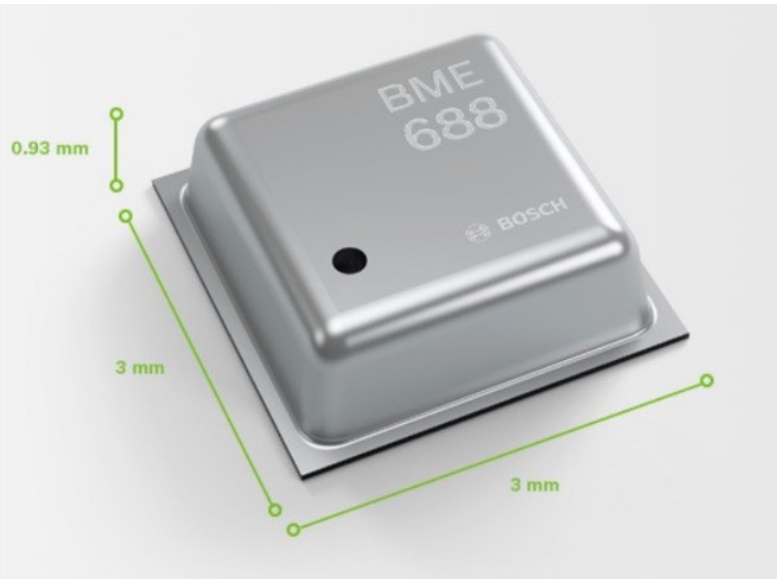
Example Applications: Gas Classification





https://www.bosch-sensortec.com/products/environmental-sensors/gas-sensors/bme680/

** Picture source: System Plus Consulting | BME680*

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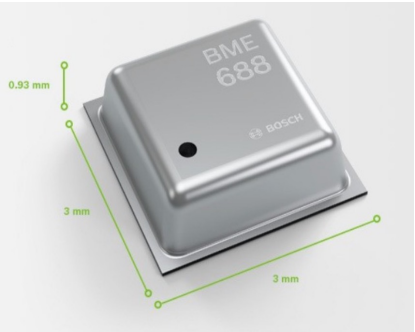
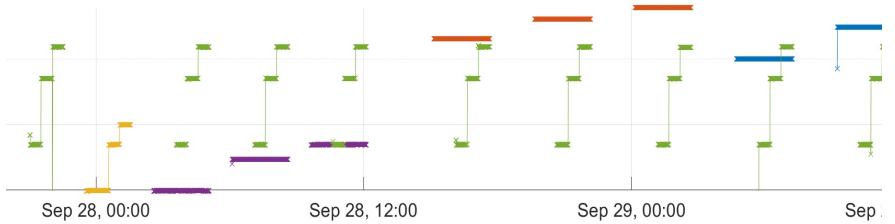
Example Applications: Gas Classification

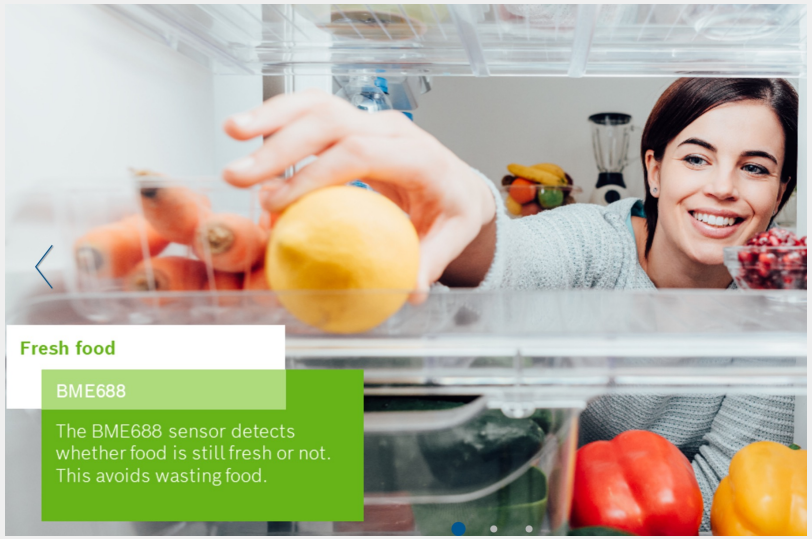


- Temperature-cycled operation of the BME gas MEMS sensor
- Characteristic patterns
- Trained classifiers

4
5
2
1

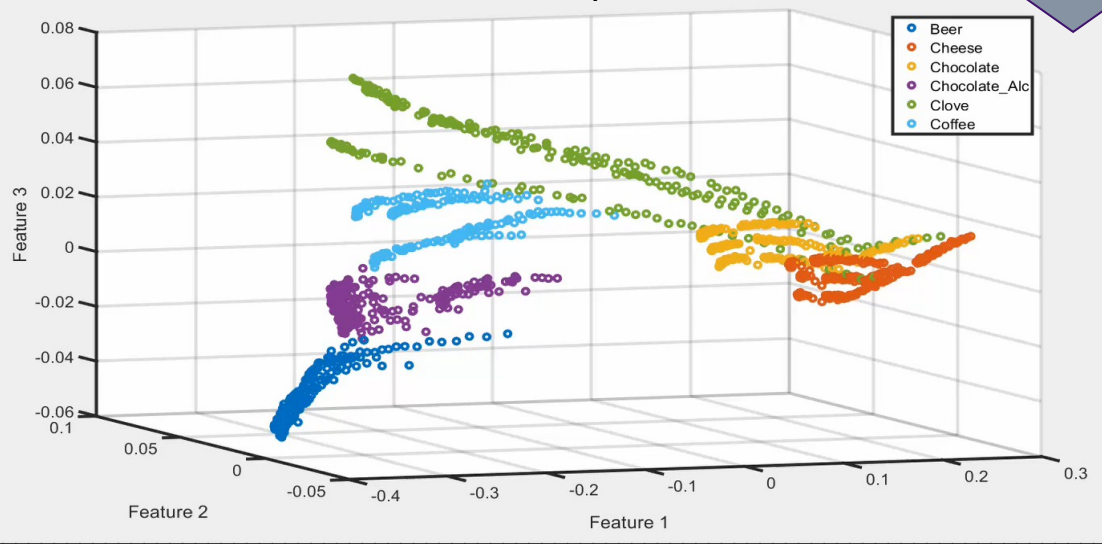
Classified Gas Mixture





Different gases and discriminative profiles can be trained for various use cases.

Feature Space



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** Source: Bosch BME680 Environmental Sensor, MEMS report by A. Lahrach, System Plus Consulting, July 2017 Paul-Lazar et al.*

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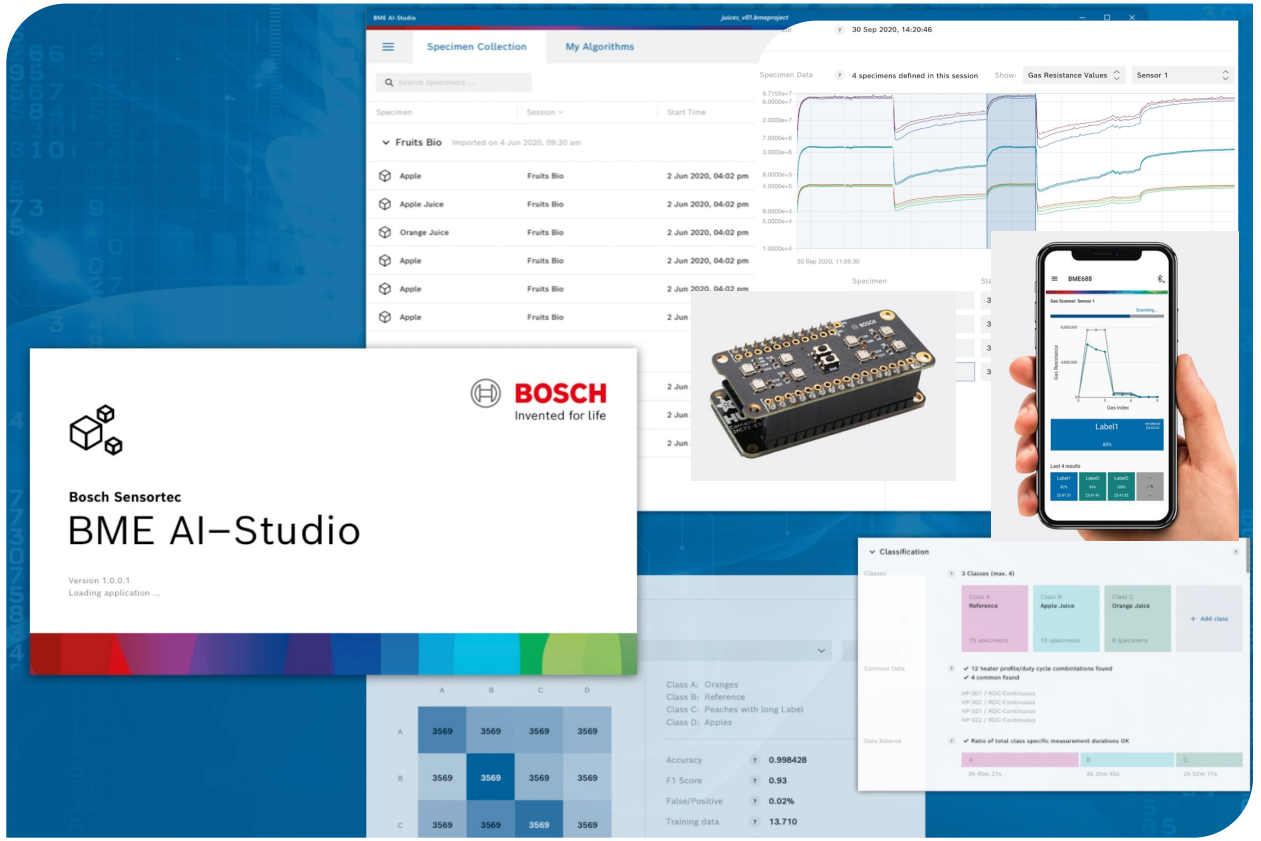
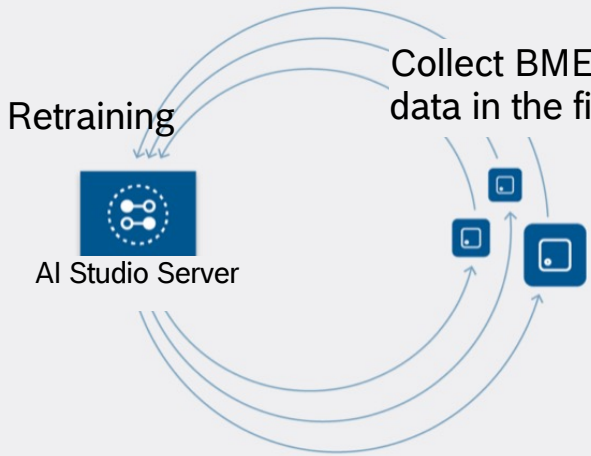
Example Applications: Gas Classification



Sensor Fleet Learning



https://www.bosch-sensortec.com/software-tools/software/bme688-software/

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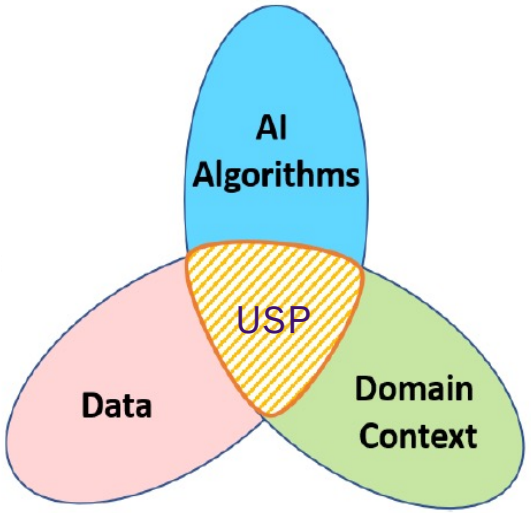
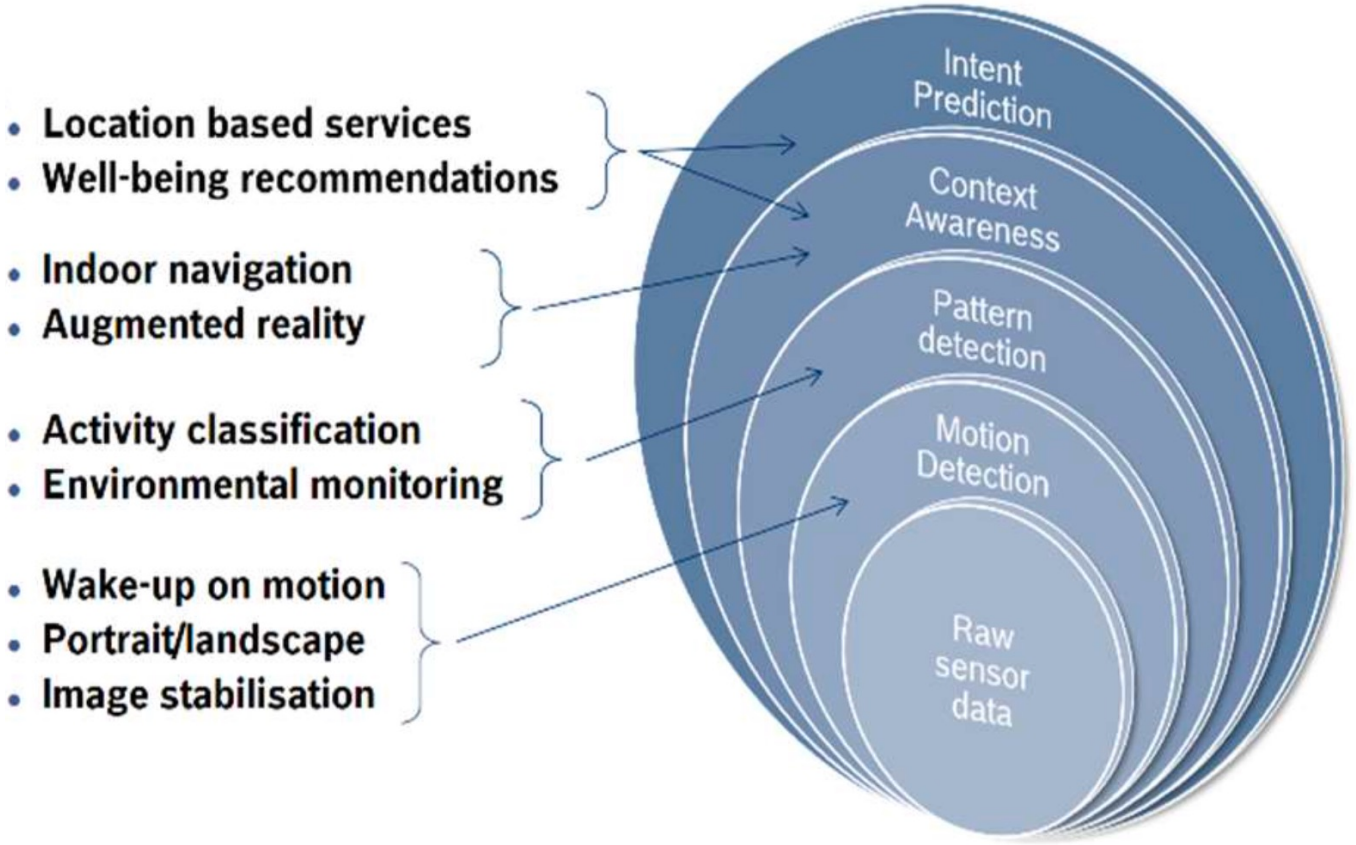
The Role of Domain Knowledge



Leveraging domain know-how, owning the data and using AI algorithms enables the generation of unique selling propositions.

Source: Santhanam P., Farchi E. & Pankratius V. 'Engineering Reliable Deep Learning Systems', *AAAI Fall Symposium Series on AI in Government & Public Sector,* November 7-9, 2019, p. 2

https://arxiv.org/abs/1910.12582



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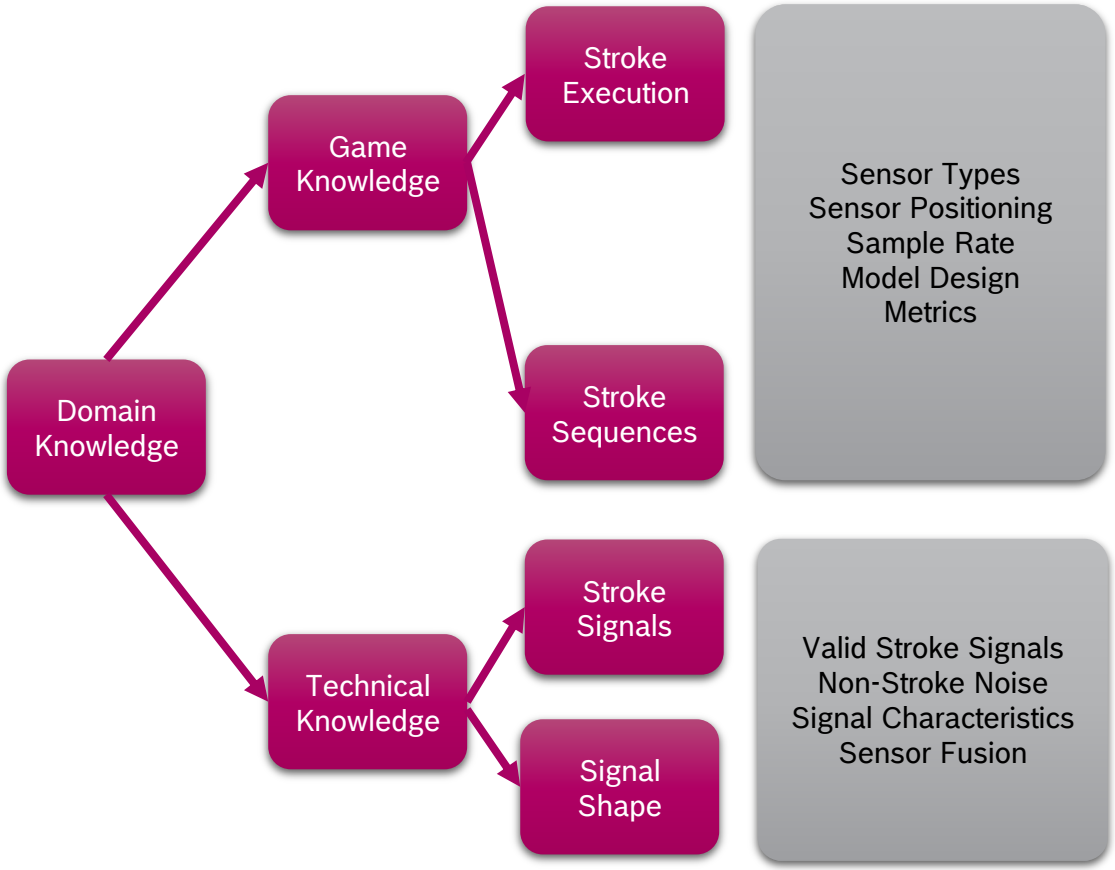
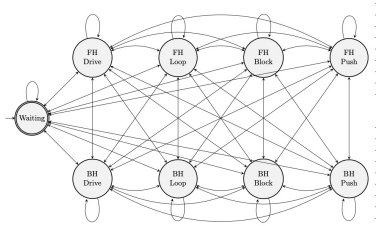
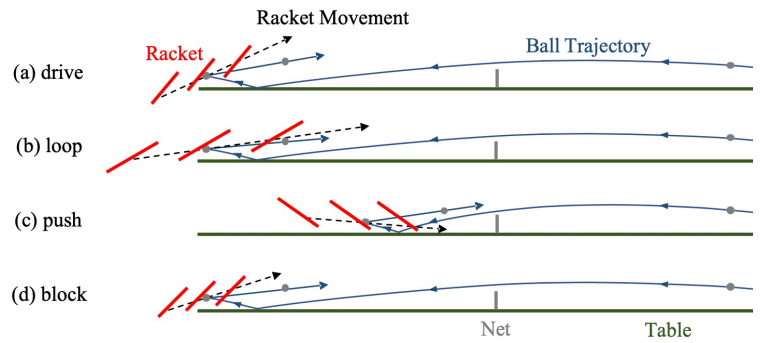
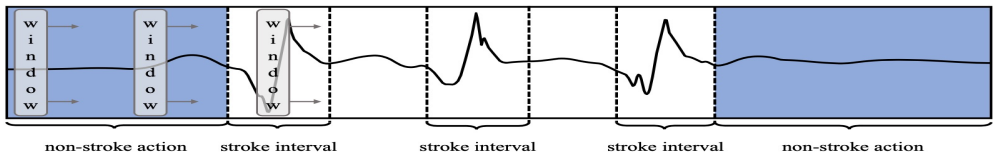
The Role of Domain Knowledge
Example: Table Tennis in 94 kB

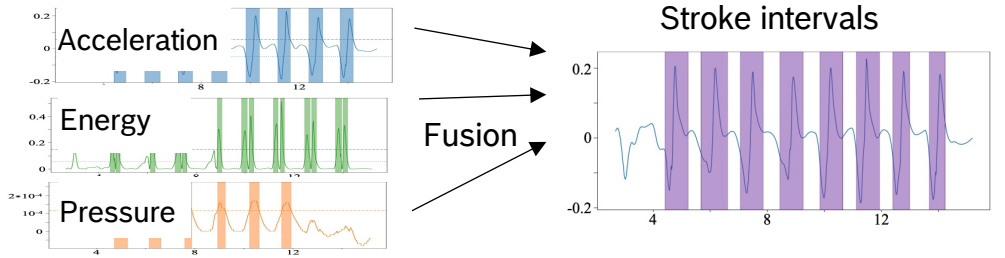




Gameplay
State, plausibility & self-correction







Source: Wieland & Pankratius, Domain-Knowledge Enhanced Machine Learning for Table Tennis Stroke Characterization, 2022, in review. Patent pending.
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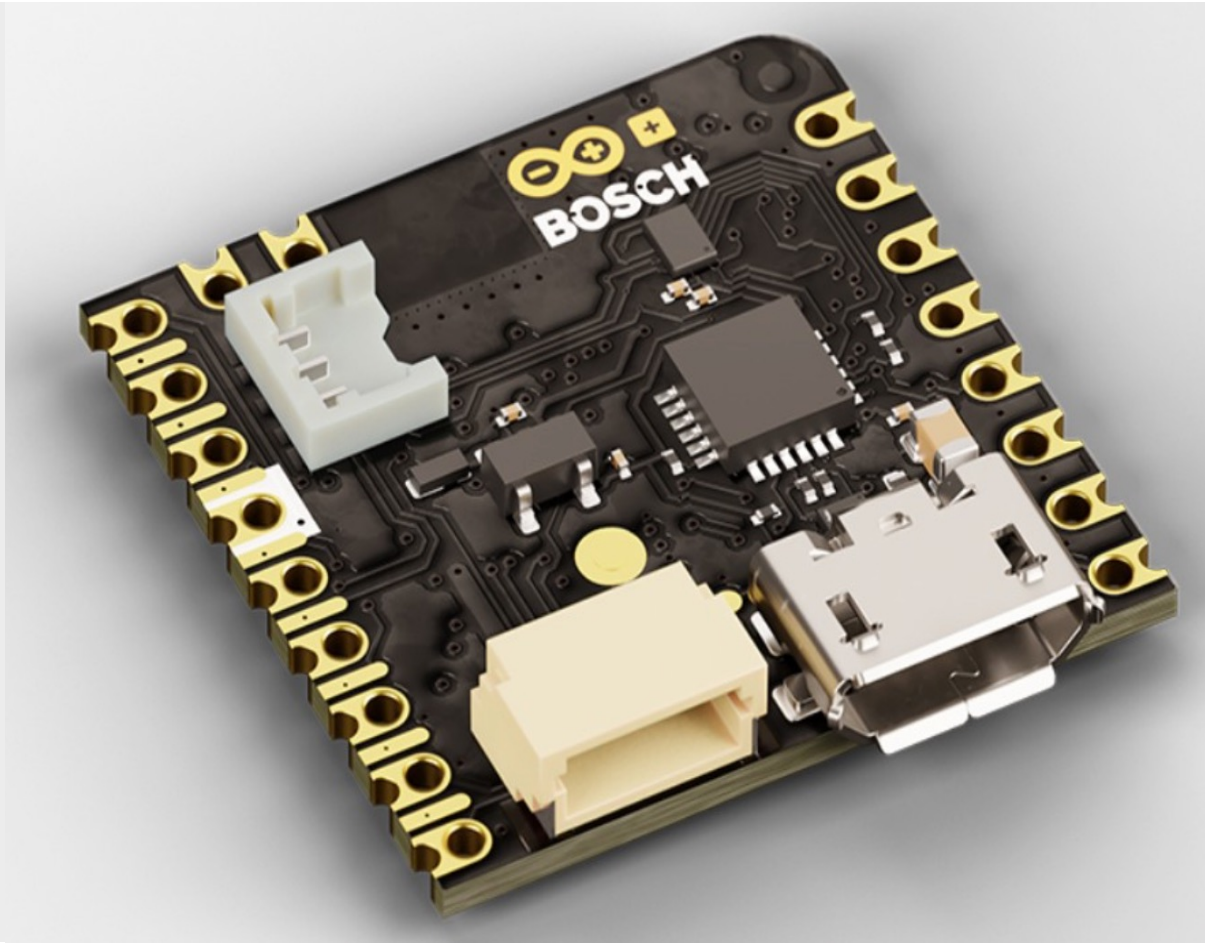
TinyML Communities

https://www.bosch-sensortec.com/software-tools/tools/arduino-nicla-sense-me/

Nicla Sense ME

- “A tiny board for sensing the big world“
- Leverage EdgeML/TinyML software ecosystem

Bosch – Arduino Partnership



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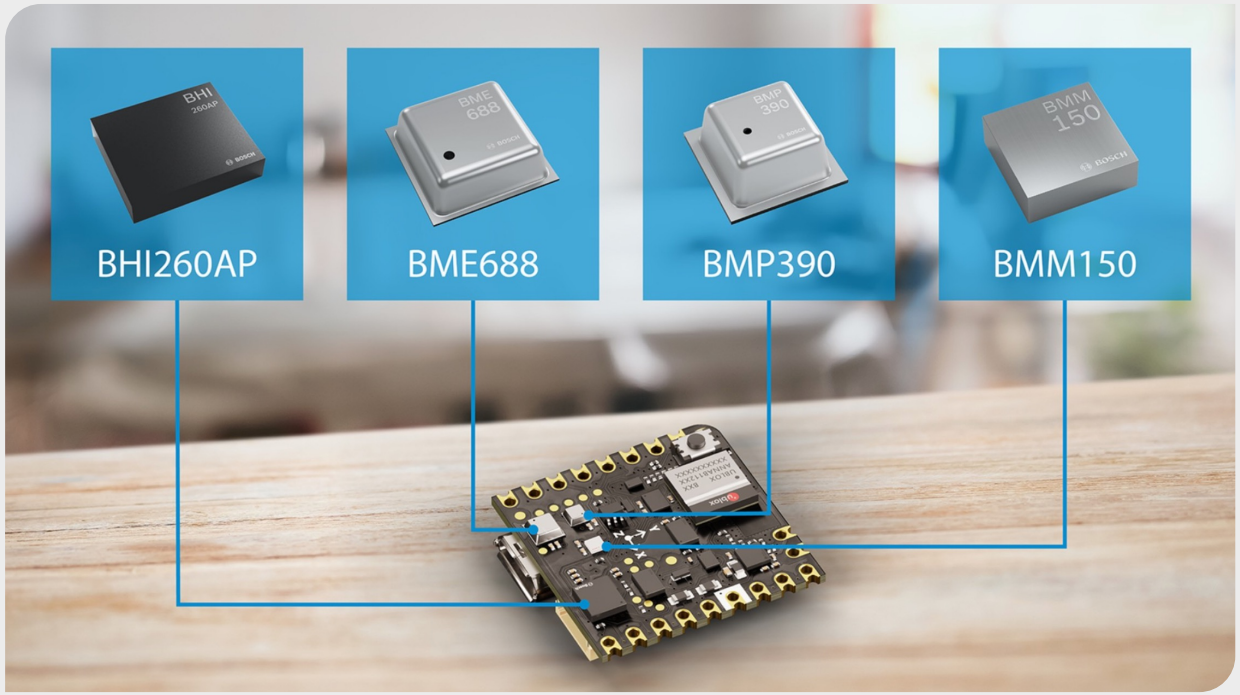
TinyML Communities

https://www.bosch-sensortec.com/software-tools/tools/arduino-nicla-sense-me/

Nicla Sense ME

….combines Multi-DoF Sensing with smart embedded processing

- 64 MHz Arm® Cortex M4 (nRF52832)
- BHI260AP - Self-learning AI smart sensor with integrated accelerometer and gyroscope
- BMP390 - Digital pressure sensor
- BMM150 - Geomagnetic sensor
- BME688 - Digital low power gas, pressure, temperature & humidity sensor with AI
- 512KB Flash / 64KB RAM, 2MB SPI Flash for storage, 2MB QSPI dedicated for BHI260AP
- Bluetooth® 4.2



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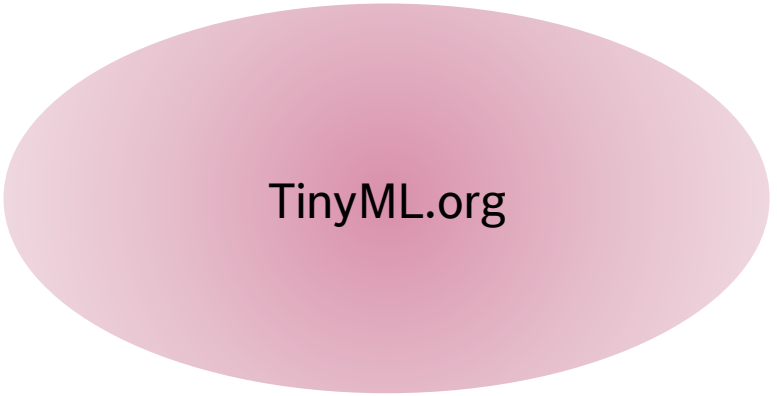
TinyML Communities

Example Software Ecosystems for Nicla Sense ME

Bosch Sensortec
https://github.com/BoschSensortec

Arduino
https://github.com/arduino/nicla-sense-me-fw

IoT Innovation Challenge
https://www.bosch-sensortec.com/about-us/events/iot-innovation-challenge



EdgeML.org (open source)
https://github.com/edge-ml

Youtube Tutorials

https://www.youtube.com/user/BoschSensortec/

+ community

...and many others

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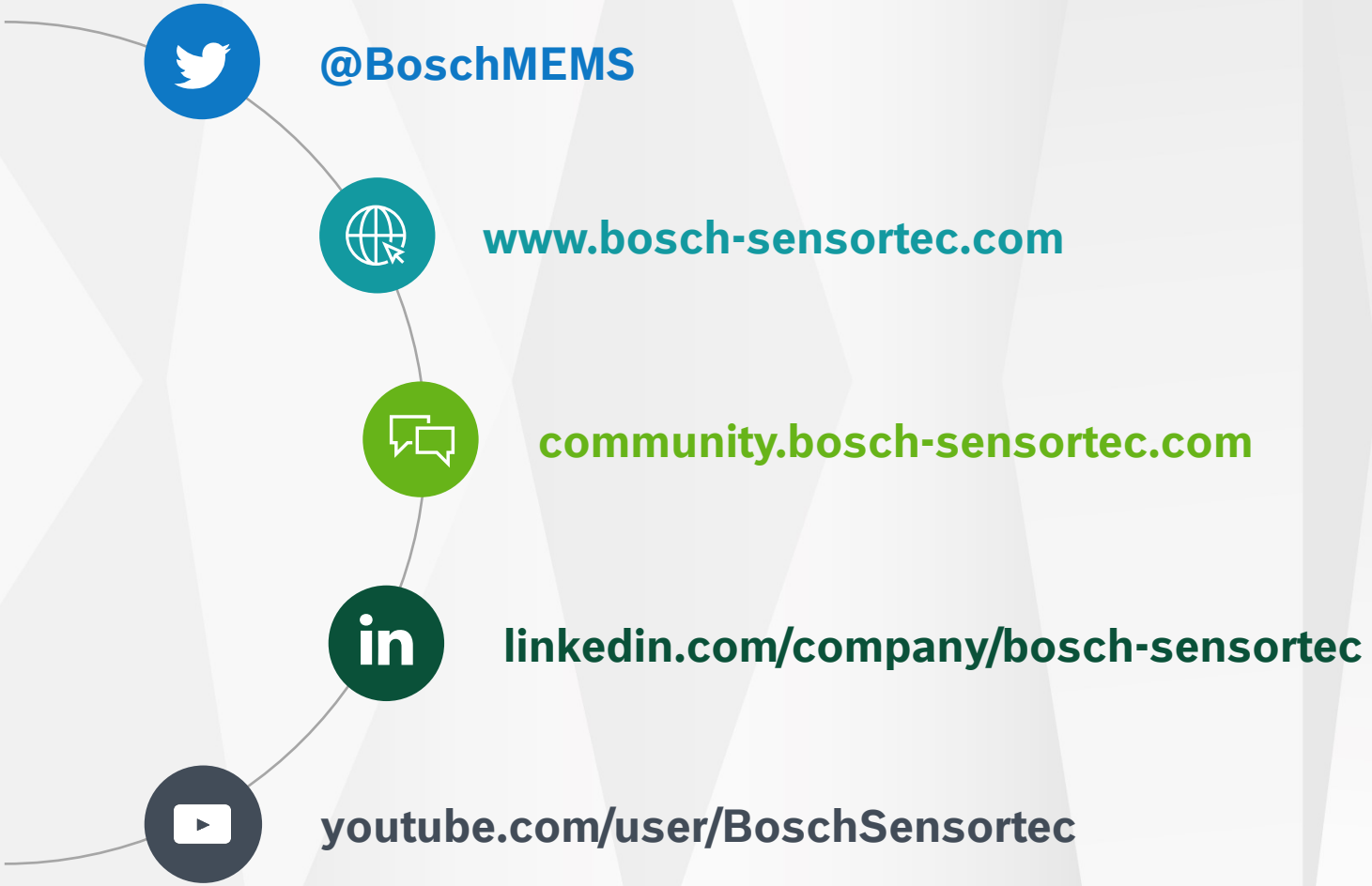
Thanks - GET IN TOUCH WITH US



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