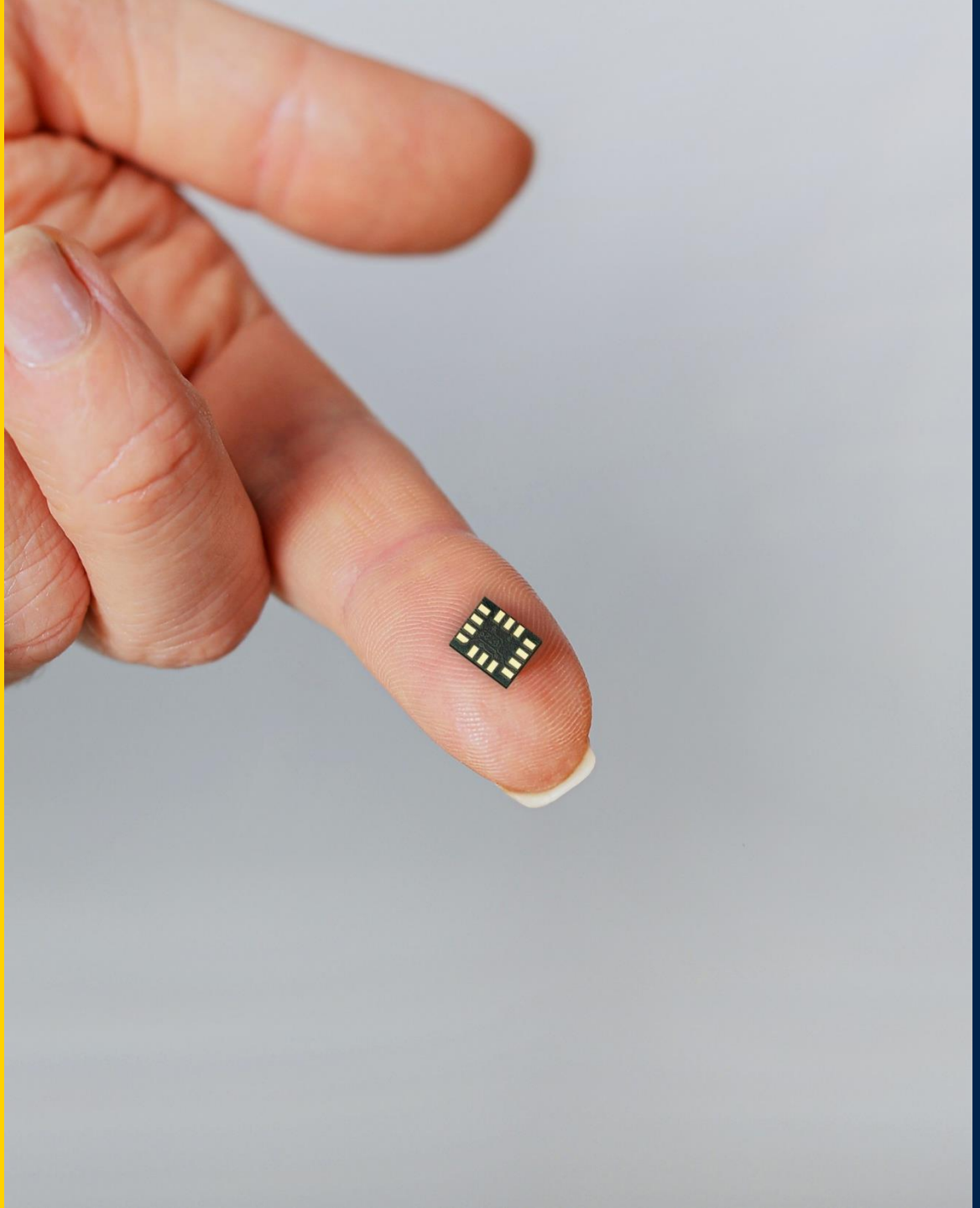


Explore the intelligent sensor processing unit (ISPU)

Artificial intelligence journey

Migrating processing at the edge

MCU computing

Sensor + MCU

Intelligence in the MCU

MCU standalone or hosted in the sensor package

Standard
MCU runs the algorithms

Runs any kind of software
provided it matches the MCU specs

In-sensor AI computing

Sensor with ISPU

Intelligent sensor processing unit

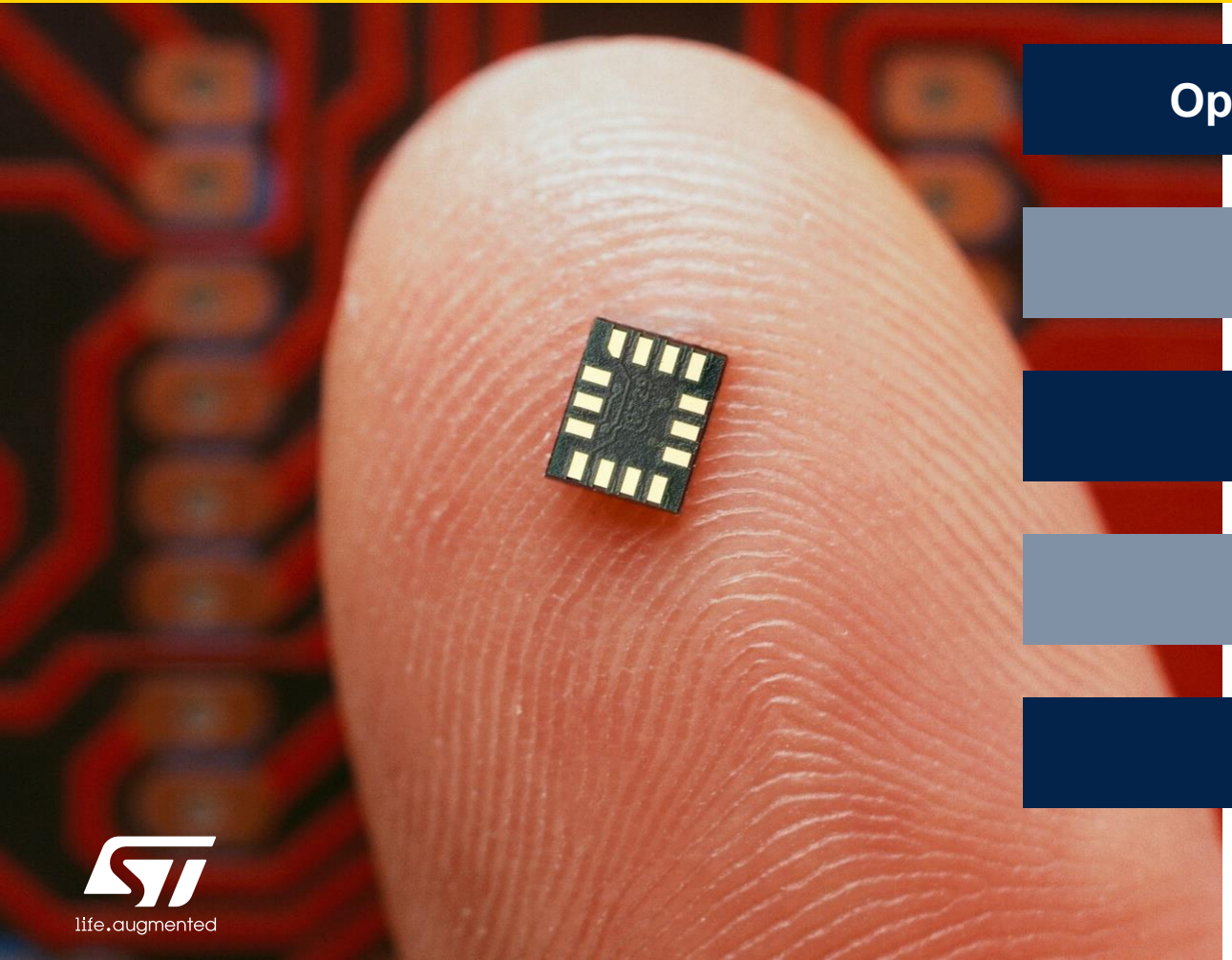
ISPU integrated in the sensor ASIC

Programmable
dedicated instruction set

Runs several AI algorithms
Full precision to 1-bit NN

Challenges for sensors in edge AI

Ability to integrate intelligent processing in a tiny piece of silicon



- Optimal power (uW) per performance capabilities
- Limited logic and memory storage
- Technology architecture
- Ecosystem compatibility
- Advanced tools for increased productivity

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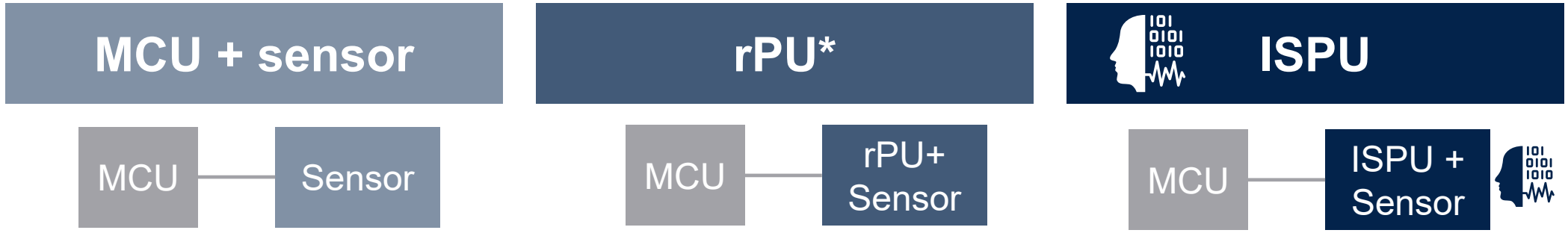
One can’t fit all, ISPU fits many



Parameters	Benefits	Benefits	Benefits
Flexibility	Ad hoc coding		Optimized for inertial data
Low power		rPU adds few uA	Integrated computing cell, MCU in standby with sensor wake up
Data transfer optimization sensor - MCU		Local processing	Local ISPU sends pre-processed data

*rPU: reconfigurable processing unit (like machine learning core (MLC) in ST sensors)

Evolution of system-based AI

Till today

Sensor + GP MCU

AI running on general purpose MCU

Today

ISPU + MCU

ISPU integrated in the sensor ASIC

Tomorrow

ISPU 2.0 + AI MCU

AI distributed among ISPU and AI MCU

ISPU

Intelligent sensor processing unit

Small area
down to 8 Kgates

Standard package
3 x 2.5 x 0.83 mm

Optimization
Power consumption vs. performance

Full precision
Floating Point Unit

Binary Neural Network
convolution acceleration

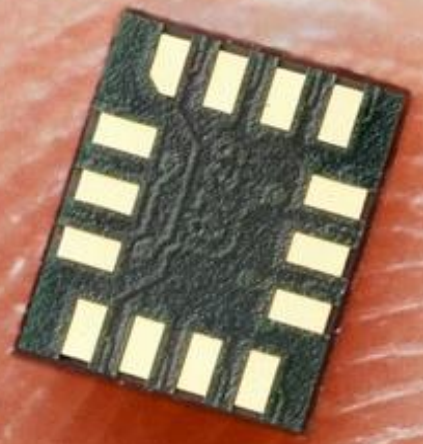
RAM based
40 kB (program + execution)

What is ISPU?

ISPU: what and why

Highly specialized DSP* for machine learning and processing

Super tiny silicon



Unique solution for **TinyML** with **machine learning** (ML), **binary neural network** (BNN), and **processing** capabilities

Lowest power consumption IoT node in the market with AI at the edge

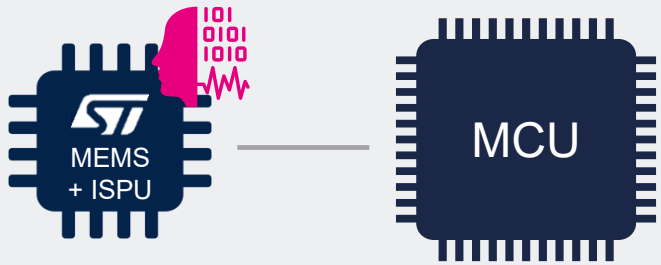
Productivity: empowers 10M+ C language developers
Complement STM32 MCU portfolio

*DSP: digital signal processing

Integrating brains into sensors

ISPU

Intelligent sensor processing unit



ISPU integrated in the sensor ASIC

Programmable core **ultralow power**

Processes data from internal (accelerometer, gyroscope, temperature) **& external sensors**

ISPU toolchain allows developers to program in **C language**

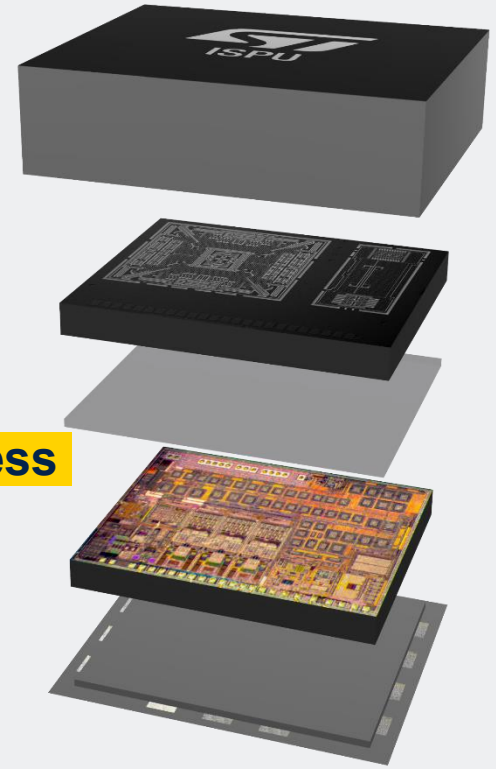
What's inside?

DSP* for real-time processing and artificial intelligence

Raw data from MEMS sensor

ISPU locally process data in a few µW

Only meaningful processed data



MEMS sensor
3-axis accelerometer & 3-axis gyroscope

Sensor hub
to collect data from additional external sensors (up to 4)

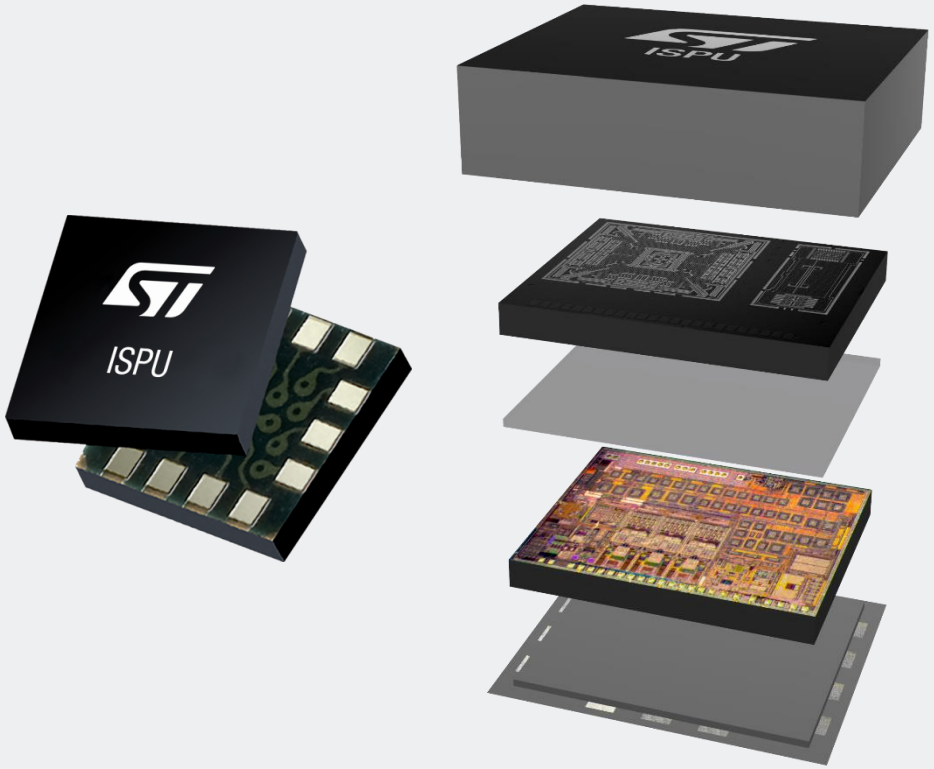
ISPU core

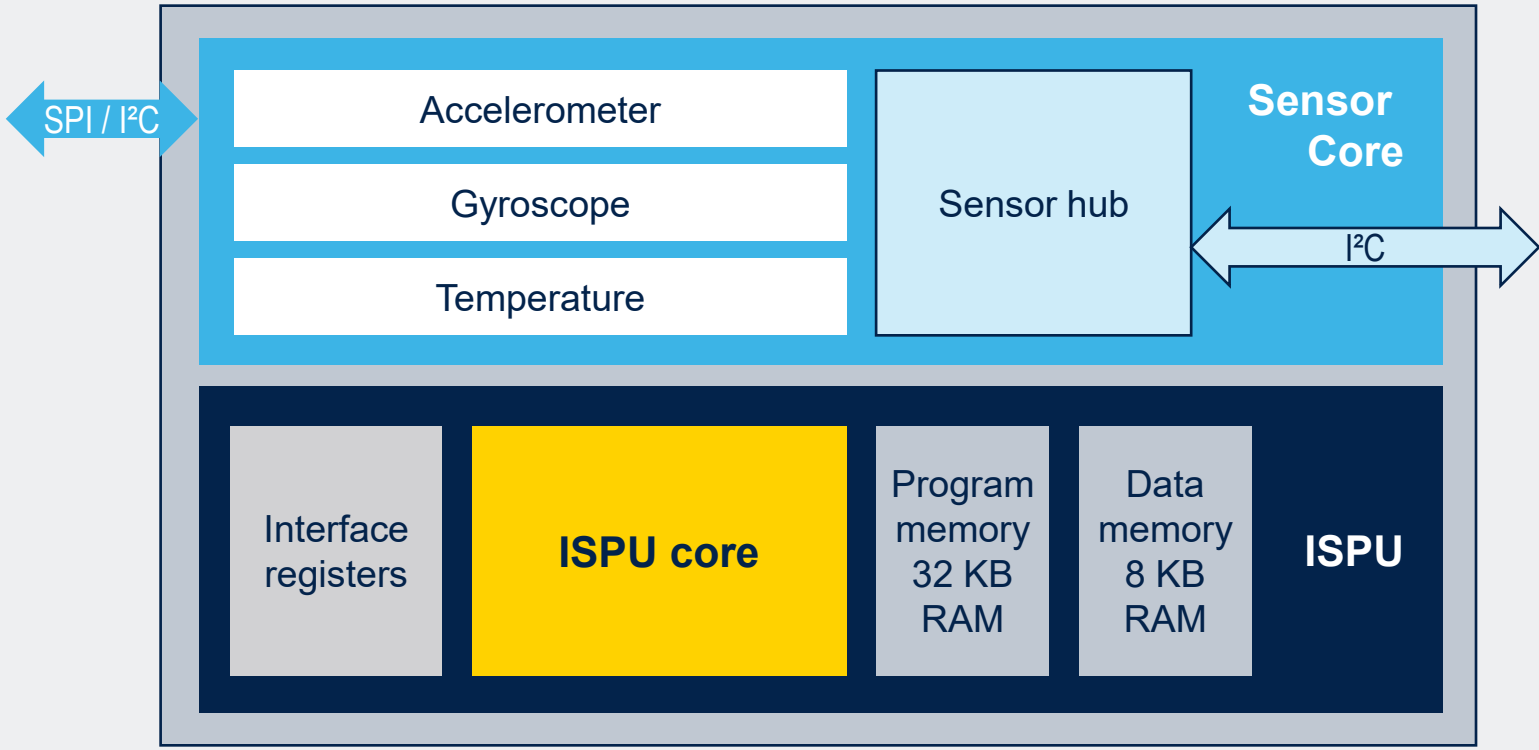
Standard package: 2.5 x 3 mm^2

*DSP: digital signal processing

ISPU: the architecture

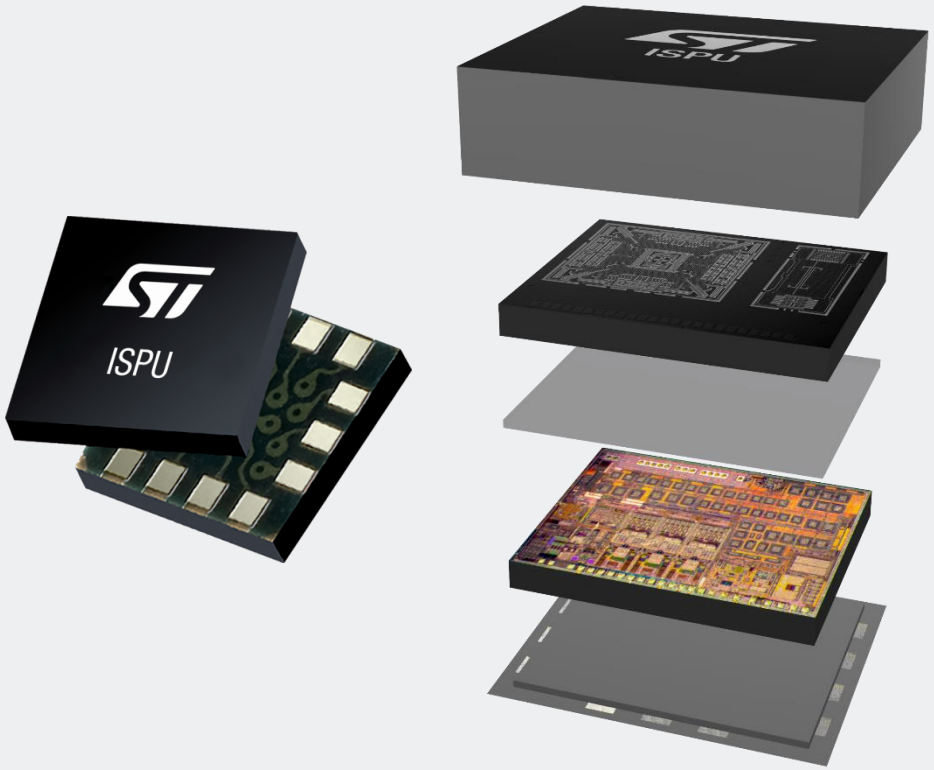
DSP for real-time processing and artificial intelligence





ISPU: play with it!

DSP for real-time processing and artificial intelligence



Small area: enhanced 32-bit RISC Harvard architecture in 8 kilogates

RAM based:
40 KB (program + execution)

Full precision: Floating point unit

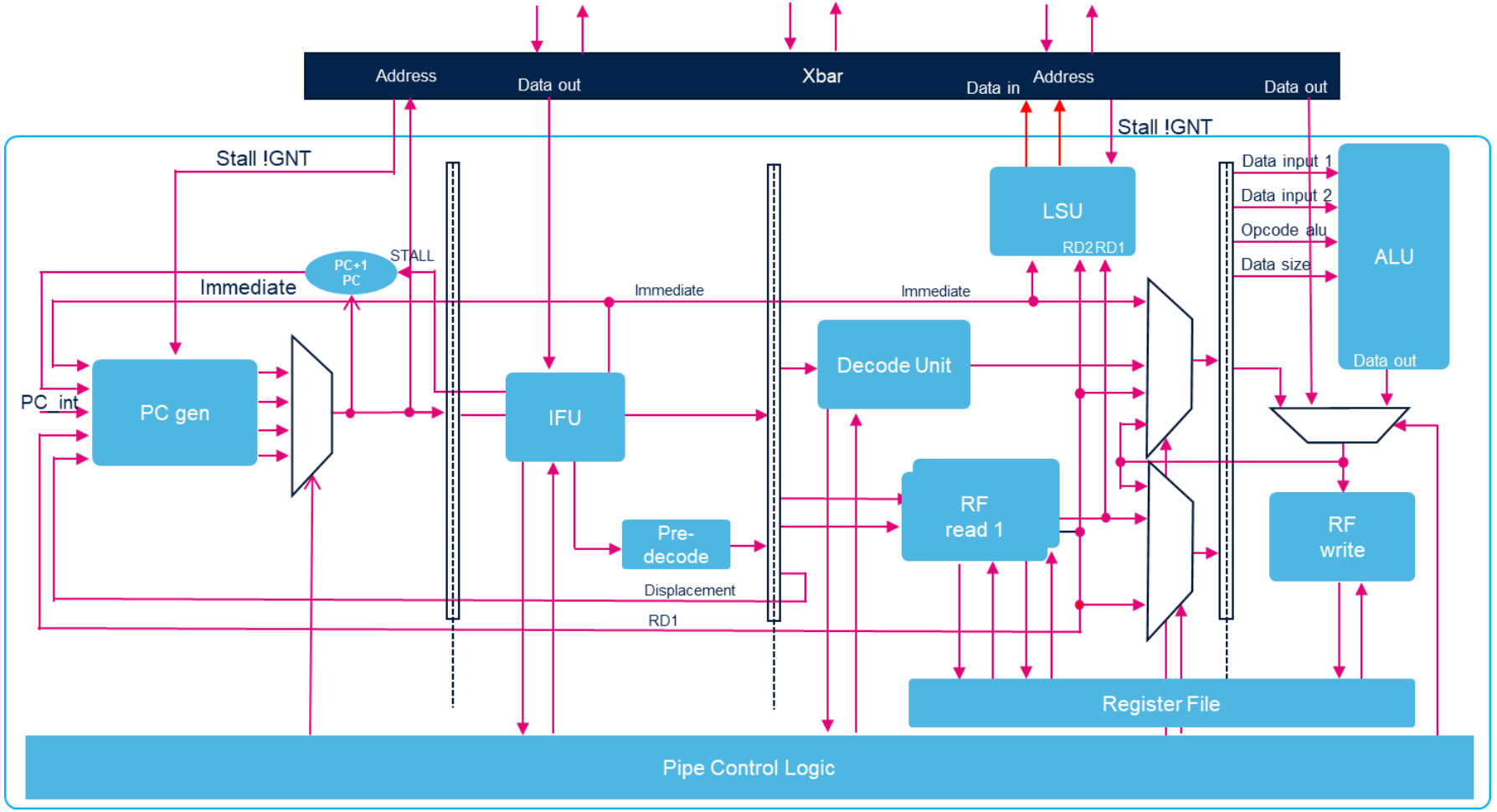
Binary neural network convolution accelerator: patented by ST

Fast interrupt response:
4 cycles vs. 15 (Cortex®)

Frequency: 5 MHz / 10 MHz
ODR max: 6.66 kHz

ISPU core: efficient, small, and fast DSP

x2 performance / area efficiency than best competitors



	ISPU
Pipeline stage	4
Instruction/data conflicts	No Harvard architecture
Multiplier	16 >32
Tiny FPU	Yes
Area	8 KGE
Branch shadow	1 to 2
CoreMark µW/MHz	70
Clock frequency	10MHz

ISPU added value

Ultra low power consumption
- Efficiency of the embedded DSP (digital signal processing)
- Very low data exchange with external MCU (MCU stay in sleep mode most of the time)

Ultra low latency
- Processing / decision taken directly in the sensor

Easily programmable with C language or with commercial or open-source AI models

ST Edge AI Suite

Data privacy & security
- Sensor data are locally processed and not provided outside

Integration / miniaturization
- MEMS mixed-signal state-of-the-art technology node
- No special purpose package

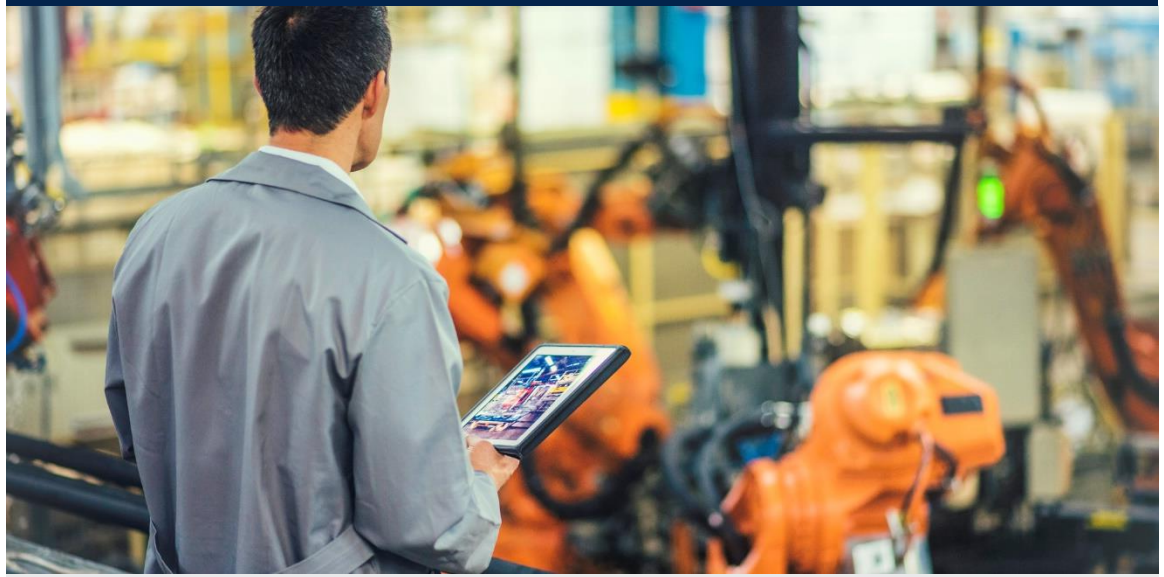
ISPU products

Be inspired by the endless possibilities of ISPU

Personal electronics & consumer IoT

- **LSM6DSO16IS**

Industrial IoT



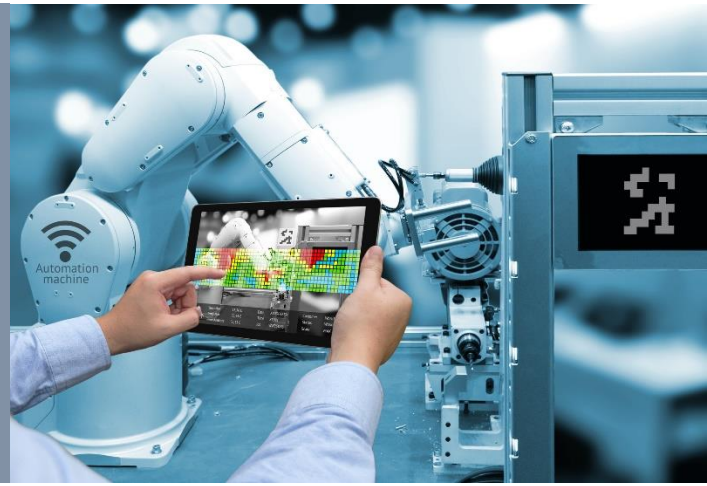
- **ISM330IS**
- **ISM330ISN***

*ISM330ISN is supported in NanoEdge AI Studio

Discover many real-world examples based on ISPU

Calibration

Anomaly detection

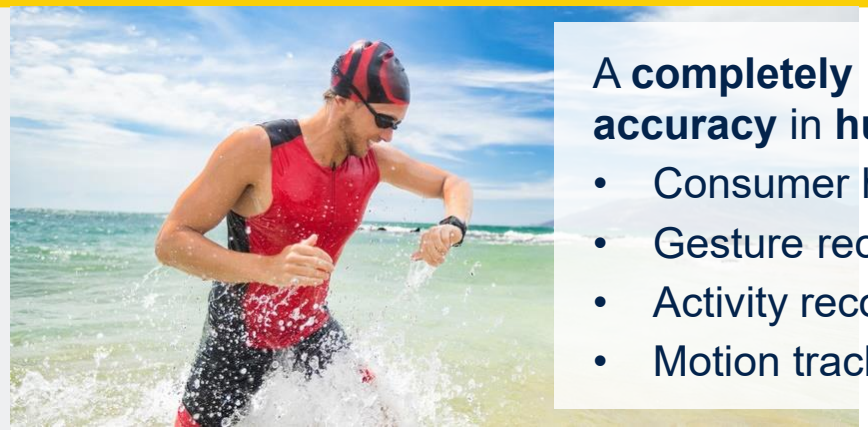


Complex gestures

3D space orientation

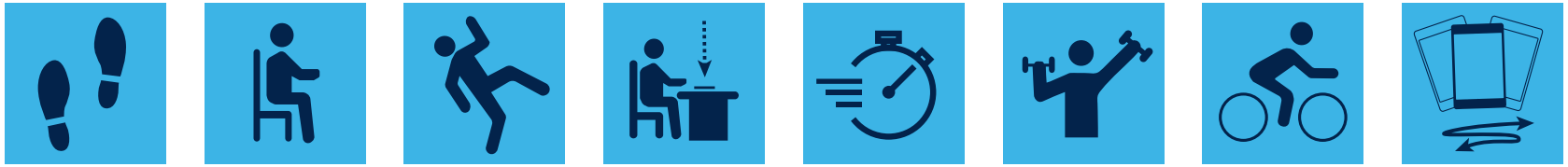
Find inspiration to create your personal application

AI at the edge with ultralow power 6-axis IMU for consumer market



A **completely new level of capabilities** and **detection accuracy** in **human activity recognition** applications:

- Consumer health
- Gesture recognition
- Activity recognition
- Motion tracking



Gait analysis | Pose estimation | Fall detection | Carry position | Active time | Fitness activities | Activity recognition | Gesture recognition

And more…

life.augmented

A new way to approach the Industry 5.0

AI at the edge with ultralow power 6-axis IMU for industrial market

Higher **detection accuracy**, **always on monitoring** in **anomaly detection** applications

- Home alarms
- Robotics
- Condition monitoring

A **completely new level of capabilities** and **detection accuracy** in **asset tracking** applications

life.augmented

ISPU products

For real-time processing and artificial intelligence

- FS: ± 2000 dps, ± 16 g
- Idd 0.59 mA (combo mode)
- Axel noise 70µg/√Hz
- Gyroscope noise 3.8mdps/√Hz
- 10MHz clock, RAM 40 KB

Optimization
Power consumption vs. performance

Standard package
3 x 2.5 x 0.83 mm

Efficiency
Floating Point, binary NN, hybrid binary NN

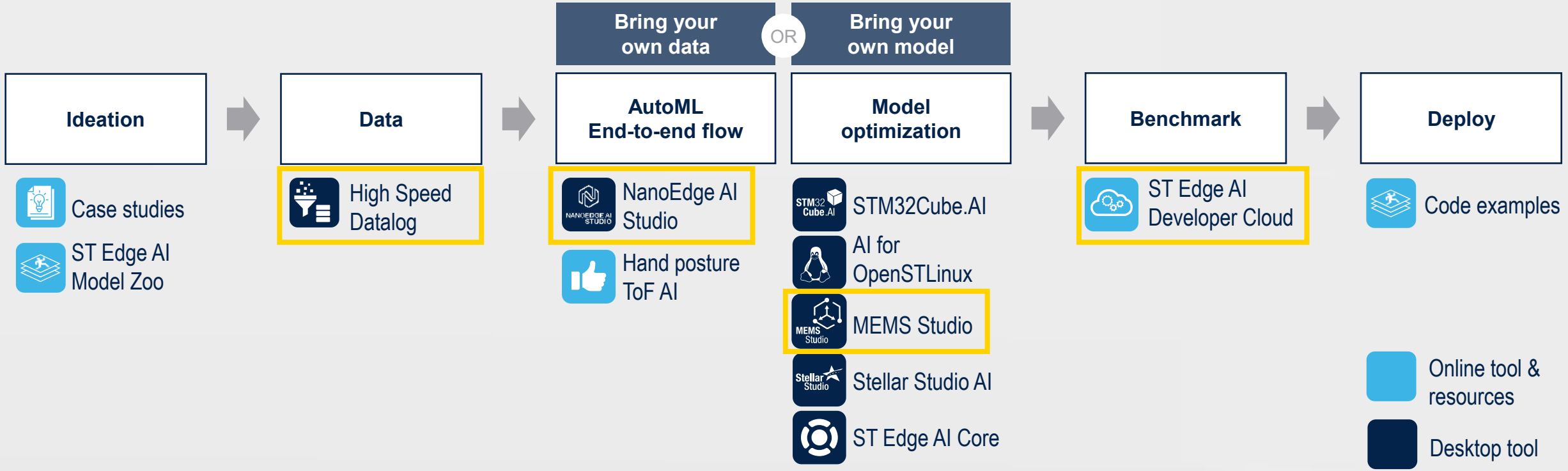
Interoperability
Machine learning and deep learning

How to program ISPU?

ST Edge AI Suite

Free tools for smart sensors with ISPU

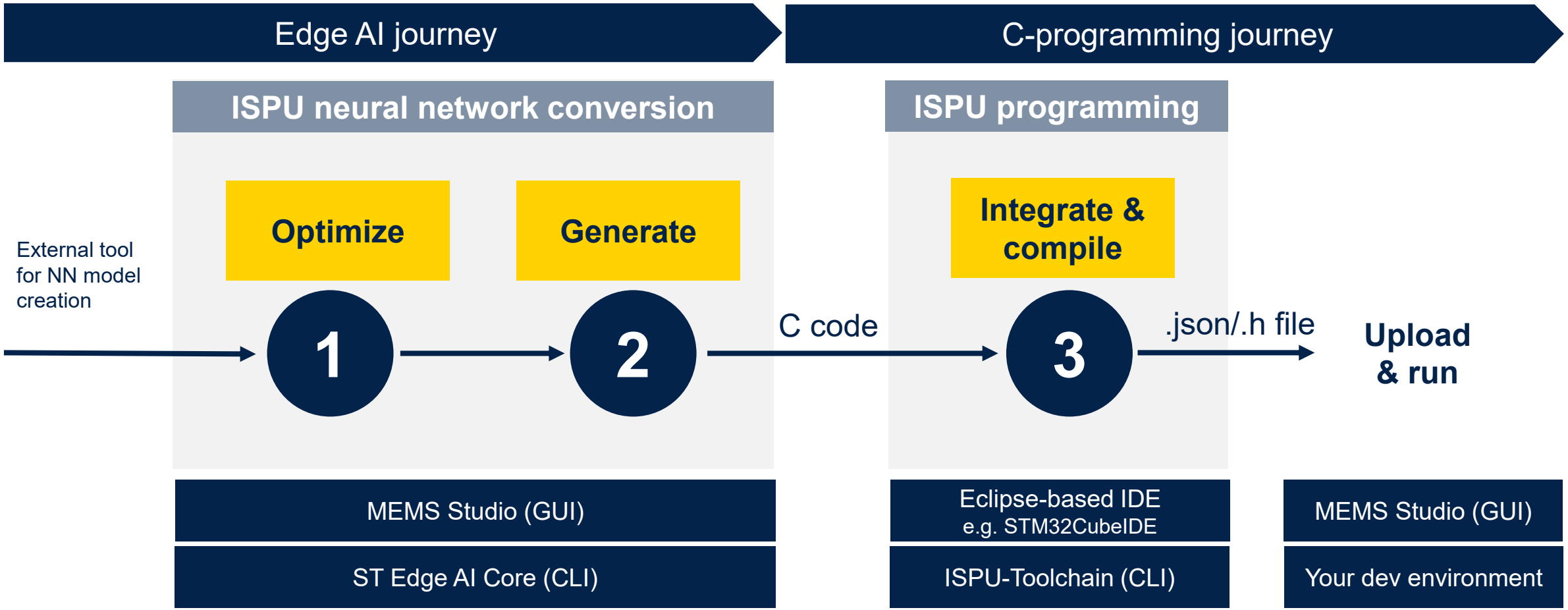
ISPU can be configured by different tools available in the **ST Edge AI Suite**



ISPU software ecosystem

Who	How	Which tool
AI expert	Command Line Interface (CLI)	**ST Edge AI Core** **ISPU toolchain**
Application developer	Desktop tool	**MEMS Studio** **NanoEdge AI Studio**
Evaluation engineer	Cloud tool	**ST Edge AI Developer Cloud**
Take inspiration	Use cases	**Model zoo in ST Edge AI Suite**
AI expert, application developer	Data collection	**High Speed Datalog**

ISPU programming steps



Steps 1 and 2 are optional, required only for neural network models

C-Compiler: how to evaluate the ISPU?

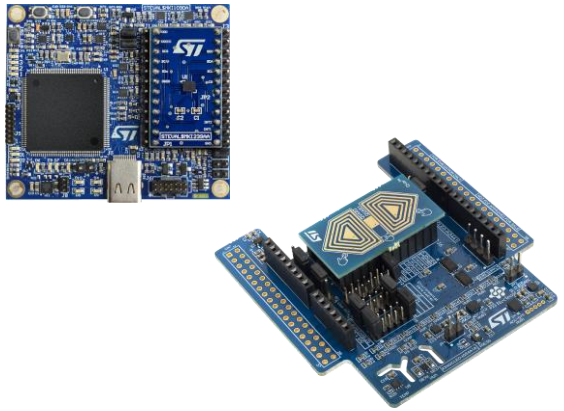
Products

LSM6DSO16IS and ISM330IS

DIL 24 adapter

DIL 24 adapter

Eval boards & kits



STM32 Nucleo:

- NUCLEO-F401RE
- X-NUCLEO-IKS4A1 (consumer)
- X-NUCLEO-IKS02A1 (industrial)

Professional MEMS tool:

- STEVAL-MKI109D

Software & package

ST Edge AI Suite

MEMS Studio

MEMS Studio

ST Edge AI Core

ST Developer Cloud

X-CUBE-ISPU

CLI and IDE compilers

ISPU: there is an AI solution for every need

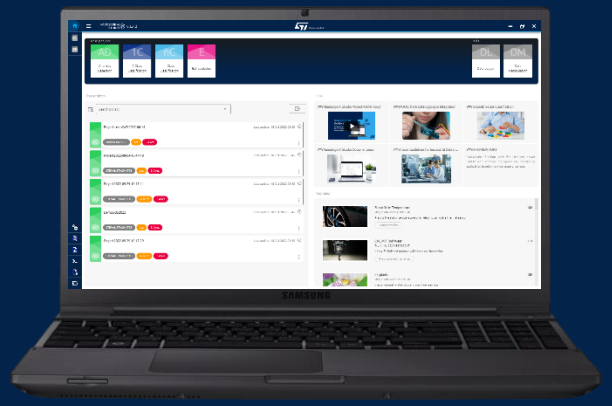
Company's profile	Use cases: Anomaly detection	Use cases: Neural networks	Use cases: Other ML classifications
Embedded developers • No dataset available • No dedicated AI team	NANOEDGE AI	Intelligent Agent Neuton MEMS Studio + ST Edge AI Core	Intelligent Agent Neuton
Team with AI expertise • Dataset available • AI team		Intelligent Agent Neuton ONNX, Keras, QKeras, TensorFlowLite MEMS Studio, ST Edge AI Core, ISPU toolchain	Intelligent Agent Neuton scikit-learn ST Edge AI Core, ISPU toolchain

ISPU easily programmed with NanoEdge AI Studio

NANOEDGE AI

ON THE PC

1 **Create the library, ONCE.**



NANOEDGE AI STUDIO

Standalone PC solution (Win/Linux)

Create and embed a self-learning engine

ON THE ISPU

2 **Use the library, MANY TIMES.**

For anomaly detection, the model is self-trained at the edge.

ST partnership for ISPU

Partnership with Neuton.AI for a tiny AI algorithm in the ISPU

Neuton.AI – No-code TinyML platform for ISPU

life.augmented Partner Program

Neuton.AI allow to build and deploy ultra-small neural networks directly into ISPU

Fixed-point signal processing and inference engine gives 10x advantage in size and processing time when running on ISPU versus general purpose CPU

End-to-end machine learning based services from data collection to production

Intelligent Agent Neuton

Solutions leveraging Neuton.AI

Gesture recognition

Human-machine interface

Human activity recognition

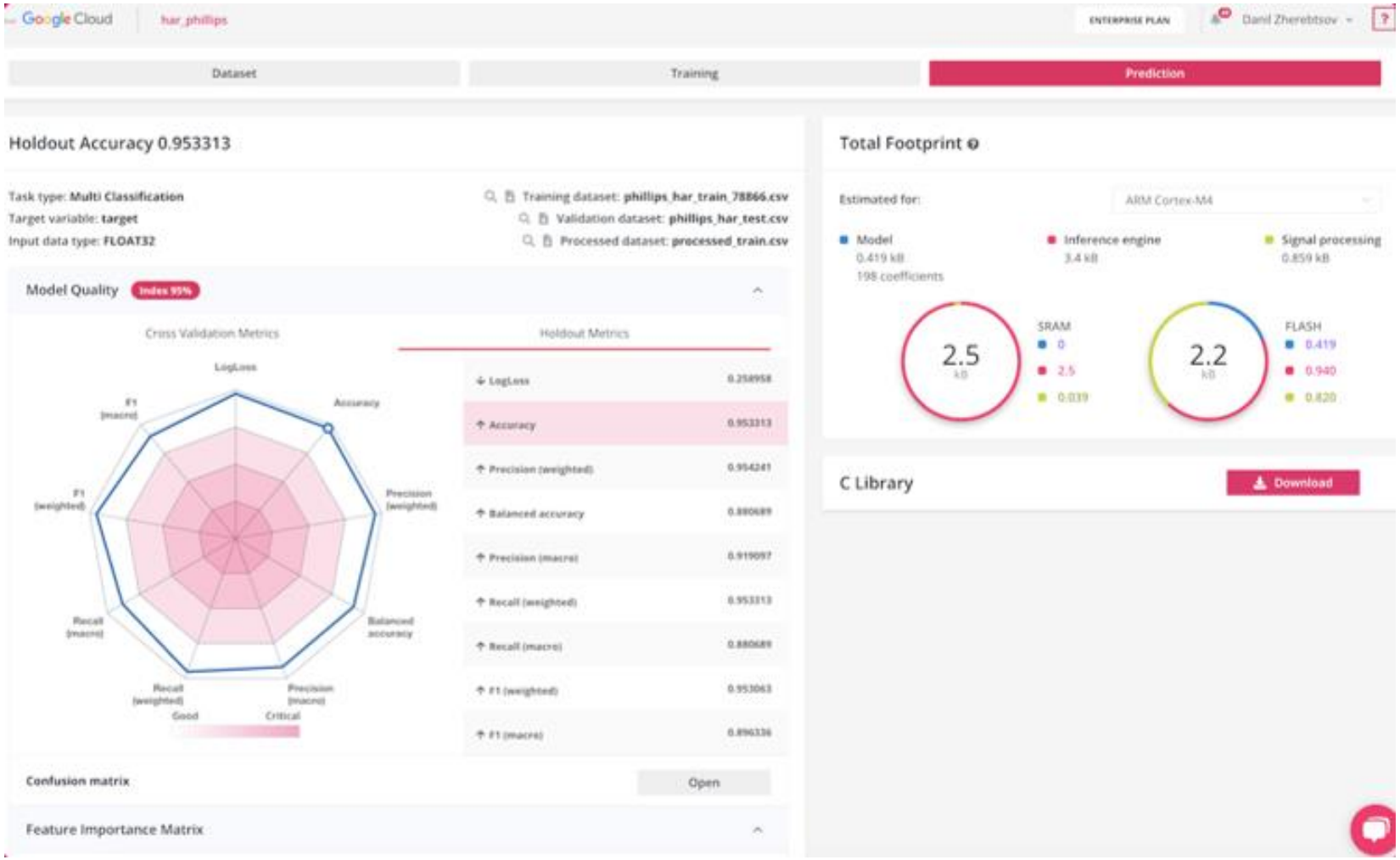
Machine fault classification

Asset tracking and monitoring

Intelligent Agent Neuton

3 simple steps to make an AI-driven ISPU

1. Import .csv file of data collected from ISPU
2. Build automatically tiniest neural networks
3. Generate compiled library for ISPU and run inference on sensor



Neuton.AI business model with ST

Evaluation → Zero gravity

- Use of ML platform is free of charge (user to cover GCP services)
- Only compiled library as output of the online tool

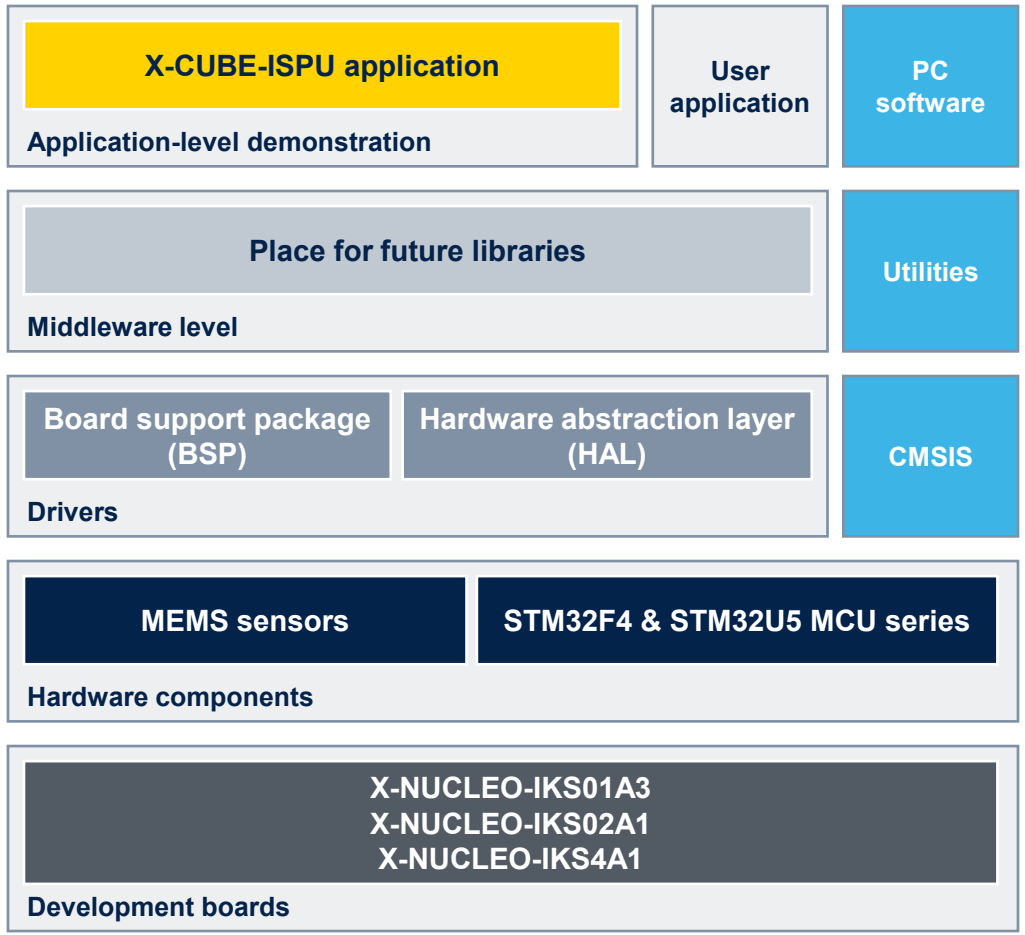
Production → Enterprise plan

- End-to-end machine learning based services from data collection to ISPU deployment
- Use case-based pricing
- No royalties or licensing fees
- Unlimited number of devices

ISPU: application examples

X-CUBE-ISPU

Include libraries, source code examples and templates



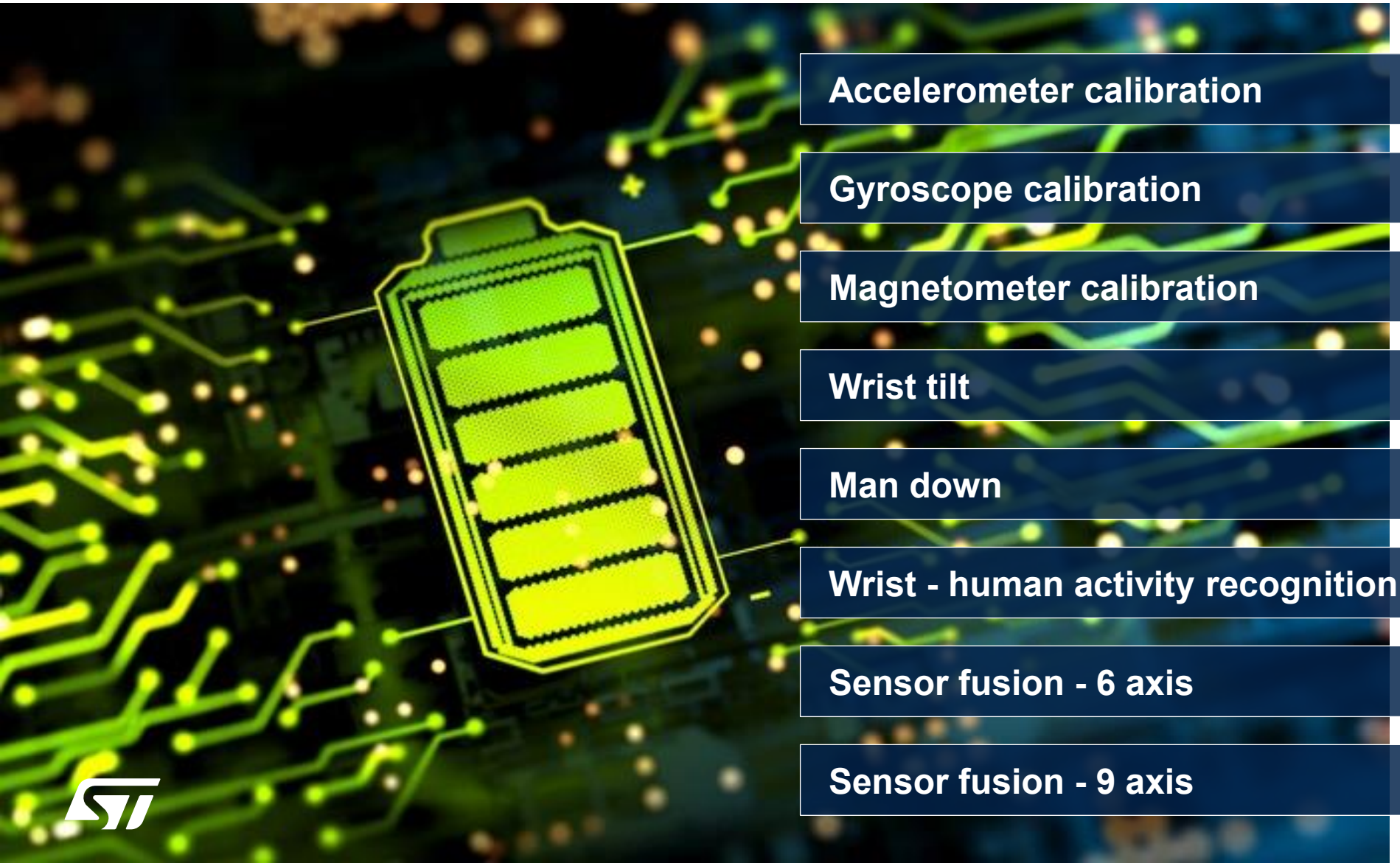
Libraries	Examples	Template
Used as building blocks for final application	**Modify & rebuild examples**	**Write your own C code**
Calibration algorithm Sensor fusion Wrist activity detection Man down Wrist tilt	ISPU project folder output folder: .h, .json	.json file can be created from a .json file example

ISPU application libraries

Calibration algorithm	Accelerometer calibration	Gyroscope calibration	Magnetometer calibration
Sensor fusion	Sensor fusion 6x	Sensor fusion 9x	
Solutions for wearable	Fall detection	Wrist tilt	Wrist - Activity recognition	Pedometer
Industrial solutions	Cyclic redundancy check	Sliding discrete Fourier transform	Vibration severity

https://github.com/STMicroelectronics/st-mems-ispu

Easily enhance your application with ISPU

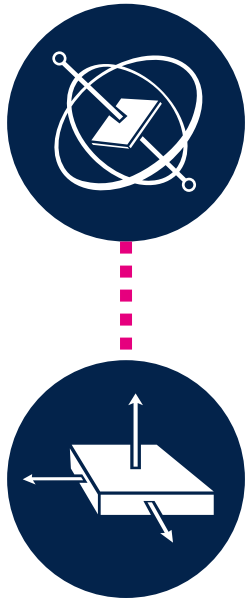


	Current consumption
Accelerometer calibration	11 µA
Gyroscope calibration	26 µA
Magnetometer calibration	21 µA
Wrist tilt	4 µA
Man down	14 µA
Wrist - human activity recognition	27 µA
Sensor fusion - 6 axis	226 µA
Sensor fusion - 9 axis	370 µA

ISPU
Sensor fusion

Sensor fusion - 6 axis

226 µA
Power consumption



Use case

The inertial sensors with **ISPU** (**LSM6DSO16IS / ISM330IS)** can be used for **6-axis sensor fusion**

Configuration & power

- **Accel. @104 Hz, 8 g,** high-perf. mode
- **Gyro. @104 Hz, 2000 dps**, high-perf. mode
- Library power consumption (no sensor): **226 µA**

Demo overview

- Sensor fusion algorithm running on the ISPU
- No processing required from MCU

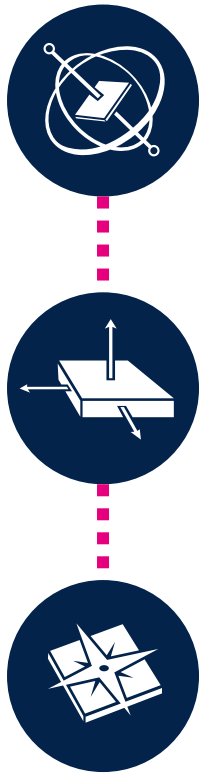
Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

ISPU
Sensor fusion

Sensor fusion - 9 axis

370 µA
Power consumption



Use case

LIS2MDL is connected to the **sensor hub** of the inertial sensors with **ISPU (LSM6DSO16IS / ISM330IS).** It can be programmed for **9-Axis sensor fusion**

Configuration & power

- **Accel. @104 Hz, 8 g,** high-perf. mode
- **Gyro. @104 Hz, 2000 dps**, high-perf. mode
- **Mag. @100 Hz** high-resolution mode with offset cancellation
- Power consumption:
  - **370 µA when calibrated**
  - **380 µA when calibration ongoing**

Demo overview

- Sensor fusion algorithm running on the ISPU
- No processing required from MCU

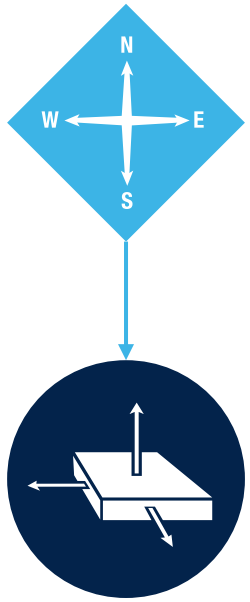
Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3 using LIS2MDL)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

ISPU
Accelerometer calibration

Accelerometer calibration

11 µA
Power consumption



Use case

- The inertial sensors with **ISPU** (**LSM6DSO16IS / ISM330IS**) can be programmed to **calibrate the accelerometer**

Configuration & power

- **Accel.** only **@52 Hz**, **8 g**, high-perf. mode
- Library power consumption (no sensor):
  - **11 µA when device is moving**
  - **19 µA when device is steady**

Demo overview

- Calibration algorithm running on the ISPU
- No processing required from MCU

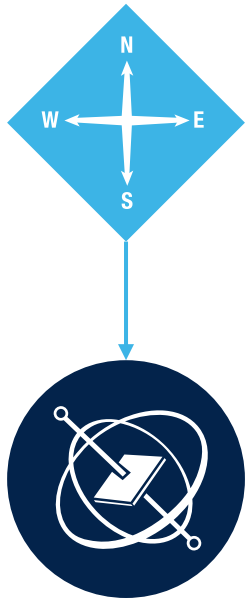
Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

ISPU
Gyroscope calibration

Gyroscope calibration

26 µA
Power consumption



Use case

The inertial sensors with **ISPU** (**LSM6DSO16IS / ISM330IS)** can be programmed to **calibrate the gyroscope**

Configuration & power

- **Accel. @52 Hz, 8 g,** high-perf. mode
- **Gyro. @52 Hz, 2000 dps**, high-perf. mode
- Library power consumption (no sensor):
  - **26 µA when device is moving**
  - **67 µA when device is steady**

Demo overview

- Calibration algorithm running on the ISPU
- No processing required from MCU

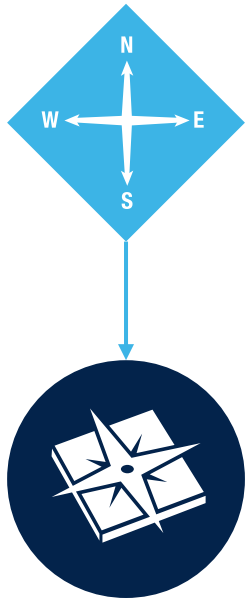
Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

ISPU
Magnetometer calibration

Magnetometer calibration

21 µA
Power consumption



Use case

LIS2MDL is connected to the **sensor hub** of the inertial sensors with **ISPU (LSM6DSO16IS / ISM330IS).** It can be programmed to **calibrate the magnetometer**

Configuration & power

- **Accel. @52 Hz**, **8 g**, high-perf mode
- **Mag. @50 Hz**, high-resolution mode with offset cancellation enabled
- Library power consumption (no sensor):
  - **15 µA when calibration not started**
  - **21 µA when calibration completed**
  - **40 µA when calibration ongoing**

Demo overview

- Calibration algorithm running on the ISPU
- No processing required from MCU

Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3 using LIS2MDL)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

ISPU
Wrist tilt

Wrist tilt

4 µA
Power consumption

Use case

- The inertial sensors with **ISPU (LSM6DSO16IS / ISM330IS)** can be programmed to detect the **wrist movement**.
- 2 different events can be identified by the ISPU:
  - **Wrist up**
  - **Wrist down**

Configuration & power

- **Accel.** only **@26 Hz**, **16 g**, low-power mode
- Power consumption: **4 µA**

Demo overview

- Wrist tilt algorithm running on the ISPU
- No processing required from MCU

Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

ISPU
Fall detection

Fall detection

14 µA
Power consumption

Use case

LPS22HH is connected to the **sensor hub** of the inertial sensors with **ISPU (LSM6DSO16IS / ISM330IS).** It can be programmed to detect a **Fall detection** event

Configuration & power

- **Accel. @104 Hz**, **16 g**, low-power mode
- **Pressure sensing @10 Hz** low-current mode with ODR / 20 bandwidth
- Power consumption: **14 µA**

Demo overview

- Fall detection algorithm running on the ISPU
- No processing required from MCU

Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3 using LPS22HH)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

Wrist - Human activity recognition

Wrist - human activity recognition

27 µA
Power consumption

Use case

- The inertial sensors with **ISPU (LSM6DSO16IS / ISM330IS)** can be programmed for wrist HAR
- The ISPU identifies 8 classes: **“Stationary”, “Standing”, “Sitting”, “Laying”, “Walking”, “Fast walking”, “Jogging”, “Other”**

Configuration & power

- **Accel. @ 26 Hz, 8 g,** high-perf. mode
- Power consumption**: 27 µA**

Demo overview

- Wrist HAR algorithm running on the ISPU
- No processing required from MCU

Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

ISPU Pedometer

Pedometer

16 µA
Power consumption

Use case

- The inertial sensors with **ISPU** (**LSM6DSO16IS / ISM330IS)** can be programmed to count the number of **steps** performed by the user having the device on the wrist.
- False positives rejection (FPR) block included

Configuration & power

- **Accel. only @26 Hz**, **16 g**, low-power mode
- Power consumption: **16 µA**

Demo overview

- Pedometer algorithm running on the ISPU
- No processing required from MCU

Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

ISPU
Sliding DFT

Sliding discrete Fourier transform

7 to 913 µA
Power consumption

Use case

The inertial sensors with **ISPU** (**LSM6DSO16IS / ISM330IS)** can be programmed to decompose a signal into its frequency components in real-time using the **sliding discrete Fourier transform**

Configuration & power

- DFT window: 32 samples
- **Accel. @1667 Hz, 8 g**, 10 MHz ISPU clock
  - Power consumption: **913 µA**
- **Accel. @12.5 Hz, 8 g**, 5 MHz ISPU clock
  - Power consumption: **7 µA**

Demo overview

- Pedometer algorithm running on the ISPU
- No processing required from MCU

Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3)**
  - **DIL24 adapter** with **LSM6DSO16IS / ISM330IS:** inertial sensors with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

ISPU
Vibration severity

Vibration severity as per ISO10816

680 µA
Power consumption

Use case

The inertial sensors with **ISPU** (**ISM330IS)** can be programmed to filter one accelerometer axis according to **ISO10816** and compute the velocity and the velocity RMS in mm/s

Configuration & power

- **Accel. @6667 Hz**, 2 g, high perf. mode
- Power consumption:
  - BP filter 2-1000 Hz: **680 µA**
  - BP filter 10-1000 Hz: **640 µA**

Demo overview

- Vibration severity algorithm (**ISO10816**) running on the ISPU
- No processing required from MCU

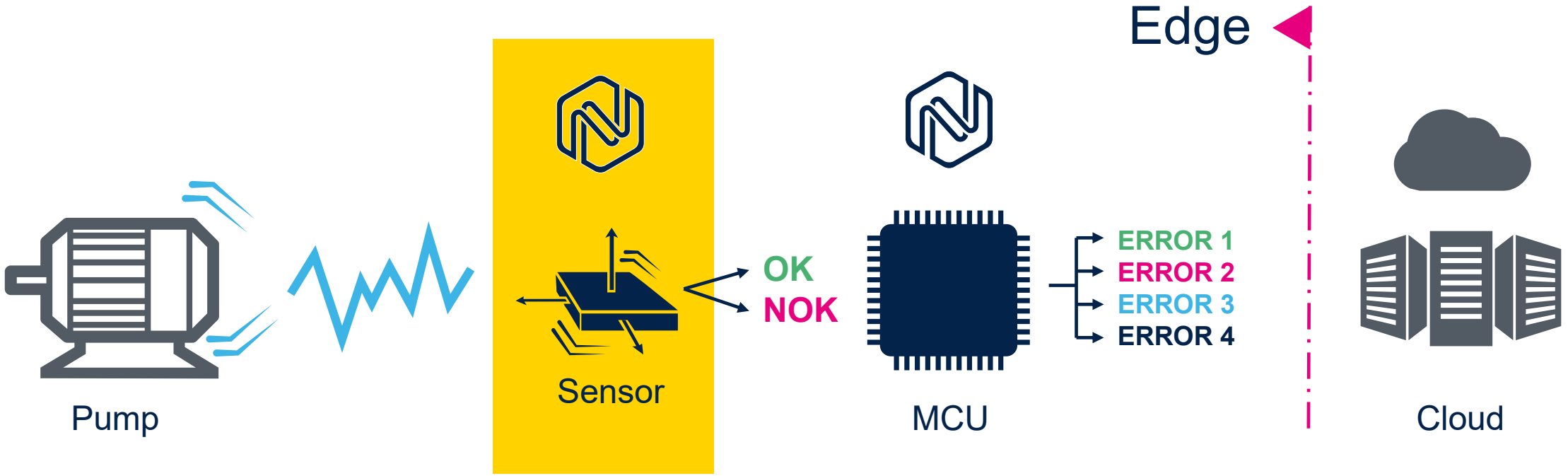
Demo setup

- Test platform: **Nucleo board + expansion board (IKS01A3)**
  - **DIL24 adapter** with **ISM330IS:** inertial sensor with 3-axis accelerometer + 3-axis gyroscope **embedding ISPU**
- Result output: **MEMS Studio**

NANOEDGE AI STUDIO

Anomaly detection with NanoEdge AI

Possibility to divide the tasks between the sensor and the MCU



Our technology starts with You

Find out more at www.st.com/ISPU