MICRO-ROS

ROS-INDUSTRIAL SPRING WORKSHOP

MAY 7TH 2018

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Partially supported by EU grant 780785

“In the future it should be possible to implement the ROS protocol directly on the devices embedded system”

ROS2 Design Wiki “Stories”

Micro-ROS

Robots are networks of devices

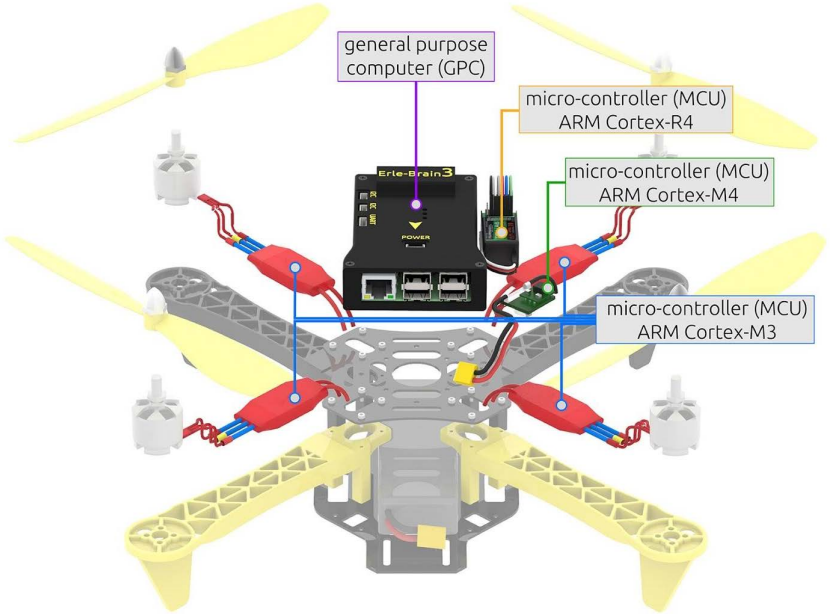


Image source: Erle Robotics, taken from OFERA proposal.

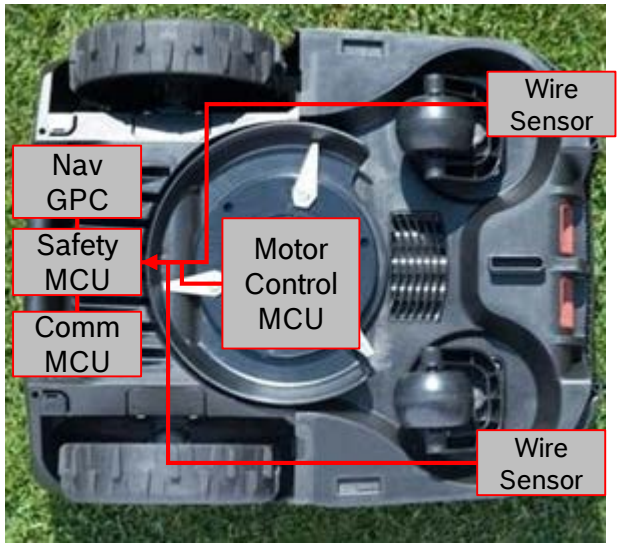
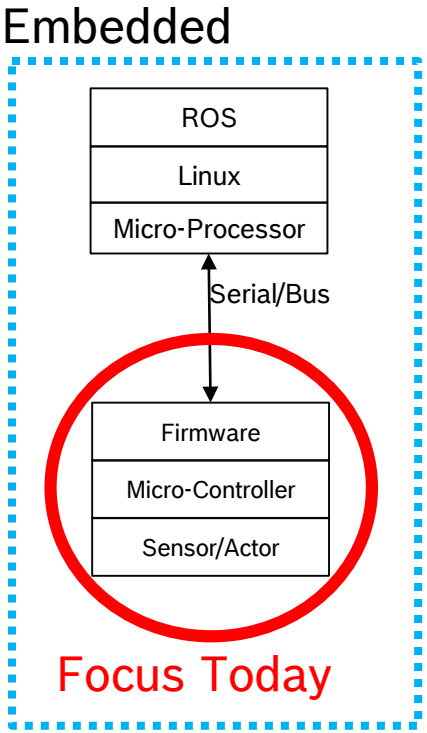


Image source: Bosch PowerTools GmbH, All rights reserved

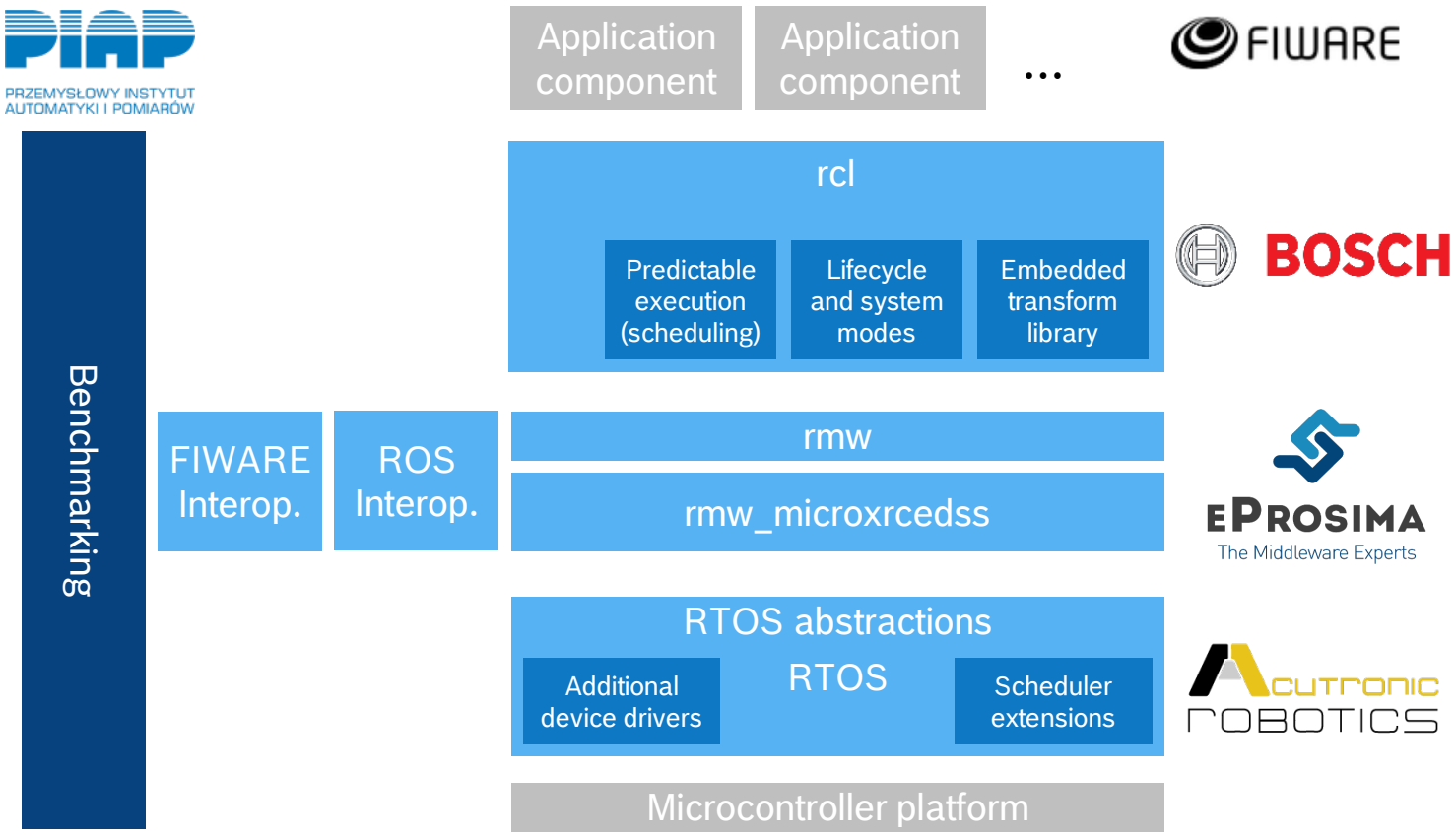


Micro-ROS
Open Framework for Embedded Robot Applications (OFERA)

OFERA will extend ROS2 to allow its use in MCUs

https://ofera.eu/

The OFERA project is funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 780785



Micro-ROS
Situation

- ROS+Linux is a powerful combo
  - Excellent libraries for perception, planning, networking, etc
  - Unified developer eco-system: One kernel, most devices
  - It's what we all have on our desks
- But…
  - Issue 1: Hardware access
  - Issue 2: Hard, low-latency RT
  - Issue 3: Power saving
  - Issue 4: Safety

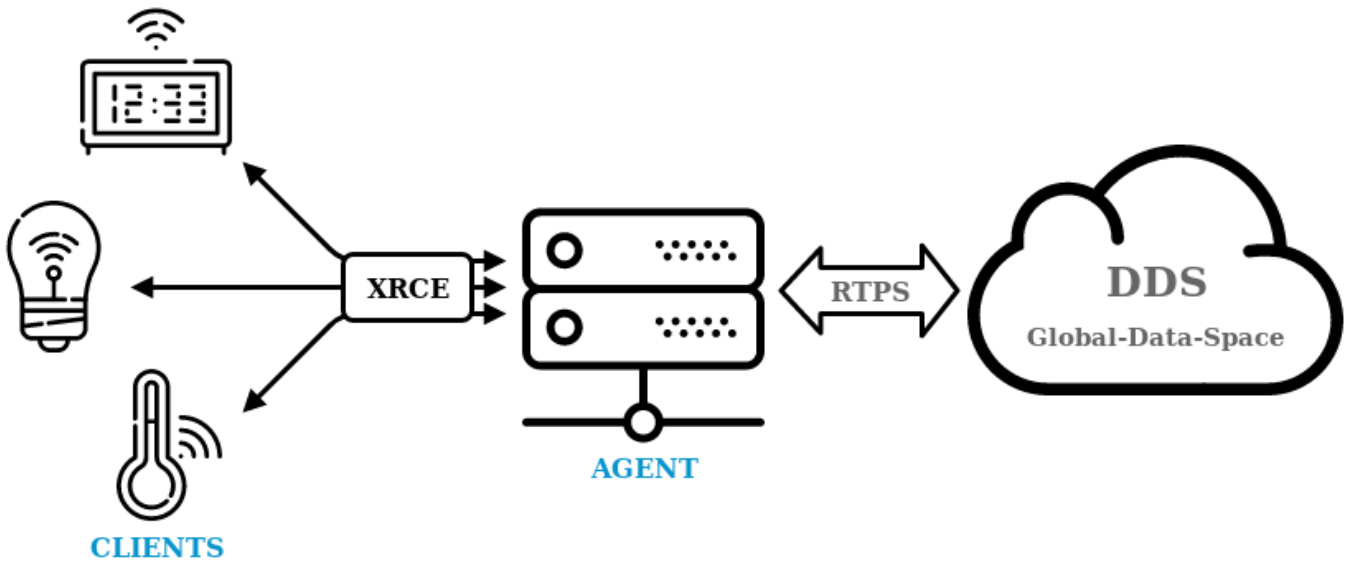
Micro-ROS
Real-Time Operating Systems (RTOSs)

- RTOSs are optimized for real-time performance
- In OFERA, we're using NuttX as the default
  - POSIX-style API makes porting easy
- Other interesting choices include RIOT, FreeRTOS, Zephyr, etc

- RTOS diversity is an issue
- Hardware diversity is an even bigger issue

- Something unifying would go a long way…

Micro-ROS
New DDS-XRCE Standard



- DDS-XRCE for e**X**tremely **R**esource **C**onstrained **E**nvironments
  … brings DDS on MCUs
- Client-server approach
  - Power-saving
  - Disconnected use

I'm assuming you heard a lot about it yesterday

Open-source at github.com/eProsima/Micro-XRCE-DDS

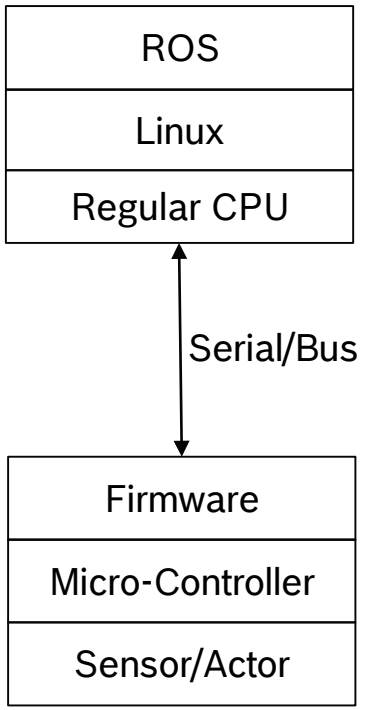
Micro-ROS
Side-by-Side Comparison

	ROS2	Micro-ROS
Hardware	X86, ARM Cortex-A, …	ARM Cortex-M, ….
Resources	>512MB RAM, >8G Disk	~100K RAM, ~1MB Flash
Communications	GBit/s, Ethernet, 802.11 WiFi	Serial, WPAN – 250k to 1MBit/s
Operating System	Linux, Windows, MacOS	RTOS (NuttX by default)
Middleware	DDS variant (by default)	XRCE-DDS (by default)
Middleware Abstraction	RMW	RMW
Client Support Library	RCL	RCL
Execution Layer	RCLCPP / RCLPY / …	**RCL** + RCLCPP
Executors	Generic	Custom

Micro-ROS
Issue 1: Hardware access

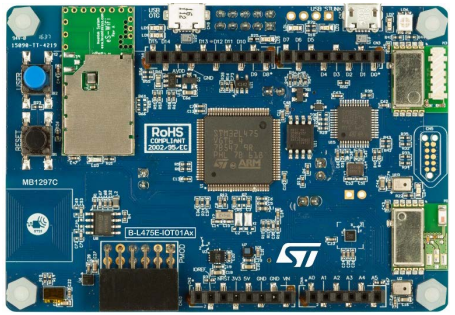
- Why not use Industrial PCs?
  - You're always talking to some piece of firmware over a comm link
  - It usually doesn't do exactly what you want
  - There's latency
- Driver implementation…
  - A multitude of serial protocols
  - Almost as bad for field buses
  - Often, important things (timing…) are not in the data-sheets
  - State management for external devices is a mess

→ We need to get into the firmware

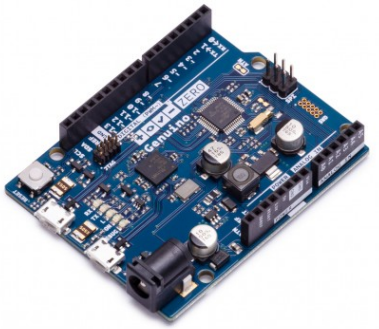


Micro-ROS
Hacker-friendly single-board computers

- Cortex-A class
  - E.g., Raspberry Pi
  - 512MB RAM, SD card storage
  - Reasonable set of I/O pins
  - WIFI, BT, Ethernet, USB
  - Linux capable



- Cortex-M4 class
  - E.g., STM32 IoT Discovery
  - ~128kB RAM, 1MB flash
  - Arduino-I/Os, PMOD
  - Low-power networks
  - Built-in sensors + I2C, SPI, etc



- Arduino-class
  - 8/32 bit MCU
  - 4-16kB RAM
  - Bare-metal
  - Arduino I/Os
  - Huge shield ecosystem

Micro-ROS
Micro-Controllers: Hardware Access

- Micro-Controller, n: Chip that contains a processor *and peripherals*
  - analog/digital converters (ADC)
  - Quadrature decoders (QED)
  - PWM generators
  - Digital IOs (GPIO)
  - ...
- Buses with register support
  - CAN, UART, SPI, I²C,...
  - Register mapping for read/write
- Much higher diversity and rate of evolution than general purpose CPUs

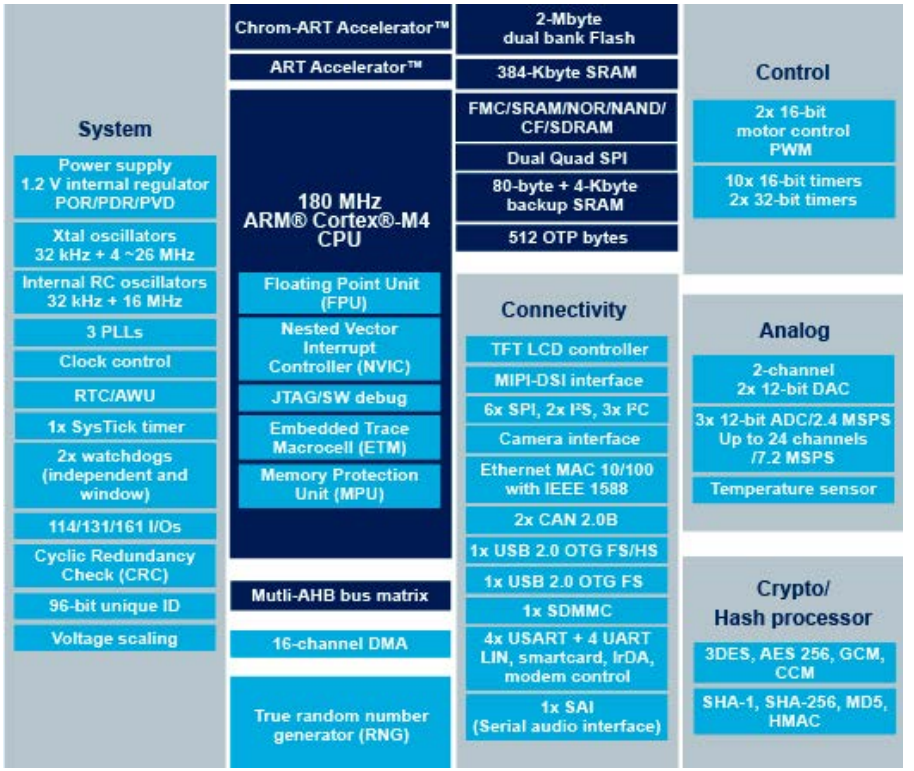
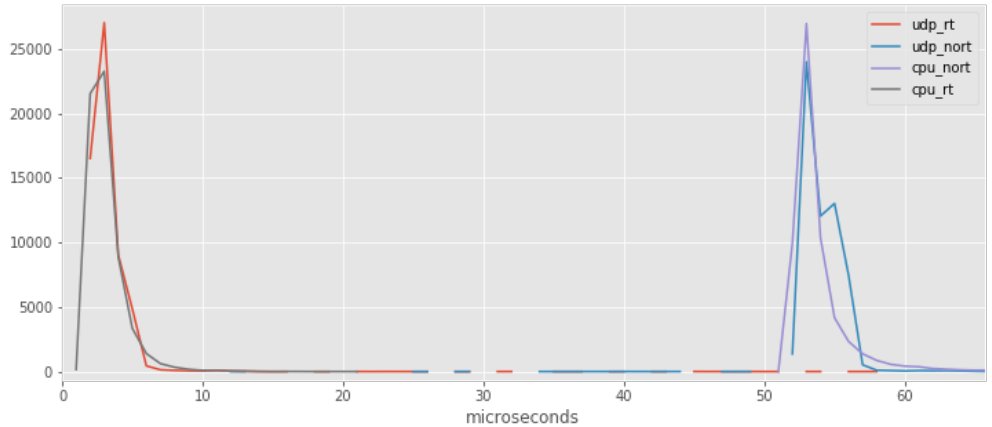


Image source: STMicro website, https://www.st.com/en/microcontrollers/stm32f479bi.html

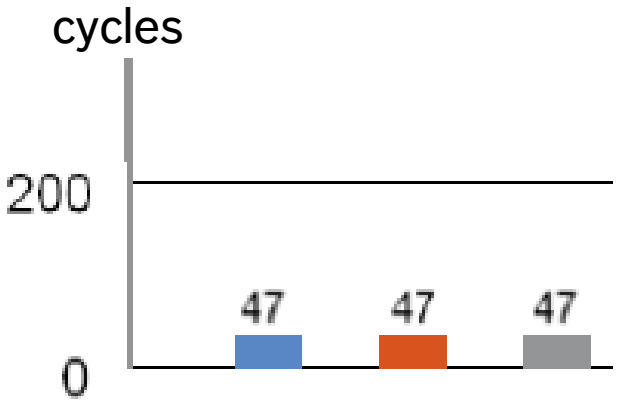
Micro-ROS
Issue 2: Status of RT on Linux

- Linux scheduler has an RT class
  - On a high-end PC, it gets you down to ~5µs task activation time
  - But kernel processes can stall it
  - Outliers up to tens of milliseconds
- Linux PREEMPT-RT Patch solves this
  - Can be difficult to integrate with other patches (e.g., BSP and proprietary drivers)
  - This is after more than a decade of work

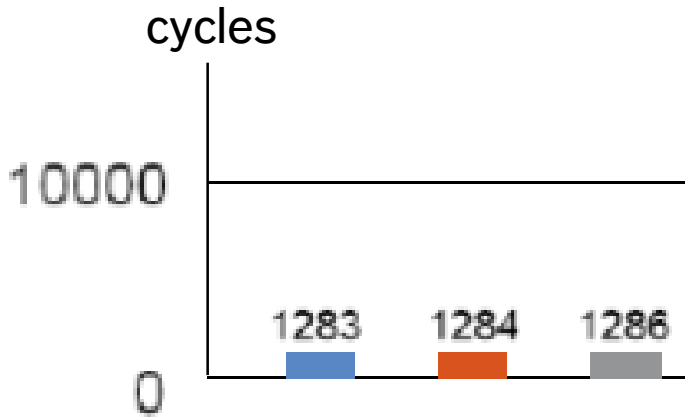


Micro-ROS

Example: Context Switch Time RTOS vs. Linux



Zephyr



Linux

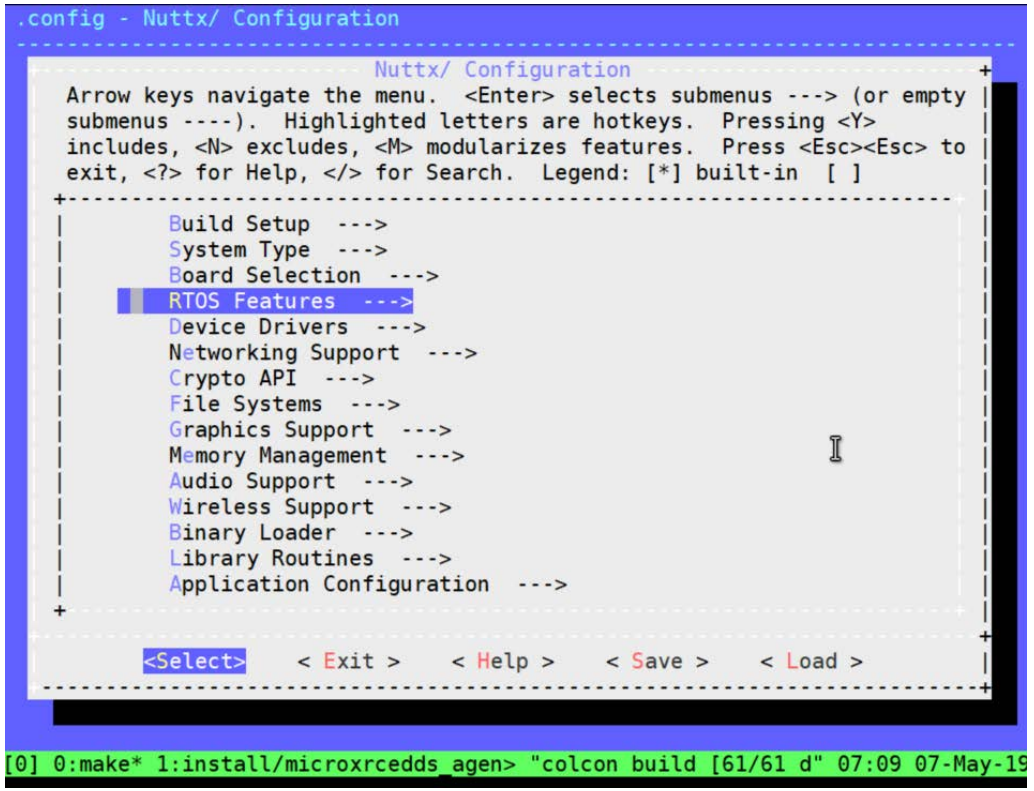
Source: “PERFORMANCE ANALYSIS USING NXP’S I.MX RT1050 CROSSOVER PROCESSOR AND THE ZEPHYR™ OS”, MAUREEN HELM, LEOTESCU FLORIN, MARIUS CRISTIAN VLAD, NXP, 2018.
https://www.nxp.com/docs/en/training-reference-material/BENCHMARK-ZEPHYR-OS-PDF.pdf

Micro-ROS
NuttX, the „Tiny Linux“

- RTOS with POSIX API
  - Released first in 2007 by Gregory Nutt
- „Batteries included“
  - Shell
  - TCP/IP
    - Incl. DHCP, NTP
  - 6LowPAN
  - C++ standard libs: libcxx or uclibc++
  - Many device drivers and BSPs
    - Focused mainly on ARM, ARC, Atmel
  - much more…
- http://nuttx.org/

RTOS	POSIX?	libstdc++?
Zephyr	Threads, Time, IPC	No
ARM Mbed	No	No
FreeRTOS	Threads, Time	No
RIOT	Partial	??

Micro-ROS
NuttX Demo



Micro-ROS
Issue 3: Power-saving

- Power use is important in many embedded applications
  - Battery-powered sensors
  - Unmanned aerial vehicles
  - Standby operation

- Linux SBC use 1-2 orders of magnitude more power

(Sources: http://www.pidramble.com/wiki/benchmarks/power-consumption, https://learn.adafruit.com/embedded-linux-board-comparison/power-usage, OFERA measurements)

Device	Idle	Operational
Rpi A	~150mA	~180mA
Rpi 3	~350mA	500-800mA
STM32L1	~3mA	~10mA
STM32F4	~10mA	~100mA

Micro-ROS
Issue 4: Safety

- Being worked on since (at least) 2011
  - SIL2Linux
  - Project P
  - …
- SIL2Linux
  - Target: Safety Integrity Level 2
    - Strips much of Linux, most notably many drivers
    - Going on for years, not clear what the outcome is
    - But do watch https://elisa.tech/ !
  - The highest SIL level is 4…
- And then there's the question of appropriate compute hardware

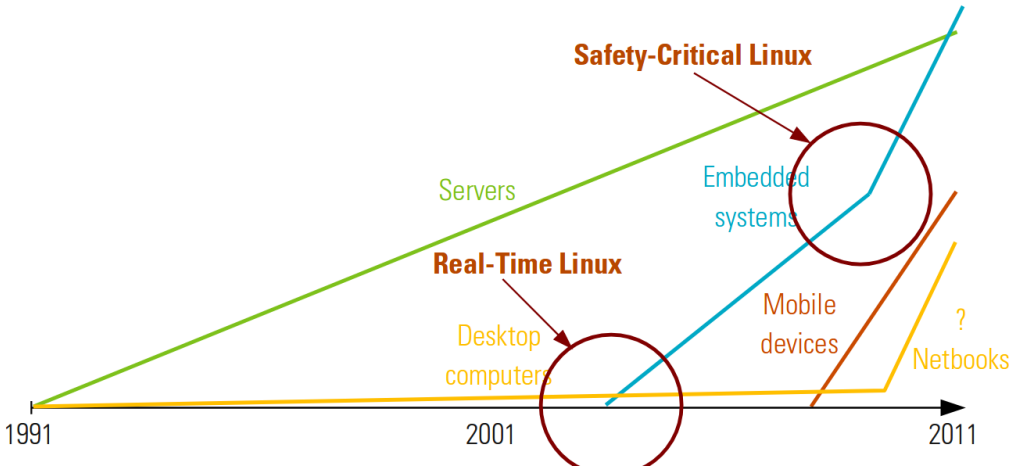
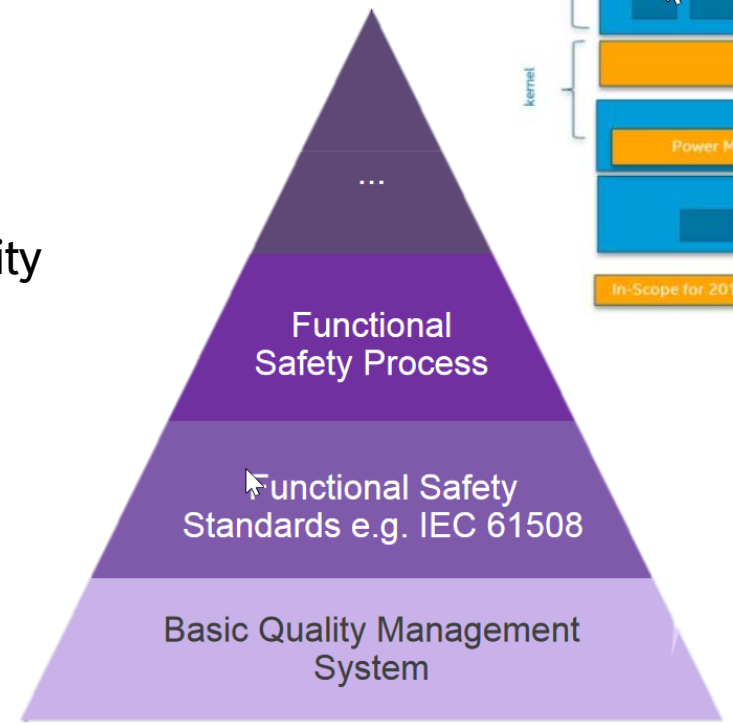


Image source: Carsten Emde, OSADL. Embedded World Presentation March 3rd 2011

Micro-ROS
Open Source and Safety

- Zephyr RTOS (a Linux Foundation project) attempts Safety Certification in 2019
- Subset of whole OS
  - Orange boxes: In scope for 2019
  - Notably no drivers!
- Based on existing work on security



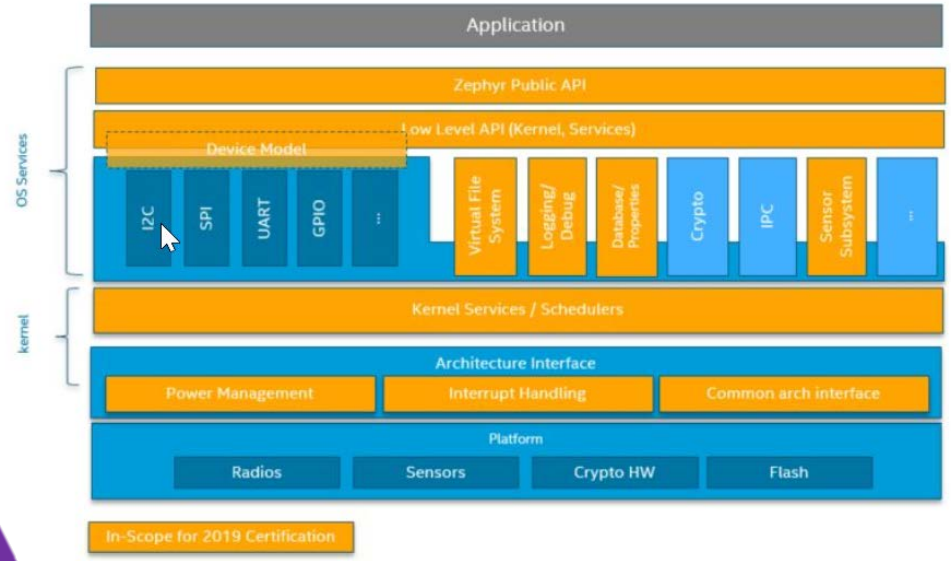
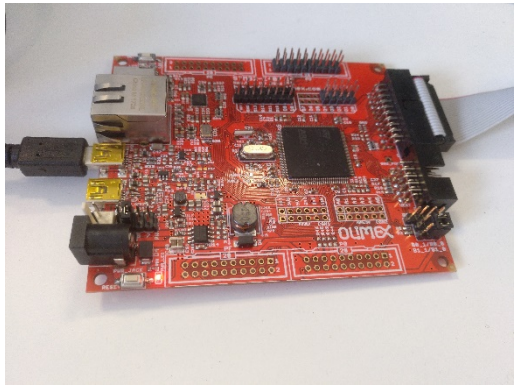


Image source: https://events.linuxfoundation.org/wp-content/uploads/2018/07/OSLS-2019_-Zephyr-Project-.pdf

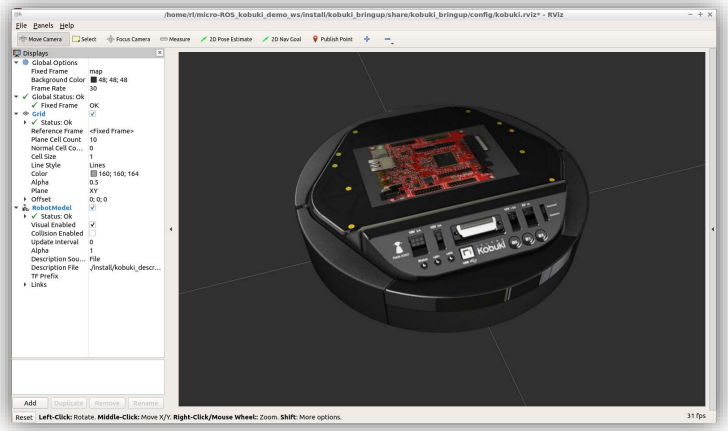
CURRENT STATUS

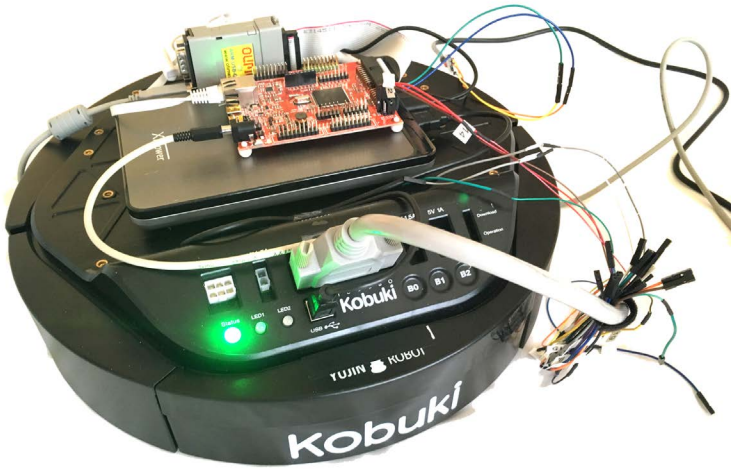
Micro-ROS
Target Devices

- Device Classes
  - Low-end: MCUs starting at 32kB RAM with low-power consumption
    - E.g., STM32L1
  - Typical: Cortex-M4 devices with ~100kB RAM
    - E.g., STM32F4
- Going below 32kB would likely require a different architectural approach and is not currently in scope
- OFERA has two references boards with full OS support provided by partner Acutronic Link Robotics
  - STM32L1-DISCOVERY
  - OLIMEX STM32E407



Micro-ROS
Turtlebot 2 Demo





ROS 2 (Crystal) running
- Visualization
- Keyboard control
- odometry to TF
- DDS <-> DDS-XRCE agent

DDS-XRCE over UDP

micro-ROS running
- thin_kobuki_driver
- DDS-XRCE client

at less than 100 KB RAM

Preliminary version at github.com/microROS/micro-ROS_kobuki_demo

Micro-ROS
Turtlebot 2 Demo

- Based on „thin kobuki“ driver
- Converted to use rcl API
  - rclcpp wasn‘t ready at the time
- Porting issues?
  - A few issues with C++ initialization

UPCOMING WORK

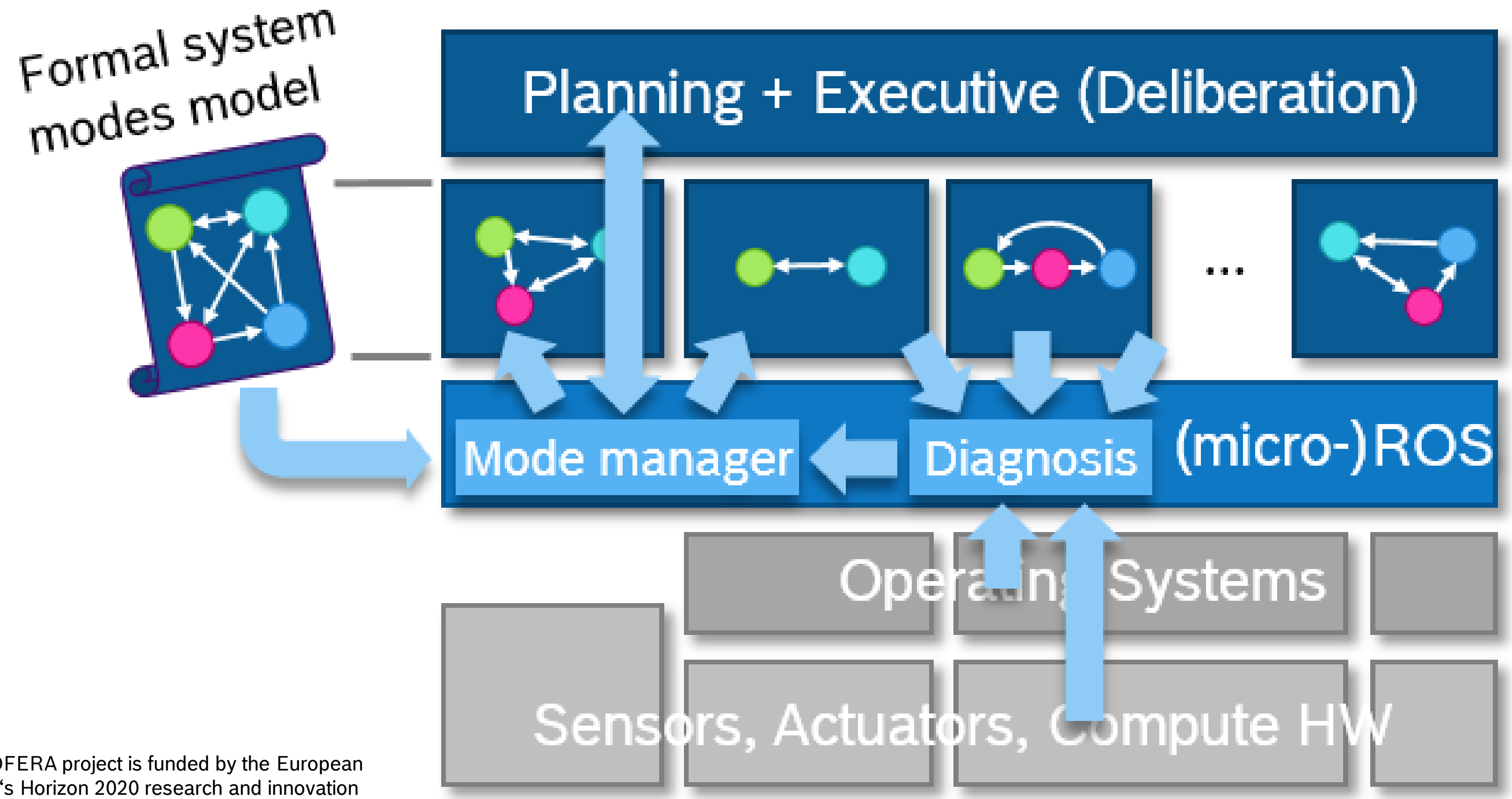
BOSCH

Micro-ROS
Recap: Composable firmware

- Nowadays, firmware provided by vendor
  - Unforeseen features? Bad luck…
- Vision: Add new features to existing firmware
  - ROS2 way: Just add nodes
- Challenge: Interference
  - Need to make sure existing stuff still works!

- Micro-ROS Approach:
  - System Modes
  - Domain-specific scheduling, towards providing guarantees

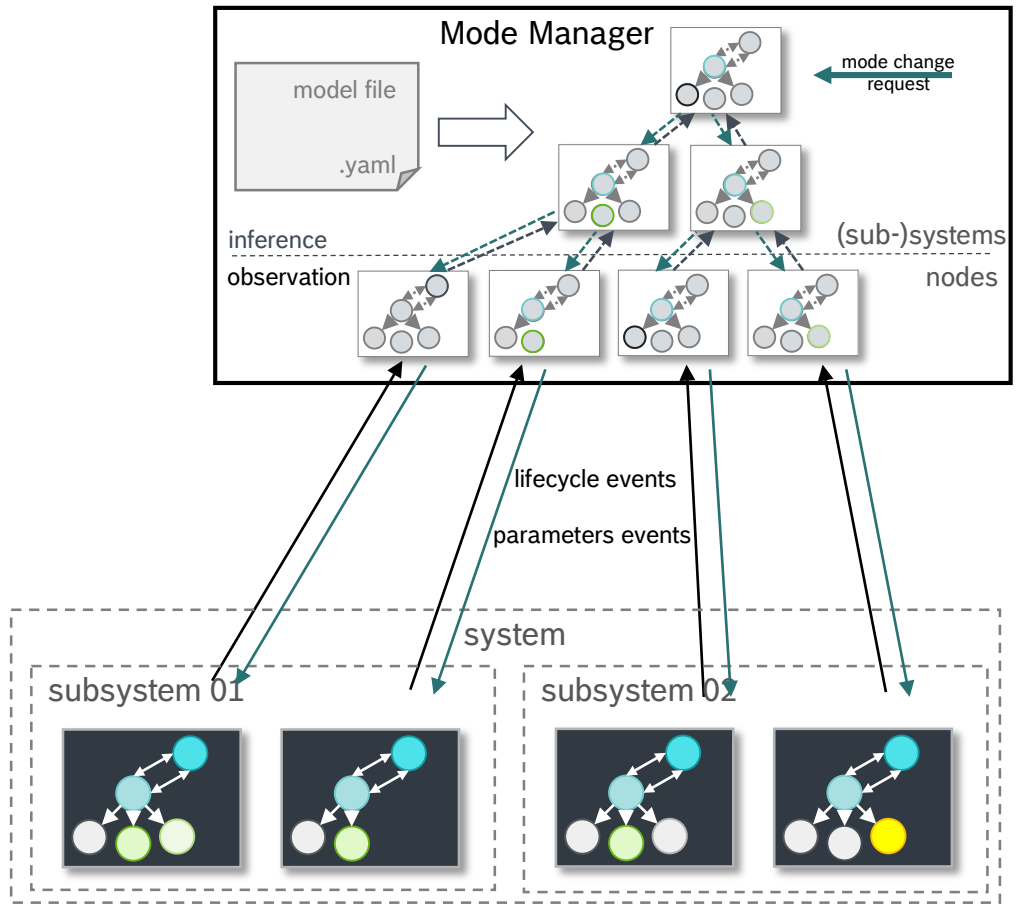
Micro-ROS
Towards explicit architecture



The OFERA project is funded by the European Union‘s Horizon 2020 research and innovation programme under grant agreement No 780785

Micro-ROS
System Modes

- Introduces **(sub-)systems** hierarchy to ROS 2
- Abstraction for hierarchical configuration, called **system modes**
- **Mode manager** manages consistent, system-wide configuration
- See **microros.github.io/system_modes/**



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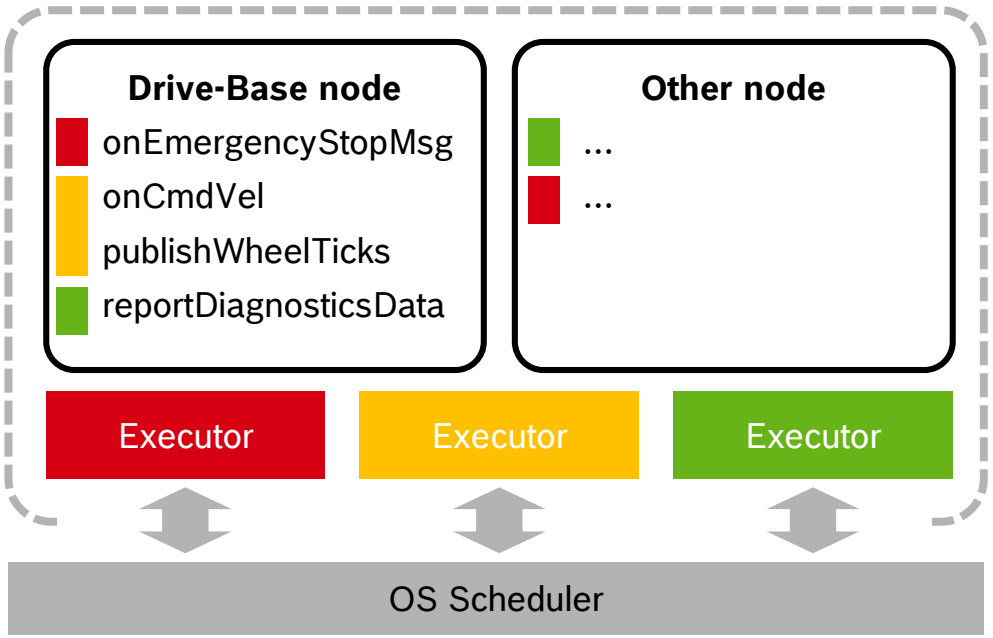
Micro-ROS
Predictable Execution

- First approach enables **multiple executors** per operating system process
- Executors can be configured individually using standard scheduling mechanisms
- Open-sourced prototype for ROS 2
- See **microros.github.io/real-time_executor/**



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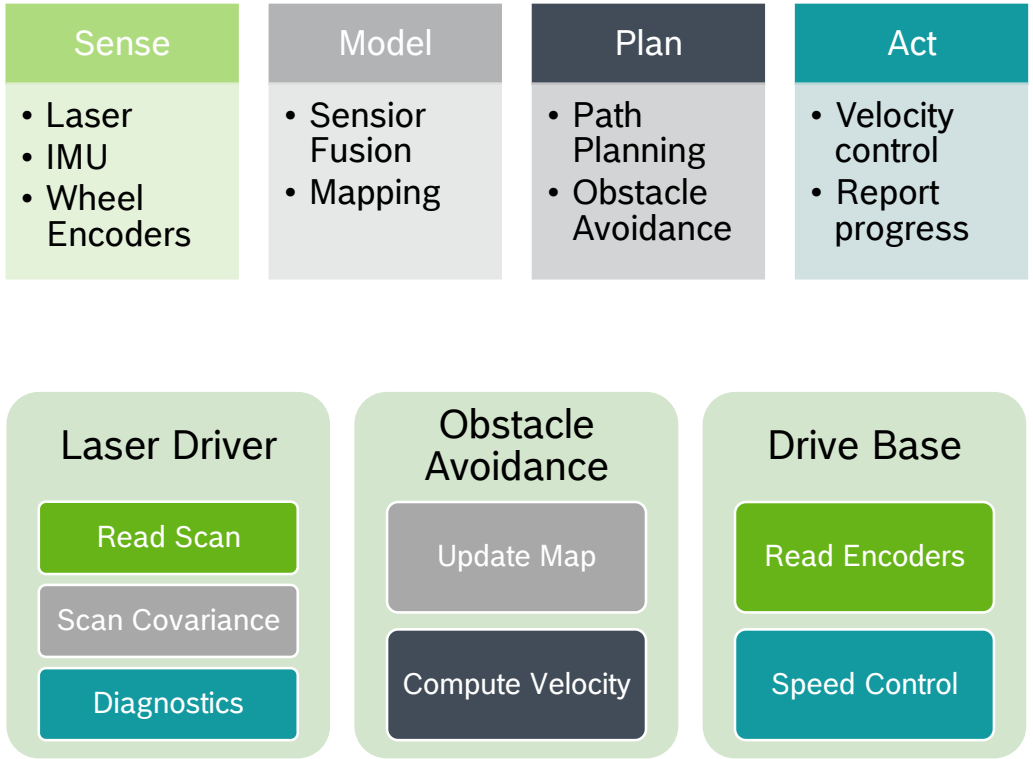
Micro-ROS
Domain-specific scheduling

- Current real-time schedulers typically use priorities
  - Not composable!
  - Not domain-appropriate
- Micro-ROS Approach: Domain-specific schedulers
  - E.g., stage-based approach with „Sense-Plan-Act“
  - Or more stages…
  - Assign callbacks to stage using callback groups
  - Derive within-group order from communication links
- Provide „budgets“ by group



BOSCH

Micro-ROS
Building micro-ROS…

- Challenge: RTOS defines toolchain and system headers
  - What‘s the build order?
- Currently: ROS2 workspace built as part of NuttX build
  - Pro: Handles toolchain (cross-compiling, etc.)
  - Con: Time consuming
  - Con: Workspace is not aware of being a micro-ROS target
- Current work: Build everything using colcon
  - NuttX vendor package to configure and build NuttX
  - Colcon configuration to configure toolchain

Micro-ROS
Building an ecosystem

- Does this mean that every ROS developer can now start using MCUs?
- Well…

ROS 2 Embedded
Further information

- microROS organization at GitHub
  - https://micro-ros.github.io/
  - https://github.com/micro-ROS/
- OFERA website: https://ofera.eu/
- ROS 2 Embedded Design Page
  - Currently at https://github.com/ros2/design/pull/197
  - After merge: http://design.ros2.org/articles/embedded.html

THANK YOU

BOSCH