Transitioning from FreeRTOS to Zephyr RTOS:
A Product Refresh Journey

Elton Shih

About us

Elton Shih

- Research engineer @Audinate
- Embedded systems & systems software

Audinate

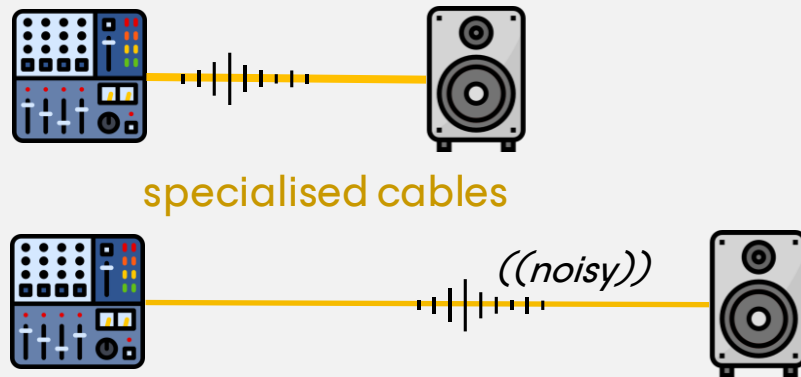- Maker of Dante (pro AV networking)

Product Refresh Story

Dante Intro

Dante replaces complex audio cabling with computer networks

How does it work?

Traditionally..

Point-to-point physical connections.

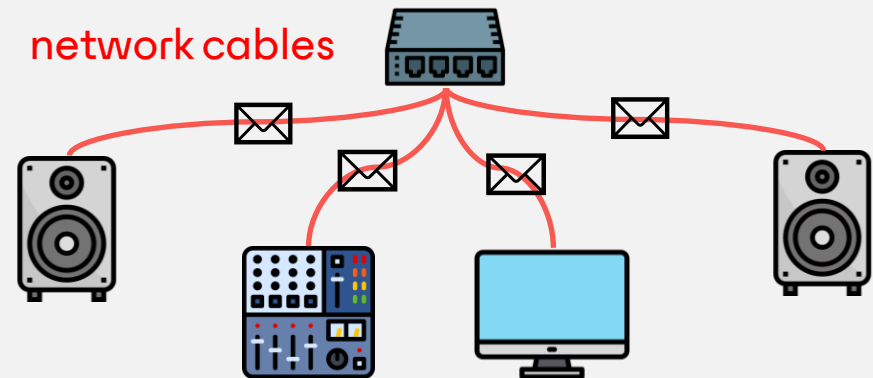specialised cables

((noisy))

Single-purpose, specialised cables..

[*Labor intensive, expensive*
distance ↑ noise & signal degradation]

With Dante

Devices are connected to the network
Connections managed through software

network cables

[*Low latency, synchronize*]

Dante replaces complex audio cabling with computer networks

Where is Dante used?
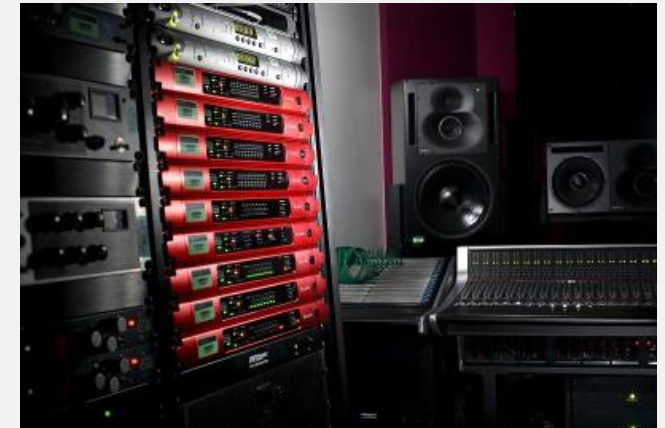
4000+ products from manufacturers   600+ Dante manufacturers

Sydney Opera House

Sydney Trains

Recording Studios

Universities, Conference Rooms, Broadcast Studios, Corporate Campuses, Houses of Worship, Arenas & Stadiums, Conference Centres, Amusement Parks, Zoos, Theatres

Dante products

Consumers

System Software
for system setup, management, and troubleshooting

AVIO Network Adaptors
{Bluetooth, USB, Analog} ↔ Dante

Dante AVIO™
2CH USB-C® I/O Adapter

PC / Mac / Cloud Software
E.g. Virtual Soundcard and more

Manufacturers (OEMs)

⭐ Embedded Audio

Hardware
Brooklyn
Broadway
Ultimo

(Chips, Cards & Modules)

Software
Dante Embedded Platform
(Linux)

Dante IP Core
(FPGA IP)

Embedded Video

Hardware

Software
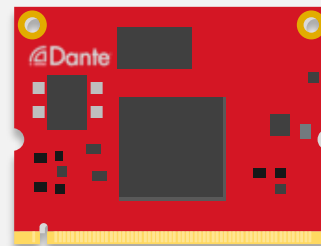
Product Refresh Story

Ultimo

Ultimo

Low-cost Dante based on FreeRTOS + MCU

tight coupling!

barebones

Application

‑⚡ Dante®

free**RTOS**

32-bit ARM MCU

Low-cost Dante stack
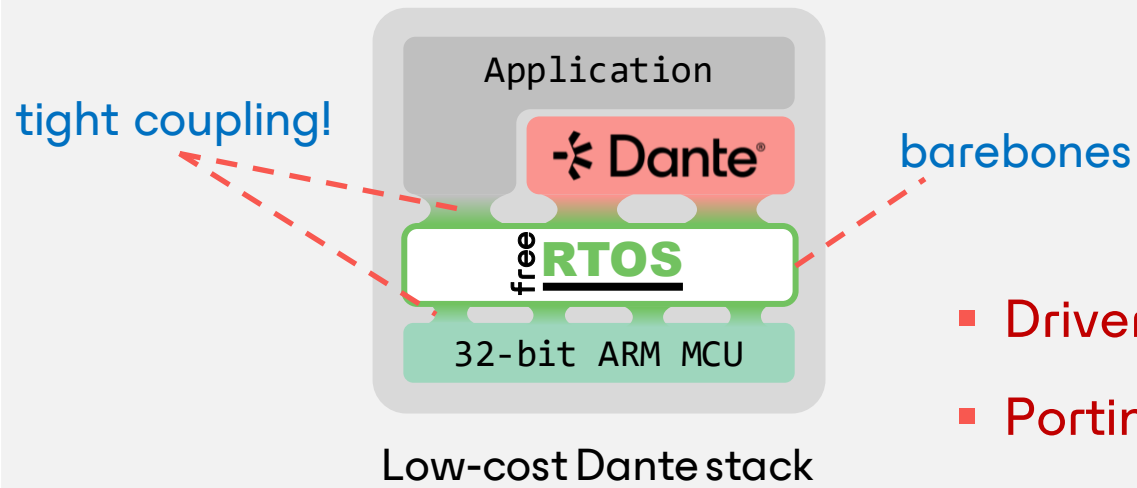
- Drivers and implementation customised over the years
- Porting effort significant!

⚠️ Hitting resource limits
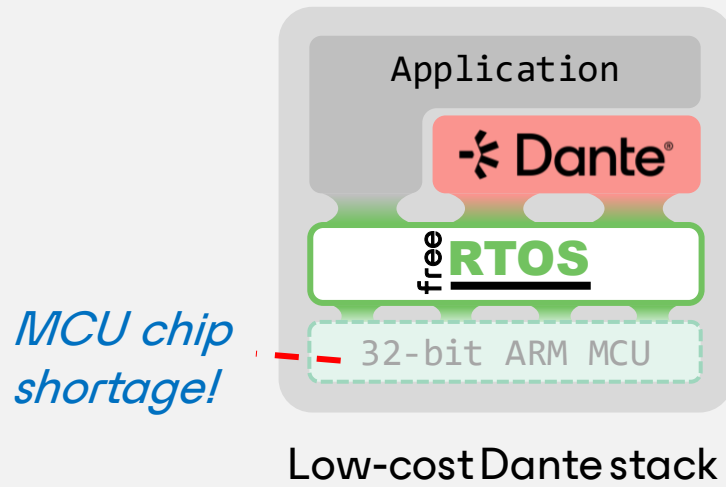
| audio encryption | cloud connectivity | new audio formats | | |

fitting more features and taking up more resources →

→ **Product refresh needed!**

running out of space for future features

"We have plenty of time!" - 2020

2020

Ultimo Low-cost Dante based on FreeRTOS + MCU

Chip supply shortage 2021 - 2023

Application

Dante®

free**RTOS**

32-bit ARM MCU

MCU chip shortage!

Low-cost Dante stack

Supply chain uncertainties..

- MCU vendor allocation was *VERY* dynamic
- *If...* porting overhead was minimal
- → **We can spin variant of different MCUs**

However..

- Tight coupling between RTOS & MCU makes porting hard
- → **Need to reduce reliance on single hardware portfolio**

"We don't have plenty of time!" - 2021

2021

Ultimo Product Refresh

(Initial) MCU selection

Technical
Flash, RAM, Ethernet MAC, I^2S, crypto, clock speed

Non-technical
BSP completeness
Vendor support activities

Commercial
Price & Availability

next-gen
Ultimo
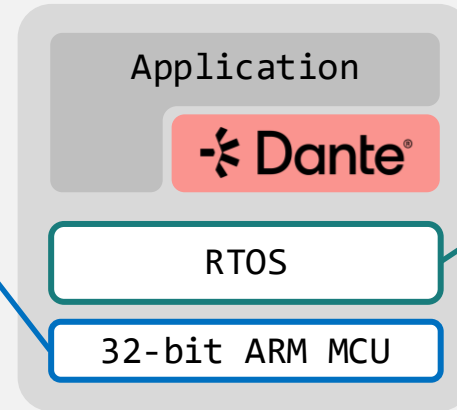
Application

Dante

RTOS

32-bit ARM MCU

RTOS selection

Technical
Modularity & Portability
Network & Connectivity
Security
Subsystems and features

Non-technical
Steering committee
Cross-vendor support
BSP
Project Roadmaps

Dante Pro S1 (2024)

Application

Dante

Zephyr

32-bit ARM MCU

- RTOS: Zephyr RTOS
- MCU: STM32H7
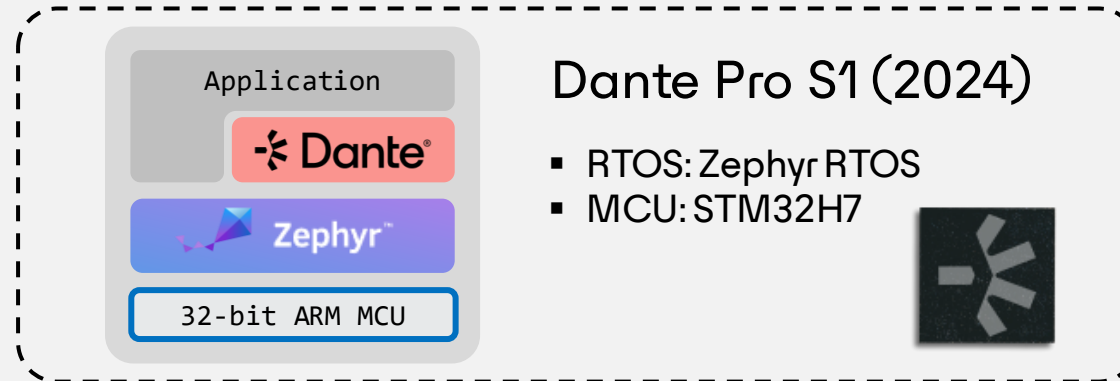
Zephyr Dev Experience

Positives

RTOS Selection

Technical
Modularity & Portability
Network & Connectivity
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Non-technical
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Cross-vendor support
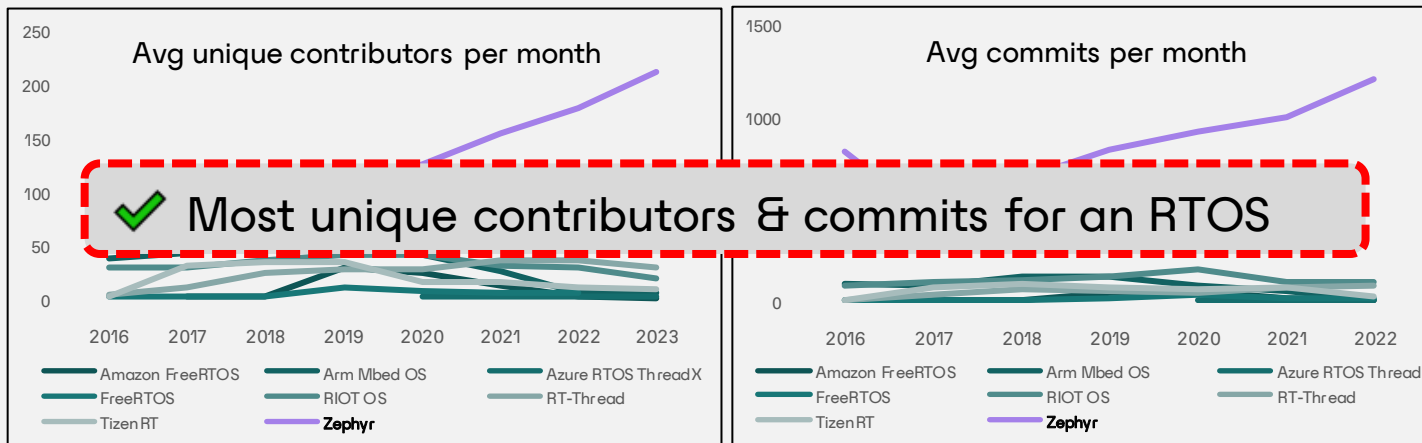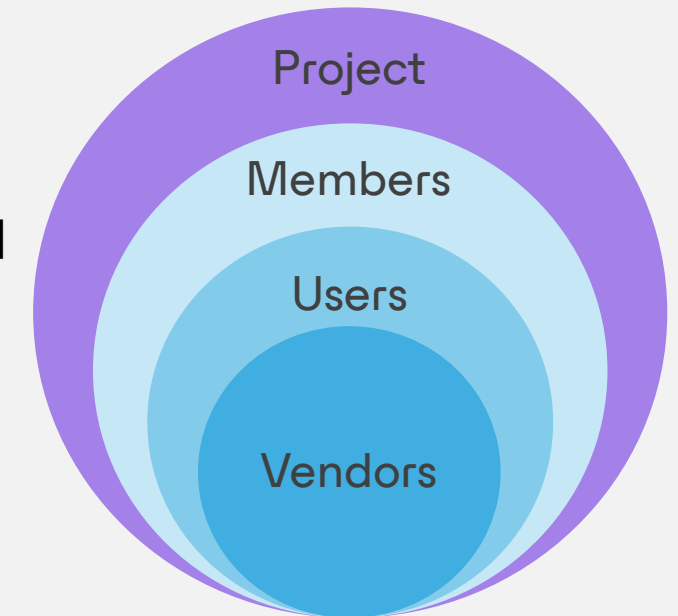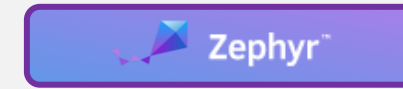BSP
Project Roadmaps

Zephyr RTOS

→ Vendor neutral

→ Vibrant community

Technical Steering Committee
[Maintainer, Collaborator, Contributor]
[hobbyists, industry reps, vendors]

Avg unique contributors per month

Avg commits per month

✅ Most unique contributors & commits for an RTOS

Amazon FreeRTOS | Arm Mbed OS | Azure RTOS ThreadX
FreeRTOS | RIOT OS | RT-Thread
Tizen RT | **Zephyr**

Project
Members
Users
Vendors

Cloud vendors purchasing RTOS

https://zephyrproject.org/wp-content/uploads/sites/38/2024/01/Zephyr-Overview-20240110.pdf
https://www.intel.com/content/www/us/en/developer/articles/community/zephyr-story-how-became-self-sustaining-ecosystem.html

RTOS Selection

Technical
Modularity & Portability
Network & Connectivity
Security
Subsystems and features

Non-technical
~~Steering committee~~
Cross-vendor support
BSP
Project Roadmaps

Cross-vendor support
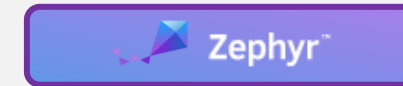
→ Cross-architecture

ARC	ARM	Intel x86	MIPS
NIOS II	RISC-V	SPARC	Xtensa

→ 100+ supported vendors

→ 600+ supported boards

Feature-rich

- Plenty of sample applications
- Working drivers out-of-the-box

✅ Fast prototyping & feature evaluation

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RTOS Selection

Technical
Modularity & Portability
Network & Connectivity
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Subsystems and features

Non-technical
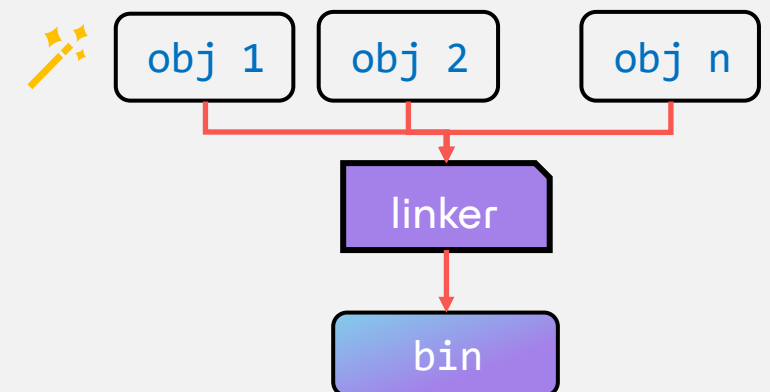Steering committee
Cross-vendor support
BSP
Project Roadmaps

Application	
	High-level API
Middleware	POSIX / FS / Networking
	Low-level API
Zephyr Kernel	
BSP	
	HAL
Hardware	

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Ultimo Product Refresh - Why Zephyr RTOS?

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RTOS Selection
Technical
Modularity & Portability
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~~Subsystems and features~~
Non-technical
~~Steering committee~~
~~Cross-vendor support~~
BSP
Project Roadmaps
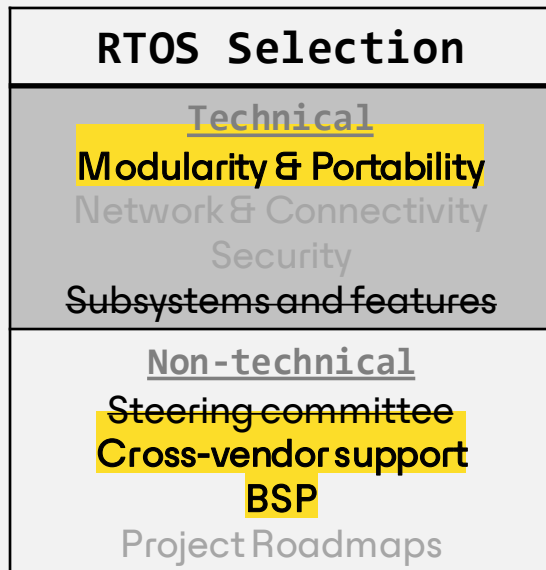
CMake   Zephyr Modules

Third-party libs, HAL, FS, IPC libs etc
included as Zephyr modules (modularity)

Reuse Dante codebase for
Linux based systems
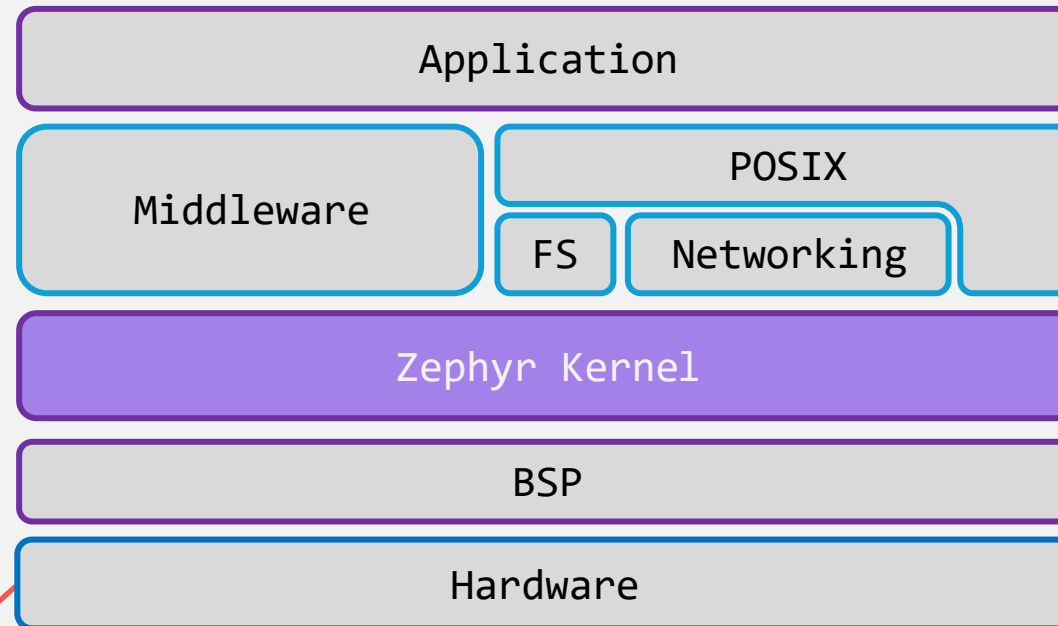
KConfig configuration
(cleanly turn on/off features)

Application

Middleware	POSIX
	FS	Networking

Zephyr Kernel

BSP

Hardware

Device-tree configurations
→ generates C headers rather than dtb

Clear abstractions, configurability,
wide range of hw-support → **more hardware agnostic**
(portability)

✅ All leveraging standard & widely used tools/frameworks

RTOS Selection

Technical

~~Modularity & Portability~~
Network & Connectivity
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~~Subsystems and features~~

Non-technical

~~Steering committee~~
~~Cross-vendor support~~
~~BSP~~
Project Roadmaps

RTOS	MPU support	Open source
FreeRTOS	Optional	Open-source
ARM Mbed	Mandatory	Open-source
Nucleus 3.X	Mandatory	Proprietary
Keil RTX	None	Proprietary
Contiki	None	Open-source
ThreadX	None	Proprietary
TinyOS	None	Open-source
TI-RTOS	None	Open-source
uC/OS-II	Optional	Proprietary
VxWorks	Optional	Proprietary

Native Connectivity Stacks

- **Network stack**
- Bluetooth
- USB stack

Dante AVIO™ Bluetooth® I/O Adapter

Dante AVIO™ 2CH USB-C® I/O Adapter

Security

- **MPU/MMU support (x86, ARM, ARC)**
- Stack overflow protection
- Kernel object & device driver permissions tracking
- Thread isolation

Application

Dante®

- Separation between Application, Dante, and Zephyr
- Limit vulnerability attack surface

Zhou, Wei, et al. "Good motive but bad design: Why ARM MPU has become an outcast in embedded systems." *arXiv preprint arXiv:1908.03638* (2019).
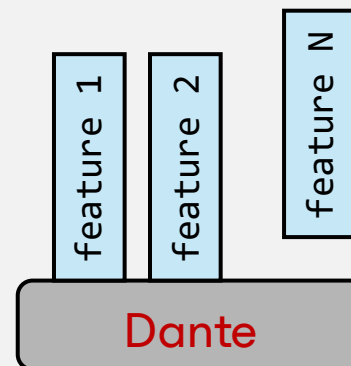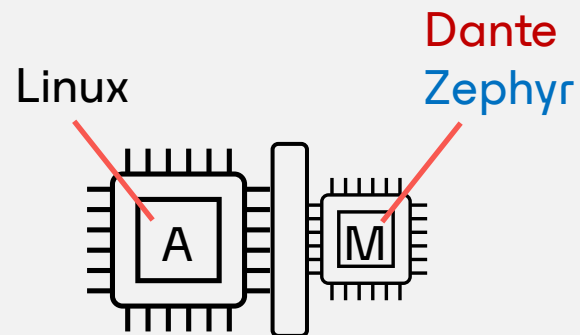
RTOS Selection
Technical
~~Modularity & Portability~~
~~Network & Connectivity~~
~~Security~~
~~Subsystems and features~~
Non-technical
~~Steering committee~~
~~Cross-vendor support~~
~~BSP~~
Project Roadmaps

Project roadmap

- Transparent
- Gaining development inspiration from the Zephyr roadmap
- Aligning timeline with the Zephyr roadmap

Some ideas:

- IoT endpoints – Dante on X
- Partitioned Dante on Cortex M of an MPSoC + Linux on Cortex A
- Linkable Loadable Extensions (LLEXT)
- Link Time Optimisations (LTO)

Linux   Dante
Zephyr

A   M

feature 1   feature 2   feature N

Dante

obj 1   obj 2   obj n

linker

bin

Risks with choosing Zephyr RTOS

⚠️ Relatively new RTOS

⚠️ Vendor's official support for Zephyr (at the time)

⚠️ Talent pool and Zephyr familiarity within the company

Zephyr Dev Experience

Challenges

Zephyr's Network stack

Still maturing..

- Dante relies heavily on the network stack!
- Stress tests the Zephyr TCP/IP stack
- Issues emerged during the project

→ Engaging with the community!

Community — *Discord, Github Maillists*

Audinate ↔ Vendor

Then

Now

Ultimo Product Refresh Challenges with Zephyr
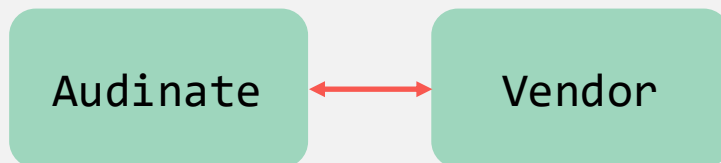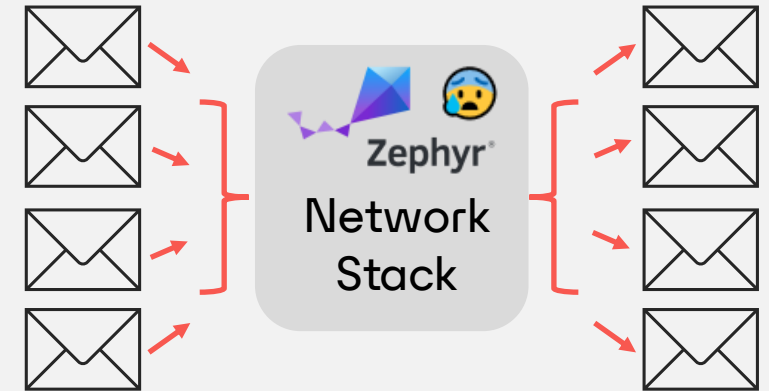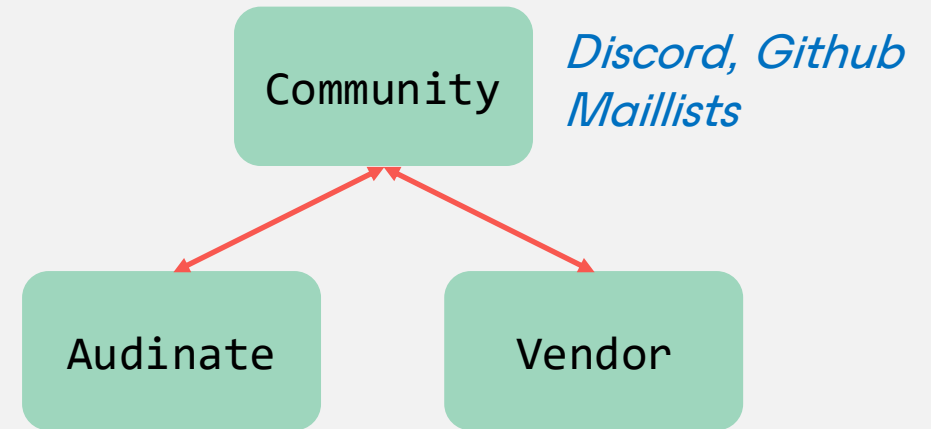
Network stack issues we've upstreamed

↕1 0 Open ✓ 7 Closed   Author ▾   Label ▾   Projects ▾   Milestones ▾   Reviews ▾   Assignee ▾   Sort ▾

ᛘ drivers: ethernet: stm32: Enabling HW checksum offloading for STM32H7. ● [area: Ethernet] [platform: STM32] [Trivial]
#67095 by cperera-aud was merged on Jan 8 • Approved

ᛘ net: ethernet: Fixes for ethernet stats reporting. ● [area: Networking]   ⊙ 1
#54083 by cperera-aud was merged on Jan 26, 2023 • Approved

ᛘ drivers: ethernet: stm32: Enabling stats for the driver. ● [area: Ethernet] [platform: STM32]   ⊙ 1   💬 10
#54081 by cperera-aud was merged on Jan 27, 2023 • Approved

ᛘ net: ipv4: Using a different API to ensure that IPv4 is enabled ● [area: Networking]   ⊙ 1   💬 1
#53914 by cperera-aud was merged on Jan 19, 2023 • Approved

ᛘ drivers: ethernet: 53773 stm32 multicast hash filter ● [area: Ethernet] [platform: STM32]   💬 29
#53850 by cperera-aud was merged on Jan 19, 2023 • Approved

ᛘ net: ipv4: Added mechanism to add 224.0.0.1 address to a multicast filter ● [area: Networking]   ⊙ 1   💬 24
#53733 by cperera-aud was merged on Jan 13, 2023 • Approved

ᛘ net: ip: Fixed IGMP V2 membership report destination address. ● [area: Networking]   ⊙ 1   💬 6
#52521 by cperera-aud was merged on Nov 25, 2022 • Approved

Not always perfect!

We faced network performance bottlenecks
- Challenging for the community to reproduce (without Dante tools)
- We were the only ones facing this issue

- Developed our own solutions that addresses our need
  - Implementation + testing
  - Challenging to upstream

Regardless, Zephyr Community is awesome!
- Open to first time contributions
- Responsive
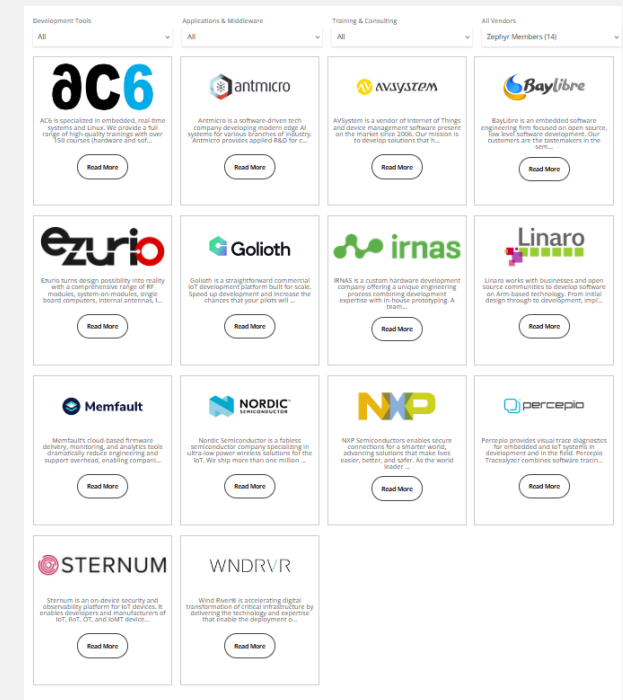- *Discord chats / friendly PR process ;)*

Project Maturity

Commercially, Zephyr is relatively new!
- Supporting industries / ecosystem still developing

Talent pool with Zephyr expertise still building up
- Fewer embedded engineers with Zephyr experience
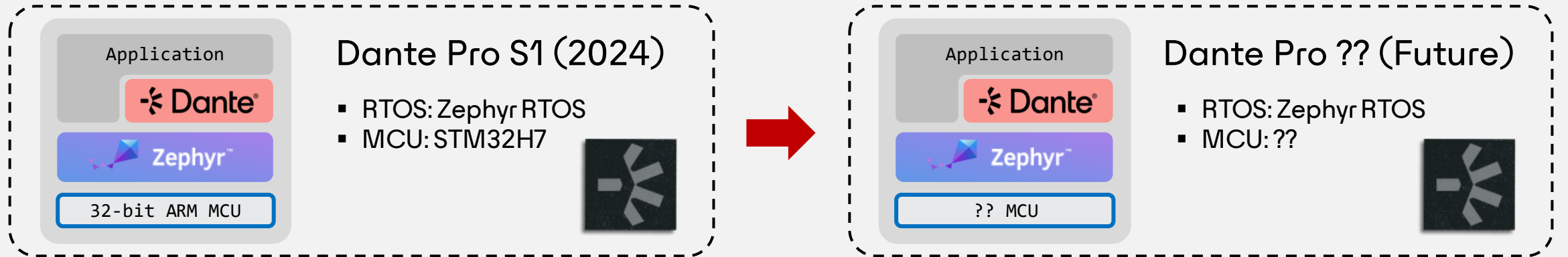- Small-ish freelance sites have less talent-pool for Zephyr

Things are changing! The future looks promising!

Zephyr Dev Experience

The future

Low-cost Dante The future

Dante Pro S1 (2024)
- RTOS: Zephyr RTOS
- MCU: STM32H7

Dante Pro ?? (Future)
- RTOS: Zephyr RTOS
- MCU: ??

1. **Portability of code** → variations of Dante on various platforms
2. **Community** → fast turnover & joint effort of the whole Zephyr community
3. **Features** → help define next generation Dante

ℹ️ We had more participation in upstreaming than previous projects!
→ and we expect this to only increase
- Upstreaming fixes
- Design discussions

Dante®

Thank you
Gladstone!

AUDINATE

EverythingOpen24, Gladstone