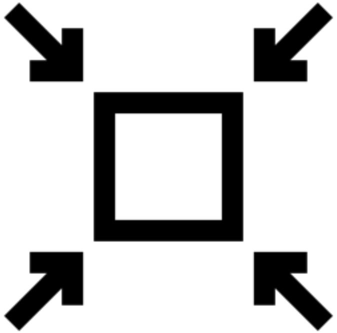
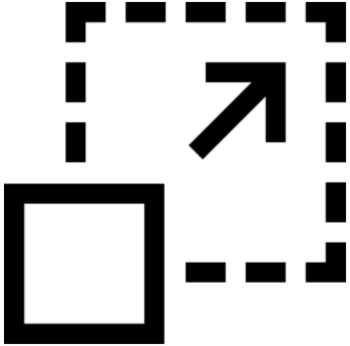
Zephyr Project Overview

A proven RTOS ecosystem, by developers, for developers

Use cases for a real-time OS





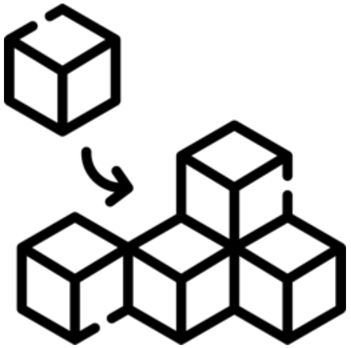
SMALL *yet* SCALABLE

< 8KB Flash

< 5KB RAM

from small sensor nodes

... to complex multi-core systems



FLEXIBLE *yet* SECURE

Heavily customizable

Out-of-the-box support for
450+ boards and 100s of sensors

Built with safety & security in mind

Certification-ready

Long-term Support

Zephyr®

OPEN-SOURCE

Permissively licensed (Apache 2.0)

Vendor-neutral governance

ECOSYSTEM

Vibrant community

Supported by major silicon vendors

Features overview

- Comprehensive, **lightweight**, kernel & supporting services
  - Fits where Linux is too big
- Inherently **portable** & **secure**
- **Highly connected**
  - Bluetooth 5.0 & BLE
  - Wi-Fi, Ethernet, CANbus, ...
  - IoT protocols: CoAP, LwM2M, MQTT, OpenThread, ...
  - USB & USB-C
- **Developer-friendly**
  - Logging, tracing, debugging, built-in shell, Windows/Linux/macOS support, ...

Products Running Zephyr Today

Proglove

Ruuvi Tag

PHYTEC Distancer

Keeb.io BDN9

Hati-ACE

Oticon More

Adhoc Smart Waste

GNARBOX 2.0 SSD

Anicare Reindeer Tracker

Safety Pod

BLiXT solid state circuit breaker

Moto Watch 100

Lildog & Lilcat pet tracker

Rigado IoT Gateway

Livestock Tracker

Laird Connectivity sensors & gateways

BeST pump monitoring

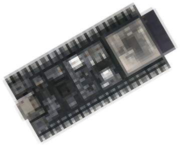
Vestas Wind Turbines

zephyrproject.org/products-running-zephyr

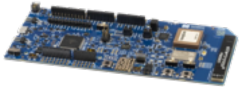
600+ supported boards... and growing

Zephyr®


Arduino Portenta H7


ESP32


Sipeed HiFive1


nRF9160 DK


STM32F746G Disco


M5StickC PLUS


TDK RoboKit 1


BBC micro:bit v2

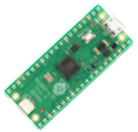

Blue Wireless Swan


Arduino Nano 33 BLE


Intel UP Squared


Dragino LSN50 LoRA Sensor Node


Microchip SAM E54 Xplained Pro Evaluation Kit


Raspberry Pi Pico


Altera MAX10


NXP i.MX8MP EVK


Adafruit Feather M0 LoRa


u-blox EVK-NINA-B3

docs.zephyrproject.org/latest/boards

180+ Sensors Already Integrated

- adt7420
- adxl345
- adxl362
- adxl372
- ak8975
- amg88xx
- ams_as5600
- ams_iAQcore
- apds9960
- bma280
- bmc150_magn
- bme280
- bme680
- bmg160
- bmi160
- bmi270
- bmm150
- bmp388
- bq274xx
- ccs811
- dht
- dps310
- ds18b20
- ens210
- esp32_temp
- fdc2x1x
- fxas21002
- fxos8700
- grove
- grow_r502a
- hmc5883l
- hp206c
- hts221
- i3g4250d
- icm42605
- icm42670
- icm42688
- icp10125
- iis2dh
- iis2dlpc
- iis2iclx
- iis2mdc
- iis3dhhc
- ina219
- ina23x
- isl29035
- ism330dhcx
- ite_tach_it8xxx2
- ite_vcmp_it8xxx2
- lis2dh
- lis2ds12
- lis2dw12
- lis2mdl
- lis3mdl
- lm75
- lm77
- lps22hb
- lps22hh
- lps25hb
- lsm303dlhc_magn
- lsm6ds0
- lsm6dsl
- lsm6dso
- lsm9ds0_gyro
- lsm9ds0_mfd
- max17055
- max17262
- max30101
- max31875
- max44009
- max6675
- mchp_tach_xec
- mcp9808
- mcux_acmp
- mhz19b
- mpr
- mpu6050
- mpu9250
- ms5607
- ms5837
- nrf5
- nuvoton_adc_cmp_npcx
- nuvoton_tach_npcx
- nxp_kinetis_temp
- opt3001
- pcnt_esp32
- pms7003
- qdec_mcux
- qdec_nrfx
- qdec_sam
- qdec_stm32
- rpi_pico_temp
- sbs_gauge
- sgp40
- sht3xd
- sht4x
- shtcx
- si7006
- si7055
- si7060
- si7210
- sm351lt
- stm32_temp
- stm32_vbat
- stmemsc
- stts751
- sx9500
- th02
- ti_hdc
- ti_hdc20xx
- tmp007
- tmp108
- tmp112
- tmp116
- vcnl4040
- vl53l0x
- wsen_hids
- wsen_itds

github.com/zephyrproject-rtos/zephyr/tree/main/drivers/sensor

Supported Hardware Architectures

ARC

arm

Cortex-M, Cortex-R
& Cortex-A

intel

x86 & x86_64

MIPS

Nios II Processor

RISC-V

32 & 64 bit

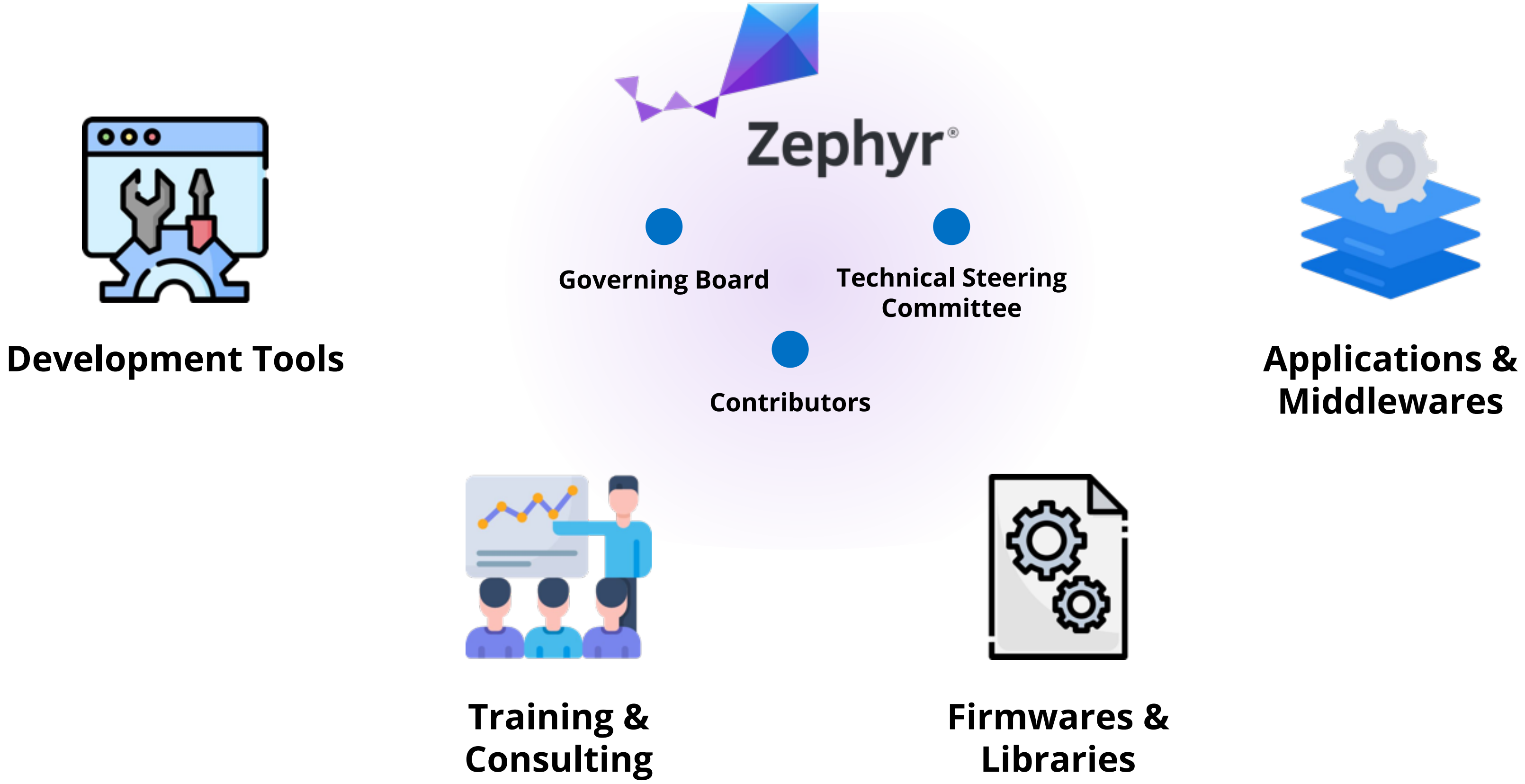
SPARC

tensilica

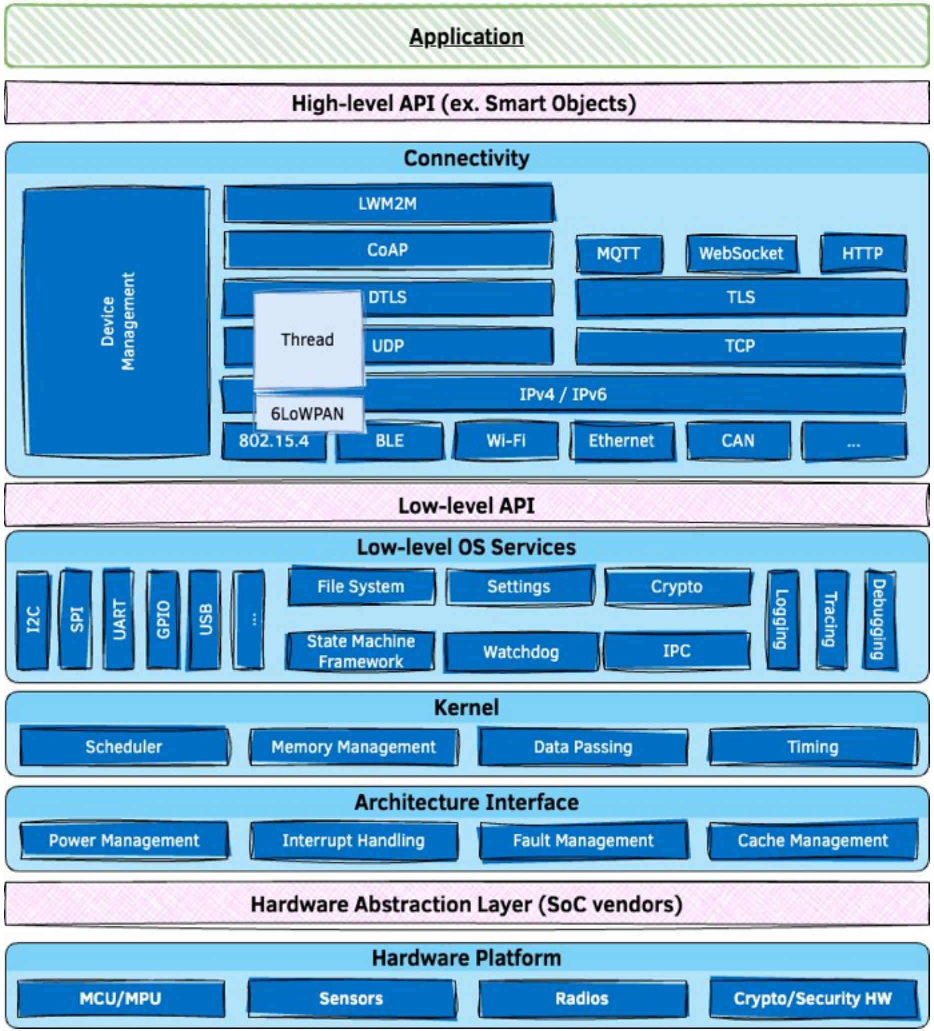
Xtensa

docs.zephyrproject.org/latest/hardware/index.html#hardware-support

Vibrant Ecosystem



Architecture



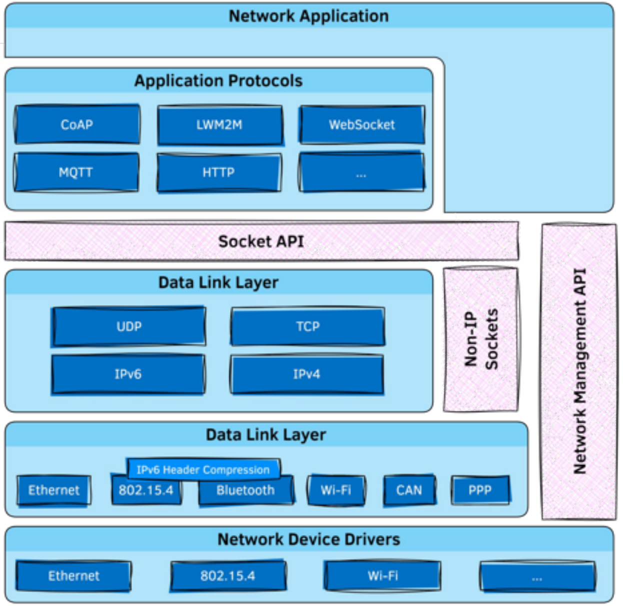
Diving into Zephyr’s features

IoT Connectivity Options

- Wide variety of **communication protocols**
  - Ethernet, 802.15.4, Thread, LoRa, Bluetooth, CAN bus, ...
- **Core network protocols** like IPv6, IPv4, UDP, TCP, ICMPv4, and ICMPv6.
- **Security** (ex. TLS, DTLS, ...)
- **Cloud integration** using MQTT, CoAP and HTTP protocols
- **Over-the-air updates**
- **Device management** using OMA LwM2M 1.1 protocol

Native IP Stack

- Built from scratch, on top of Zephyr native kernel concepts
- Dual mode **IPv4/IPv6 stack**
  - DHCP v4, IPv4 autoconf, IPv6 SLAAC, DNS, SNTP
- Multiple network interfaces support
- Time Sensitive Networking support
- **BSD Sockets**-based API
- Supports IP offloading
- **Compliance and security** tested



Bluetooth Host and Mesh

- **Bluetooth 5.3 compliant**
- Highly configurable
- Portable to all architectures supported by Zephyr
- Low Energy & experimental Bluetooth Classic
- IPSP/6LoWPAN for IPv6 connectivity over Bluetooth LE
- Multiple HCI transports

Bluetooth Low Energy Controller

- **Bluetooth 5.3 compliant** and qualified (5.1)
- Support for multiple BLE radio hardware architectures
  - Nordic nRF5x on Arm Cortex-M
  - VEGAboard on RISC-V
- Proprietary radios (downstream only)
- Unlimited role and connection count
- Concurrent multi-protocol support ready
- Multiple advertiser and scanner instances

Zephyr USB Device Stack

- **USB 2.0** & **USB-C** support
- Supports multiple MCU families (STM32, Kinetis, nRF, SAM,...)
- Supports most common devices classes: CDC, Mass Storage, HID, Bluetooth HCI over USB, DFU, USB Audio, etc.
- Tight integration with the RTOS
- Native execution support for emulated development on Linux
- WebUSB support

Power Management

- Goal: use as little power as possible
- Cross-platform (architecture / SoC agnostic)
- Tickless scheduler
- Handled by the kernel / Customizable by the user

Devicetree

Describe & **configure** the available hardware on the target system

Decouple the application from the hardware

docs.zephyrproject.org/latest/build/dts

```
&i2c1 {
    pinctrl-0 = <&i2c1_scl_pb8 &i2c1_sda_pb9>;
    pinctrl-names = "default";
    clock-frequency = <I2C_BITRATE_FAST>;
    status = "okay";

    lsm6dsl@6a {
        compatible = "st,lsm6dsl";
        reg = <0x06a >;
    };

    hts221@5f {
        compatible = "st,hts221";
        reg = <0x5f >;
    };

    // …
};
```

.dts file example

Secure boot / Device Management

- Leverage **MCUboot** as secure bootloader
- Application binary can be signed/encrypted
  - Can use hardware keys
- But also:
  - Downgrade prevention
  - Dependency checks
  - Reset and failure recovery
- Over-the-air (OTA) upgrades
  - OMA LwM2M, Eclipse hawkBit
  - Vendor offerings

Hardware security

- **Cryptography APIs**
  - Random Number Generation, ciphering, etc.
  - Supported by crypto HW, or SW implementation (TinyCrypt)
- **Trusted Firmware** integration
  - Firmware verification/encryption
  - Device attestation
  - Management of device secrets

Building on POSIX

- **Zephyr apps can run as native Linux applications**
  - Easier to debug/profile with native tools
  - Connect to real devices using TCP/IP, Bluetooth, CAN
  - Helps minimize hardware dependencies during the development phase
- **Re-use existing code & libraries by accessing Zephyr services through POSIX API**
  - Easier for non-embedded programmers
  - Implementation is optimized for constrained systems
  - Supported POSIX subsets: PSE51, PSE52, and BSD sockets

i docs.zephyrproject.org/latest/guides/portability/posix.html

A real-time OS

Benchmark on Arm Cortex-M4F running at 120 MHz

Operation	Time
Thread create	2.5 µs
Thread start	3.6 µs
Thread suspend	3.3 µs
Thread resume	3.8 µs
Context switch (yield)	2.2 µs
Get semaphore	0.6 µs
Put semaphore	1.1 µs

github.com/zephyrproject-rtos/zephyr/tree/main/tests/benchmarks

Graphical User Interfaces

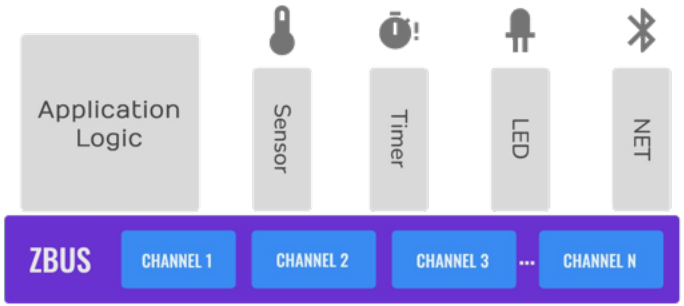
- Drivers available for various types of displays
  - LCD
  - OLED
  - Touch panel displays
  - E-ink
- LVGL integration
- Support for video capture and output

Inter-Process Communication

- **Built-in kernel services** (see table)
- **IPC service**
  - 1-to-1 or 1-to-many communications
  - No-copy API
- **zbus** (Zephyr Message Bus)
  - 1-to-1, 1-to-many, or many-to-many channel-based communications
  - Synchronous or asynchronous

Object	Bidirectional?	Data structure
FIFO	✘	Queue
LIFO	✘	Queue
Stack	✘	Array
Message queue	✘	Ring buffer
Mailbox	✔	Queue
Pipe	✘	Ring buffer

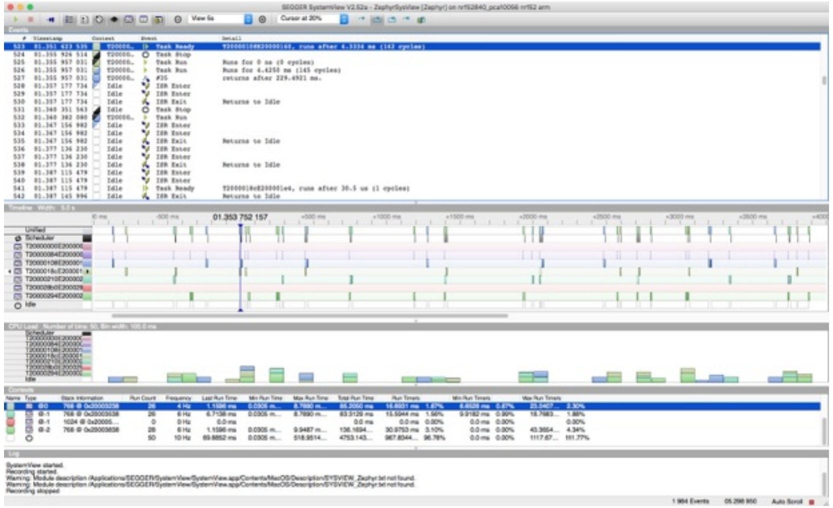
Data passing objects available in Zephyr kernel



A typical zbus application architecture

Tracing & Debugging

- Advanced **logging** framework
  - Multiple backends (UART, network, file system, ...)
  - Compile-time & runtime filtering
- **Tracing** framework
  - Visualize the inner-working of the kernel and its various subsystems
  - Object tracking (mutexes, timers, etc.)

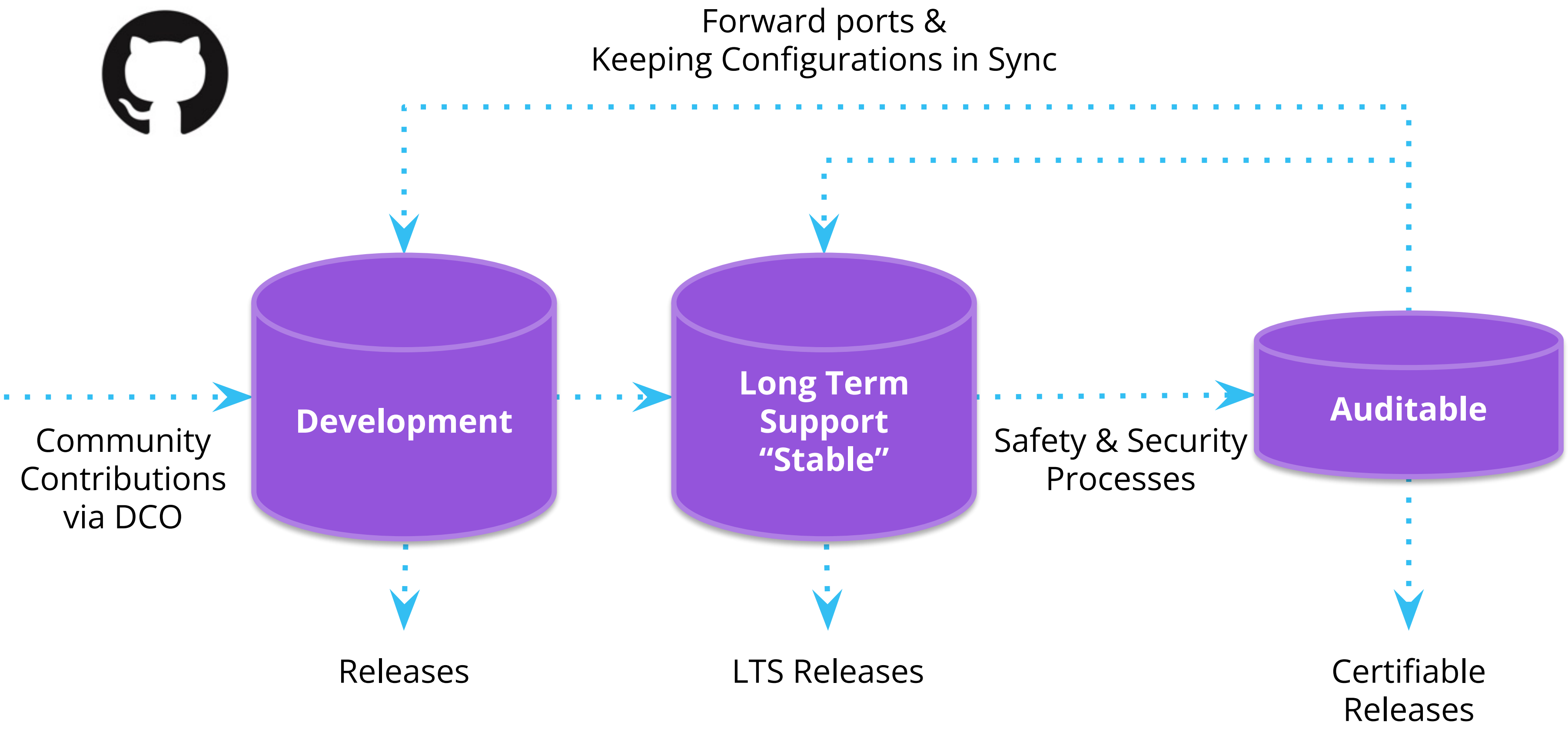


Zephyr 3.5 (Oct. 2023) – What’s new?

- **Dynamic modules** (LLEXT)
- **Picolibc** as the new default C standard library
- Static Code Analysis using **CodeChecker**
- **Native simulator**
- Improved integration with **LVGL**
- … and more, see Release notes 3.5.

Safety & Security

Code Repositories

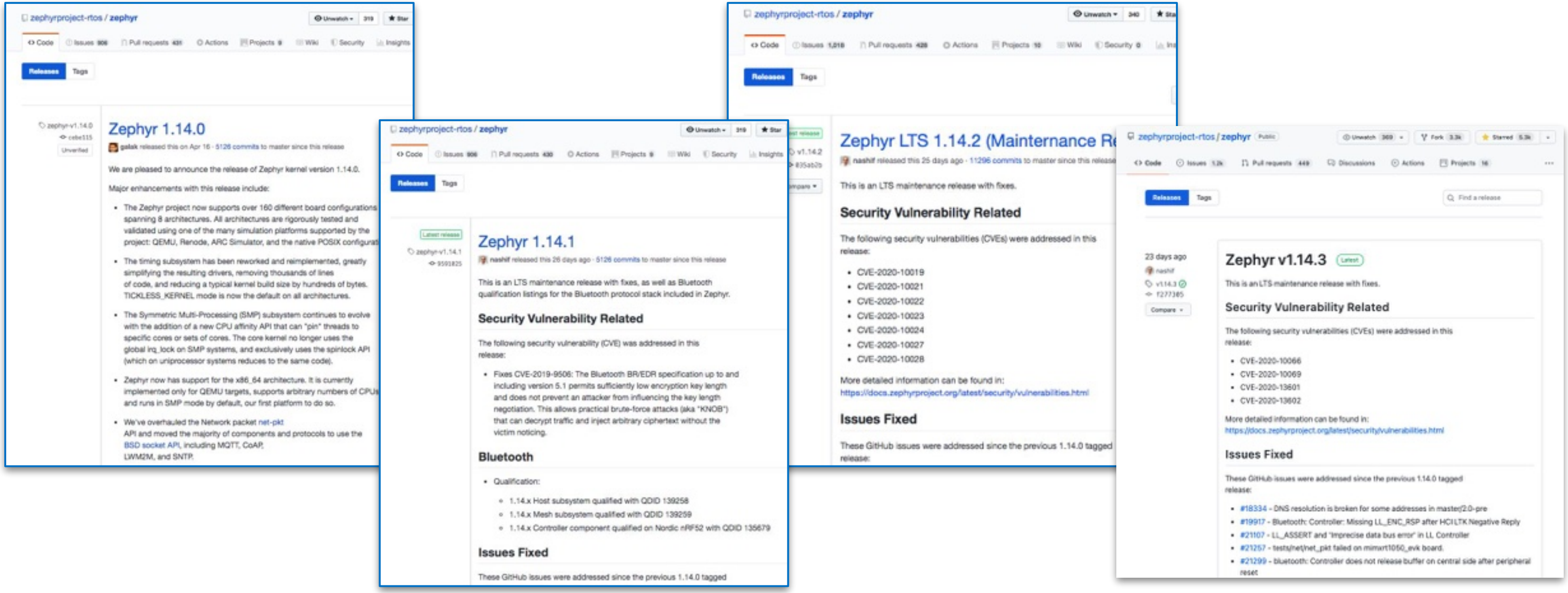


Long Term Support (Zephyr 2.7.x)

- **Product Focused**
- Current with latest **Security Updates**
- Compatible with new hardware
  - Functional support for new hardware is regularly backported
- **Tested**: Shorten the development window and extend the Beta cycle to allow for more testing and bug fixing
- **Supported for 2+ years**
- ⚠️ **Doesn't include cutting-edge functionality**

github.com/zephyrproject-rtos/zephyr/releases/tag/zephyr-v2.7.0

Long Term Support (LTS - 1.14)



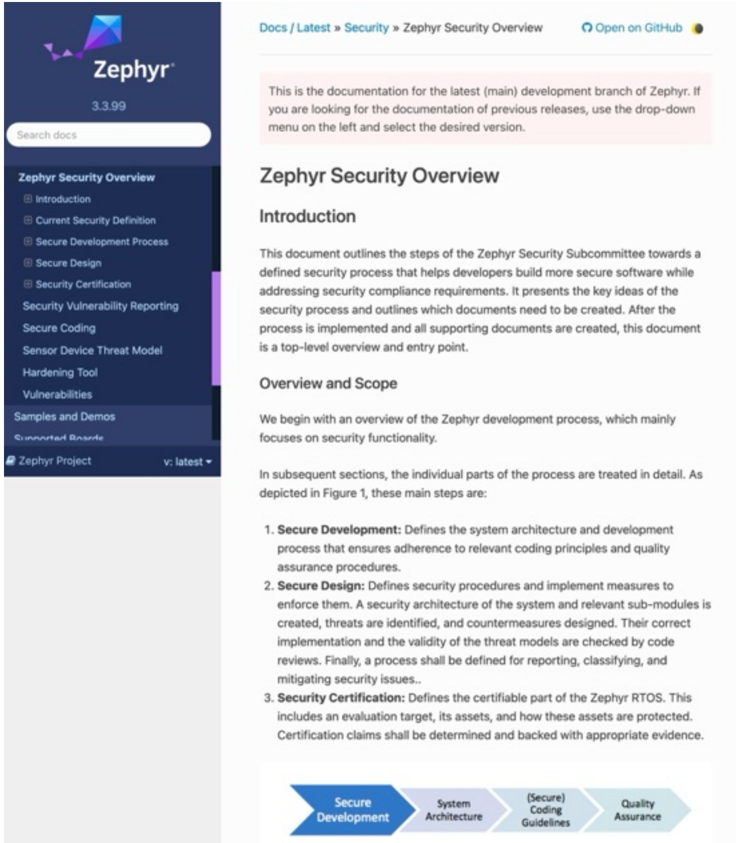
Delivered bug fixes and latest security updates for 2 years!

Auditable

- An **auditable code base** will be established from a **subset of the Zephyr OS LTS**
- Code bases will be kept in sync
- More rigorous processes (necessary for certification) will be applied to the auditable code base.
- Processes to achieve selected certification to be:
    - Determined by Safety Committee and Security Committee
    - Coordinated with Technical Steering Committee

Project Security Documentation

- [Project Security Overview]
- Started with documents from other projects
- Built around Secure Development, Secure Design, and Security Certification
- Ongoing process, rather than something to just be accomplished



Software Supply Chain

- Zephyr ships an **SBOM** (Software Bill of Materials) with each release
- Downstream consumers can leverage built-in tools to, in turn, generate source & build SBOMs for their deliverables

```
[...]
FileName: ./zephyr/zephyr.elf
SPDXID: SPDXRef-File-zephyr.elf
FileChecksum: SHA1: e74cebcac51dabd799957ac51e4edcd32541103d
[...]
Relationship: SPDXRef-File-zephyr.elf GENERATED_FROM SPDXRef-File-dev-handles.c
Relationship: SPDXRef-File-zephyr.elf GENERATED_FROM SPDXRef-File-isr-tables.c
Relationship: SPDXRef-File-zephyr.elf STATIC_LINK SPDXRef-File-libapp.a
Relationship: SPDXRef-File-zephyr.elf STATIC_LINK SPDXRef-File-libzephyr.a
Relationship: SPDXRef-File-zephyr.elf STATIC_LINK SPDXRef-File-libisr-tables.a
Relationship: SPDXRef-File-zephyr.elf STATIC_LINK SPDXRef-File-libkernel.a
[...]
```

CVE Numbering Authority

- [Registered with MITRE]() in 2017
  - We issue our own CVEs
- **Zephyr Project Security Incident Response Team** (PSIRT)
  - Volunteers from the Security Subcommittee led by the Zephyr Security Architect.

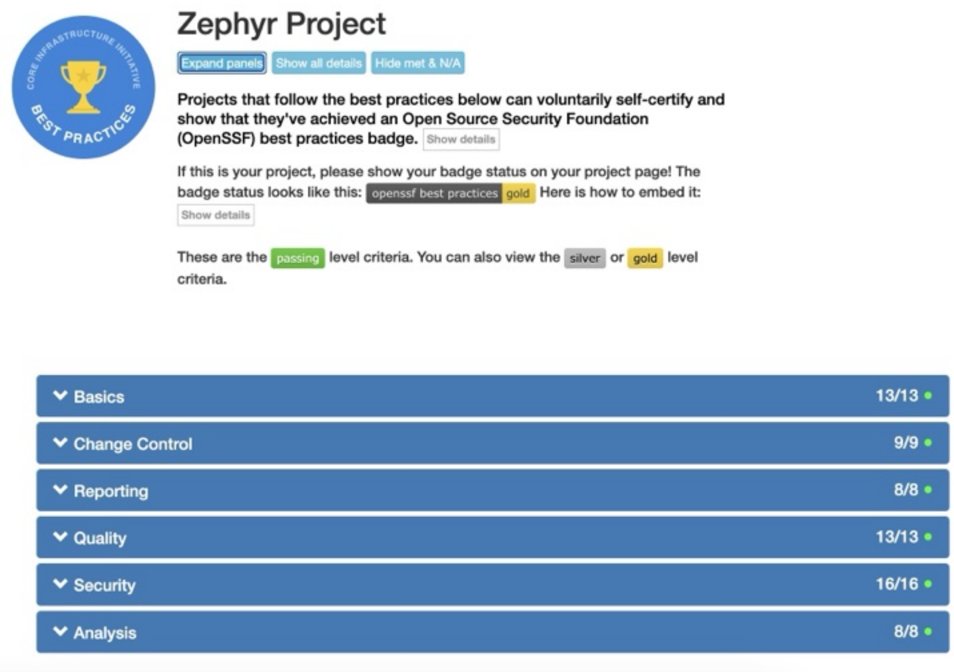
Zephyr Project

The majority of the links on this page redirect to external websites; these links will open a new window or tab depending on the web browser used.

Scope	Zephyr project components, and vulnerabilities that are not in another CNA's scope
Root	MITRE Corporation
Security Advisories	View Advisories
Program Role	CNA
Organization Type	Vendors and Projects
Country*	USA

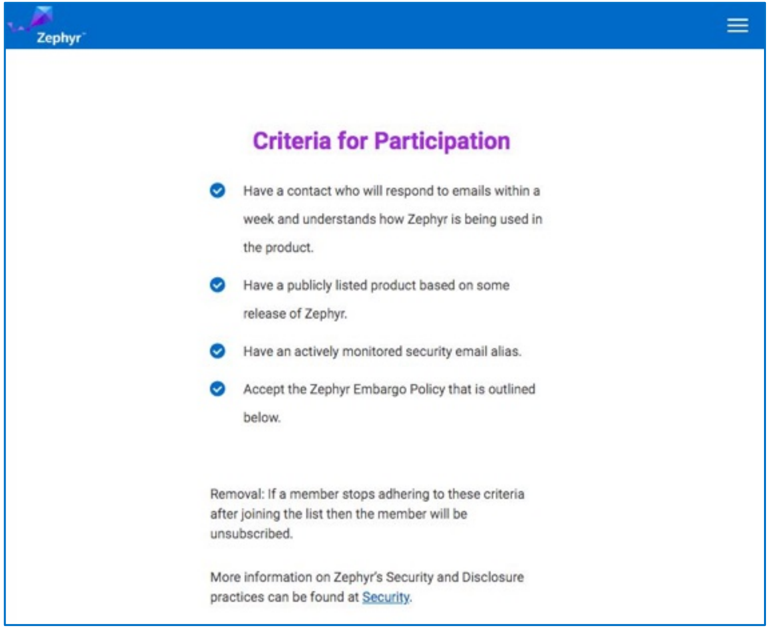
OpenSSF Gold Badge

- Core Infrastructure Initiative Best Practices Program
- Awards badges based on “project commitment to security”
- Mostly about project infrastructure: is project hosting, etc following security practices
- Gold status since Feb, 2019



Vulnerability Alert Registry

- For an **embargo** to be effective, product makers need to be **notified early** so they can **remediate**
- **Goal**: Zephyr to **fix issues within 30 days** to give vendors 60 days before publication of vulnerability
- Product makers can register to receive these alerts for free by signing up at Vulnerability Alert Registry



Zephyr PSIRT: Remediation and Response

Advisory Issued by project on 20201208:

- Zephyr current release (2.4) does not use Fnet or other stacks.
- The Zephyr LTS release 1.14 contains an implementation of the TCP stack from Fnet.

Of the vulnerabilities reported in Fnet, 2, CVE-2020-17468, and CVE-2020-17469, are in the IPv6 Fnet code, one, CVE-2020-17467, affects Link-local Multicast Name Resolution LLMNR), and 2, CVE-2020-24383, and CVE-2020-17470 affect DNS functionality.

None of the affected code has been used in the Zephyr project, while 1.14 does use the Fnet TCP, it does not use the affected IPv6, DNS or LLMNR code.


FORESCOUT
Active Defense for the Enterprise of Things
AMNESIA:33 | EXECUTIVE SUMMARY

AMNESIA:33
Research Report Executive Summary

- Forescout Research Labs has launched Project Memoria, **an initiative** that aims at providing the community with the **largest study on the security of TCP/IP stacks**. Project Memoria's goal is to develop the understanding of common bugs behind the vulnerabilities in TCP/IP stacks, identifying the threats they pose to the extended enterprise and how to mitigate those.
- **AMNESIA:33** is the first study we have published under Project Memoria. In this study, we discuss the results of the security analysis of seven **open source TCP/IP stacks** and report a bundle of **33 new vulnerabilities** found in four of the seven analyzed stacks that are used by major IoT, OT and IT device vendors.
- **Four of the vulnerabilities in AMNESIA:33 are critical**, with potential for remote code execution on certain devices. Exploiting these vulnerabilities could allow an attacker to take control of a device, thus using it as an entry point on a network for internet-connected devices, as a pivot point for lateral movement, as a persistence point on the target network or as the final target of an attack. For enterprise organizations, this means they are at increased risk of having their network compromised or having malicious actors undermine their business continuity. For consumers, this means that their IoT devices may be used as part of large attack campaigns, such as botnets, without them being aware.

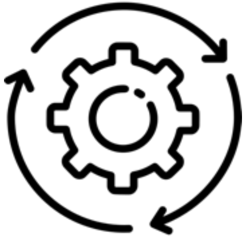
150+
VENDORS AFFECTED

1

forescout.com/amnesia33/ research@forescout.com toll free 1-866-377-8771

zephyrproject.org/zephyr-security-update-on-amnesia33

Zephyr Security Summary



Documented secure coding practices

Vulnerability response criteria publicly documented

Weekly Coverity scans

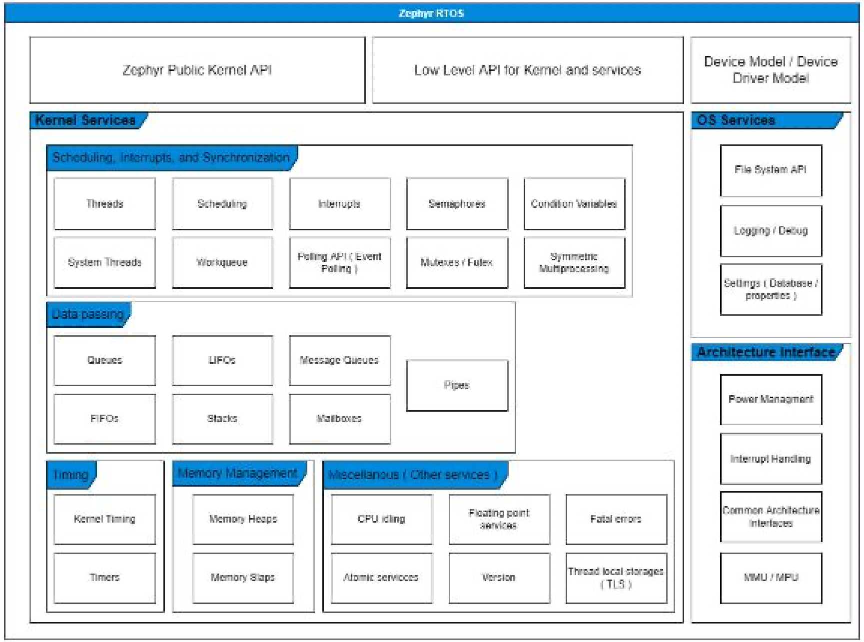
MISRA scans

SBOM generation

Certification

Initial certification focus

- Start with a limited scope of kernel and interfaces
- Initial target is IEC 61508 SIL 3 / SC 3 (IEC 61508-3, 7.4.2.12, Route 3s)
- x86 and ARM is initial focus
- Scope will be **extended** to include **additional components** as determined by the safety committee



Safety Collateral Proposal

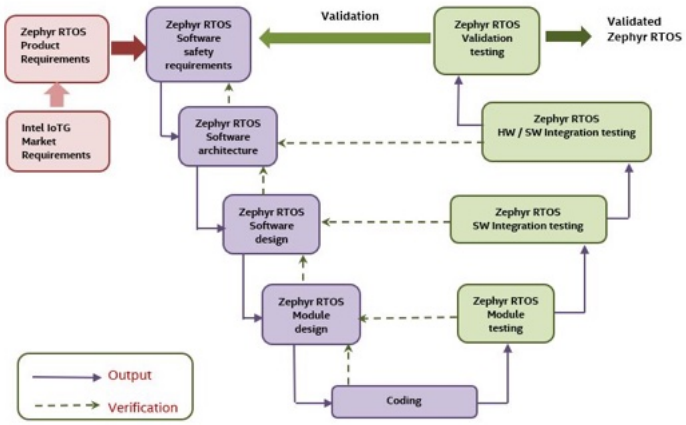
Draft (pending approval by Certification Authority)				
Phase	**Assumed Collateral**	**Type of Doc**	**Owner**	**Sharing Model**
Safety Concept	Safety Plan and Safety Assessment Plan	Plan/Process	FSM	Platinum
	Verification / Validation / Integration Test Plans	Plan/Process	Testing WG	Public
	Software Development Plan	Plan/Process	TSC	Public
	Configuration and Change Management Plans	Plan/Process	TSC	Public
	Software Architecture and Module Design Specification	Plan/Process	TSC	Public
	Coding Guideline	Plan/Process	TSC	Public
	Tools Documentation	Plan/Process	TSC	Public
	Software Requirements	Code	TSC	Public
	Software Safety Requirements Specification	Result Artifact	Safety WG	Platinum
Detailed Test Phase	Tests (Integration, Arch / Module, Validation)	Code	TSC	Public
	Code Review Report	Result Artifact	Safety WG	Platinum
	Verification / Validation / Integration Test Reports	Result Artifact	Testing WG	Platinum
	Fault Injection Test Report	Result Artifact	Testing WG	Platinum
	Tools Classification	Result Artifact	Safety WG	Platinum
	Tools Validation	Result Artifact	Safety WG	Platinum
	Traceability Report	Result Artifact	Testing WG/FSM	Platinum
	Test Coverage Report	Result Artifact	Testing WG/FSM	Platinum
	Coding Guideline Compliance Report	Result Artifact	Safety WG	Platinum
	Safety Analysis (e.g., FMEA)	Result Artifact	FSM	Platinum
	Source Code	Code	TSC	Public
	Software User Manual	Result Artifact	TSC	Platinum
	Safety Manual	Result Artifact	FSM	Platinum
Silver members have limited access, restricted use to Platinum artifacts based on participation				

Compliant Development: V-model

It is difficult to map a stereotypical open-source development to the V-model

- Specification of features
- Comprehensive documentation
- Traceability from requirements to source code
- Number of committers and information known about them

Zephyr RTOS functional safety work products mapping to IEC 61508-3 V model



⇒ Provide the evidences that open source developers can map to compliance and meet all requirements

Ecosystem & Governance

Zephyr Project: Platinum Members

ANALOG DEVICES

antmicro

Google

intel

Meta

NORDIC SEMICONDUCTOR

NXP

oticon life-changing technology

Qualcomm Innovation Center

ZEISS

Zephyr Project: Silver Members

Zephyr

ac6
ARDUINO
AVSYSTEM
Baumer
Baylibre
blues
Golioth
infineon
irnas
Laird CONNECTIVITY
Linaro
Memfault
percepio SENSING SOFTWARE
RENESAS
SILICON LABS
STERNUM
life.augmented
SYNOPSYS
TEXAS INSTRUMENTS
TII Technology Innovation Institute
WNDRVR

Vibrant Ecosystem

Zephyr®

- Governing Board
- Technical Steering Committee
- Contributors

Development Tools

Applications & Middlewares

Training & Consulting

Firmwares & Libraries

Ecosystem // **Dev Tools**

Development Tools

Training & Consulting

Firmwares & Libraries

Applications & Middlewares

IDE

Compilers

Debuggers / Tracing Tools

Emulation / Simulation

Ecosystem // **Training & Consulting**

Development Tools

Training & Consulting

Firmwares & Libraries

Applications & Middlewares

Training

NORDIC SEMICONDUCTOR

Golioth

THE LINUX FOUNDATION

percepio SENSING SOFTWARE

ac6

Services & Consulting

Baylibre

NXP

Laird CONNECTIVITY

antmicro

WNDRVR

AVSYSTEM

Ecosystem // **Firmwares & Libraries**

Zephyr®

Development Tools

Training & Consulting

Firmwares & Libraries

Applications & Middlewares

Security

Mbed TLS

wolfSSL

TinyML

TensorFlow Lite

EDGE IMPULSE

Language runtimes

MicroPython

Others

SOUND OPEN FIRMWARE

zscilib

Memfault

Ecosystem // **Apps & Middlewares**

Zephyr®

Development Tools

Training & Consulting

Firmwares & Libraries

Applications & Middlewares

Remote Management

HERALD

Golioth

AVSYSTEM

Memfault

STERNUM

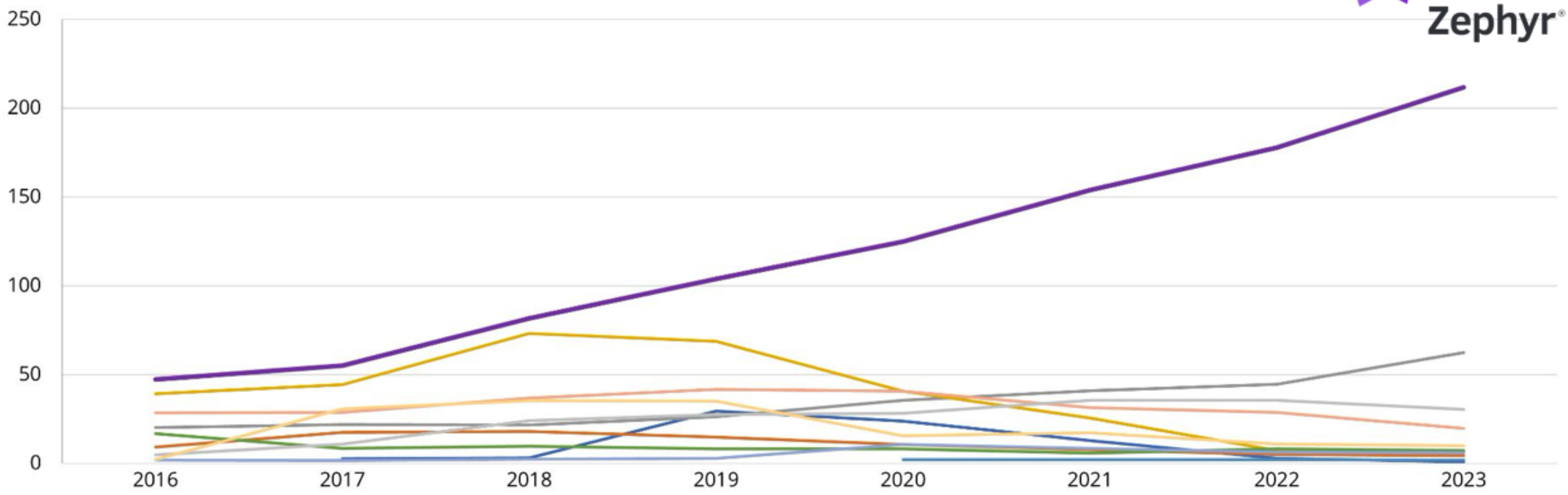
blues wireless

Robotics

µROS

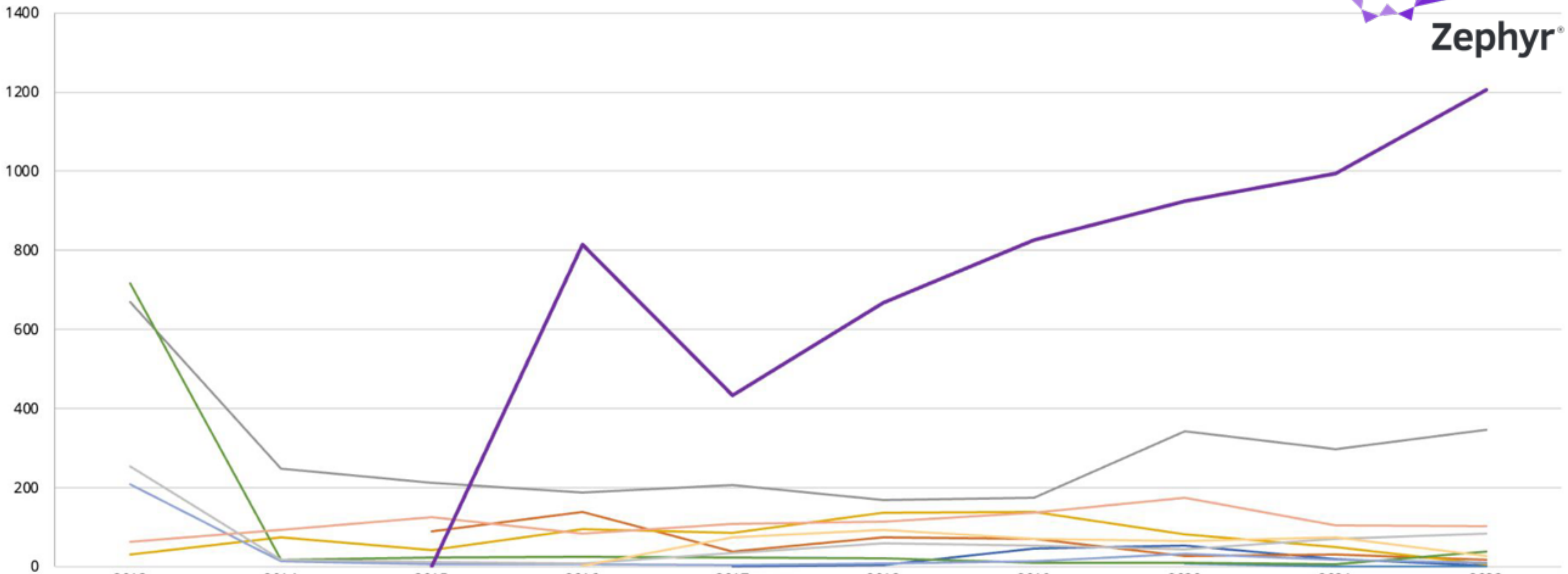
Zephyr in the RTOS landscape

Average Number of Unique Contributors per Month



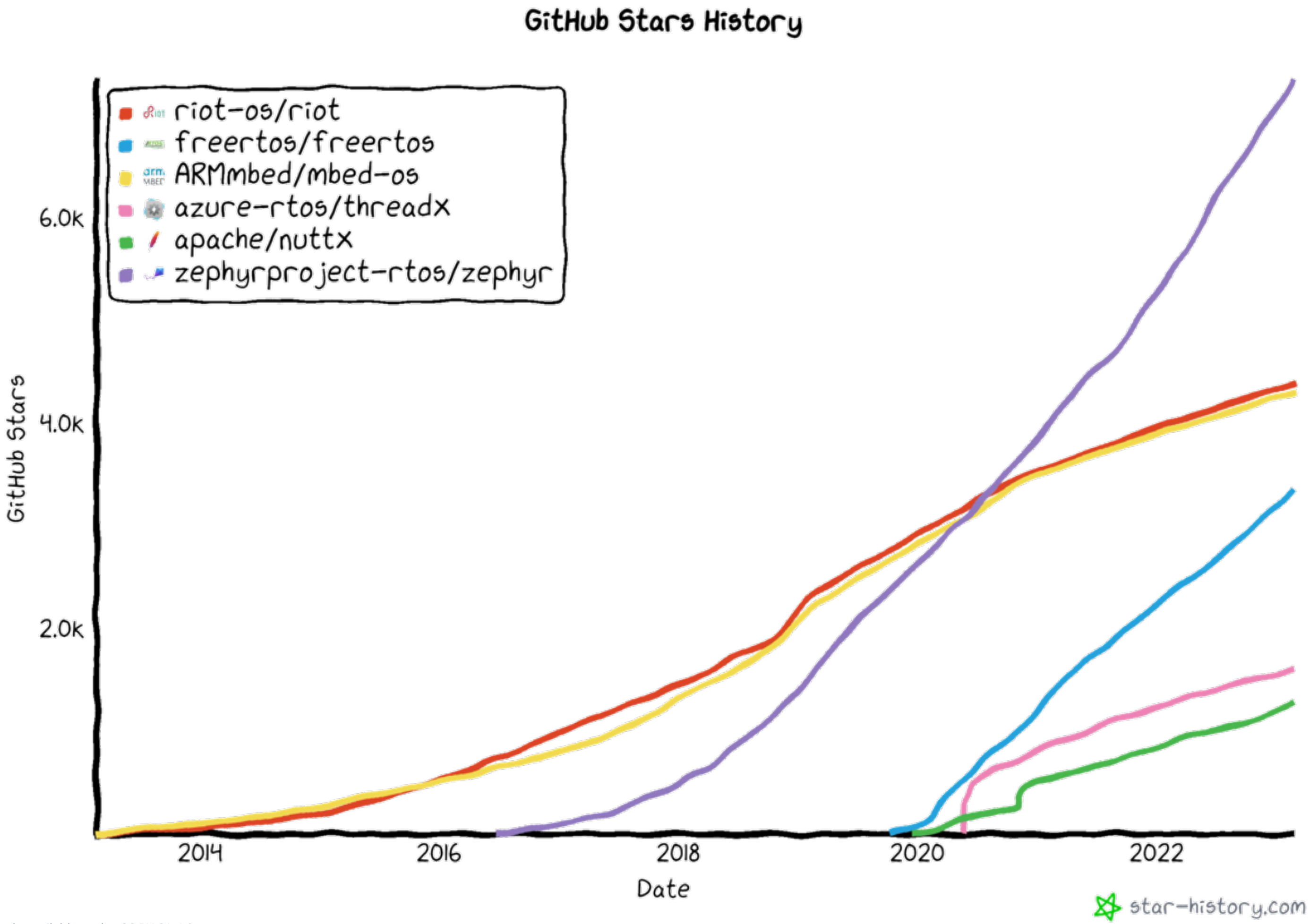
	2016	2017	2018	2019	2020	2021	2022	2023
Amazon FreeRTOS		3	3	30	24	13	3	1
Apache Mynewt	9	18	18	15	11	8	5	4
Apache NuttX	20	22	22	26	36	41	45	62
Arm Mbed OS	39	44	73	69	41	26	7	7
Azure RTOS ThreadX					2	2	2	2
Contiki-NG	17	9	10	8	8	6	8	7
FreeRTOS	2	2	2	3	11	8	6	6
RIOT OS	29	29	37	42	41	31	29	20
RT-Thread	5	11	24	28	28	36	36	30
TizenRT	2	31	35	35	16	17	11	10
Zephyr	47	55	82	104	125	154	178	212

Average Number of Commits per Month



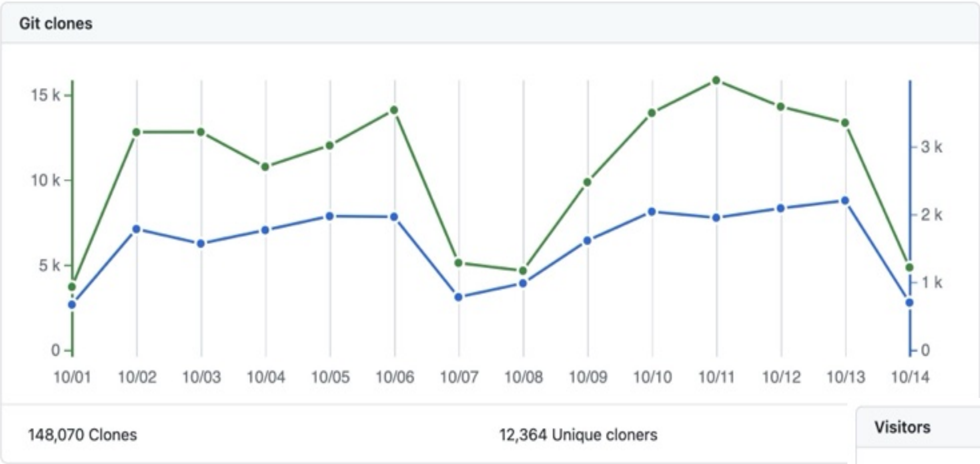
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Amazon FreeRTOS					2	4	47	53	20	2
Apache Mynewt			90	138	38	74	70	27	31	18
Apache NuttX	670	248	212	187	206	169	174	343	297	347
Arm Mbed OS	30	74	42	95	86	136	138	82	51	6
Azure RTOS ThreadX								7	1	2
Contiki-NG	717	17	23	25	23	22	9	11	7	38
FreeRTOS	209	13	6	6	4	8	13	32	17	11
RIOT OS	63	93	126	84	108	115	136	175	105	103
RT-Thread	253	18	13	9	35	60	53	43	70	84
TizenRT				2	73	93	71	64	74	27
Zephyr			0	814	434	667	825	924	995	1206

Zephyr



GitHub Stars History
riot-os/riot
freertos/freertos
ARMmbed/mbed-os
azure-rtos/threadx
apache/nuttx
zephyrproject-rtos/zephyr
6.0k
4.0k
2.0k
GitHub Stars
2014
2016
2018
2020
2022
Date
star-history.com

GitHub Clones & Unique Visitors



2023-10-01 → 2023-10-14

~883 unique clones per day
~1212 unique visitors per day

Zephyr Participation Information

Zephyr®

zephyrproject.org

github.com/zephyrproject-rtos

lists.zephyrproject.org

chat.zephyrproject.org zephyrproject.org