Zephyr's Roadmap to a Pre-Certified Kernel for Safety-Critical Systems

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Hello,

I am Tobias Kaestner!

Solution Architect Medical IoT at inovex GmbH
#FOSS4MEDICAL

- PhD in Physics (long ago)
- SW/System Architect since 15+ years
  - mainly Medical Devices
- Trainer & Technical Consultant
  - SW-Architecture, Zephyr, Yocto
- In Love w/ Zephyr since 2016
  - realised several prototype projects for life-science R&D
  - currently serving as the project's Safety Architect

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Functional **Safety & Open Source**

Open Source is everywhere ... almost.

- Open Source technologies de-facto choice for non-differentiating software features, driving
  - standardization, collaboration and cost sharing
- Huge number of embedded systems perform safety-critical functions
- Failure of system function can lead to severe injuries or even death of people

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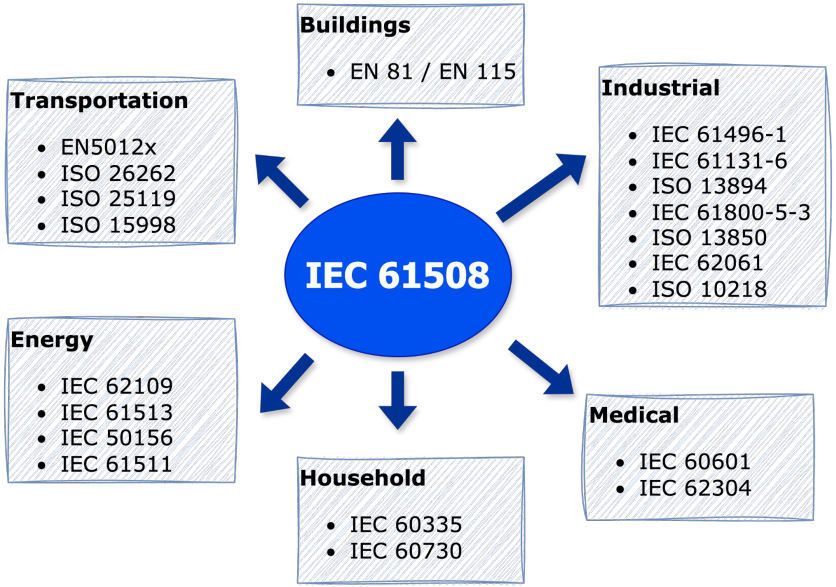
The many standards of Functional Safety.



taken from https://www.tuvsud.com/ko-kr/-/media/global/pdf-files/infographics/tuvsud-functional-safety-in-a-nutshell-infographic.pdf

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Functional Safety & FOSS - The good, the bad & the ugly.

More and more examples where FOSS aims to enter the safety-critical domain

- **Zephyr**
- XEN Hypervisor
- ELISA (Embedded Linux in Safety Applications)
- RTEMS
- Eclipse ThreadX

Adopting FOSS for safety-critical systems faces severe challenges:

- **Non-free standards restrict participation:** This includes most ISO/IEC/EC standards and MISRA Coding Guidelines.
- **Safety isn't a priority for all FOSS stakeholders,** unlike security.
- **Safety standards focus on the development process,** which must be tailored to business processes.

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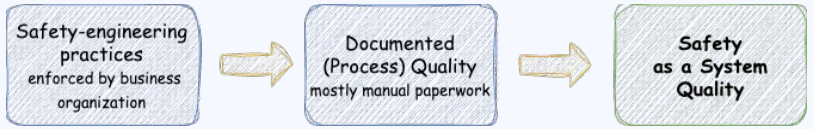
The Open Source Dilemma: Contribution-Driven vs Requirements-Driven.

Safety Standards are Process Standards

- Assume enforcement by business owners (liability)
- However, FOSS projects have a governance structure (at best)
  - have control over contribution guidelines to reject unsuitable work
  - but **no way to mandate "required" work to happen**



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Contribution-Driven (The Power of Open Source)

- Bottom-up, dynamic, fast-paced
- Prioritizes innovation and community participation

Requirements-Driven (The Mandate of Functional Safety)

- Top-down, methodical, favors stability
- Prioritizes rigor, predictability, and auditable proof

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Safety Engineering for Software

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Functional Safety is more than just good code.

Functional Correctness

reliable & dependable,
no defects
all tests green

Active Safety

hazard detection &
protection, safe-states are
known and entered

Reasoning

arguments can be made that
safety was a key design
concern backed by evidence

What happens when things go wrong?

"Absence of Unreasonable Risk** From **Hazards** Caused by **System Malfunctions"

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No Safety without Security.

Security:

Protect machines from (maliciously acting) humans

Safety:

Protect humans from machines going wild

- Most devices are connected by now
- Insecure systems un-safe, too
  - e.g. attackers could nullify safety measures to harm people
- Yet, securing systems may introduce safety risks
  - e.g. FOTA updates to mitigate CVEs

https://www.hipaajournal.com/security-issues-identified-in-75-of-infusion-pumps/
https://www.ahajournals.org/doi/10.1161/CIRCULATIONAHA.118.037331

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Why things break - Cosmic rays and Human Error.

Distinction in standards like **IEC 61508** and **ISO 26262**

Random Hardware Failure

- probabilistic in nature & unpredictable (memory bit-flip from radiation, physical disconnect of a sensor)

Manage by Architectural solutions

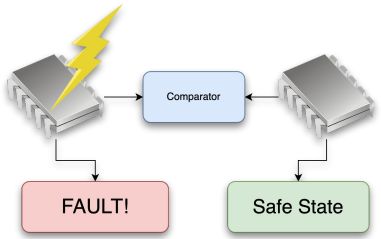
- redundancy, error detection, memory protection, watchdogs

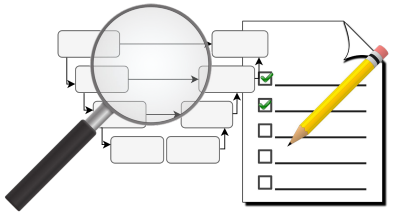
Systematic Failures

- deterministic faults in the design/code (bugs)

Minimize by rigorous, methodical processes

- traceability, coding standards, verification





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Demonstrating **Systematic Capability**

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Zephyr's way towards systematic capability.

IEC 61508-3, Clause 7.4.2.12

“Where a **pre-existing software element** is **reused** to implement all or part of a safety function, the element shall meet both requirements a) and b) below for systematic safety integrity:

a) Meet the requirements of one of the following compliance routes:

- Route 1s: compliant development. Compliance with the requirements of this standard for the avoidance and control of systematic faults in software;
- Route 2s: proven in use. Provide evidence that the element is proven in use. See 7.4.10 of IEC 61508-2;
- **Route 3s**: assessment of non-compliant development. Compliance with 7.4.2.13

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Zephyr's way towards systematic capability.

IEC 61508-3, Clause 7.4.2.13

“To comply with Route 3s a pre-existing software element shall meet all of the following **requirements** a) to i) … “

- Providing a **safety scope definition**
- Creating **requirements** & establishing **traceability** to code & tests
- Creation of **system- & software specification**
- Definition of the **safety claims**
- Using the existing tests, establishing traceability & enhancing coverage
- Creation of the **safety manual**

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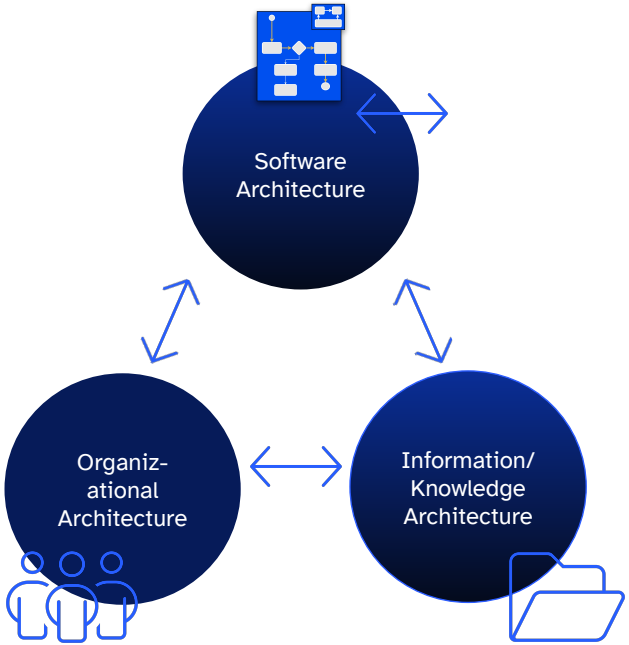
Functional Safety's profound impact.

Software creation is a **socio-technical** endeavour
Interdependencies between

- The organization creating the software
- The way information is recorded & disseminated
- The software's actual architecture & design

To demonstrate **systematic capabilities**
requires adaptation of all three



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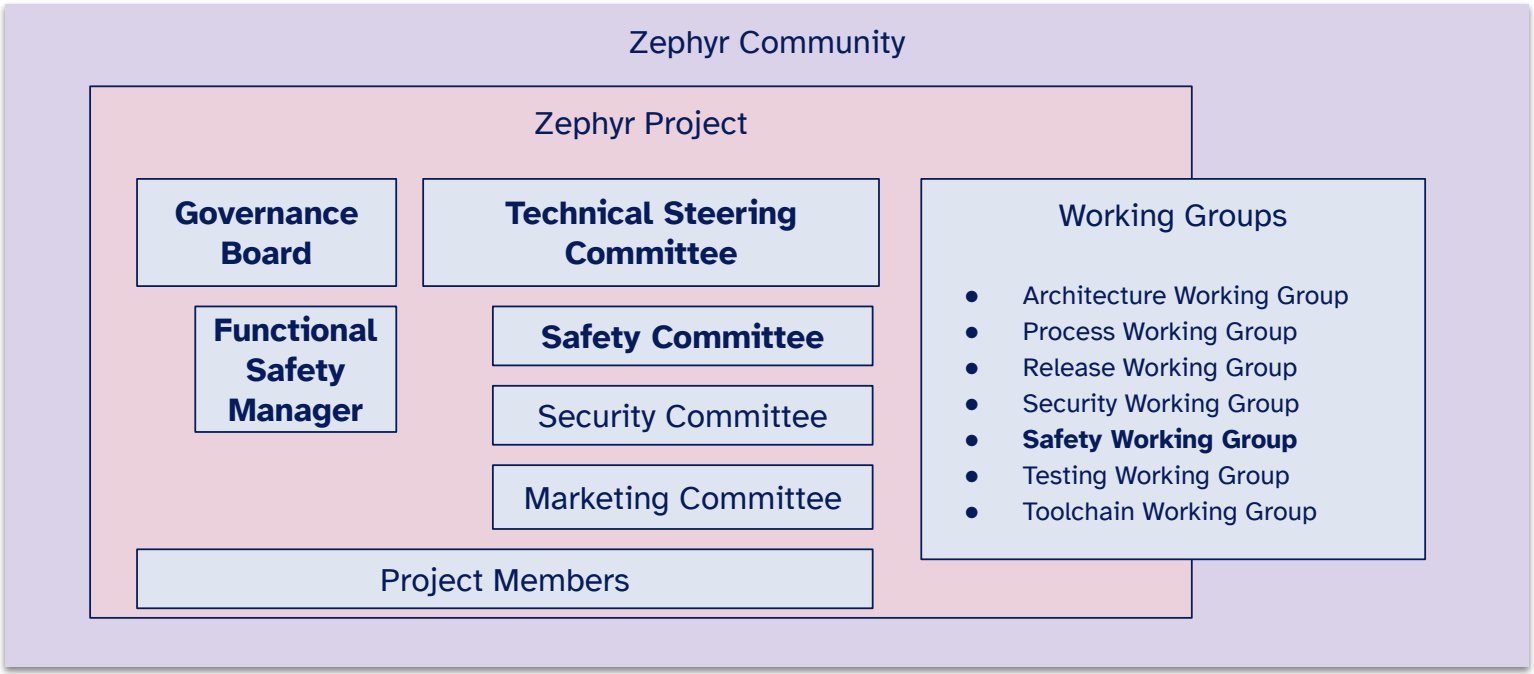
A Safety View on Zephyr's Project Governance.



https://github.com/zephyrproject-rtos/zephyr/wiki/Zephyr-Committee-and-Working-Groups

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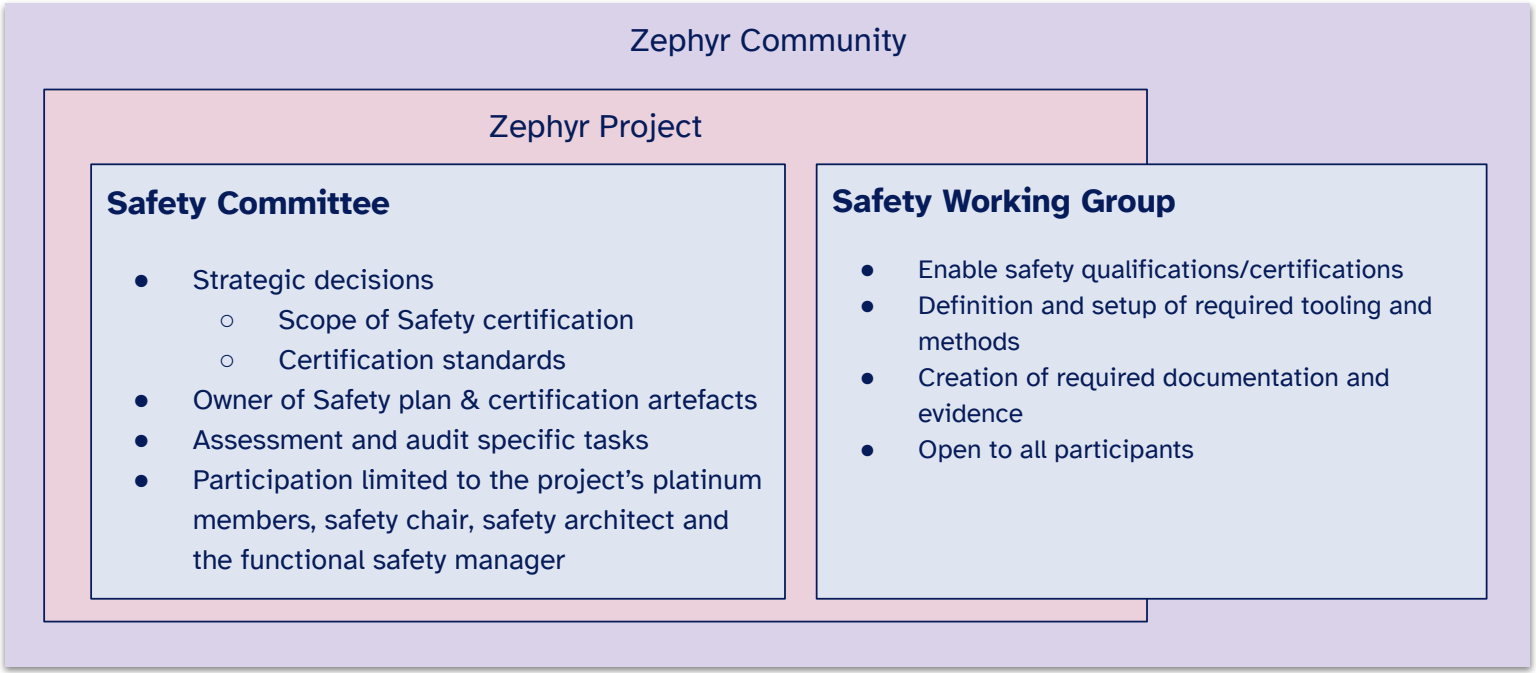

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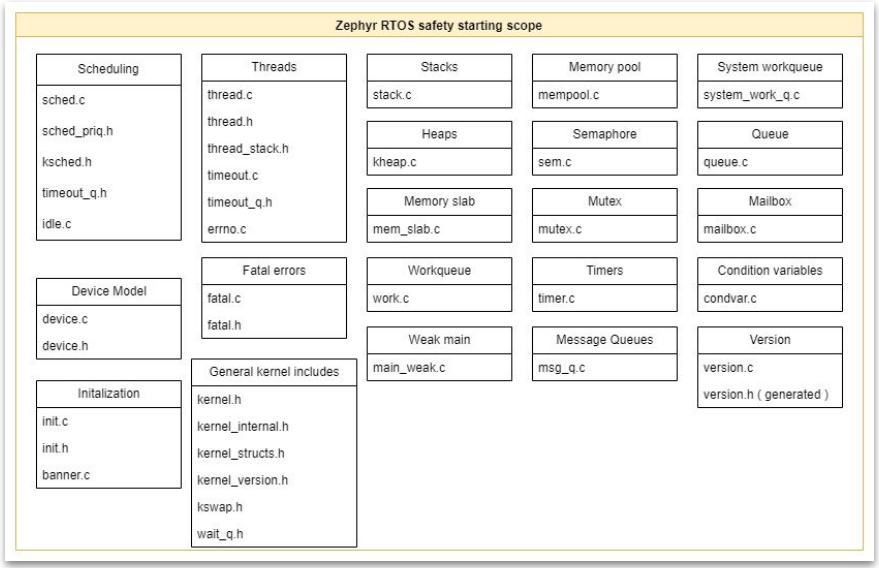
Zephyr's Safety Scope.

Certifying all of Zephyr is infeasible!

Focus for Safety is on

- System Initialization
- Kernel Services & Kernel API
- selected safety-related Subsystems, ie. Task Watchdog

15k LoC out of 2.4M LoC



Discussion and current consensus
https://github.com/zephyrproject-rtos/zephyr/issues/57702

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Safety Artifacts & Evidence

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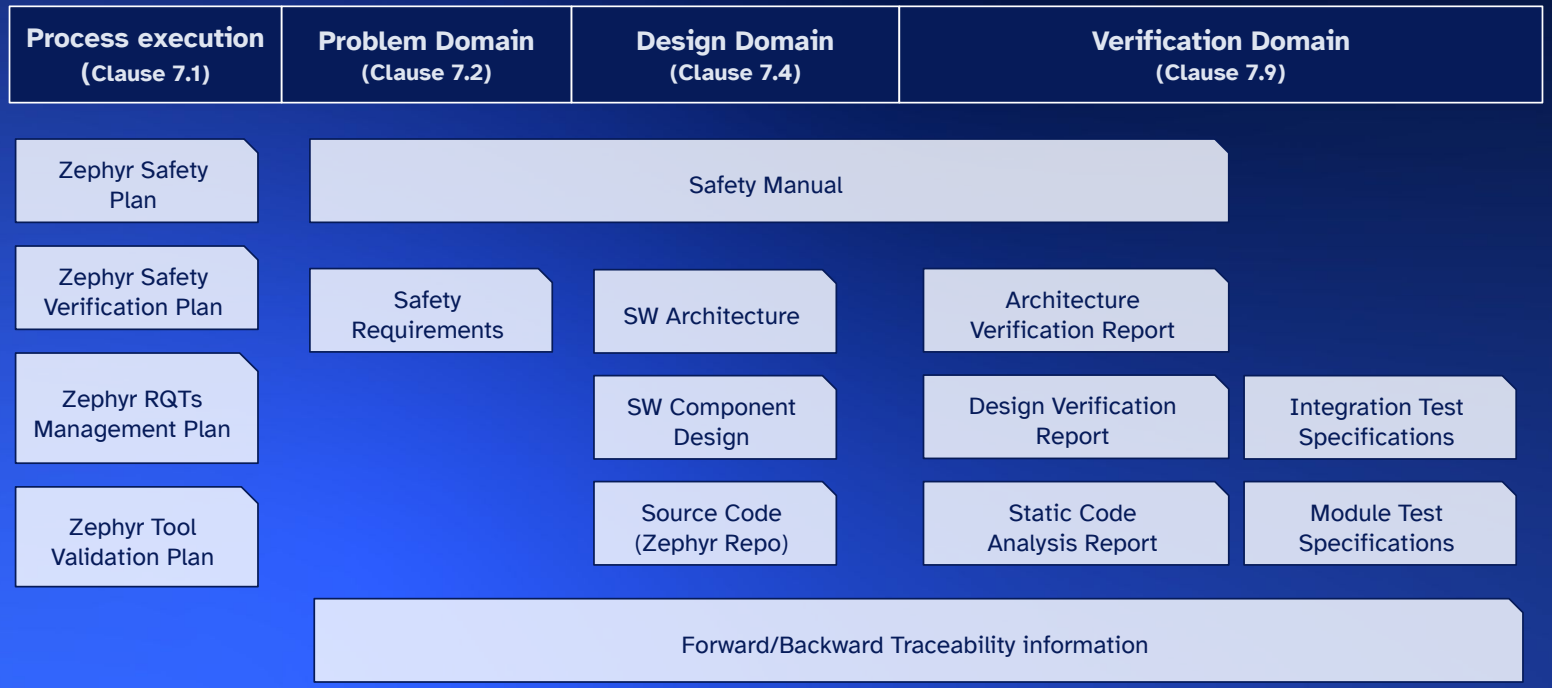
Compiling the evidence for the safety scope.



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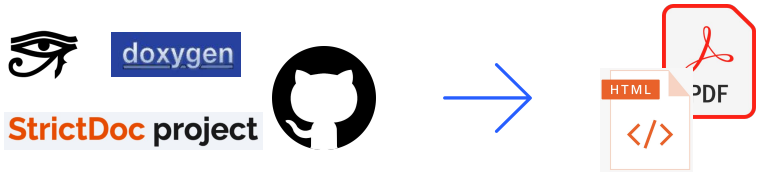
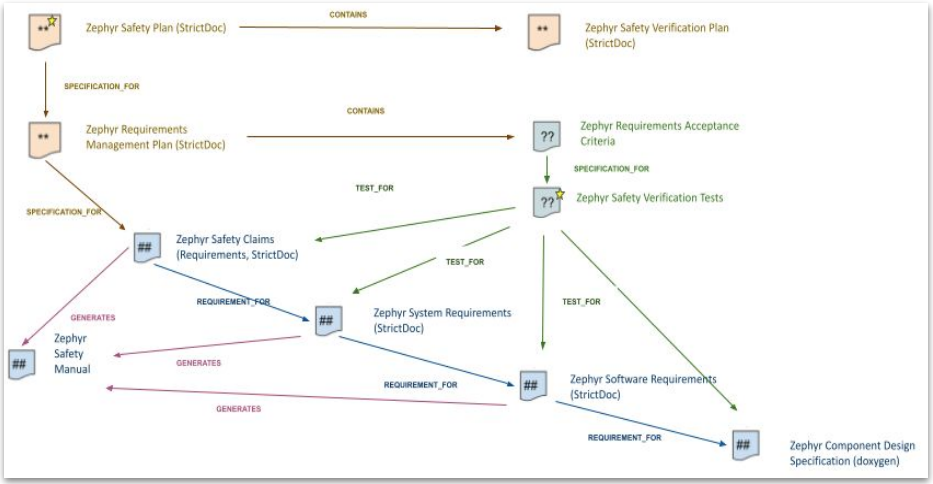
Compiling the evidence for the safety scope.





Tools & Methods

- need to be compatible with FOSS practices and free to use
- Developer-friendly tooling
- Docs as Code
  - keep specifications as close to actual code as possible
  - ensure consistency with actual code base
- Version control everything through git
- Automation through integration with Zephyr's Github workflows

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Zephyr as Safety Element out of Context.

Provider

must provide rules how to integrate

Integrator

must adhere to integration rules

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Zephyr's Architecture
for safe and secure systems

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Freedom from interference - A typical example.

Hazards

A low-prio task enters an infinite loop/monopolizes the CPU, preventing high-prio safety-critical task (brake controller) to execute on time

A faulty pointer in a non-critical task writes outside of its own memory area, corrupting the data or stack of a safety-critical task, causing it to behave erratically or crash.

Safety Requirement (no temporal interference)

The SW shall guarantee that a high-priority task can always preempt a lower-priority one to meet its deadline.

Safety Requirement (no spatial interference)

The SW shall enforce strict memory boundaries between software components, ensuring one cannot corrupt another.

pre-emptive, priority-based task scheduler

RTOS responsibilities

HW (MPU) assisted memory partitioning and exception handling

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Freedom from interference - Zephyr's solution.

Safety Requirement (no spatial interference)

The RTOS shall enforce strict memory boundaries between software components, ensuring one cannot corrupt another.

Architectural Solutions:
HW assisted memory partitioning and exception handling,
KConfig for SW Feature management, CMake build system, System Call semantics

Assumptions:
ARCH_HAS_USERSPACE
ARCH_HAS_STACK_PROTECTION

KConfig Feature:
USERSPACE,
HW_STACK_PROTECTION

Build System:
`Linker scripts, Linking stages`
`Features excluded by default`

Safety Application Configuration:
CONFIG_USERSPACE=y
CONFIG_HW_STACK_PROTECTION=y

Tooling:
kconfiglib,
gen_sycalls.py, gen_kobject_list.py
and many more

Source Code:
#ifdef CONFIG_USERSPACE ...

Safety Application Design:
Only enable required features
Tasks as user mode threads,
Safety functions in highest priority threads

Documentation & Verification required

Obligations by the Safety Manual

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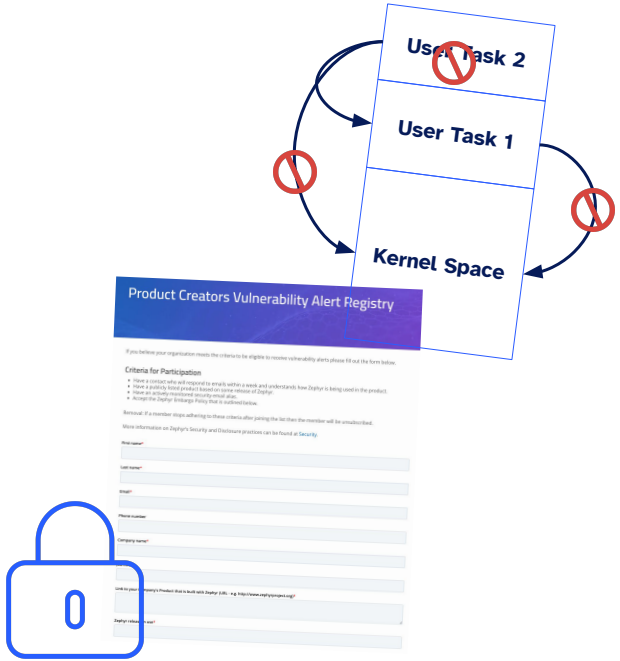
Additional Safety/Security Features available today.

- Error handling and safe-state handlers
- No dynamic memory usage inside kernel
- APIs to assign all Kernel objects memory at link time
- Watchdogs
- Crypto API for secure communication
- TF-M supported for Cortex-M incl. secure boot
- Vulnerability Alert Registry and CVE Numbering Authority



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Current Status & Outlook

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Achieved Milestones.

- **Safety Plans in place**

  Initial set of plans created, reviewed and submitted to TÜV Süd

- **Coding Guidelines**

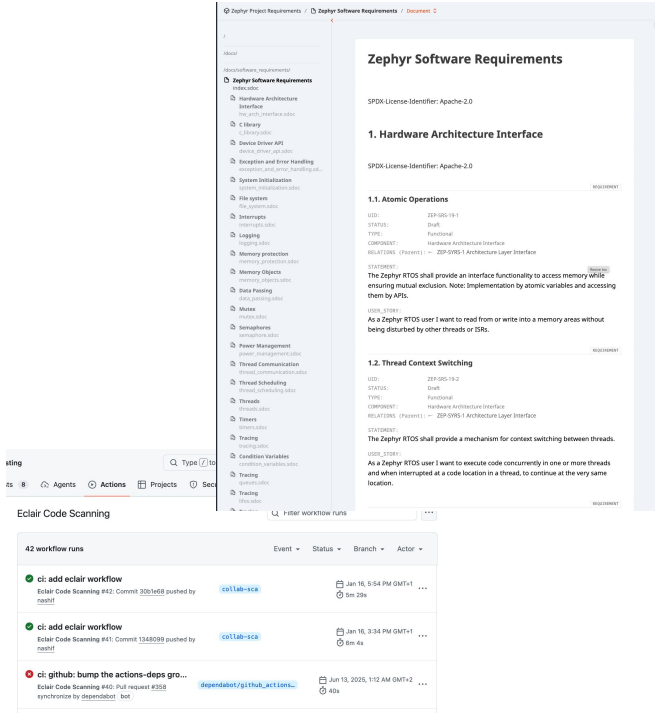
  Defined Zephyr-specific MISRA-C 2012 subset; SCA integrated into Zephyr Build system; automated check integration in progress.

- **Requirements Repository Established**

  https://github.com/zephyrproject-rtos/reqmgmt
  https://zephyrproject-rtos.github.io/reqmgmt/

- **TÜV Concept Approval**

  TÜV Süd confirmed Zephyr's certification concept is feasible.



Key to success: Involving the community

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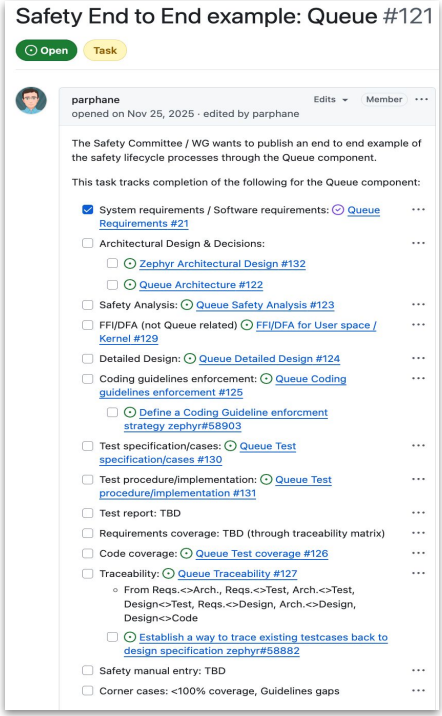
Overall Roadmap and next milestones.

01 Create organizational structures
- Safety Committee, Safety-WG, Budget
- Safety Chair, Safety Architect...

02 Create End to End working model
Define the Safety Scope
- Methods, Content, Tooling
- Kernel API, Arch independent code

03

04 Compile the evidence
- It's done when it's done



https://github.com/zephyrproject-rtos/regmgmt/issues/121

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But Your Certificate is Already Late - Towards Continuous Certifiability.

Zephyr is ever evolving: ~6,000 commits/release (40k commits from 2.7 to 3.7)

- **So is the Safety Scope:** avg 60 commits/release (500 commits from 2.7 to 3.7)
- **Security mandates timely updates, too - And no safety without security**

What happens for Safety must (eventually) happen on main

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But Your Certificate is Already Late - Towards Continuous Certifiability.

Ideal situation (from a Safety & Security perspective):

- Safety documentation remains in sync with **main** (for Safety scope)
- Security updates provably not interfering with Safety claims
- Re-Certification of major (LTS) releases become no-brainers

Safety Working model must accommodate for this

- need to find right balance between innovation and stability for Safety scope
  - additional compliance checks
  - additional manual reviews for PRs affecting Safety scope
- Automate “everything”: Static Code analysis, Traceability Checks, Document generation

No prior experiences - Zephyr is at the frontier of known procedures

Want to make it happen faster? Join the project!

Initial target is **IEC 61508 SIL 3 / SC 3** (with Option for 26262 ASIL D)

- **Zephyr** to be treated as **Safety Element out of Context** (SEooC)
- Limited scope of kernel functions and interfaces similar to other RTOSs

Safety Working Group

subscribe	**Mailing List**	https://lists.zephyrproject.org/g/safety-wg
chat	**Discord**	https://discord.gg/mgZkSmq2
meet	**Video Call every 2nd Tuesday 4pm CET**	

Hall 4
Booth 170

Thank you!

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