A New Perspective on Criticality: Efficient State Abstraction and Run-Time Monitoring of Mixed-Criticality Real-Time Control Systems (Artifact)

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Abstract

The increasing complexity of real-time control systems, comprising control tasks interacting with physics and non-control tasks, comes with substantial challenges: meeting various non-functional requirements implies conflicting design goals and a pronounced gap between worst and average-case resource requirements up to the overall timeliness being unverifiable. Mixed-criticality systems (MCS) are a well-known mitigation concept that operate the system in different criticality levels with timing guarantees given only to the subset of critical tasks. In many real-world applications, the criticality of control applications is tied to the system's physical state and control deviation, with safety specifications becoming a crucial design objective. Monitoring the physical state and adapting scheduling is inaccessible to MCS but has been dedicated mainly to control engineering approaches such as self-triggered (model-predictive) control. These, however, are hard to schedule or expensive at run time.

This paper explores the potential of linking both worlds and elevating the physical state to a criticality criterion. We, therefore, propose a dedicated state estimation that can be leveraged as a run-time monitor for criticality mode changes. For this purpose, we develop a highly efficient one-dimensional state abstraction to be computed within the operating system's scheduling. Furthermore, we show how to limit abstraction pessimism by feeding back state measurements robustly. The paper focuses on the control fundamentals and outlines how to leverage this new tool in adaptive scheduling. Our experimental results substantiate the efficiency and applicability of our approach.

2012 ACM Subject Classification Computer systems organization → Real-time systems; Computer systems organization → Embedded and cyber-physical systems; Computer systems organization → Dependable and fault-tolerant systems and networks

Keywords and phrases Real-time Control, Mixed-Criticality, Switched Systems, State Monitoring

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1 Scope

Except for the wall clock time measurement for the design-time heuristic, this artifact allows for repeating all parts of the evaluation presented in the related article.

2 Content

Find two files in the provided archive: an .ova virtual machine (VM) image for VirtualBox containing all sources, tools, and configurations for repeating the paper's evaluation as well as a README.md (also available as pandoc'ed .html on the VM's desktop) which gives detailed instructions on how the individual results are obtained.

The relevant source repositories are publicly available under
`https://gitlab.cs.fau.de/qronos-state-abstractions/`.

The toolchain comprises a Python interpreter, an arm-none-eabi toolchain (pinned as it may influence the execution time measurements), and some other tools (e.g., Doxygen).

Note: The execution-time benchmark of the evaluation (Section 4.4) requires an STM32F411E-Discovery board [3]. However, we also included the original serial readout to allow for exploring the data and recreating the evaluation results.

3 Getting the artifact

The artifact endorsed by the Artifact Evaluation Committee is available free of charge on the Dagstuhl Research Online Publication Server (DROPS). In addition, the artifact is also available at: `https://sys.cs.fau.de/research/data/qronos/ecrts23/ecrts23-paper11-ae.zip`

4 Tested platforms

All tests were performed on the following reference host platform:

- CPU: AMD Ryzen 5 5600X
- RAM: 16 GB
- OS: Arch Linux, Kernel 6.2.12-arch1-1
- VirtualBox: Version 7.0.8r156879 with virtualbox-host-modules-arch both from official repo.

Note that the VM is configured for 12 GB of RAM as the JSON parser used to evaluate the execution-time serial readout requires a vast amount of memory.

5 License

This artifact is based on two source code repositories with individual licenses:

Sources	License	Sections in Rel. Article	Repo. (Commit)
Simulative Evaluation	BSD 3-clause	Secs. 4.3 and 4.5, Thm. 9	Link (49bb3e28)
Execution Time Benchmark	GPLv3	Sec. 4.4	Link (58f0d2a9)

6 MD5 sum of the artifact

2a2a14c9ef0268107ca32fcd703aeb8d

7 Size of the artifact

3.07 GiB

A Additional Requirements

- A valid MOSEK [2] license (free for academia) is required for the simulative evaluation.
- Repeating the execution-time measurements requires an STM32F411E-DISCO board [3]. The VM is set up for flashing the STM32F4 controller via the Black Magic Probe [1].

References

1 Piotr Esden-Tempski and Rachel Mant. Black Magic Probe. Accessed 28. April 2023. URL: https://black-magic.org/.
2 Mosek. MOSEK. Accessed 28. April 2023. URL: https://www.mosek.com/.
3 STMicroelectronics. 32F411EDISCOVERY – Discovery kit with STM32F411VE MCU. Accessed 28. April 2023. URL: https://www.st.com/en/evaluation-tools/32f411ediscovery.html.