# DMAC: Deadline-Miss-Aware Control


**Paolo Pazzaglia**, **Claudio Mandrioli, Martina Maggio and Anton Cervin**

*Scuola Superiore Sant'Anna, Pisa, Italy*
*Department of Automatic Control, Lund University, Sweden*

paolo.pazzaglia@santannapisa.it

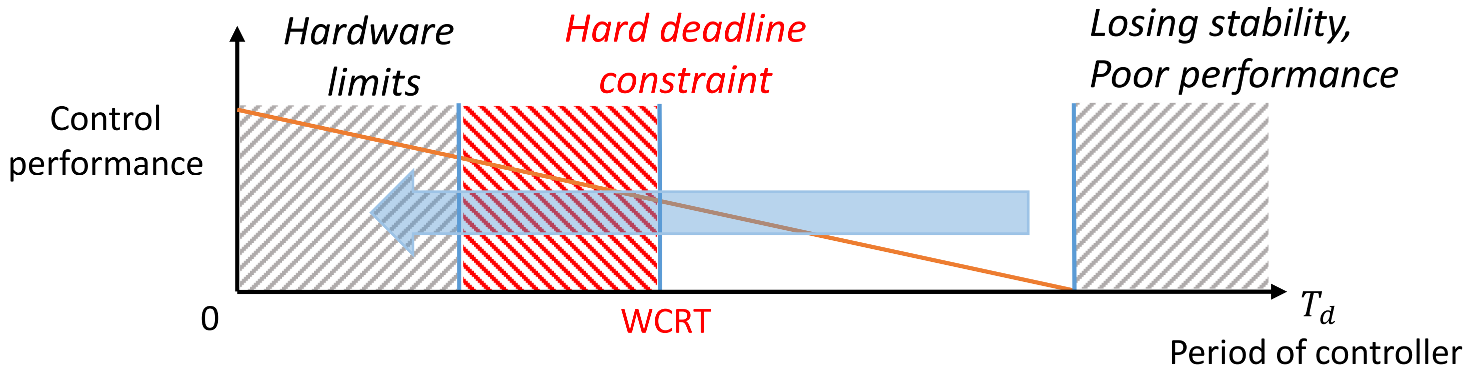


**ECRTS 2019**, Stuttgart - July 9, 2019

# Introduction

- **Starting problem:** Optimal design of a control task to be run alongside a pre-existing real-time system

- Co-design: combining (conflicting) requirements from control theory and real-time systems

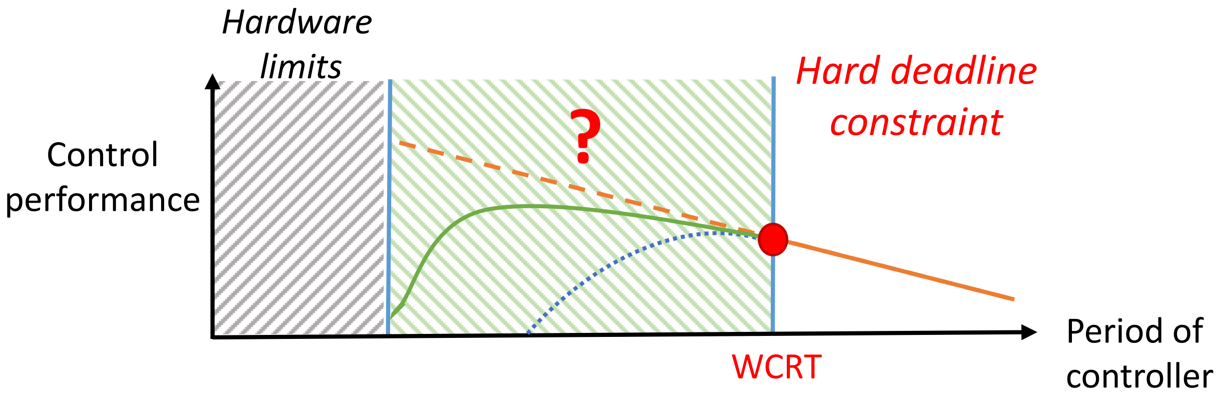



- Hard deadline model → periods are constrained to be longer than WCRT

# An alternative approach

- Hard deadline requirements may be too tight for many real-world systems
- "*Good control design*" should guarantee robustness to a limited number of deadline misses
- ... And overload conditions are relatively rare

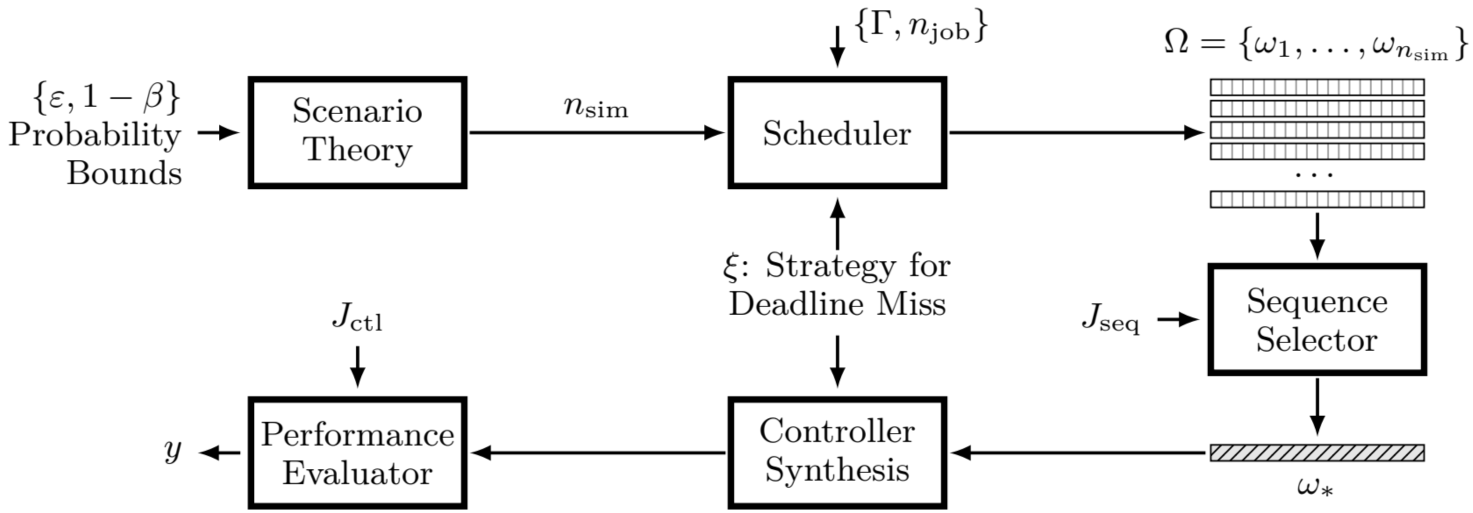
- **Idea**: Explore the interval of periods $T_d < WCRT$, explicitly taking into account the probability of **deadline misses**



# Our proposal

- Leverage probability of **sequences of deadline miss and hits** to build an **optimal** (on average) **fixed** controller

- Sequences obtained by simulation, with formal guarantees coming from the **scenario theory**

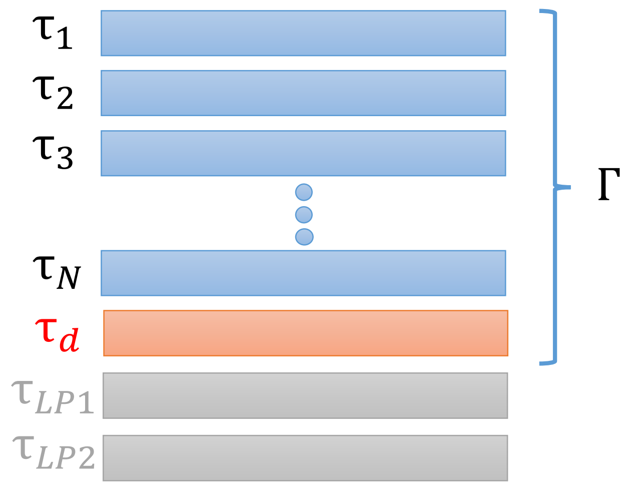


# Task model

- Initial taskset $\Gamma' = \{\tau_1, \tau_2, \ldots \tau_N\}$, fixed priority

- Control task $\tau_d$ to be added as the one with **lowest priority**

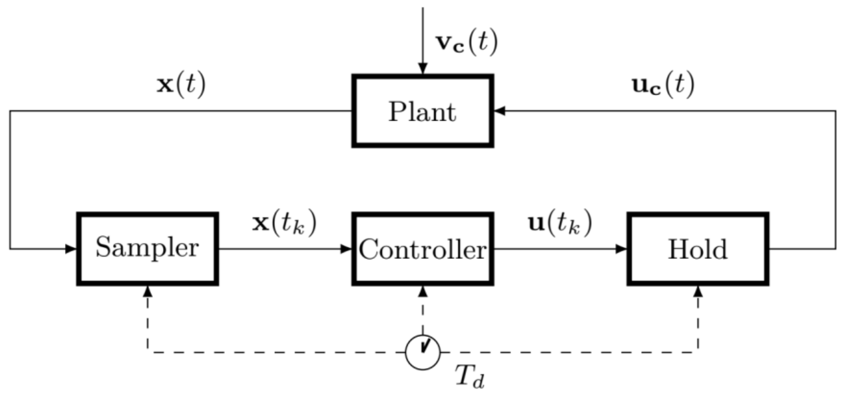
- $\tau_i = \{C_i, f_i^C, D_i, T_i\}$




- Execution time described as a **random independent** variable with known probability density, implicit deadline ($D_i = T_i$)

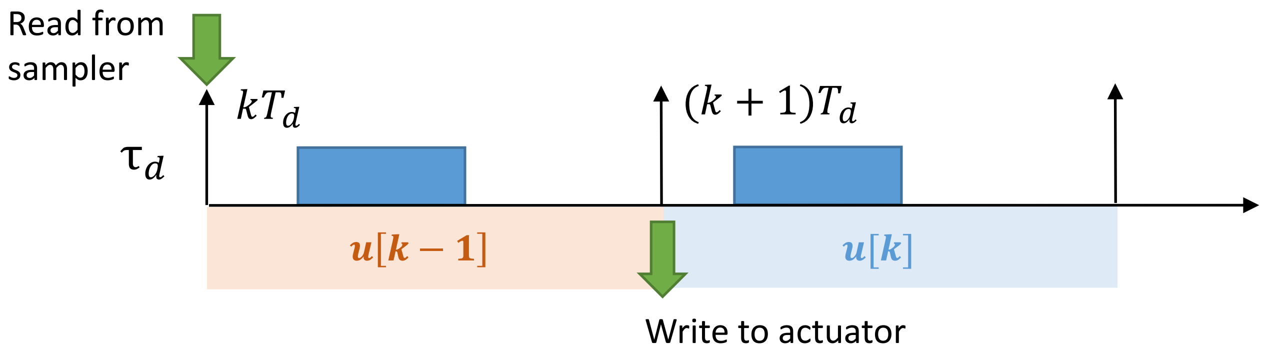
- Period $T_d$ of control task $\tau_d$ is our design variable

# System model



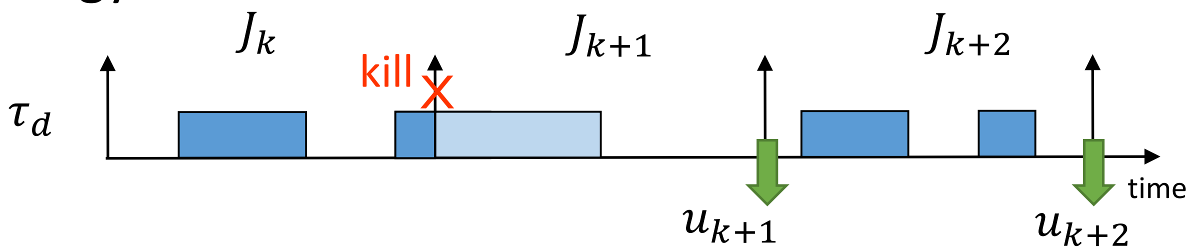

- Plant to be controlled is LTI MIMO, with white noise disturbance

- Periodic control task $\tau_d$ executes under **Logical Execution Time** paradigm

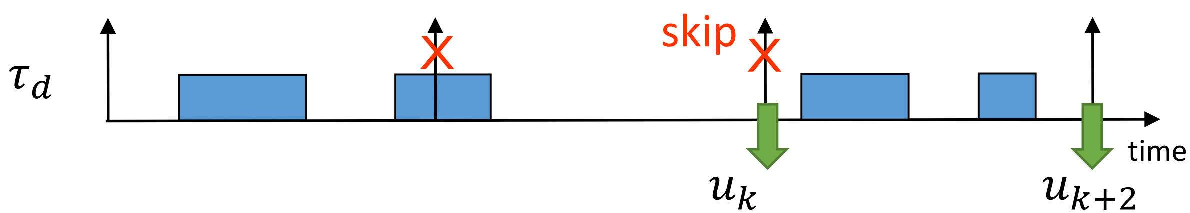


# Deadline miss handling

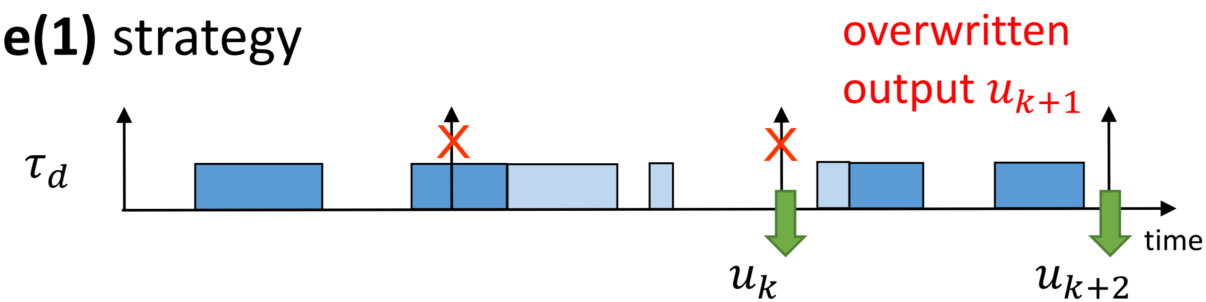
- Focus on three strategies: Kill – Skip Next – Queue(1)
- **Kill** strategy




- **Skip-next** strategy

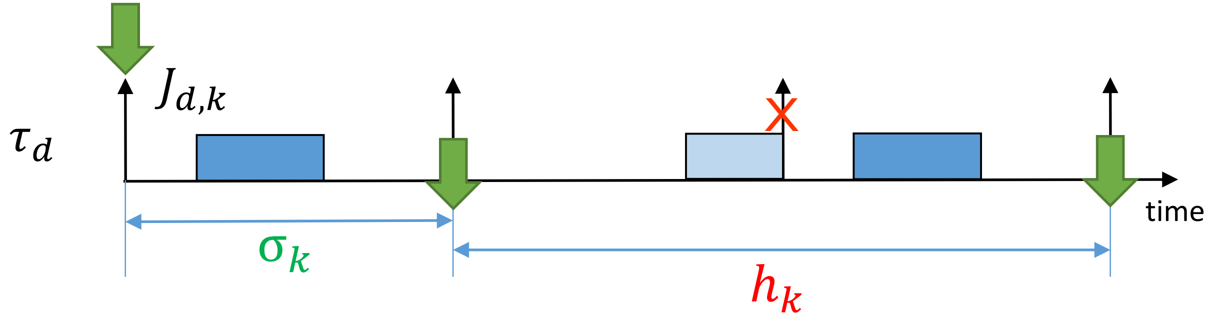



- **Queue(1)** strategy



# Effects of deadline misses

- Deadline misses **produce *jitter*** in the control output pattern
- The dynamic of the system behaves as a <u>switched-linear system</u>
- Extract timing properties → **Delay** $\sigma_k$ and **hold** $h_k$




- **Delay** $(\sigma_k)$ is computed from response time
- **Hold** $(h_k)$ depends on the **next** update
- <u>Remark</u>: Killed, skipped and overwritten jobs do not contribute to control!

# Effects of deadline misses

- We associate $(\sigma_n, h_n)$ to each **valid control job**
  - depending on **specific following subsequence** and d.m. strategy

Ex: kill strategy

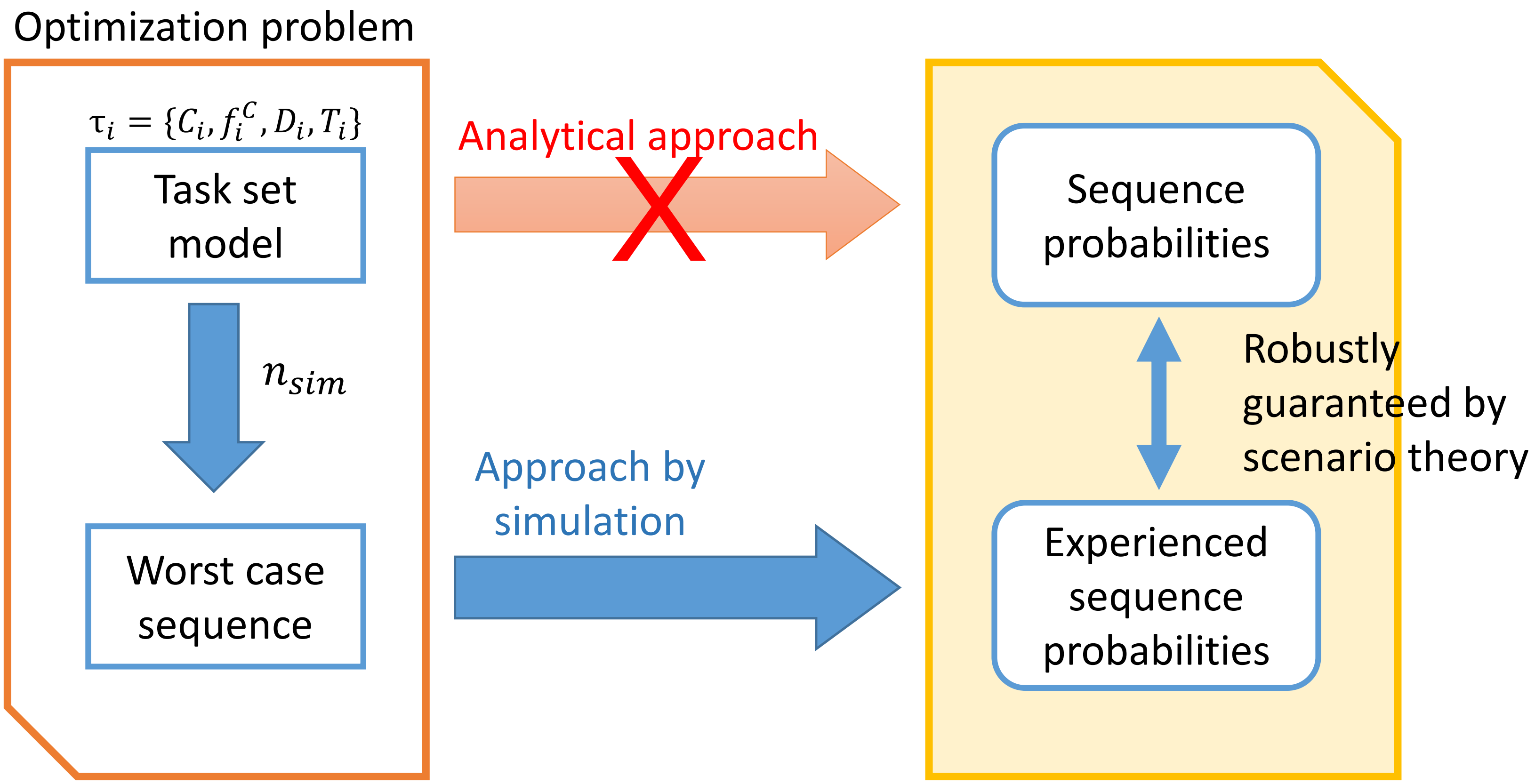

- What is the probability of having a specific $(\sigma_n, h_n)$? We need to know <u>how often each possible subsequence occurs</u>

- Analytic approach is not available…

- <u>Focus on estimation with **robustness**</u>

# Approach by simulation: scenario theory

- **Alternative approach**: Evaluation of probability of deadline misses using **scenario theory**



# Deadline-Miss-Aware Control

- Ideally, optimal control should be adaptive and clairvoyant → not realizable in real applications

- **Fixed robust control** based on statistical properties of the system: Deadline-Miss-Aware Control (DMAC)

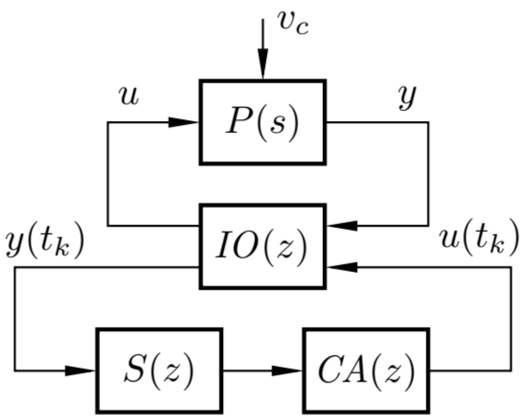
$$u(t_n) = -\bar{L}\,\hat{\boldsymbol{x}}(t_n)$$

- Matrix $\bar{L}$ built using stochastic Riccati equation, based on the possible values of $(\sigma_n, h_n)$ and their probability

- On average, it works as the ideal adaptive clairvoyant controller

# Evaluating the performance: JitterTime

- The performance of the controlled system for a given schedule is computed using **JitterTime** [*]
- Matlab-based analysis tool inspired by *Jitterbug* and *TrueTime*
- Used to analyze performance in scenarios with non-ideal timing, continuous and discrete blocks
- Transitions with arbitrary rules



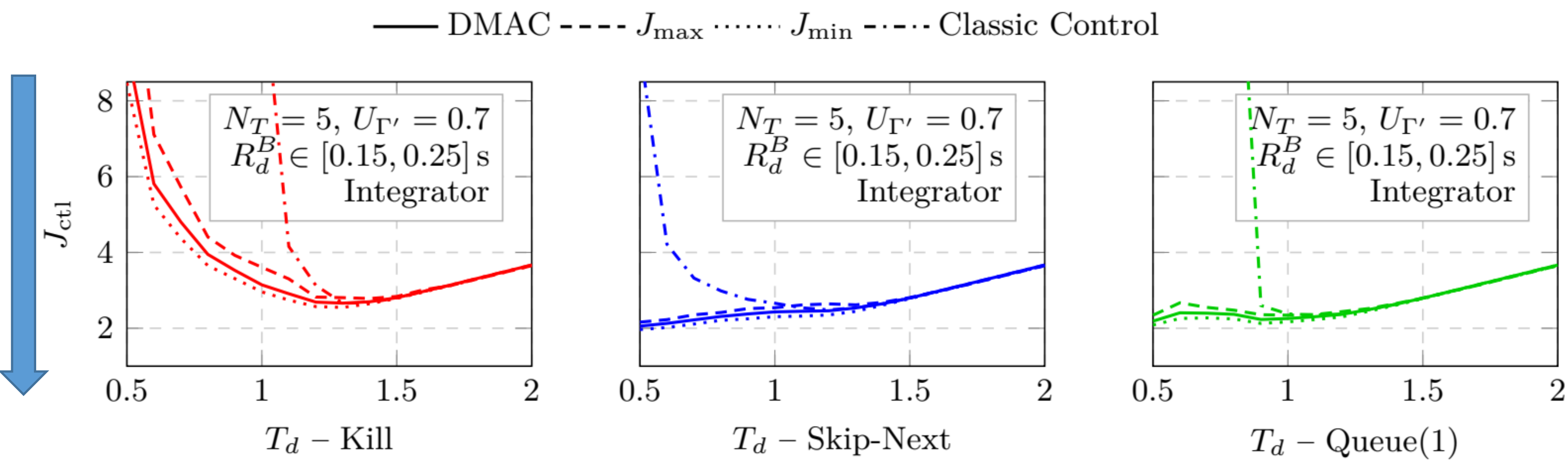

JitterTime is freeware! Online manual: http://www.control.lth.se/jittertime


[*] Anton Cervin, **Paolo Pazzaglia**, Mohammadreza Barzegaran, Rouhollah Mahfouzi, "**Using JitterTime to Analyze Transient Performance in Adaptive and Reconfigurable Control Systems**" *ETFA 2019, Zaragoza, Spain,* September 10-13, 2019.

# Experimental evaluation

- Starting taskset randomly generated with UUnifast
- Generate WCET and probability distributions for all tasks
- Target task $\tau_d$ with WCRT≈2 sec, interval of interest of $\mathrm{T_d} = [0.5, 2]$sec
- Scenario theory parameters: ε = 0.003, β = 0.01 → $n_{sim}$ = 1533
- Scheduling obtained using an ad-hoc simulator using the three different deadline miss strategies – kill, skip-next, queue(1)
- Design controller with DMAC using worst-case sequence
- Performance computed using JitterTime

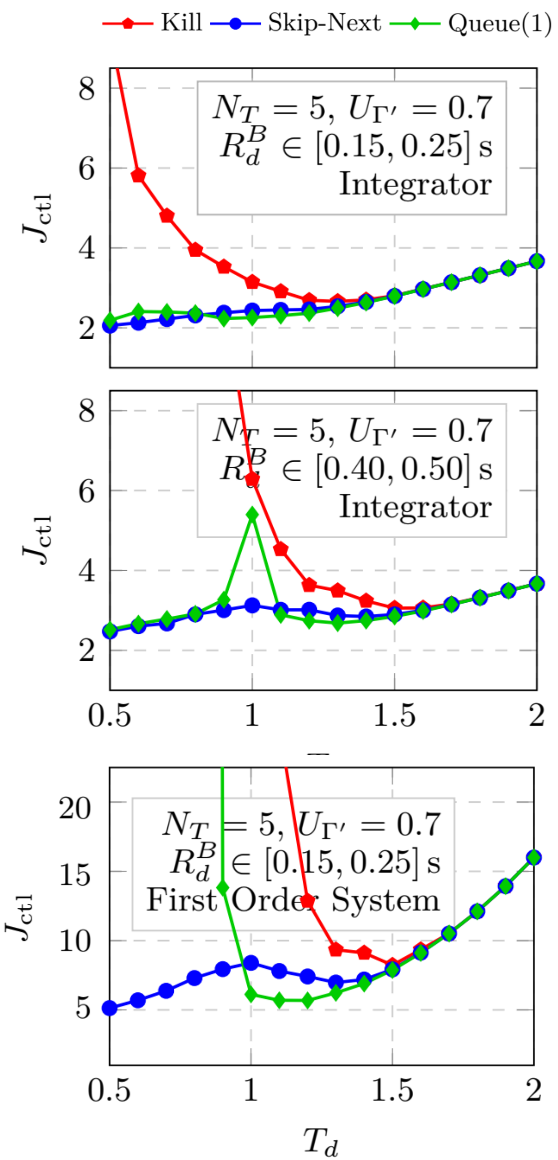
# Experimental evaluation




- DMAC design **outperforms classic control design** for all chosen deadline miss strategies
- Limited gap between maximum and minimum → good robustness

# Experimental evaluation

- Testing DMAC with different initial taskset configurations
- It is not simple to define which deadline miss handling strategy is the best one
  - Depends on the system to be controlled
- Choosing the worst-case sequence differently may affect the overall control performance
  - Require more tests



# Conclusion

- Problem: optimal design of controller that can miss some deadline, with probabilistic execution times
- Three deadline miss strategies: kill, skip-next and queue(1)
- Deadline miss probabilities of subsequences of jobs extracted using Scenario Theory
- Proposed **DMAC**: Deadline-Miss-Aware Control design
- Experimental testing showed that it easily outperforms standard design techniques with good robustness

Giveaway message: control systems may be efficaciously designed to be robust to deadline misses

# Any questions?

Thank you!

[paolo.pazzaglia@santannapisa.it](mailto:paolo.pazzaglia@santannapisa.it)

*Want to know more details?*
*Check our paper!* →

**DMAC: Deadline-Miss-Aware Control**


**Paolo Pazzaglia**
Scuola Superiore Sant'Anna, Pisa, Italy
Department of Automatic Control, Lund University, Sweden
paolo.pazzaglia@sssup.it

**Claudio Mandrioli**
Department of Automatic Control, Lund University, Sweden
claudio.mandrioli@control.lth.se

**Martina Maggio**
Department of Automatic Control, Lund University, Sweden
martina.maggio@control.lth.se

**Anton Cervin**
Department of Automatic Control, Lund University, Sweden
anton.cervin@control.lth.se



**Abstract**

The real-time implementation of periodic controllers requires solving a co-design problem, in which the choice of the controller sampling period is a crucial element. Classic design techniques limit the period exploration to *safe* values, that guarantee the correct execution of the controller alongside the remaining real-time load, i.e., ensuring that the controller worst-case response time does not exceed its deadline. This paper presents DMAC: the first formally-grounded controller design strategy that explores shorter periods, thus explicitly taking into account the possibility of missing deadlines. The design leverages information about the probability that specific sub-sequences of deadline misses are experienced. The result is a *fixed* controller that on average works as the ideal clairvoyant time-varying controller that knows future deadline hits and misses. We obtain a safe estimate of the hit and miss events using the *scenario theory*, that allows us to provide probabilistic guarantees. The paper analyzes controllers implemented using the Logical Execution Time paradigm and three different strategies to handle deadline miss events: killing the job, letting the job continue but skipping the next activation, and letting the job continue using a limited queue of jobs. Experimental results show that our design proposal – i.e., exploring the space where deadlines can be missed and handled with different strategies – greatly outperforms classical control design techniques.



**2012 ACM Subject Classification** Computing methodologies → Computational control theory; Computer systems organization → Embedded software; Software and its engineering → Real-time systems software; Theory of computation → Stochastic control and optimization

**Keywords and phrases** Weakly-Hard Real-Time Systems, Deadline Miss Handling, Control Design