Static Response-Time Analysis of Complex Real-Time Systems: Time for Rethinking?

CASTOR Workshop on Dependable and Secure Systems
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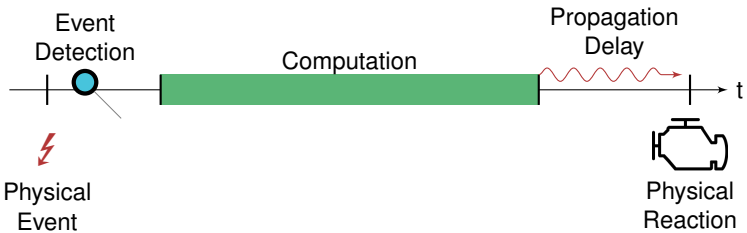
dortmund

Response Time of Control Systems



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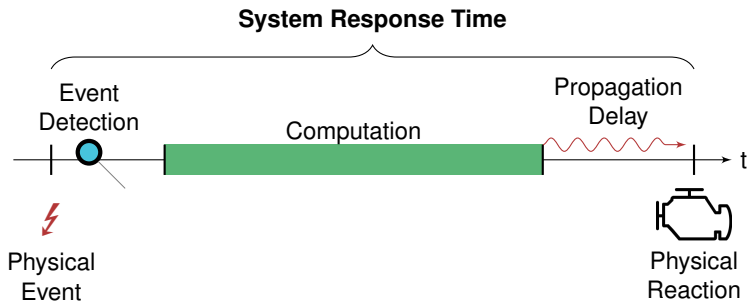
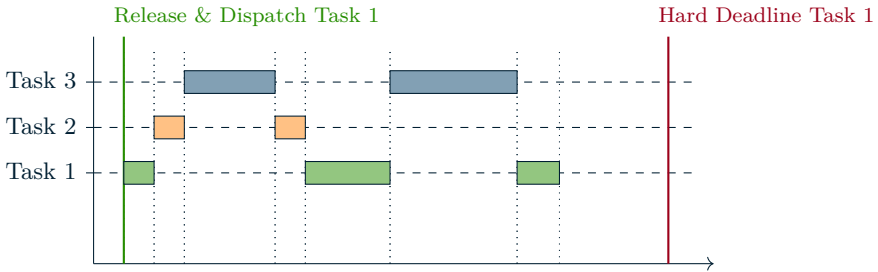
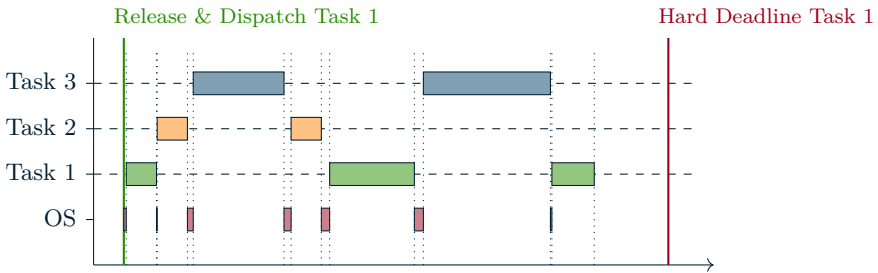


Scheduling View: Worst-Case Execution Times



Operating-System Overheads



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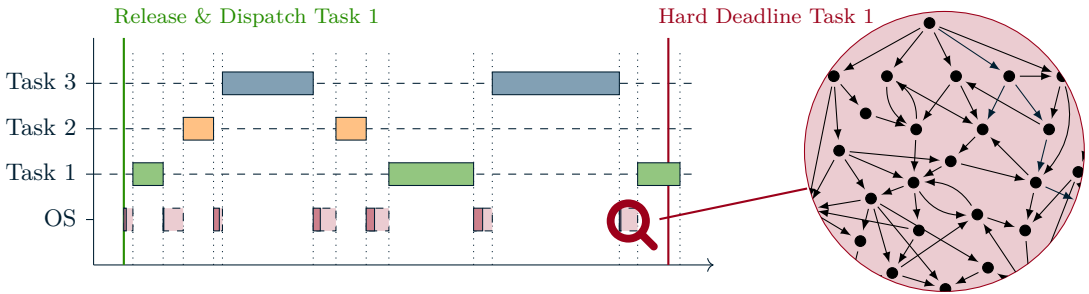

✗ **High level of pessimism** due to missing context information

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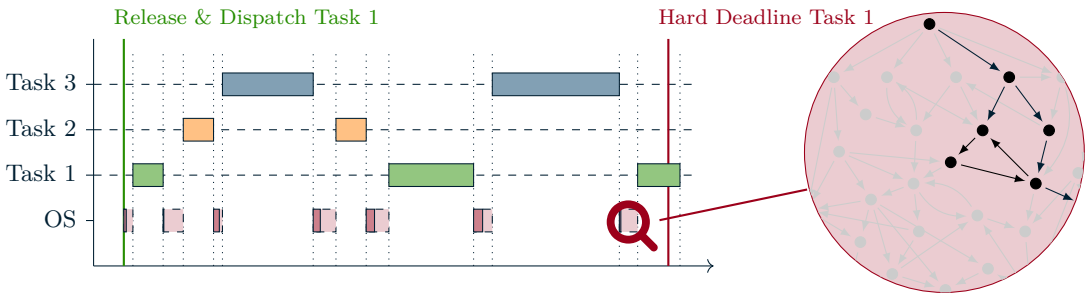

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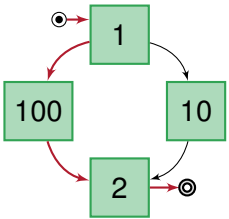
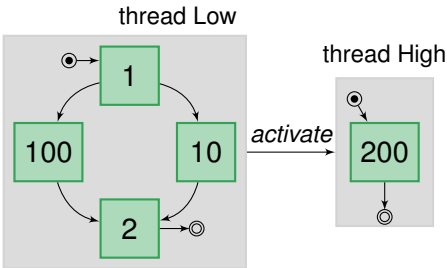
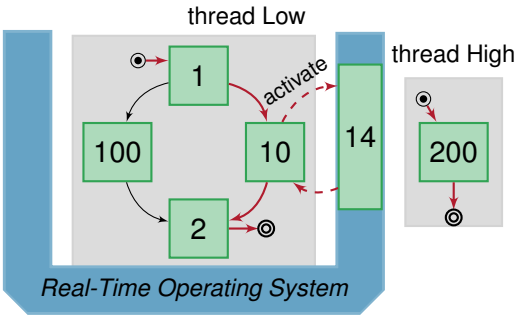
Whole-System Response-Time Analysis



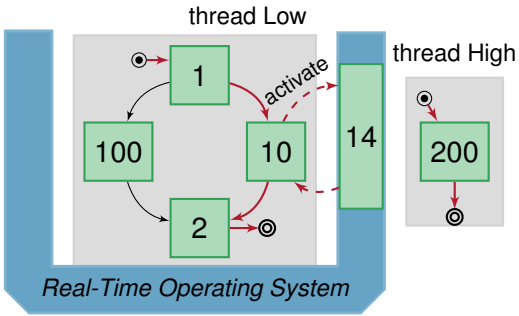
Worst-Case Response Time (WCRT): 103 cycles



Worst-Case Response Time (WCRT): 103 + 200 + t(RTOS) cycles?



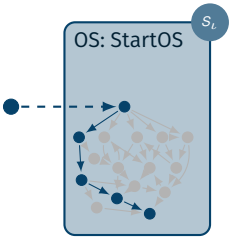
Worst-Case Response Time (WCRT): **331** cycles



Worst-Case Response Time (WCRT): **331** cycles

- Compositional approach on WCRT is **overly** pessimistic

→ Whole-system approach incorporating operating system semantics?

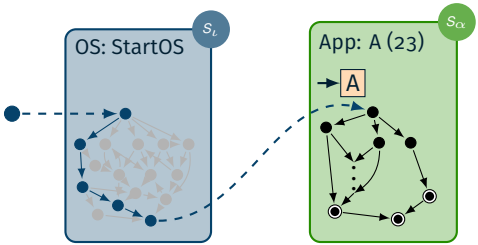


Status enumeration:

- Single-core system
- Fixed-priority scheduling
- OSEK-compatible

→ **Feasible system states**

Modeling Operating-System Semantics



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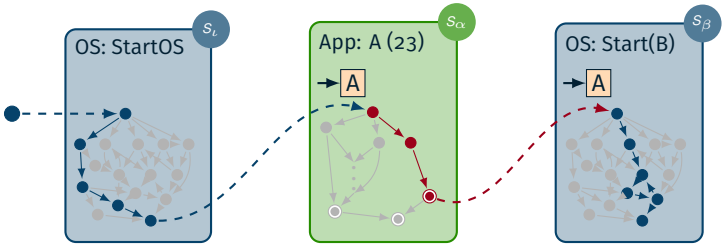

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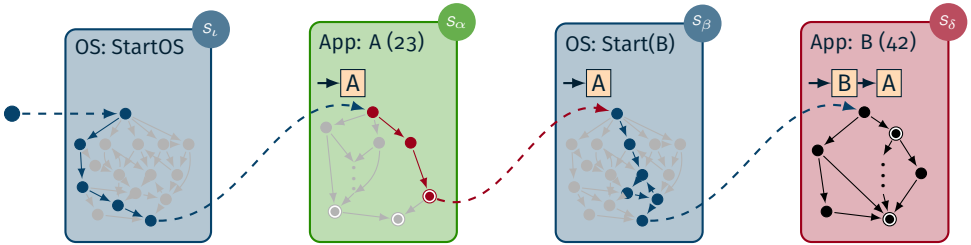

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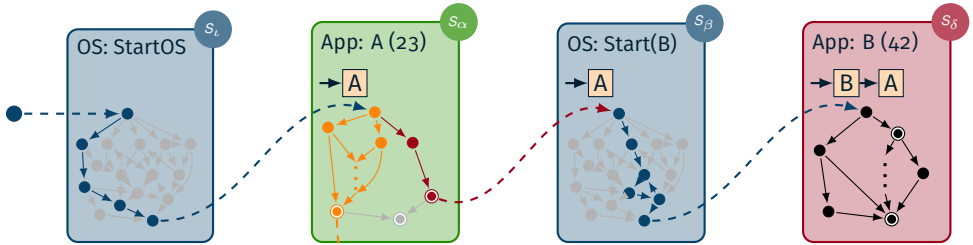

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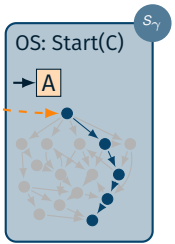

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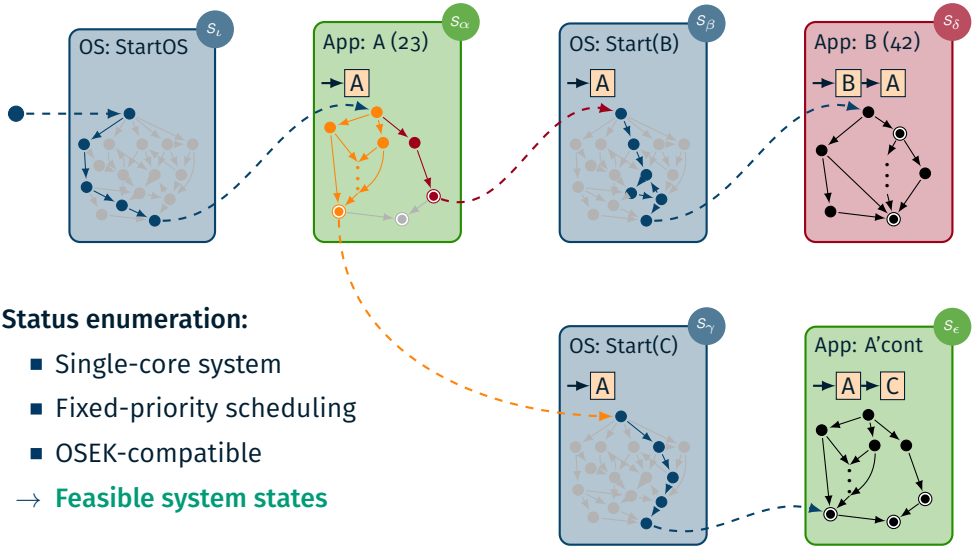

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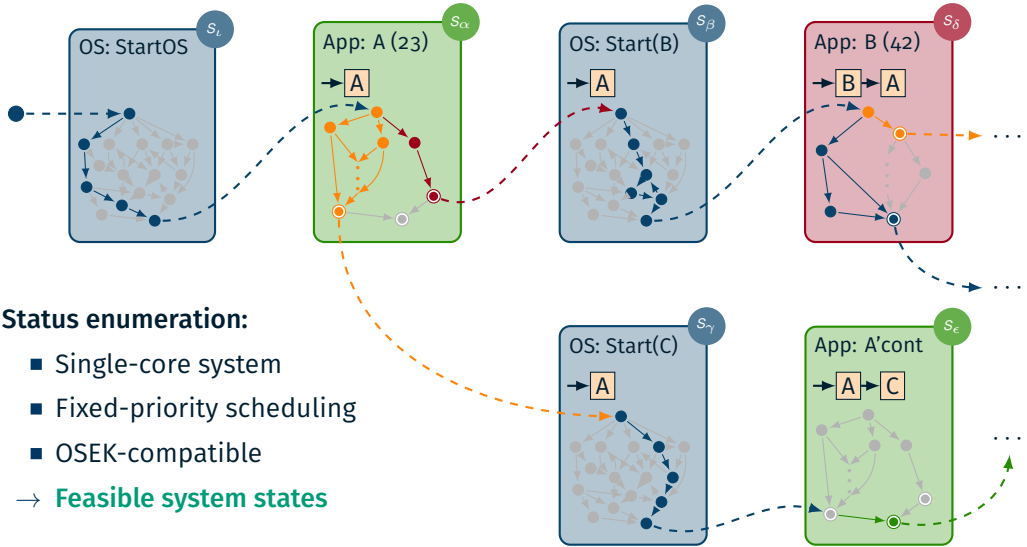

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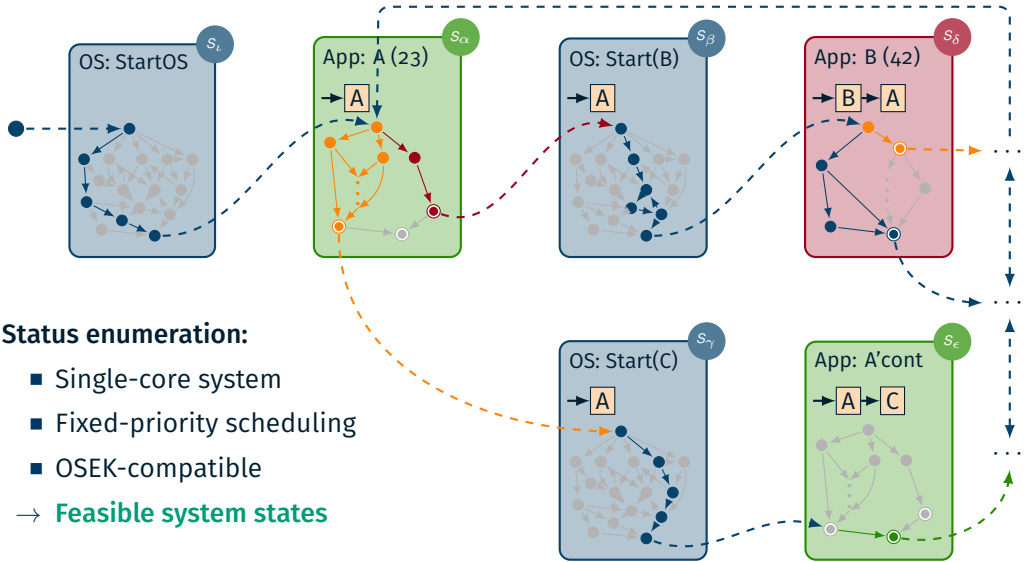

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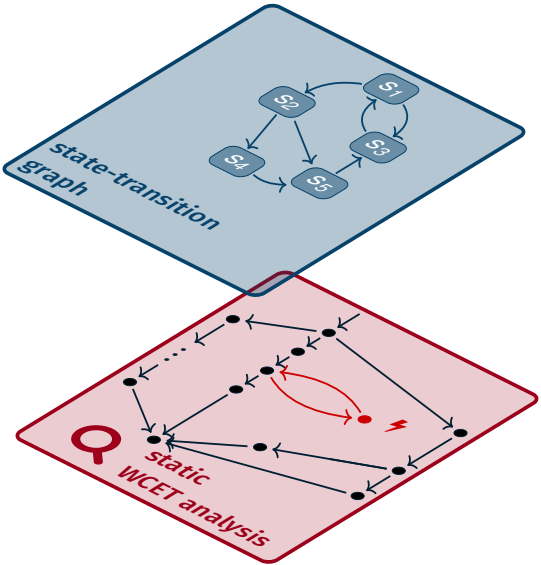
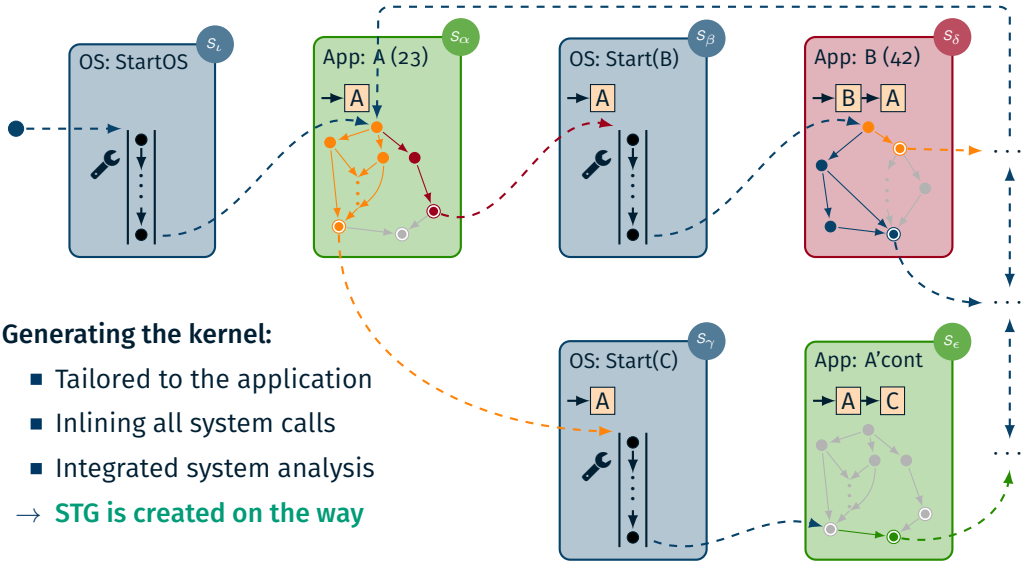
Static Execution-Time Analysis of System Calls



Tailoring of System Calls

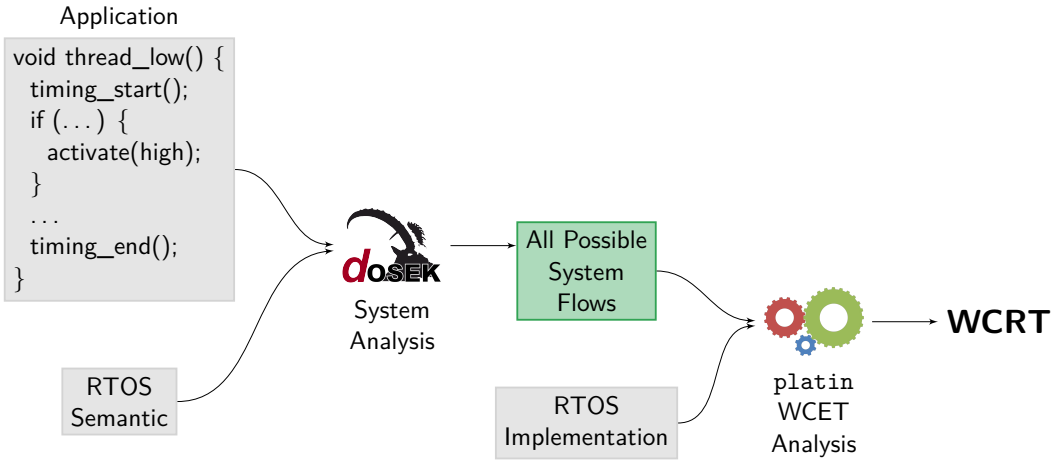


Generating the kernel:

- Tailored to the application
- Inlining all system calls
- Integrated system analysis

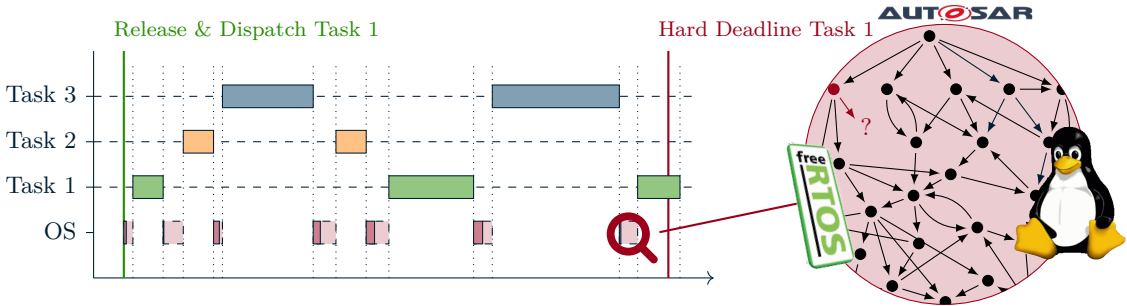
→ **STG is created on the way**

The SysWCET Approach – Overview



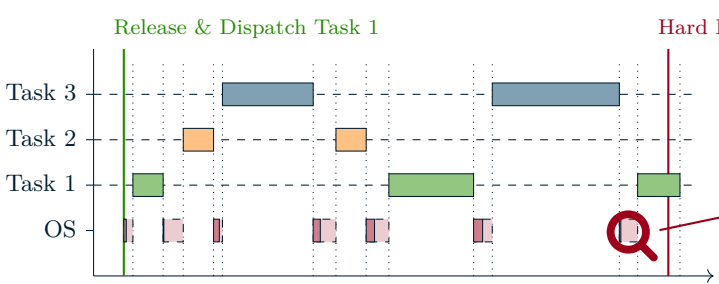
- Dietrich, Wägemann, Ulbrich, Lohmann.
SysWCET: Whole-System Response-Time Analysis for Fixed-Priority Real-Time Systems.
23rd Real-Time and Embedded Technology and Applications Symposium (*RTAS'17*)

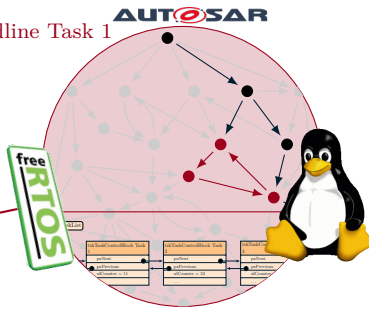
Operating-System Overheads (cont.)



- ✗ **High level of pessimism** due to missing context information
- ✗ **Control-flow reconstruction** difficult in some cases

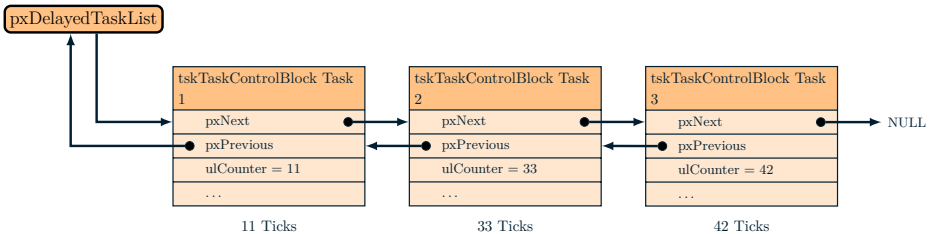
Operating-System Overheads (cont.)





- ✗ **High level of pessimism** due to missing context information
- ✗ **Control-flow reconstruction** difficult in some cases
- ✗ **Indeterminable upper bound** due to application-dependent data structures

Operating System's Dynamic Data Structures



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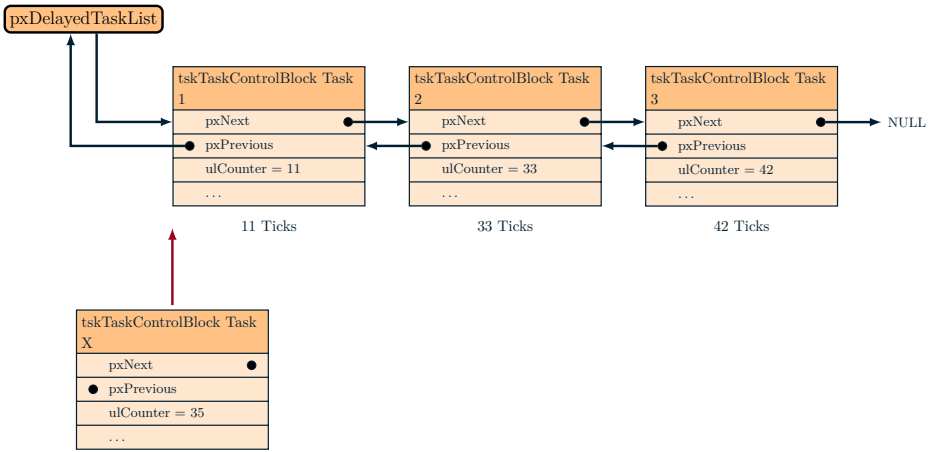

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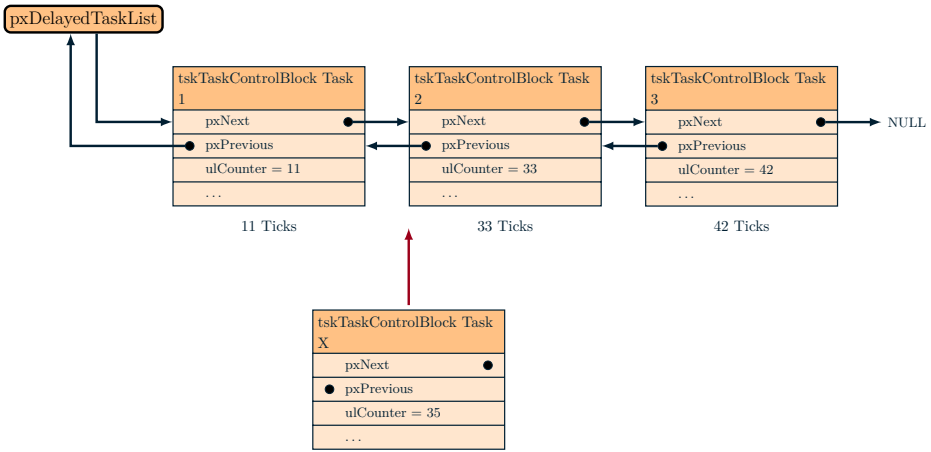

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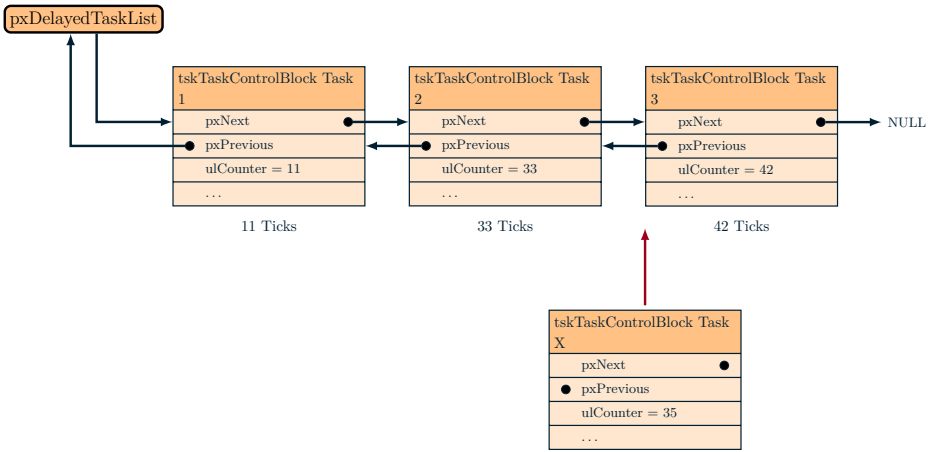

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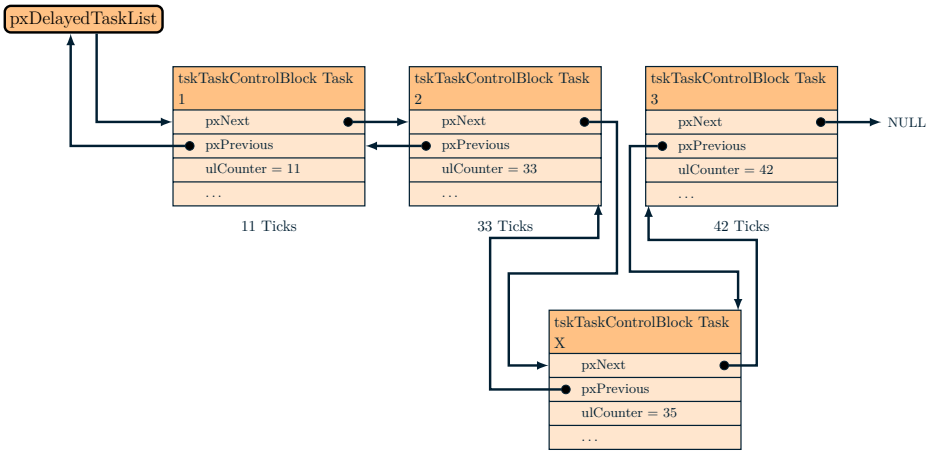
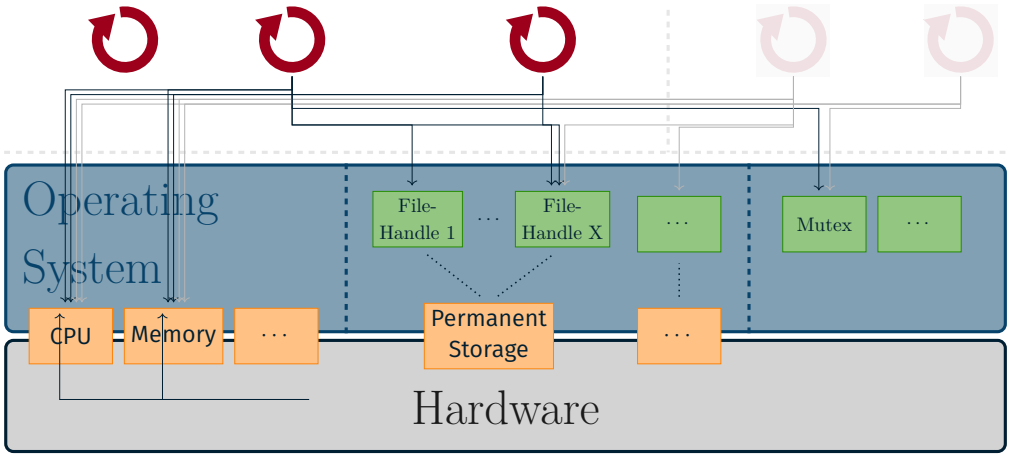
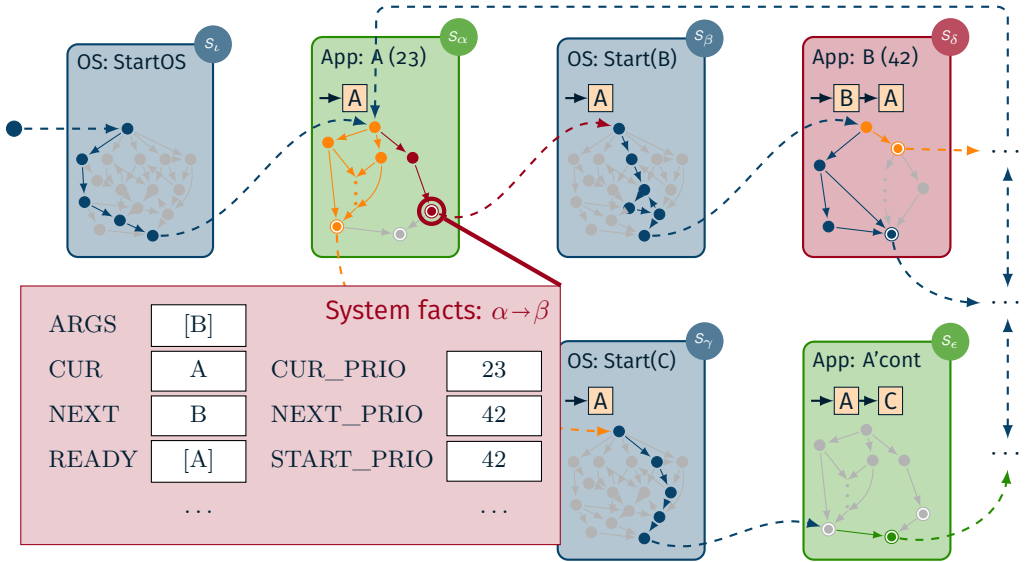


Operating System's Dynamic Data Structures

There are plenty of them!



Deriving System Facts From the State Graph



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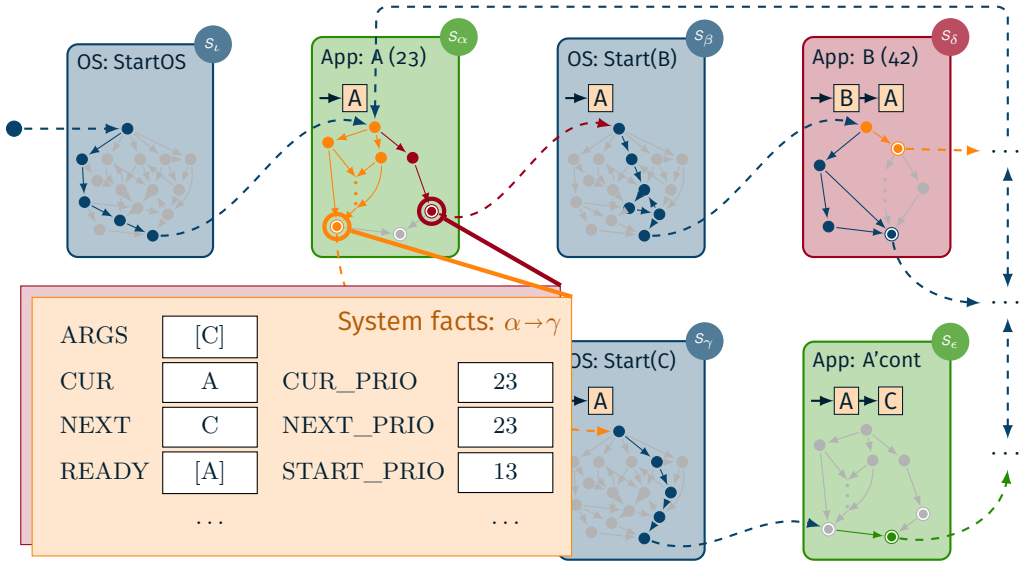

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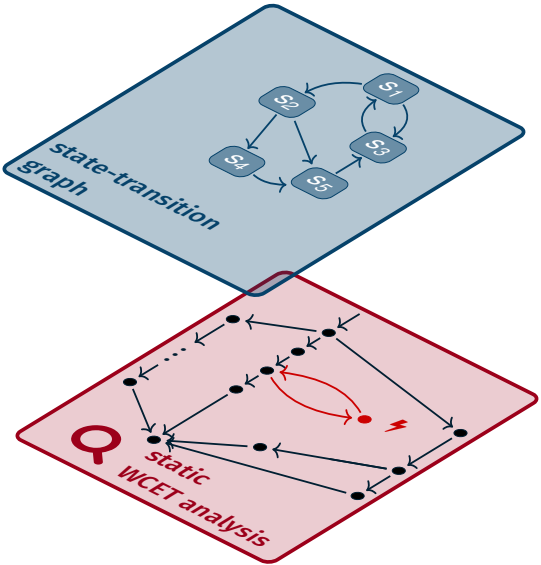
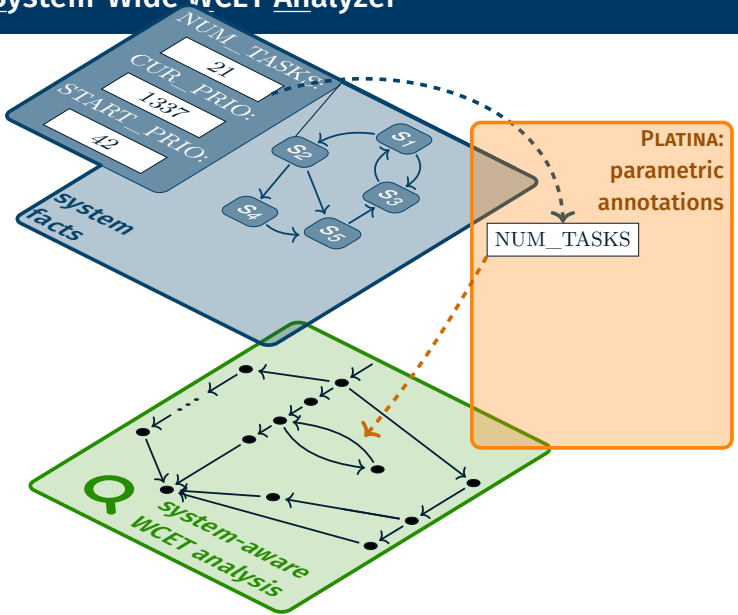


SWAN: System-Wide WCET Analyzer



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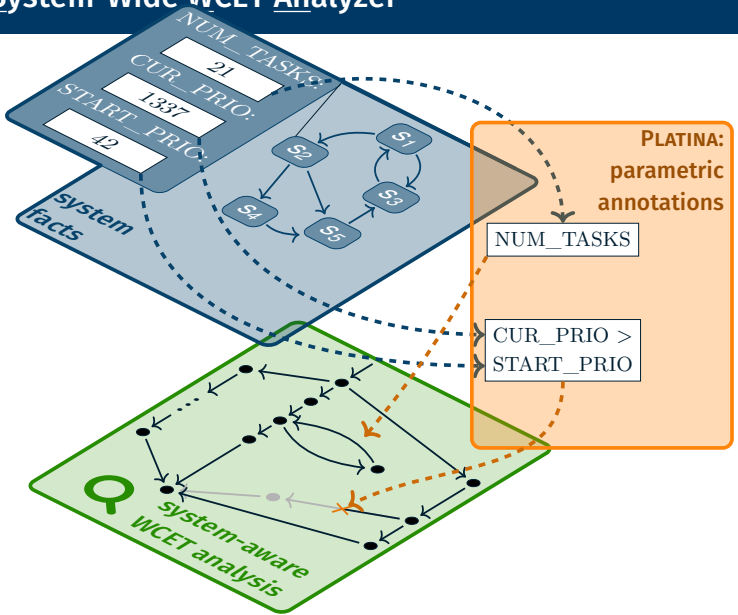

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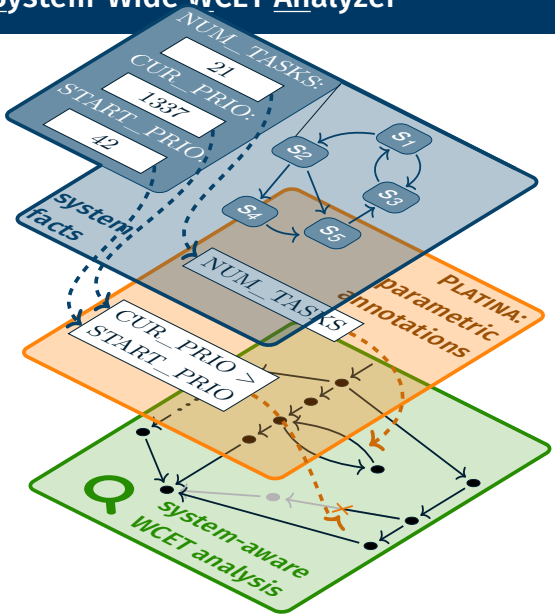
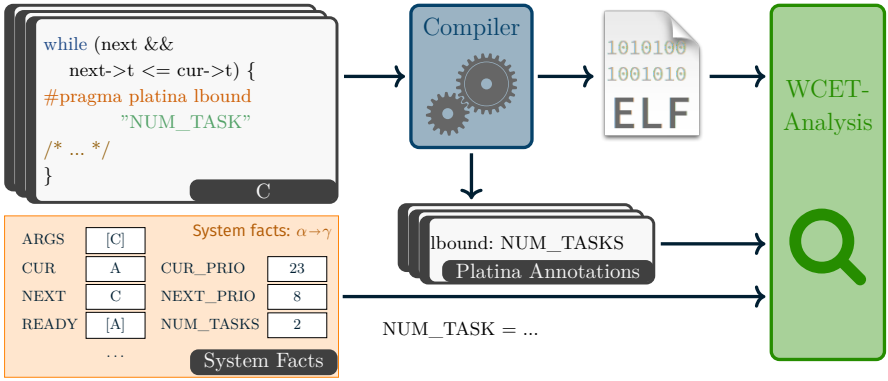


Information transport

The SWAN Toolchain



▶ Schuster, Wägemann, Ulbrich, Schröder-Preikschat.
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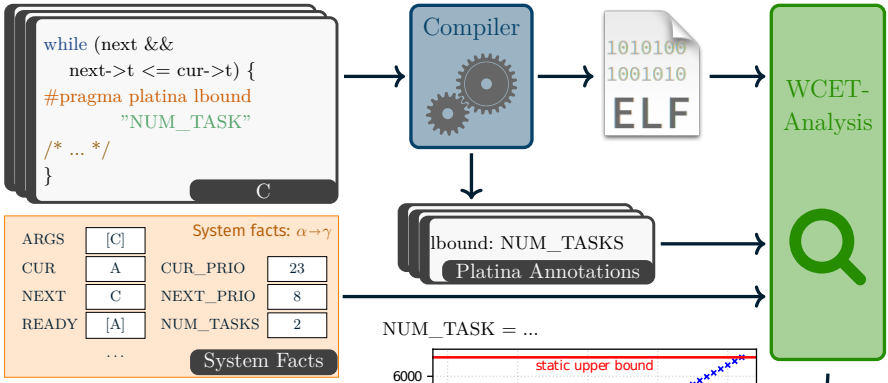

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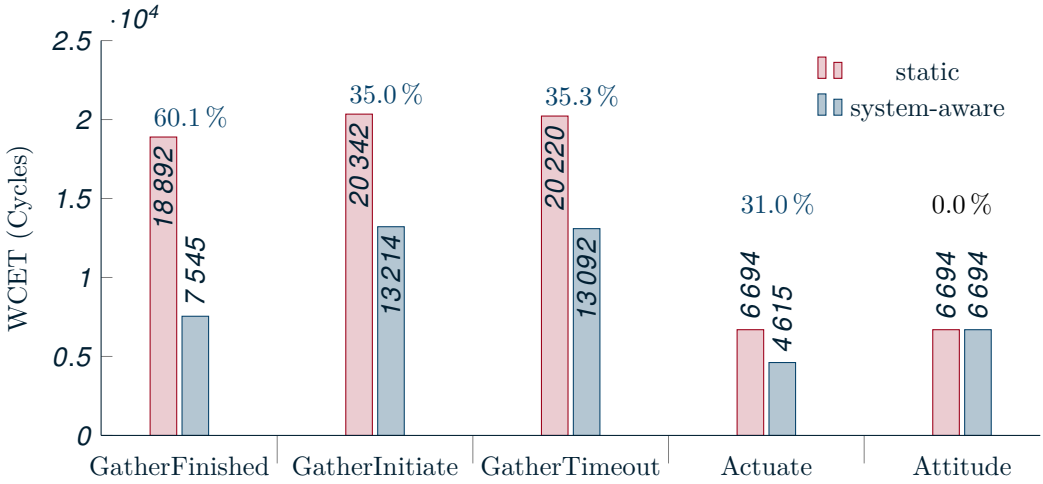
Evaluation Results



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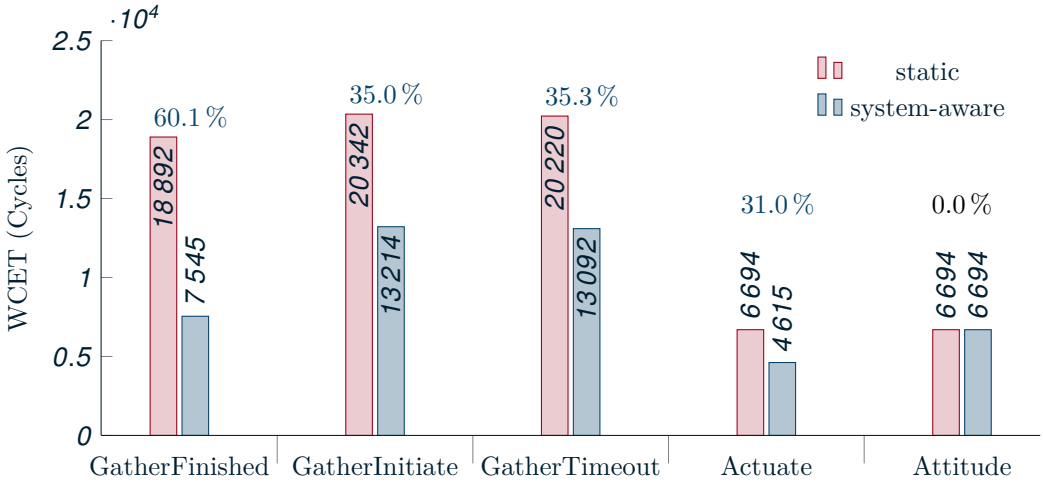
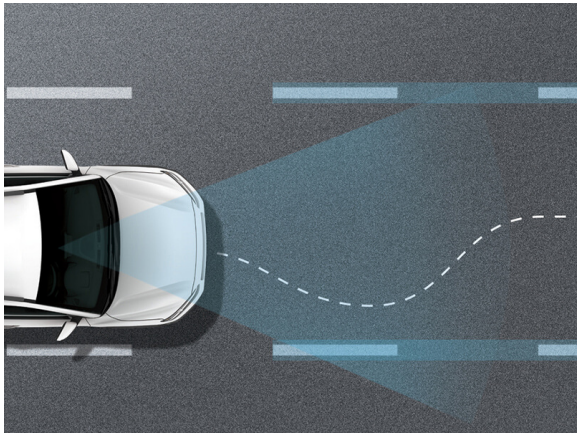


⇒ Reduction in WCRT by up to ***40.7***%

Runtime Adaptivity and Application-Centric Abstractions

Motivating Example: Human Drivers



Goal: Safe driving

- Keep lane adequately
- Omit obstacles

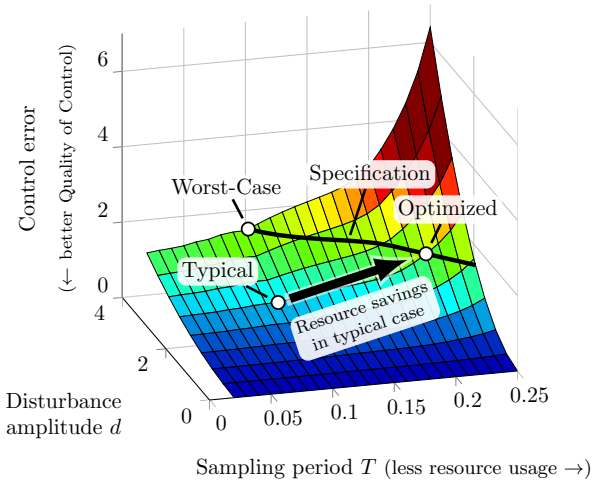
→ **Even in the worst case**

Situational awareness

- Reduced attention in normal traffic
- Focused in emergency situations

→ **Efficient use of resources**

Application's Work and OS's Contribution



Quality of control (QoC)

- Characterized by control error
- Degraded by environmental disturbance
- Implies resource demand

→ **Application-level constraints**

Quality of service (QoS)

- Resource allocation (periodicity)
- Deadline obedience

→ **OS-level timing constraints**

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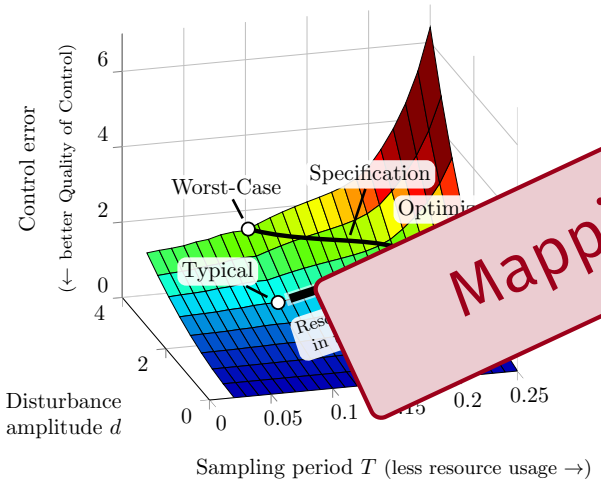

Mapping?

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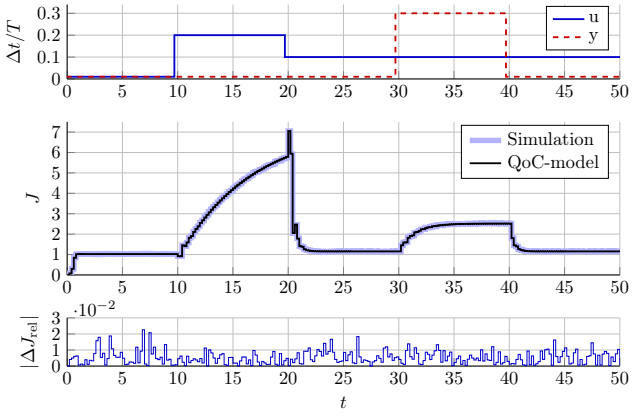
Linking Qualities of Control and Service



Job-level runtime adaptivity

- Application constraints $\neq$ controller stability
- QoC is state-dependent

$\rightarrow$ **QoC prediction non-trivial**

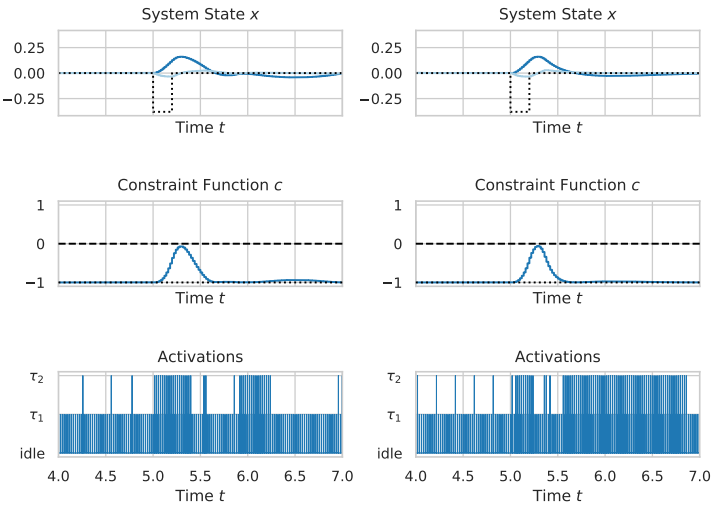
QRONOS: Quality-Aware Real-Time Control Systems

- QoC model (stochastic or deterministic)
- QoS mapping (deadlines)

$\rightarrow$ **Efficient yet reliable**

- Gaukler, Michalka, Ulbrich, Klaus.
  A New Perspective on Quality Evaluation for Control Systems with Stochastic Timing.
  21st ACM International Conference on Hybrid Systems: Computation and Control (*HSCC '18*)

Experimental Results (Work in Progress)



Good QoC obedience

- ≈100 % observed experimentally
- 71.0 % drop rate (NN)
  79.2 % drop rate (MPC)

Low overheads

- x86: MPC 93 ms
  vs. NN 1 ms (worst-case)
- Cortex-M4: NN 50 µs

→ **Feasible for scheduling**

Conclusion

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Whole-System Response-Time Analysis

- Based on semantic analysis of operating system states

→ **SysWCET: Code tailoring of system calls**

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Tackling Universal Operating Systems

- Code annotation and context-aware analysis

→ **SWAN: Tailoring the analysis**

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- Based on semantic analysis of operating system states

→ **SysWCET: Code tailoring of system calls**

Tackling Universal Operating Systems

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→ **SWAN: Tailoring the analysis**

Future Real-Time Design

- Are we hitting the pessimism wall?
- Deadlines are (often) inept!

→ **QRONOS: Application-level constraints as 1st class citizen**