Partitioned and Overhead-Aware Scheduling of Mixed-Criticality Real-Time Systems

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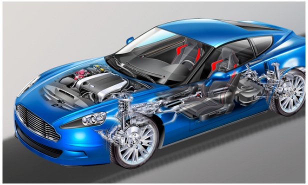
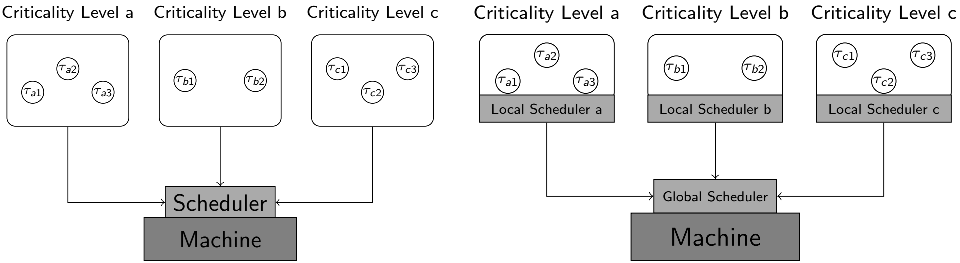
Overview

Mixed-Criticality Systems (MCS)

- Tasks with different criticalities share computation resources
- Criticality used in functional safety, e.g., automotive
- Industrial safety standards
  - ISO 26262 – road vehicles
  - DO 178C – avionics software
  - IEC 61508 – generic standard
- Core concept for MCS is sufficient independence



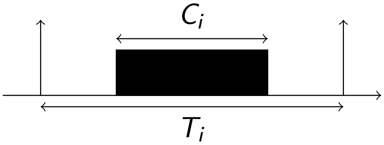
Partitioned Scheduling (Hierarchical Scheduling)



(a) Integrated Architecture (b) Partitioned Architecture

- **Global Scheduler** assign system resources to Local Scheduler
- Tasks scheduled by **Local Scheduler**
- Misbehaviors do not affect tasks with different criticality levels
- Online local scheduler (flexible), Offline global scheduler (predictable)

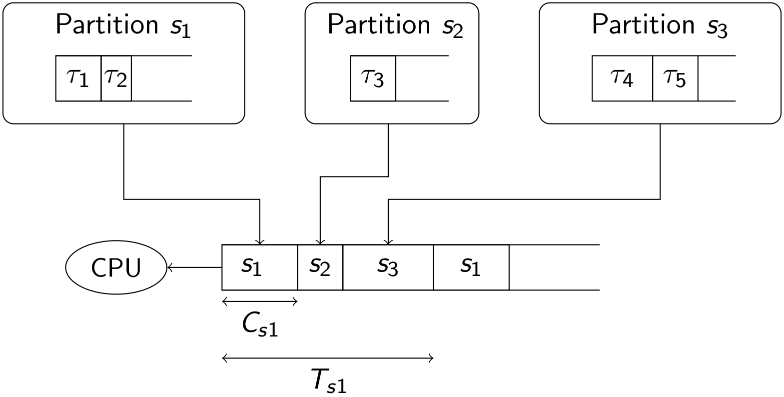
Task Model



- Single-core platform
- Timing parameters for task τ_i
  - Worst-case Execution Time (WCET) C_i
  - Period T_i
  - Relative Deadline D_i ($D_i \leq T_i$)
  - Fixed Priority P_i
- Criticality level SIL_i

Partition Model

- Periodic partition:
  - Period T_s
  - Deadline D_s ($D_s = T_s$)
  - Capacity C_s



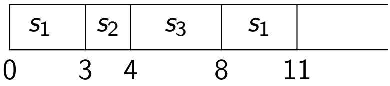
Design of Partitions

- Need to be determined
  - Allocation tasks to partitions
  - Period : T_s, Capacity : C_s
- (C_s, T_s) pairs of each partition obtained[1]
  - Cost function of each partition (e.g., Utilization) defined
- Tasks within partitions are guaranteed schedulable

[1] Almeida L, Pedreiras P. Scheduling within temporal partitions: response-time analysis and server design[C]//Emsoft. 2004: 95-103.

Motivation – Offline Partition Scheduling

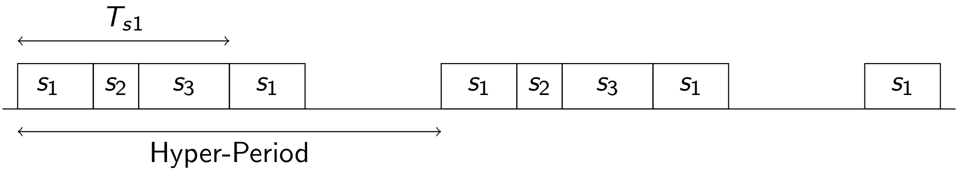
- Offline scheduling
  - Schedule table determined before system runs
  - Schedule table size affect : **Synthesis time**, **Memory usage**



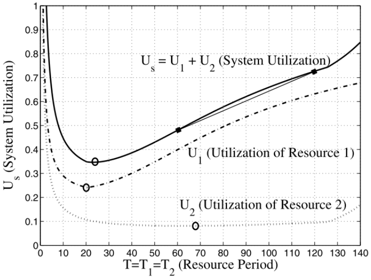
Partition	Start Time	End Time
S_1	0	3
S_2	3	4
S_3	4	8
S_1	8	11

Motivation – Hyper-Period

- Hyper-Period
  - Schedule is same cross Hyper-Period (HP)
  - Least Common Multiple of periods
- Very long Hyper-Period
  - Example 1: HP{15, 16, 31, 32, 33} = 163680
- Harmonic relations
  - $\frac{T_{i+1}}{T_i} \in N^+$
  - Example 2: HP{16, 16, 32, 32, 32} = 32



Motivation – Period vs Utilization

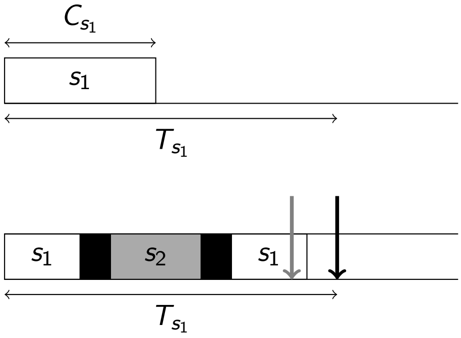


- Partitions' utilization increased by setting different periods[2]
  - e.g., harmonic periods
- Research problem: to **trade-off** hyper-period length and system schedulability

[2]Yoon M K et al. Holistic design parameter optimization of multiple periodic resources in hierarchical scheduling[C]//DATE,2013: 1313-1318.

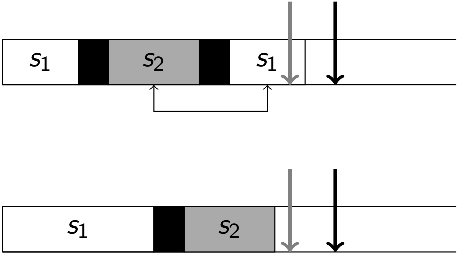
Motivation – Overhead between Partitions

- Construct **offline** schedule table
  - Preemptive EDF to simulate within hyper-period
    - ⋯ Utilization $\leq 1 \rightarrow$ schedulable
  - Several partition slices due to preemption
  - Scheduling overhead between partition slices



Motivation – Overhead between Partitions (Cont.)

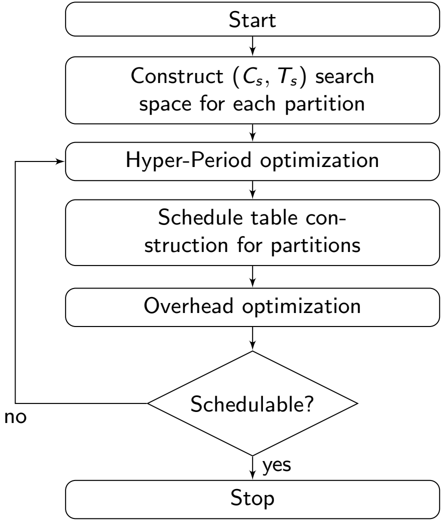
- Too many partition slices → too much scheduling overhead → impact schedulability
- EDF is not optimal when overhead considered
- Combine partition slices → reduce utilization → improve schedulability
  - Deadline and release constraints not violated
  - Possible due to offline scheduling



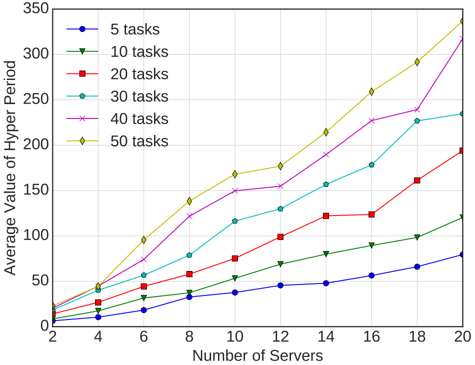
Problem Formulation

- Input:
    - Task Parameters (including WCET, Deadline, Period, Criticality Level)
- Output:
    - Offline schedule table for partitions
- Constraints:
    - System is schedulable
    - Reduce partition schedule length

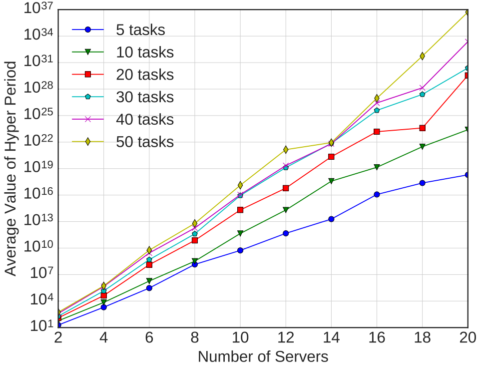
Overall Approach



Experimental Results (Hyper-Period Value)



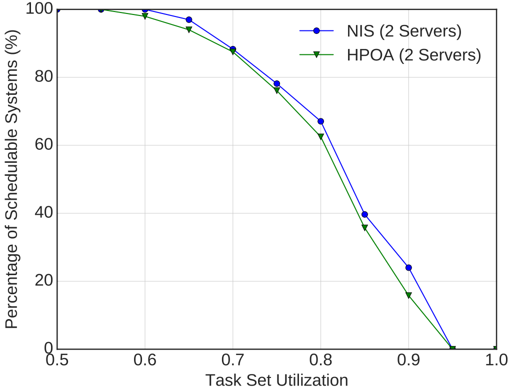
(a) Proposed Approach



(b) Straight-forward Approach

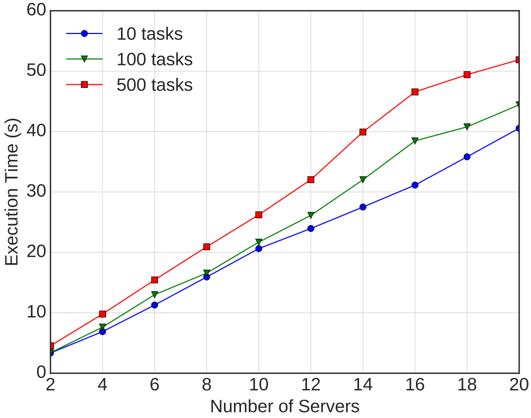
- Proposed approach is within several hundreds
- Straight-forward approach (NIS): rounded into nearest integer
    - from several hundreds to 10^{37}

Experimental Results (System Schedulability)



- HPOA : proposed approach, NIS : straight-forward approach
- Differences in schedulability are smaller than 10%
- Large reduction in hyper-period, small sacrifice on schedulability

Experimental Results (Scalability)



- Synthesis is done within scalable time

Conclusions

- Partitioned and overhead-aware scheduling **framework** for mixed-criticality systems
- Synthesis schedule table for partitions with **reduced schedule length** and **preserved system schedulability**
- **Re-scheduling algorithm** to reduce runtime overhead between partitions