Bounding and Shaping the Demand of Mixed-Criticality Sporadic Tasks

Pontus Ekberg & Wang Yi

Uppsala University, Sweden

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**Mixed-criticality sporadic tasks**

Task $\tau_i$

- $C_i(\text{LO})$: WCET at low-criticality
- $C_i(\text{HI})$: WCET at high-criticality
- $D_i$: Relative deadline
- $T_i$: Period
- $L_i$: Criticality (LO or HI)

$(C_i(\text{LO}) \leq C_i(\text{HI}))$
Mixed-criticality sporadic tasks

$\tau_1 (L_1 = \text{LO})$:  

$\tau_2 (L_2 = \text{HI})$:  

$\tau_3 (L_3 = \text{HI})$:  

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Mixed-criticality sporadic tasks

\( \tau_1 (L_1 = \text{LO}) : \) 

\( \tau_2 (L_2 = \text{HI}) : \) 

\( \tau_3 (L_3 = \text{HI}) : \)
Mixed-criticality sporadic tasks

\( \tau_1 (L_1 = \text{LO}): \)

\( \tau_2 (L_2 = \text{HI}): \)

\( \tau_3 (L_3 = \text{HI}): \)
A task set $\tau$ is schedulable if

$$\forall \ell \geq 0 : \sum_{\tau_i \in \tau} \text{dbf}(\tau_i, \ell) \leq \text{sbf}(\ell).$$
A task set $\tau$ is schedulable if

$$\forall \ell \geq 0 : \sum_{\tau_i \in \tau} \text{dbf}(\tau_i, \ell) \leq \text{sbf}(\ell).$$
Schedulability analysis

A task set $\tau$ is schedulable if both A and B hold:

**A**: \[ \forall \ell \geq 0 : \sum_{\tau_i \in \tau} \text{dbf}_{\text{LO}}(\tau_i, \ell) \leq \text{sbf}_{\text{LO}}(\ell) \]

**B**: \[ \forall \ell \geq 0 : \sum_{\tau_i \in \text{HI}(\tau)} \text{dbf}_{\text{HI}}(\tau_i, \ell) \leq \text{sbf}_{\text{HI}}(\ell) \]

Mixed-criticality EDF analysis

Low-criticality mode

High-criticality mode

Time
Each $\tau_i$ behaves exactly like a standard sporadic task with WCET $C_i(\text{LO})$. 

Diagram:

- **Low-criticality mode**
- **High-criticality mode**

**Time**
Demad-bound functions

Use dbfs from Baruah et al., 1990!

Each $\tau_i$ behaves exactly like a standard sporadic task with WCET $C_i(\text{LO})$.

Time

Low-criticality mode

High-criticality mode
Demand-bound functions

Each $\tau_i$ behaves similar to a standard sporadic task with WCET $C_i(\text{HI})$.

Use dbfs from Baruah et al., 1990!

Each $\tau_i$ behaves exactly like a standard sporadic task with WCET $C_i(\text{LO})$.

Low-criticality mode

High-criticality mode

Time
Each $\tau_i$ behaves similar to a standard sporadic task with WCET $C_i(\text{HI})$.

Use dbfs from Baruah et al., 1990!

Each $\tau_i$ behaves exactly like a standard sporadic task with WCET $C_i(\text{LO})$.

Half-finished jobs are carried over to high-criticality mode.
**Half-finished** jobs are carried over to high-criticality mode.

Restricting to the interesting cases

To show $A \land B$, we show $A \land (A \rightarrow B)$. 
**Half-finished** jobs are carried over to **high**-criticality mode.

Restricting to the interesting cases

To show $A \land B$, we show $A \land (A \rightarrow B)$. 
Switch to **high-criticality mode**

- Release of $\tau_i$
- Absolute deadline $t + D_i$

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**Carry-over jobs**
**CARRY-OVER JOBS**

Switch to high-criticality mode

Remaining scheduling window

Release of $\tau_i$

Absolute deadline

$t + D_i$
**Carry-over jobs**

Switch to high-criticality mode

Remaining scheduling window

Release of $\tau_i$

Absolute deadline

$t$

$t + D_i$
**CARRY-OVER JOBS**

Switch to **high-criticality mode**

**Remaining scheduling window** $C_i^{(HI)} - C_i^{(LO)}$

Release of $\tau_i$

$T_i$

$T_i + D_i$

Absolute deadline

Time
Adjusting the demand of carry-over jobs

Release of $\tau_i$ at time $t$

Deadlines in low- and high-criticality mode at $t + D_{i(LO)}$ and $t + D_{i(HI)}$
Adjusting the Demand of Carry-over Jobs

Switch to **high**-criticality mode

Release of $\tau_i$

Deadlines in **low-** and **high**-criticality mode

$t + D_{i(\text{lo})}$

$t + D_{i(\text{hi})}$

Switch to **high**-criticality mode
Adjusting the demand of carry-over jobs

Switch to high-criticality mode

Release of \( \tau_i \)

Remainder scheduling window

Deadlines in low- and high-criticality mode

Switch to high-criticality mode

Time

Deadlines in low- and high-criticality mode
Switch to high-criticality mode

Remaining scheduling window

Release of $\tau_i$

Deadlines in low- and high-criticality mode
Adjusting the demand of carry-over jobs

Switch to **high**-criticality mode

Remaining scheduling window

Release of $\tau_i$

Deadlines in **low**- and **high**-criticality mode
Demand-bound functions for high-criticality mode

\[ \text{dbf}_{\text{HI}}(\tau_i, \ell) \]
Demand-bound functions for high-criticality mode

\[ \text{Demand} \]

\[ \text{Time interval length (}\ell\text{)} \]

\[ \text{dbf}_{\text{HI}}(\tau_i, \ell) \]

\[ \text{dbf}_{\text{LO}}(\tau_i, \ell) \]
The effect of the low-criticality relative deadline

Shifting lemma

If $D_i(\text{LO})$ is decreased by $\delta \in \mathbb{Z}$, then

$$
\text{dbf}_\text{LO}(\tau_i, \ell) \leadsto \text{dbf}_\text{LO}(\tau_i, \ell + \delta)
$$

$$
\text{dbf}_\text{HI}(\tau_i, \ell) \leadsto \text{dbf}_\text{HI}(\tau_i, \ell - \delta)
$$
The effect of the low-criticality relative deadline
A task set $\tau$ is schedulable if both A and B hold:

A: $\forall \ell \geq 0: \sum_{\tau_i \in \tau} \text{dbf}_{LO}(\tau_i, \ell) \leq \text{sbf}_{LO}(\ell)$

B: $\forall \ell \geq 0: \sum_{\tau_i \in \text{HI}(\tau)} \text{dbf}_{HI}(\tau_i, \ell) \leq \text{sbf}_{HI}(\ell)$

Mixed-criticality EDF analysis

Is there a valid assignment of $D_{i(LO)}$s to each high-criticality task $\tau_i$ such that both A and B hold?
A task set $\tau$ is schedulable if both $A$ and $B$ hold:

\[ A : \quad \forall \ell \geq 0 : \sum_{\tau_i \in \tau} dbf_{lo}(\tau_i, \ell) \leq sbf_{lo}(\ell) \]

\[ B : \quad \forall \ell \geq 0 : \sum_{\tau_i \in Hi(\tau)} dbf_{hi}(\tau_i, \ell) \leq sbf_{hi}(\ell) \]

Is there a valid assignment of $D_i(LO)$s to each high-criticality task $\tau_i$ such that both $A$ and $B$ hold?
SHAPING THE DEMAND OF THE TASK SET

\[
\sum \text{dbf}_{\text{HI}} \quad \sum \text{dbf}_{\text{LO}}
\]

Demand

\begin{align*}
\text{Time interval length (\(\ell\))} &:
\end{align*}

0 10 20 30 40 50 60 70 80 90 100

Demand

\begin{align*}
\sum \text{dbf}_{\text{HI}} \quad \sum \text{dbf}_{\text{LO}}
\end{align*}

\begin{align*}
\text{Time interval length (\(\ell\))} &:
\end{align*}

0 10 20 30 40 50 60 70 80 90 100
SHAPING THE DEMAND OF THE TASK SET

\[
\sum \text{dbf}_{HI} \quad \sum \text{dbf}_{LO}
\]

Time interval length ($\ell$)
SHAPING THE DEMAND OF THE TASK SET
**Shaping the Demand of the Task Set**

![Graph showing the demand shaping of mixed-criticality sporadic tasks](image)

- **∑ dbf_{HI}**
- **∑ dbf_{LO}**

**Equation:**

\[
\sum dbf_{HI} \quad \sum dbf_{LO}
\]
**SHAPING THE DEMAND OF THE TASK SET**

![Graph showing the demand of high and low priority tasks over time intervals](image)

- Red line: $\sum \text{dbf}_{HI}$
- Blue line: $\sum \text{dbf}_{LO}$

**Demand** vs **Time interval length ($\ell$)**
SHAPING THE DEMAND OF THE TASK SET

\[ \sum \text{dbf}_{HI} \]

\[ \sum \text{dbf}_{LO} \]
SHAPING THE DEMAND OF THE TASK SET
SHAPING THE DEMAND OF THE TASK SET
Evaluation

![Graph showing acceptance ratio vs average utilization for different algorithms including Our, OCBP-prio, AMC-max, Vestal, EDF-VD, OCBP-load, and Naive.](image)

- **Our**: High acceptance ratio across average utilization, indicating efficient task scheduling.
- **OCBP-prio**: Moderate acceptance ratio, lower than Our.
- **AMC-max**: Lower acceptance ratio compared to Our and OCBP-prio.
- **Vestal**: Lower acceptance ratio compared to Our, OCBP-prio, and AMC-max.
- **EDF-VD**: Lowest acceptance ratio, showing the least efficiency among the algorithms.
- **OCBP-load**: Intermediate acceptance ratio, between Vestal and EDF-VD.
- **Naive**: Lower acceptance ratio than Vestal and EDF-VD.

The graph illustrates the comparison of acceptance ratios for different algorithms across various average utilization levels.
Evaluation

![Graph showing weighted acceptance ratio (%) vs. probability of high-criticality for different algorithms.]

- **Our**
- **OCBP-prio**
- **AMC-max**
- **Vestal**
- **EDF-VD**
- **OCBP-load**
- **Naive**
Evaluation

![Graph showing weighted acceptance ratio (%) against maximum ratio of high- to low-criticality WCET. The graph compares different priority schemes: Our, OCBP-prio, AMC-max, Vestal, EDF-VD, OCBP-load, Naive. The graph indicates that Our scheme performs the best, followed by OCBP-prio and AMC-max, while Naive performs the worst.]

Weighted acceptance ratio (%)

Maximum ratio of high- to low-criticality WCET
Conclusions

1. Demand-bound functions are useful *also for mixed-criticality systems.*

2. The particulars of mixed-criticality demand-bound functions allow us to easily *shape the demand* to the supply of the platform.

3. Experiments indicate that this approach *performs well.*
Questions?