An engineering approach to synchronization based on overrun for compositional real-time systems

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Outline

• Introduction
• Real-Time Scheduling Model
• Related Work
• Improved Analysis
• Evaluation
• Implementation
• Conclusion
Integration problem

• Increasing complexity in systems:
  – High number of nodes,
  – Trend: Fewer and more powerful nodes.

• Isolation:
  – Temporal isolation (processor),
  – Spatial isolation (memory).

• Development and analysis:
  – Independent analysis of applications,
  – Application specific scheduling algorithms,
  – Compositional systems.

• Applications may share logical resources.
A Solution: Hierarchical Scheduling

- subsystem: server, set of tasks and (local) scheduler
- server: a budget allocated each period
Global resource sharing problem

- Applications may share logical resources,
- Budget depletion during a critical section can lead to excessive blocking times.

A SRP-based solutions for fixed-priority scheduling:

- HSRP: React upon budget depletion while a resource is locked; i.e. allow to use an overrun budget
  - with payback: the consumed overrun budget is subtracted from the next budget provisioning,
  - no payback: no penalty for overrun consumption.
Context and Motivation

- Two-level HSF with FPPS based on
  - Periodic resource model,
  - Overrun without payback.

- Motivation:
  - Analysis for large overruns,
  - Successful deployment of HSF techniques,
  - *Tight* and *simpler* analysis.
Real-Time Scheduling Model

System Model: A system $Sys$ contains:
- a single processor
- a set $S$ of $N$ subsystems ($S_1, S_2, \ldots, S_N$)
- a set $R$ of $M$ global resources ($R_1, R_2, \ldots, R_M$)
- a set $B$ of $N$ budgets

Subsystem Model: A subsystem $S_s$:
- is specified by $<P_s, Q_s, X_s>$
- contains a set $T_s$ of $n_s$ periodic tasks

Task Model: A task $\tau_{si}$:
- is specified by $<T_{si}, C_{si}, D_{si}, C_{si}>$ where $C_{si} \leq D_{si} \leq T_{si}$
Related Work

• Original schedulability analysis (OSA) is found pessimistic,

\[ x = B_s + (Q_s + X_s) + \sum_{t<s} \left\lfloor \frac{x}{P_t} \right\rfloor (Q_t + X_t), \]

• It can be shown as,

\[ WR_s^P(B_s + Q_s + X_s) \]

• For global schedulability,

\[ \forall 1 \leq s \leq N \quad WR_s \leq P_s. \]
Related Work

• Initially improved schedulability analysis (IISA):
  – OSA is improved
    • Limited preemption during overrun budget,
    • Blocking starts before overrun.

• A further improvement suggested:
  • The deadline only holds for normal budget.
Related Work

- IISA reduces pessimism in both local and global schedulability,
Related Work

- IISA reduces pessimism in both local and global schedulability,

\[ S_s \]

- Tighter but complex analysis,
- Analysis should be performed for each global shared resource.
New Analysis (NSA)

- The deadline (period) only holds for normal budget.
New Analysis

• The worst-case response time of the normal budget of a subsystem,

\[ WR_s^Q = \max_{0 \leq k < wI_s} WR_{sk}^Q, \]

• where,

\[ wI_s = \left\lceil \frac{WL_s}{P_s} \right\rceil, \]

• and

\[ WR_{sk}^Q = WR_s^P (B_s + (k + 1)Q_s + kX_s) - kP_s. \]
New Analysis

Subsystem characteristics of $S_{Y1}$.

<table>
<thead>
<tr>
<th>subsystem</th>
<th>$P_s$</th>
<th>$Q_s + X_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>$S_2$</td>
<td>8</td>
<td>$Q_2 + X_2$</td>
</tr>
<tr>
<td>$S_3$</td>
<td>10</td>
<td>$1 + X_3$</td>
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New Analysis

**Subsystem characteristics of $S_{ys1}$.**

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![Diagram](image)
New Analysis

• Our new analysis (NSA) is considerably simpler compared to IISA:
  – It does not address the preemptions of the overrun budget,
  – No need to determine schedulability for each global resource for the case of multiple resources.

• NSA is less pessimistic globally,

• IISA local analysis no longer applies to NSA.
Evaluation

- Incomparable overall schedulability between IISA and NSA.
Implementation

- Implemented in OSEK-compliant RTOS, μC/OS-II.
  - Time complexity: Additional overhead due to budget-timer manipulation

<table>
<thead>
<tr>
<th>Event</th>
<th>SRP</th>
<th>Overrun</th>
<th>Improved overrun</th>
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<tr>
<td></td>
<td>BC</td>
<td>WC</td>
<td>BC</td>
</tr>
<tr>
<td>Lock</td>
<td>124</td>
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<td>196</td>
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<tr>
<td>Unlock</td>
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<td>106</td>
<td>196</td>
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<tr>
<td>Replenish</td>
<td>-</td>
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</tr>
</tbody>
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Best-case (BC) and worst-case (WC) execution times for overrun measured in number of processor instructions.
Conclusion

- Considerably simplified analysis:
  - Particularly useful for dynamic systems.

- Does not significantly affect the overall schedulability,

- A preferable engineering approach.
Questions

Thanks for attention…