Conditionally Optimal Task Parallelization for Global EDF on Multi-core Systems

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Youngeun Cho, Do Hyung Kim, Daechul Park,
Seung Su Lee, Chang-Gun Lee

Seoul National University
Overview

- Complex computations and massive data processing

Overview (2)

- Parallelization freedom
  - multiple runtime versions

Our Contribution

- Optimal algorithm
- Polynomial time complexity
- Significant schedulability improvement

Measured thread execution times of a lane tracking program
Motivation

- Example – Autonomous Driving
  - \( \tau_1 \): Sensor read/process
  - \( \tau_2 \): Lane Tracking
  - \( \tau_3 \): Object detection/labeling
  - \( \tau_4 \): Steering actuation
    …

- Parallelization Options
  - Different multi-thread versions by OpenCL/OpenMP

Our Problem

- $n$ sporadic tasks with parallelization freedom, $m$ CPU cores

→ Assign optimal parallelization option to each task to maximize schedulability
Solution Approach

- Monotonic increasing property of both tolerance and interference

- Optimal parallelization option assignment

- Property 1

- Property 2
Interference-Based Schedulability Analysis

- Execution of a task of interest:

- … can be interfered by other tasks:

- Scheduling Condition†:

\[
I_{\tau_k}(D_k) = \frac{1}{m} \sum_{\tau_i \neq \tau_k} I_{\tau_i, \tau_k}(D_k) \leq D_k - C_k
\]

† M. Bertogna, M. Cirinei, and G. Lipari, “Improved schedulability analysis of edf on multiprocessor platforms,” ECRTS, 2005
Worst-Case Workload in G-EDF

- Interference is bound by total workload†:

\[
\frac{1}{m} \sum_{\tau_i \neq \tau_k} I_{\tau_i, \tau_k}(D_k) \leq \frac{1}{m} \sum_{\tau_i \neq \tau_k} \left( \min(C_i, D_k \mod T_i) + \left\lfloor \frac{D_k}{T_i} \right\rfloor C_i \right) \leq D_k - C_k
\]

† M. Bertogna, M. Cirinei, and G. Lipari, “Improved schedulability analysis of edf on multiprocessor platforms,” ECRTS, 2005
Property 1

- Monotonic increasing property of tolerance of $\tau_k$. 

- \[\begin{align*}
\text{core 1} & \quad \tau_k^1(1) \quad \tau_k^1(2) \\
\text{core 2} & \quad \tau_k^2(2)
\end{align*}\]

- \[\begin{align*}
time & \quad D_k \\
tolerance & \quad D_k - e_k^1(1) \\
\text{interference from other tasks} & \quad D_k - e_k^1(2)
\end{align*}\]

- Increase of parallelization option

- Increase of room for accommodating interference
Property 2

- Monotonic increasing property of interference given by $\tau_k$ to another task $\tau_i$.

\[
\begin{align*}
\min(e_k^1(1), D_i \mod T_i) + \min(e_k^2(2), D_i \mod T_i) & \leq \left\lfloor \frac{D_i}{T_k} \right\rfloor e_k^1(1) + \left\lfloor \frac{D_i}{T_k} \right\rfloor e_k^2(2)
\end{align*}
\]
Optimal Parallelization Option Assignment

- Begin from the lowest parallel option.

- For all tasks, iteratively,
  1. Calculate the interference from other tasks.
  2. Raise parallelization option to the ‘barely tolerable’ option.

- Initial:

  \[
  \text{tolerance of each option} \\
  \text{(monotonically increases – Property 1)}
  \]

  \[
  \begin{align*}
  \tau_1 & \quad \tau_1(1) & \tau_1(2) & \tau_1(3) & \tau_1(4) \\
  \tau_2 & \quad \tau_2(1) & \tau_2(2) & \tau_2(3) & \tau_2(4) \\
  \tau_3 & \quad \tau_3(1) & \tau_3(2) & \tau_3(3) & \tau_3(4)
  \end{align*}
  \]

  \[\text{Begin from the lowest option} \]

  \[\text{received interference} \]
Optimal Parallelization Option Assignment (2)

- First iteration:

  Calculate received interference (monotonically increases – Property 2)

  Select the barely tolerable option
Optimal Parallelization Option Assignment (3)

- Second iteration:
Optimal Parallelization Option Assignment (4)

- Termination – schedulable:

- Termination – not schedulable:
Simulation Results

- Normalized task set schedulability vs. task set utilization ($\sum \frac{C_i}{T_i}$).
- $10^6$ synthesized tasks scheduled on $m = 4$ CPU cores.

(a) Base  
(b) High parallelization overhead  
(c) Tight deadline
Implementation Results

- Measured response times ($\mu$s) of autonomous driving tasks on 4 CPU cores.
- ($\tau_1$: sensor, $\tau_2$: lane track, $\tau_3$: object detection, $\tau_4$: motor).

(a) Single  (b) Max  (c) Random  (d) Ours
Conclusion

- Optimal parallelization option assignment for global EDF
- Polynomial time complexity
- Significant schedulability improvement

Future work: Extension towards…
- Different state-of-the-art schedulability analyses
- Multi-segment/DAG task model
Thank You