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

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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
  
  ... Parallelize

- 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

```
\tau_k
\tau_k(1) \quad \tau_k^1(1) \quad e_k(1)
\tau_k(2) \quad \tau_k^1(2) \quad e_k(2)
\vdots
\tau_k(4) \quad \tau_k^1(4) \quad e_k(4)
\vdots
\tau_k^4(4) \quad e_k^4(4)
```
Solution Approach

- Monotonic increasing property of both tolerance and interference

  Property 1

  \( \text{Tolerance} \)

  \( \text{Parallelization Option} \)

  Property 2

  \( \text{Interference} \)

  \( \text{Parallelization Option} \)

- Optimal parallelization option assignment

  \( \tau_1 \)

  \( \tau_2 \)

  \( \tau_3 \)

  ‘Barely tolerable’ Parallelization Option
Interference-Based Schedulability Analysis

- Execution of a task of interest:

- … can be interfered by other tasks:

- Scheduling Condition†:

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

\[\text{sum of interference from other tasks} \quad \text{task’s tolerance}\]

† 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‡:

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

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

- Monotonic increasing property of tolerance

\[ \tau_k^1(1) \]

\[ \tau_k^1(2) \]

\[ \tau_k^2(2) \]

\[ D_k \]

\[ D_k - e_k^1(1) \]

\[ D_k - e_k^1(2) \]

interference from other tasks

tolerance

increase of parallelization option

increase of room for accommodating interference

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Property 2

- Monotonic increasing property of interference

increase of parallelization option

\[ \tau_k^1(1) \]

\[ \tau_k^1(2) \]

\[ \tau_k^2(2) \]

more carry - in interference to \( \tau_i \)

more body job interference to \( \tau_i \)

\[ \min(e_k^1(1), D_i \mod T_i) \]

\[ \frac{D_i}{T_k} e_k^1(1) \]

\[ \min(e_k^1(2), D_i \mod T_i) \]

\[ \min(e_k^2(2), D_i \mod T_i) \]

\[ \frac{D_i}{T_k} e_k^1(2) + \frac{D_i}{T_k} e_k^2(2) \]

\[ D_i \]

time

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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:

```plaintext
Initial:
- Begin from the lowest parallel option.
  1. Calculate the interference from other tasks.
  2. Raise parallelization option to the ‘barely tolerable’ option.

Graph:
- Begin from the lowest option.
- Tolerance of each option (monotonically increases – Property 1)

Diagram:
- Venn diagrams indicating
  - τ1
  - τ2
  - τ3
- τ1(1), τ1(2), τ1(3), τ1(4)
- τ2(1), τ2(2), τ2(3), τ2(4)
- τ3(1), τ3(2), τ3(3), τ3(4)
- Received interference
```
Optimal Parallelization Option Assignment (2)

- First iteration:

\[ \tau_1 \]
\[ \tau_2 \]
\[ \tau_3 \]

Calculate received interference
(monotonically increases – Property 2

Select the barely tolerable option

\[ \tau_1 \]
\[ \tau_2 \]
\[ \tau_3 \]
Optimal Parallelization Option Assignment (3)

- Second iteration:

\[ \tau_1, \tau_2, \tau_3 \]

\[ \tau_1(1), \tau_1(2), \tau_1(3), \tau_1(4) \]

\[ \tau_2(1), \tau_2(2), \tau_2(3), \tau_2(4) \]

\[ \tau_3(1), \tau_3(2), \tau_3(3), \tau_3(4) \]

received interference

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Optimal Parallelization Option Assignment (4)

- **Termination – schedulable:**

  All tasks received smaller interference than their tolerance

- **Termination – not schedulable:**

  Received larger interference than its maximum tolerance
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 of autonomous driving tasks (\(ms\)).
- \((\tau_1: \text{sensor}, \tau_2: \text{lane track}, \tau_3: \text{object detection}, \tau_4: \text{motor})\).

(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