WCET Analysis for Preemptive Scheduling

Sebastian Altmeyer[1] Gernot Gebhard[2]

[1]Saarland University

[2]AbsInt GmbH

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Overview

1. Preemptive Scheduling
   - Targeted System
   - Preemptive vs. Non-preemptive Scheduling
2. Influence Preemption Costs
   - Cache Set Classification
   - Cost Function
   - Optimization
3. WCET Analysis for Preemptive Scheduling

Targeted System and Notation

- set of n tasks $\tau_1 \ldots \tau_n$
- scheduled preemptively
- combined data/instruction cache
- k-way LRU or direct-mapped caches
  (for the sake of simplicity)

- task-to-task relation: $\tau_i \vdash \tau_j \Leftrightarrow$ task τ_i can preempt task τ_j
  (for instance, given by priorities, data dependencies, etc.)
- set of data fragments $D_i = \{d_{i,1}, \ldots, d_{i,l}\}$ for each task
  (continuous data block such as arrays, instruction block, etc.)

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Preemptive vs. Non-preemptive Scheduling

Non-preemptive scheduling

- tasks are running to completion
- (nearly) no inter-task cache-interference
- timing analysis feasible

Preemptive scheduling

- tasks may be preempted
- strong inter-task interference
- timing analysis much more complex (due to cache interference)

- some task-sets only schedulable using preemptive scheduling

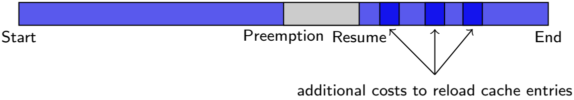
Preemptive vs. Non-preemptive Scheduling - Example

Non-preemptive scheduling:

- unknown cache states only at the beginning
- tasks are running to completion

Preemptive scheduling:

- possible preemptions at unknown points
- unknown cache states at the beginning and after preemption
- preempting task changes cache state of preempted task

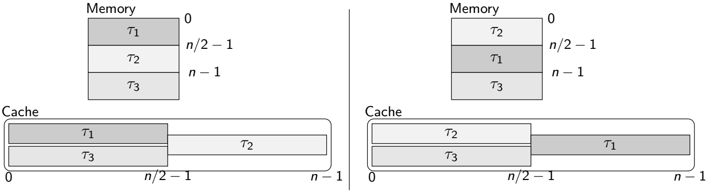


Influence of the Memory Layout

Evicted cache-entries determined by the memory layout
(i.e. the arrangement of code and data in the memory)

Example:

- direct mapped cache of size n
- 3 tasks (τ_1, τ_2, τ_3) of size $n/2$
- τ_1 can preempt the other two $(\tau_1 \vdash \tau_2$ and $\tau_1 \vdash \tau_3)$



Layout 1
bad performance

Layout 2
good performance

Cache-Set Classification

all data fragments $d_{i,j}$ on all cache sets s are classified as follows

$$cl(d_{i,j}, s) =$$

persistent: $d_{i,j}$ does not occupy s or at most k data fragments of tasks that can preempt task τ_i occupy cache set s
$\Rightarrow$ even if task τ_i is preempted, $d_{i,j}$ on cache set s still cached

endangered: $d_{i,j}$ occupies s and at least $k+1$ data fragments of tasks that can preempt task τ_i occupy cache set s
$\Rightarrow$ if task τ_i is preempted, $d_{i,j}$ on cache set s could be evicted

Changing the Memory Layout

Different memory layouts lead to different preemption costs.
We need

- metric to compare different memory layouts,
- optimization method.

Metric on Memory Layouts

costs of memory layout C_L determined by all endangered data fragments over all cache sets

$$C_L = \sum_{d_{i,j}} \sum_{cache\ set\ s} W(d_{i,j}) \cdot confl(d_{i,j}, s)$$

with

$$confl(d_{i,j}, s) = \begin{cases} 1 & \text{if } cl(d_{i,j}, s) = \text{ endangered} \\ 0 & \text{if } cl(d_{i,j}, s) = \text{ persistent} \end{cases}$$

- weight function W used to increase precision

Metric on Memory Layouts (cont'd)

Data fragments do not contribute equally to the preemption costs (for instance, straight-line code vs. loops)

- weight function only approximates preemption costs
- weight data fragments according to their uses
- evaluation and testing of different weight function still future work

Optimization

- restriction to hole-free layouts
  $\Rightarrow$ layout represented as a permutation
- finding optimal layout (still) NP-complete
  $\Rightarrow$ find local instead of global optimum

Hill-climbing:

1. start with random layout L
2. search for a better layout L' in the set of neighbors of L
3. if L' exists, goto 1 with $L := L'$
4. restart searching with next best layout at most P times

- step 4 is used to jump over local hills
- parameter P determines how often

WCET Analysis for Preemptive Scheduling

- cache-set classification is new input to the analysis
- between cache analysis and low-level analysis

WCET Analysis for Preemptive Scheduling (cont'd)

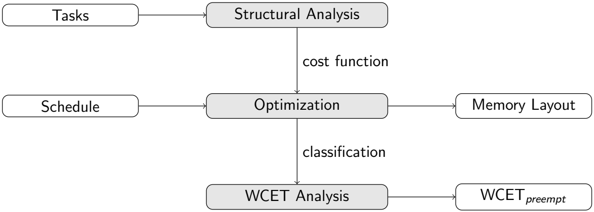
In case a cache-entry is classified as:

persistent analysis behaves as usual (even in case of preemption, cache-entry still valid)

endangered depends on the cache-analysis:

- **hit:** cache-hit or cache-miss
- **miss:** surely a cache-miss
- **unknown:** cache-hit or cache-miss

Structure of the Approach



Conclusions...

- optimization and analysis of the memory layout
- classification into endangered and persistent cache-entries
- straight-forward extension of the WCET analysis

... and Future Work

- implement and evaluate the approach
- evaluate (and improve) metric on the memory layouts
- extend by information about preemption points

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Thanks for your attention!