Improving the Precision of Approximations in WCET Analysis for Multi-Core Processors

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Introduction

WCET Analysis

- Timing-critical applications
  - Strict deadlines on the response times
- WCET bound of a program
  - Upper bound on the execution times
  - Depends on behavior at microarch. level
  - Obtained by **WCET analysis**
- Modern processors are complex
  - Designed for average-case performance
  - Too many behaviors at microarch. level
  - Exhaustive simulation not possible
- Need for **approximation**
  - Hide some microarchitectural details

Multi-Core Processors

- Resources shared between the cores
  - Data buses
  - Caches
- Advantages
  - Reduced weight
  - Reduced energy consumption
  - Reduced production costs
- Shared resource **interference**
  - Performance can drop
- Challenge for WCET analysis
  - Consider all access interleavings
- Need for **approximation**

Existing Approaches

- Limited to particular...
  - ...classes of processors
  - ...ways of approximation
- Formalisms and algorithms differ
- Yet, they follow a **common methodology**
  - Coarse approximation as baseline
  - Exclude some spurious behavior

Our Contribution

- A **meta approach**
  - Formalizes common methodology

Meta Approach

- For simplicity
  - One program per core
  - Each program is run at most once
- Concrete execution behavior of given system

$$\mathit{Traces} \subseteq \mathit{Universe}$$

- WCET of program on core C

$$\mathit{WCET}_C = \max_{t \in \mathit{Traces}} \mathit{et}_C(t)$$

- Approximation by abstract traces
  - Abstract model $(\widehat{\mathit{Traces}}, \gamma_{\mathit{trace}})$
  - Overapproximates concrete behavior

$$\bigcup_{\hat{t} \in \widehat{\mathit{Traces}}} \gamma_{\mathit{trace}}(\hat{t}) \supseteq \mathit{Traces}$$

  - Provides WCET bound

$$\max_{\hat{t} \in \widehat{\mathit{Traces}}} {}^{\mathit{UB}}\mathit{et}_C(\hat{t}) \geq \mathit{WCET}_C$$

- Infeasible abstract traces

$$\widehat{\mathit{Infeas}} = \{\hat{t} \mid \hat{t} \in \widehat{\mathit{Traces}} \wedge \gamma_{\mathit{trace}}(\hat{t}) \cap \mathit{Traces} = \emptyset\}$$

  - Only describe spurious behavior
  - May dominate WCET bound calculation
- System properties

$$\mathit{Prop} = \{\boldsymbol{P}_1, \ldots, \boldsymbol{P}_{\#\mathit{Prop}}\}$$

  - Hold for each system behavior

$$\forall t \in \mathit{Traces} : \forall \boldsymbol{P}_i \in \mathit{Prop} : \boldsymbol{P}_i(t)$$

- Lifting properties to abstract traces
  - Soundness criterion for lifted version $\widehat{\boldsymbol{P}_i}$ of $\boldsymbol{P}_i$

$$[\, \exists t \in \gamma_{\mathit{trace}}(\hat{t}) : \boldsymbol{P}_i(t) \,] \Rightarrow \widehat{\boldsymbol{P}_i}(\hat{t})$$

  - Detecting infeasible abstract trace $\hat{t}$

$$[\, \exists \boldsymbol{P}_i \in \mathit{Prop} : \neg \widehat{\boldsymbol{P}_i}(\hat{t}) \,] \Rightarrow \hat{t} \in \widehat{\mathit{Infeas}}$$

- Remove some infeasible abstract traces

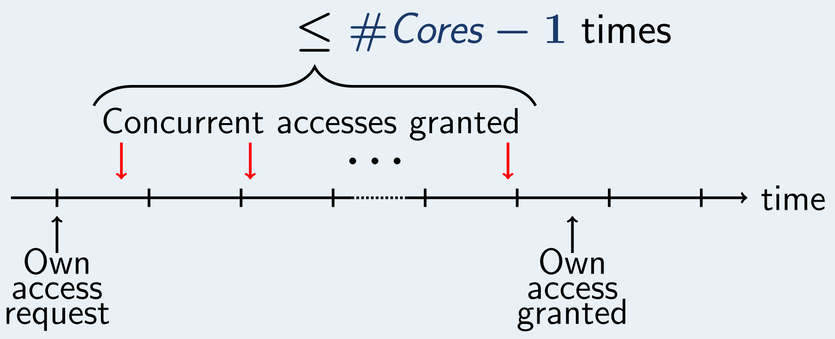
$$\widehat{\mathit{LessTraces}} = \{\hat{t} \mid \hat{t} \in \widehat{\mathit{Traces}} \wedge \forall \boldsymbol{P}_i \in \mathit{Prop} : \widehat{\boldsymbol{P}_i}(\hat{t})\}$$

- Potentially **improved** WCET bound

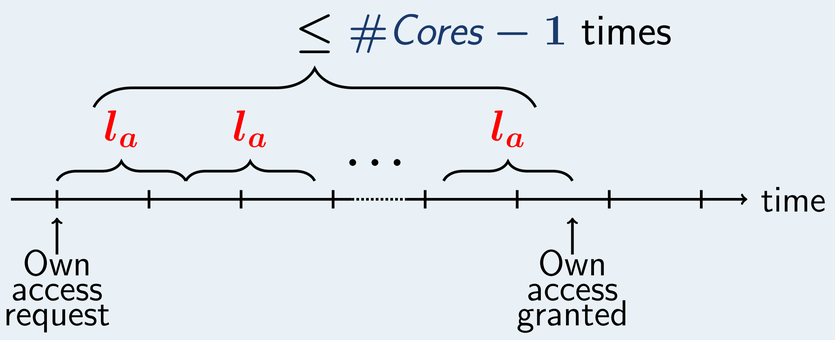
$$\max_{\hat{t} \in \widehat{\mathit{Traces}}} {}^{\mathit{UB}}\mathit{et}_C(\hat{t}) \geq \max_{\hat{t} \in \widehat{\mathit{LessTraces}}} {}^{\mathit{UB}}\mathit{et}_C(\hat{t}) \geq \mathit{WCET}_C$$

Property Lifting Example

- Round-robin bus arbitration
  - Before a requested bus access is granted, at most one bus access per concurrent core is granted.



- Blocked cycles for a single bus access
  - No access takes longer than l_a cycles



- A round-robin property
  - Shall hold for all $t \in \mathit{Traces}$

$$\boldsymbol{P}_{rr}(t) \Leftrightarrow [\, \#\mathit{blockedCycles}_C(t) \leq \#\mathit{accesses}_C(t) \cdot (\#\mathit{Cores} - 1) \cdot l_a \,]$$

- Lifting $\boldsymbol{P}_{rr}$ to abstract traces

$$\begin{aligned}
&\exists t \in \gamma_{\mathit{trace}}(\hat{t}) : \boldsymbol{P}_{rr}(t) \\
&\Leftrightarrow \exists t \in \gamma_{\mathit{trace}}(\hat{t}) : \\
&\quad \#\mathit{blockedCycles}_C(t) \leq \#\mathit{accesses}_C(t) \cdot (\#\mathit{Cores} - 1) \cdot l_a \\
&\Rightarrow {}^{\mathit{LB}}\#\mathit{blockedCycles}_C(\hat{t}) \leq {}^{\mathit{UB}}\#\mathit{accesses}_C(\hat{t}) \cdot (\#\mathit{Cores} - 1) \cdot l_a \\
&\Leftrightarrow : \widehat{\boldsymbol{P}_{rr}}(\hat{t})
\end{aligned}$$

Acknowledgement

http://www.uni-saarland.de
AVACS
http://www.avacs.org