Predicting WCET Trends in Long-lived Real-time Applications

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Background | Motivation

• Worst-case execution time (WCET)
  o is important in timing analysis (DO-178 and ISO26262)
  o static and measurement-based
  o pWCET

Background | Motivation

• Current understanding of WCETs:
  o A theoretical boundary exists, if designed and programmed with constrained models.
  o Known as a static, upper-bound value of execution times

Issues | Motivation

• Data accessing time ↑
  o relevant data growth
  o hard disk fault/fragmented
Issues | Motivation

- Hardware ageing: computer systems age just like humans
  - CPU *transistor ageing*: fundamental speed ↓
  - Thermal performance decreased: lacking maintenance
Issues | Motivation

• Emerging systems
  o Self-adaptive systems: increased software complexity
  o Machine that learns and evolves, e.g., autonomous robots
Issues (continue) | Motivation

• Contribute **negative** and **non-deterministic** effects on WCETs.
• Subtle in a short period, but noticeable in long-term.
• Traditional WCET analysis could solve this by giving a very **pessimistic** boundary.

• A new perspective on WCET: a **dynamic view** of WCET (dWCET), as an extension of traditional WCET analysis.
dWCET | Motivation

• Run-time modelling of WCET.
• Enhanced Parametric WCET: \( WCET = f(t, \text{ system changes}, \text{ mode}, \text{ state}, \text{ input}, \ldots) \).

• Pro 1: Early detection of potential timing errors, and achieve graceful degradation.
• Pro 2: Utilize resources better (with feedback scheduling).
Adaptive Feedback Scheduling

- A variation of Feedback Control Scheduling (FBS)
- Adaptive
  - ability to handle unexpected events
  - understanding of the system increases

In Practice | A-FBS

• A-FBS uses with an adaptive control system:
Advantages | A-FBS

- Explicitly monitoring and modelling the system.
- Handling uncertainties in run-time executions.
- Increase system resilience: automated the process of (proactive) fault tolerance.
- Dynamic resource allocation: run-time optimization of scheduling.
What’s Next?

• The activation of system changes/degrades will be propagated in the system and reflects on WCETs.

• There are many ways we can model dynamics in WCETs.

• In this initial study, we consider one of these: trends in WCET.

• Use a linear model to describe trend.
Many techniques in the literature:
  o AR / ARMAX
  o Regression Analysis
  o Non-parametric
  o EVT
  o Neural Network
  o Decision Tree Regression
  o …

but not all of them fit our case:
  o data points are execution times
  o distribution is not known
  o few prior knowledge
  o need a long-term prediction
Methods | Trend Identification

- Non-parametric Methods
  - TSE: Theil-Sen Estimator
- Regression Analysis
  - OLS: Ordinary least-squares regression (OLS-regression)
- Extreme-value Theory
  - EVD: Generalized Extreme-value distribution
- Machine Learning Methods
  - SVR: Support Vector Regression

- These methods have never been used to analysis trends in WCETs. How to evaluate?

Dataset | Evaluation

- Use synthetic data to make it evaluable.
- One observation represents a high watermark of run-time executions.
- Markov model with multiple dominated paths.
- An increasing trend only in the worst-case path.

<table>
<thead>
<tr>
<th>Group</th>
<th>Subgroup</th>
<th>Dataset Index</th>
<th>Data Size</th>
<th>Increasing Trend</th>
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<td>A1</td>
<td>1 - 10</td>
<td>5,000</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>B1</td>
<td>11 - 20</td>
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<td>B2</td>
<td>21 - 30</td>
<td>2,500</td>
<td>2%</td>
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<tr>
<td></td>
<td>B3</td>
<td>31 - 40</td>
<td>1,667</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>B4</td>
<td>41 - 50</td>
<td>1,250</td>
<td>4%</td>
</tr>
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</table>
Evaluation

• The Evaluation Framework
Evaluation

• The Evaluation Framework
Evaluation

• The Evaluation Framework
Evaluation

• The Evaluation Framework
Evaluation

• The Evaluation Framework
Evaluation

• The Evaluation Framework
Evaluation

• The Evaluation Framework
Evaluation

- The Evaluation Framework
Pre-processing | Evaluation

- Evaluated with raw, block maxima and r-largest
- Mean (absolute) error of trend magnitude
Pre-processing | Evaluation

- Evaluated with raw, block maxima and r-largest.
- Mean (absolute) error of trend magnitude.
Dataset Sensitivity | Evaluation

- All methods use block maxima
- Subgroups are separated by dashed lines
## Trend Error | Evaluation

- Evaluate Trend error (= actual k - predicted k):

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Median</th>
<th>Mean</th>
<th>Maximum</th>
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<tr>
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<td>30.20</td>
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Normalized Performance | Evaluation

Valid Estimations

Invalid Estimations

True Positives

False Positives

False Negatives

k = 0  k = 1%  k = 2%  k = 3%  k = 4%

IDP-MAX  LR-MAX  TSE-MAX  SVR-MAX  EVD-MAX
Normalized Performance | Evaluation

Valid Estimations

Invalid Estimations

True Positives

False Positives

False Negatives

- $k = 0$
- $k = 1$
- $k = 2$
- $k = 3$
- $k = 4$

Legend:
- IDP-MAX
- LR-MAX
- TSE-MAX
- SVR-MAX
- EVD-MAX
Mean Penalties | Evaluation

![Graph showing penalty with FP and FN segments.]

**Table 4.** Mean penalties over all datasets for each prediction method

<table>
<thead>
<tr>
<th></th>
<th>OLR</th>
<th>TSE</th>
<th>SVR</th>
<th>EVD</th>
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<td>42.26</td>
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<td>58.2</td>
<td>53.82</td>
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<td>55.76</td>
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Conclusion

• Introduced dWCET and A-FBS
• Evaluated data pre-processing methods
• Result is sensitive to datasets
• Best two methods: svr-max and tse-max

• Future work
  o More dedicated dataset: e.g., with non-linear trend
  o Other analysis: anomaly detection, pattern recognition
  o Multiple variables + PCA
  o Evaluate with real-world data
Thank You for your attention!

Any Question/Comment?