On the Representatativity of Execution Time Measurements: Studying Dependence and Multi-Mode Tasks

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Real-time Embedded Systems

Real-time computing, or reactive computing, describes hardware and software systems subject to "timing constraints"

Key requirement: **Timing constraints & Predictability**
Real-time Embedded Systems

Worst case properties hard to guarantee: systems and environment complexity
Timing analysis (modeling) and schedulability analysis for predictability

Guarantees [to be provided] on modeling and on analysis

Focus on modeling system parameters:
Static Timing Analysis, Measurement Based Timing Analysis, Static Probabilistic Timing Analysis, Measurement Based Probabilistic Timing Analysis (MBPTA)
A probabilistic real-time system is a realtime system where at least one parameter is described as a random variable.
Probabilistic Timing Analysis

**MBPTA**
- generalizes Worst Case Execution Time (WCET) into the probabilistic WCET (pWCET)
- makes use of the Extreme Value Theory (EVT) for inferring pWCETs
Probabilistic Timing Analysis

![Graph showing execution time profiles and probabilistic WCET](image)

Probabilistic WCET
Measurement Based Probabilistic Timing analysis

The Measurement-Based Probabilistic Timing Analysis (MBPTA) toolchain

Probabilistic WCET estimate on the basis of the Extreme Value Theory (EVT)
Extreme Value Theory

EVT - Predict the unknown from measurements

- **SAFETY has to be built**: worst-case distribution, every possible conditions
- **Limitations**: applicability, input dependent (representativity), multiple conditions, ...
EVT Applicability

Generalizing from iid (independence and identical distribution)

<table>
<thead>
<tr>
<th>iid case $H$</th>
<th>stationary case $H'$ (Generalized EVT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_1$ identically distributed from a distribution</td>
<td>$h'_1$ stationarity</td>
</tr>
<tr>
<td>$h_2$ independent measurements</td>
<td>$h'_{2.1}$ short range dependence</td>
</tr>
<tr>
<td>$h_3$ in the Maximum Domain of Attraction of a Generalized Extreme Value distribution</td>
<td>$h'_{2.2}$ local independence of the peaks</td>
</tr>
<tr>
<td></td>
<td>$h'_3$ experimental distribution of the peaks matches the theoretical distribution</td>
</tr>
</tbody>
</table>

EVT has to be applicable to time randomized and non-time randomized architectures!
EVT Applicability

Generalizing from iid (independence and identical distribution)

- Trace $\mathcal{T}$
  - Stationarity - $h_1'$?
    - Yes
    - Short range Independence - $h_2'$?
      - Yes
      - Select $u$
      - Extremal independence - $h_2''$?
        - Yes
        - PoT are iid
        - Matching - $h_3'$?
          - Reliable
          - $<\text{distance}$
        - Not reliable
        - $\xi \land \alpha_u \land u$
      - Non id/ Not reliable
      - Matching - $h_3'$?
        - Not reliable
      - $\xi \land \alpha_u \land u$
      - $<\text{distance}$
    - No
    - Non id/ Not reliable
- No
  - Time dependent/ Not reliable
  - Matching - $h_3'$?
    - Reliable
    - $<\text{distance}$
    - Not reliable
    - $\xi \land \alpha_u \land u$
    - $<\text{distance}$
MBPTA in Practice

- Formal definition (parameters, ...)
- Applicability (dependence and non identical distribution, ...)
- Unknown distribution/unknown worst-case (guarantees from multiple conditions, ...)
- Representativity of the input (represent the actual behavior)

Representativity: Dependence and Multi-paths
Dependence [1/2]

![Graph showing local dependence (clustering)](image1)

![Graph showing extreme dependence](image2)
Dependence [1/2]

With dependence, rare events are more probables! The pWCET estimate in case of extremal independence $\overline{C}^{ei}$ is greater than or equal to The pWCET estimate in case of independence $\overline{C}^{i}$:

$$\text{icdf}_{\overline{C}^{ei}} \geq \text{icdf}_{\overline{C}^{i}}.$$
Dependence [2/2]

![Graphs showing execution time and probability for different versions (V1 to V5).]
Cover every scenario

\( J = \{j\} \) finite set of possible measurement execution conditions for a system (scenarios)

\[
T_C = \bigcup_{j \in J} T_{Cj}
\]

EVT applies to \( T_C \)

Trace-merging

Merging all the traces \( T_{Cj} \) \( \forall j \in J \) within a unique trace \( T_C \)
Cover every scenario
$J = \{j\}$ finite set of possible measurement execution conditions for a system (scenarios)

Envelope
EVT applied to each measurement condition $j$, $\bar{C}^j$ for all $j \in J$

\[
\bar{C} \overset{\text{def}}{=} \max_{j \in J} \{\bar{C}^j\}
\]

\[
icdf_{\bar{C}}(C) \overset{\text{def}}{=} \max_{j \in J} \{\nicdf_{\bar{C}^j}(C)\}
\]

$\bar{C}$ upper bounds every $j \in J$
Multi-path/Multi-scenario [2/2]
Conclusion and Future Work

Representativeness is important

- Depend measurements have to remain dependent
- Path coverage (not just the worst-case): input have to represent that
Conclusion and Future Work

Ongoing work:

- Contentions within the processor shared resources (coverage/worst-case)
- Task input parameters (coverage)
- Faults and more extreme conditions (coverage/guarantees)
Thank you

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