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

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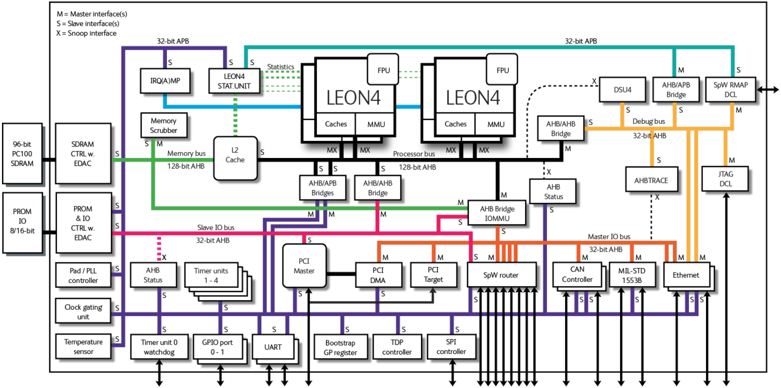
Real-time Embedded Systems

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



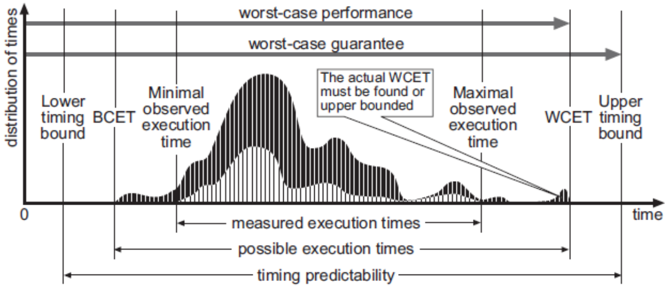
Predictability for Real-Time Systems

- 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)

Probabilistic Real-time systems

A probabilistic real-time system is a realtime system where at least one parameter is described as a random variable

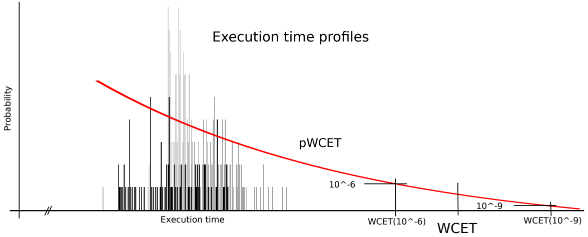


Probabilistic Timing Analysis

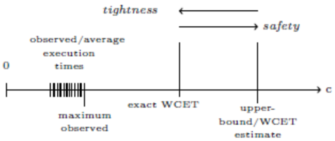
MBPTA

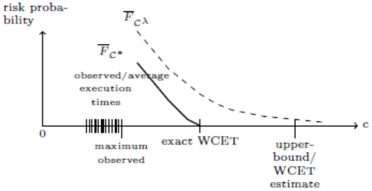
- generalizes Worst Case Execution Time (WCET) into the probabilistic WCET (pWCET)
- makes use of the Extreme Value Theory (EVT) for infering pWCETs

Probabilistic Timing Analysis

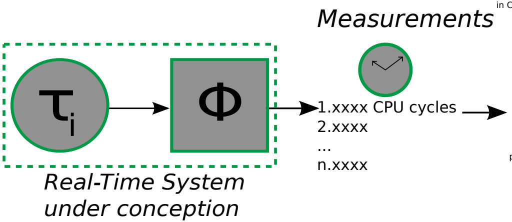


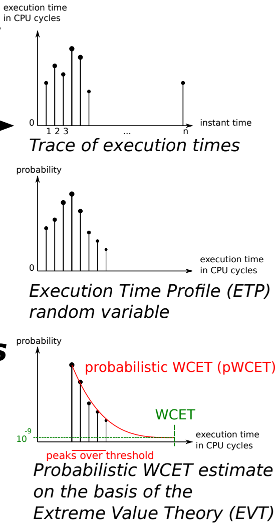
Probabilistic WCET





Measurement Based Probabilistic Timing analysis





The Measurement-Based Probabilistic Timing Analysis (MBPTA) toolchain

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

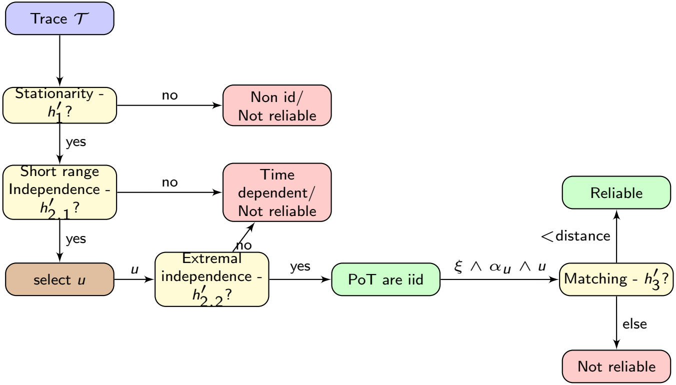
Generalizing from iid (independence and identical distribution)

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

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

EVT Applicability

Generalizing from iid (independence and identical distribution)

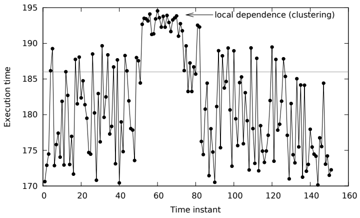


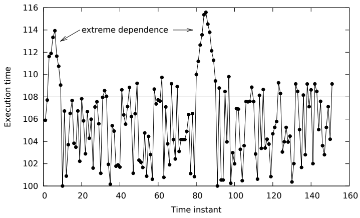
MBPTA in Practice

- Formal definition (parameters, ...)
- Applicability (dependece and non identical distibution, ...)
- 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]



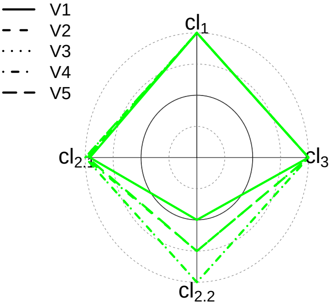


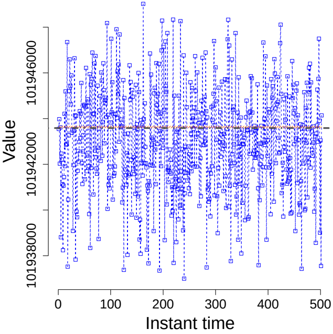
Dependence [1/2]

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

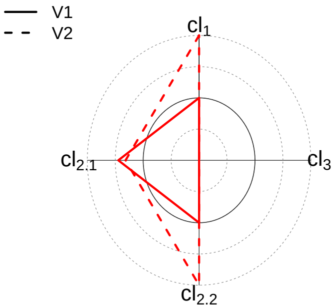
$$\mathrm{icdf}_{\overline{\mathcal{C}}^{ei}} \geq \mathrm{icdf}_{\overline{\mathcal{C}}^{i}}.$$

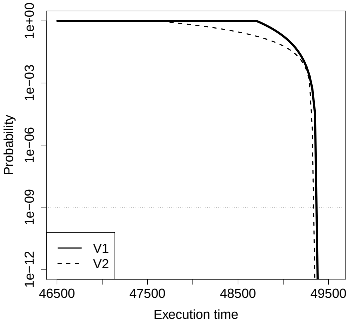
Dependence [2/2]



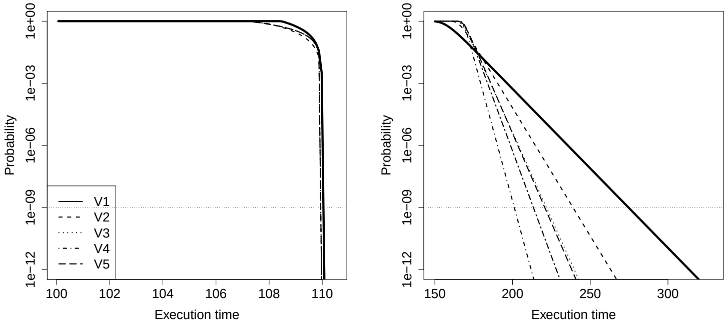


Dependence [2/2]

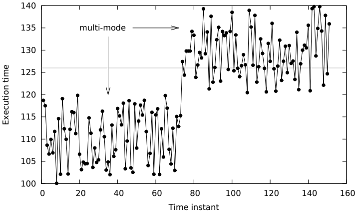


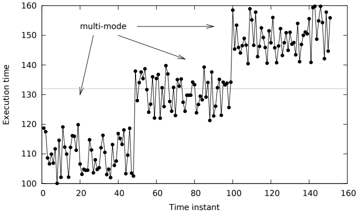


Dependence [2/2]



Multi-path/Multi-scenarios [1/2]





Multi-path/Multi-scenarios [1/2]

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

Trace-merging
Merging all the traces $\mathcal{T}_{\mathcal{C}^j}$ $\forall j \in J$ within a unique trace $\mathcal{T}_{\mathcal{C}}$

$$\mathcal{T}_{\mathcal{C}} \stackrel{def}{=} \bigcup_{j \in J} \mathcal{T}_{\mathcal{C}^j}$$

EVT applies to $\mathcal{T}_{\mathcal{C}}$

Multi-path/Multi-scenarios [1/2]

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

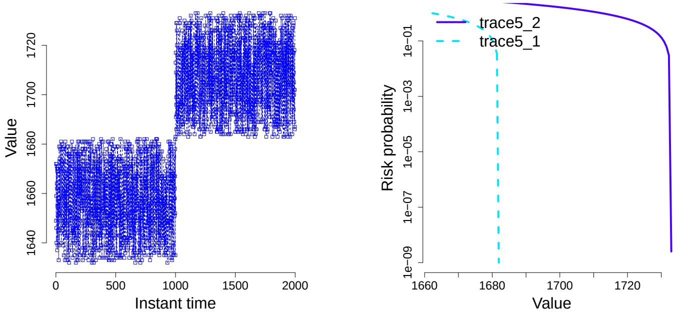
Envelope
EVT applied to each measurement condition j, $\overline{\mathcal{C}}^j$ for all $j \in J$

$$\overline{\mathcal{C}} \stackrel{def}{=} max_{j \in J}\{\overline{\mathcal{C}}^j\}$$

$$\text{icdf}_{\overline{\mathcal{C}}}(C) \stackrel{def}{=} max_{j \in J}\{\text{icdf}_{\overline{\mathcal{C}}^j}(C)\}$$

$\overline{\mathcal{C}}$ upper bounds every $j \in J$

Multi-path/Multi-scenario [2/2]



Conclusion and Future Work

Representativity 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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