Revising Measurement-Based Probabilistic Timing Analysis

RTAS 2017

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ONERA - The French Aerospace Lab

Agenda

Introduction

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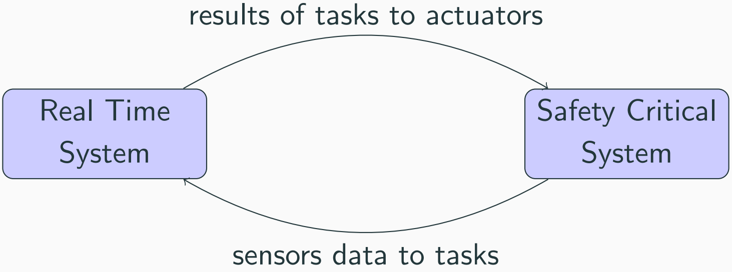
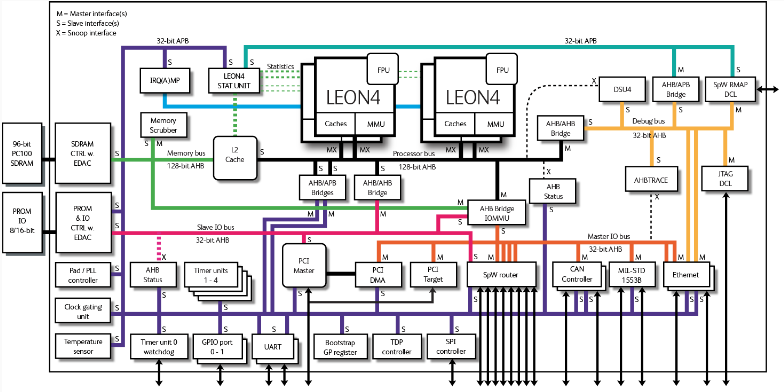
- **Predictability** is of paramount importance in real time systems



Introduction

- **Predictability** is of paramount importance in real time systems
- Worst case properties are hard to guarantee due to todays systems complexity



Introduction

- **Predictability** is of paramount importance in real time systems
- Worst case properties are hard to guarantee due to todays systems complexity

- Measurement-Based Probabilistic Timing Analysis (MBPTA) translates the Worst Case Execution Time (WCET) into the probabilistic WCET (pWCET)
- MBPTA makes use of the Extreme Value Theory (EVT) for infering pWCETs from execution time measurements

Contributions

- Guidelines for a systematic and complete EVT application
- Algorithms for best estimating the pWCET parameters wrt measurements
- Quantification of the pWCET estimate reliability
- Application of the proposed approach to non-time randomized and time randomized systems

Background

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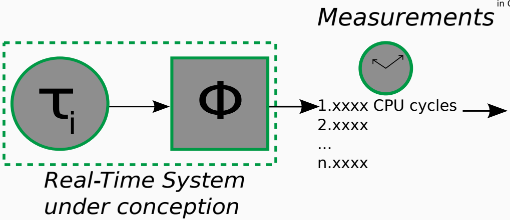

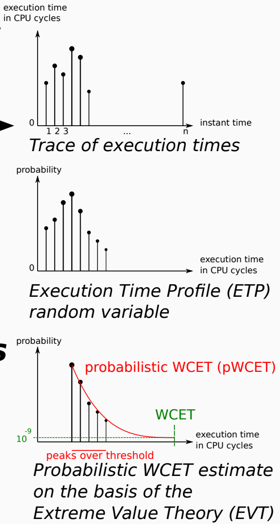

The Measurement-Based Probabilistic Timing Analysis (MBPTA) toolchain

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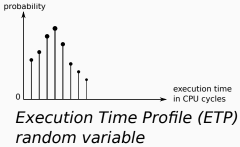
Background

$C_1, \ldots, C_n$ a trace of independent and identically distributed (iid) execution time measurements from the ETP $\mathcal{C}$ of cumulative distribution function $F_{\mathcal{C}}$, and we denote

$$F^u(c) = P\{\mathcal{C} \leq u + c \mid \mathcal{C} > u\},$$

the distribution of the peaks over the threshold u

(a) Trace



(b) $\mathcal{C}$

Background

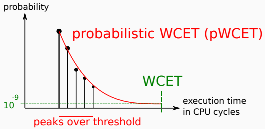
[Pickands theorem] $F_{\mathcal{C}}$ is in the Maximum Domain of Attraction of a Generalized Extreme Value distribution of shape parameter ξ iff

$$\lim_{u \to c_0} \sup_{0 \leq c \leq c_0 - u} |F^u(c) - GPD_\xi(c)| = 0,$$

with GPD_ξ the Generalized Pareto Distribution (GPD) defined as:

$$P(\mathcal{C} \leq c) = GPD_\xi(c) = \begin{cases} 1 - (1 + \xi \times (c-u)/\alpha_u)^{-1/\xi} & \text{if } \xi \neq 0, \\ 1 - \exp(-(c-u)/\alpha_u) & \text{if } \xi = 0, \end{cases}$$

defined on $\{c, 1 + \xi(c-u)/\alpha_u > 0\}$



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

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- $\xi < 0$ Weibull distribution
- $\xi = 0$ Gumbel distribution
- $\xi > 0$ Frechet distribution

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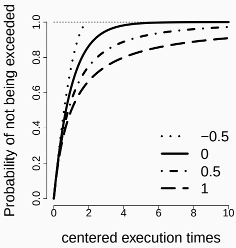
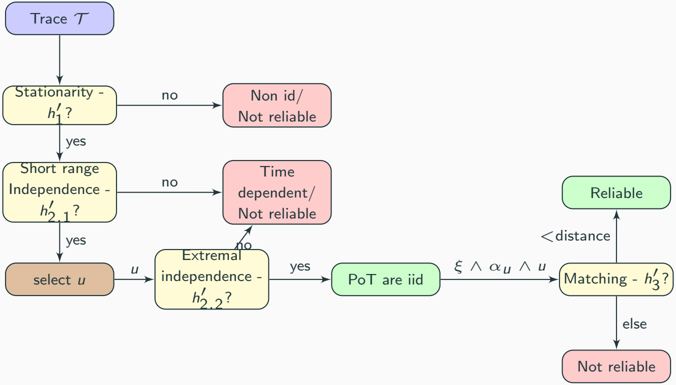


EVT Applicability

EVT Applicability

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 Applicability



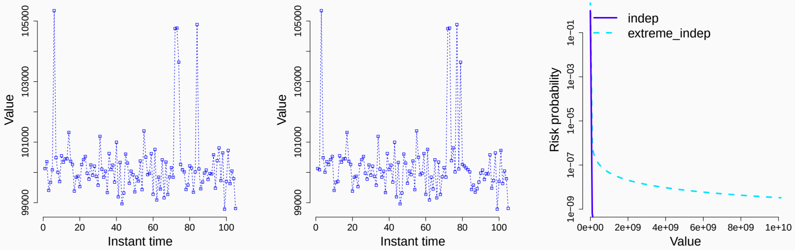
MBPTA decision diagram with tests and action applied.

EVT Applicability

The pWCET estimate in case of extremal independence $\overline{\mathcal{C}}^{ei}$ is greater than or equal to the one in case of independence $\overline{\mathcal{C}}^{i}$:

$$\overline{\mathcal{C}}^{ei} \geq \overline{\mathcal{C}}^{i}$$

Dependent measurements provide more pessimistic pWCET estimates than the independence



(a) Extremal independence (b) Artificially inducted independence (c) pWCETs

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MBPTA in Practice

MBPTA in Practice

Industrial safety-critical embedded system *trace*1

Robotic embedded system *trace*2, *trace*3

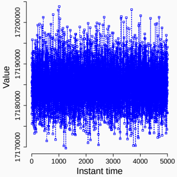
Multicore real time system *trace*4 to *trace*7

GPU CUDA system *trace*8, *trace*9

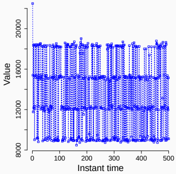
Artificial traces *trace*10 to *trace*12

FPGA real time system *trace*13, *trace*14

MBPTA in Practice

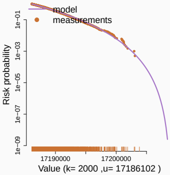


(d) *trace*1

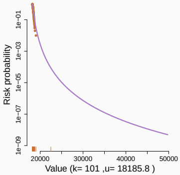


(e) *trace*4

Traces of executions times: variability of execution time with non-time randomized architectures.



(a) *trace*1



(b) *trace*4

pWCET models from input traces. Execution times are in logarithmic scale.

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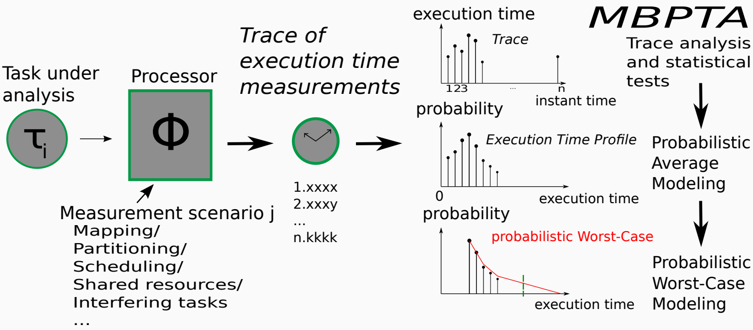
MBPTA in Practice

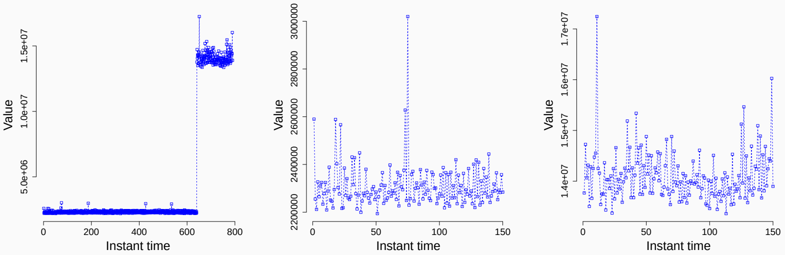


MBPTA in Practice

With J the finite set of possible measurement scenarios for the system

1. *Trace-merging* $\mathcal{T}_\mathcal{C}$, $\mathcal{T}_\mathcal{C} \overset{def}{=} \bigcup_{j \in J} \mathcal{T}_{\mathcal{C}^j}$
2. *Envelope* pWCET model of $\overline{\mathcal{C}}^j$ for all $j \in J$. The worst-case distribution $\overline{\mathcal{C}}$ for every $j \in J$ is such that:

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

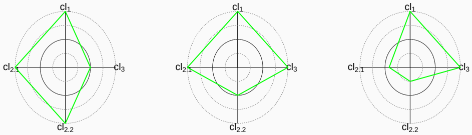


(a) *exploration* (b) exp_1 (c) exp_2

Multi-scenario trace and single-scenario traces.

MBPTA in Practice: EVT applicability

- *pWCET Reliability:* the pWCET estimate is safe if for all hypotheses in H' are verified
  Each hypothesis h'_i is tested and returns a confidence level cl_i from 0 (low confidence) to 4 (high confidence) on the acceptance of h'_i
  The set of hypotheses H' is verified if for all i $cl_i \geq 1$



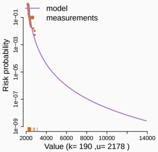
(a) *trace*2 (b) *trace*3 (c) *trace*4

- *pWCET accuracy:*

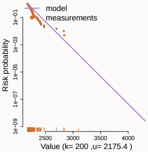
$$acc \stackrel{def}{=} \frac{\langle WCET; p\rangle - max(\mathcal{T})}{max(\mathcal{T})}$$

MBPTA in Practice: Best fitting algorithms

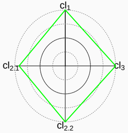
- *Gumbel model restriction*



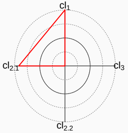
(d) *trace*6 (no Gumbel)



(e) *trace*6 − *G* (Gumbel)

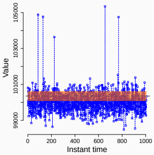


(f) *trace*6 (no Gumbel)

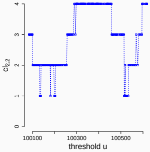


(g) *trace*6 − *G* (Gumbel)

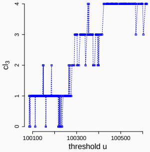
- *Threshold selection*



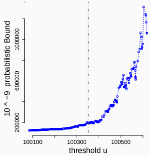
(h) Threshold exploration to select u



(i) $cl_{2.2}$ variation respect to the threshold u



(j) cl_3 maximization



(k) $\langle WCET; 10^{-9} \rangle$ and threshold u

Conclusion and Future Work

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- Decision diagram for applying the EVT
- Algorithms for best fitting the execution time measurements
- Metrics for quantifying the pWCET estimate reliability and accuracy
- EVT diagnosed to be applicable to both time and non-time randomized systems
- Worst-case guarantees of the measurement scenarios

Ongoing work: What are the measurement scenarios for trustful pWCET estimates?

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Ongoing work: What are the measurement scenarios for trustful pWCET estimates?

- Contentions within the processor shared resources
- Task input parameters

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Questions?