
Probabilistic Real-Time

Achievements and open problems

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Probabilistic Real-Time System

« A probabilistic real-time system is a system where at least one parameter is described with a probability distribution »

Modeling and schedulability analysis with probabilities

Open Problems

THE TRUE OPEN PROBLEM FOR THE PROBABILITIES IS: BEING ACCEPTED

1. « I don't trust probabilities for hard real-time/predictability»
Guarantees out of probability: making predictability from probabilities
2. Being formal with probabilities: independence assumed, vconditional probabilities, etc.

Modeling and Analysis with Probabilities

Modeling with probabilities

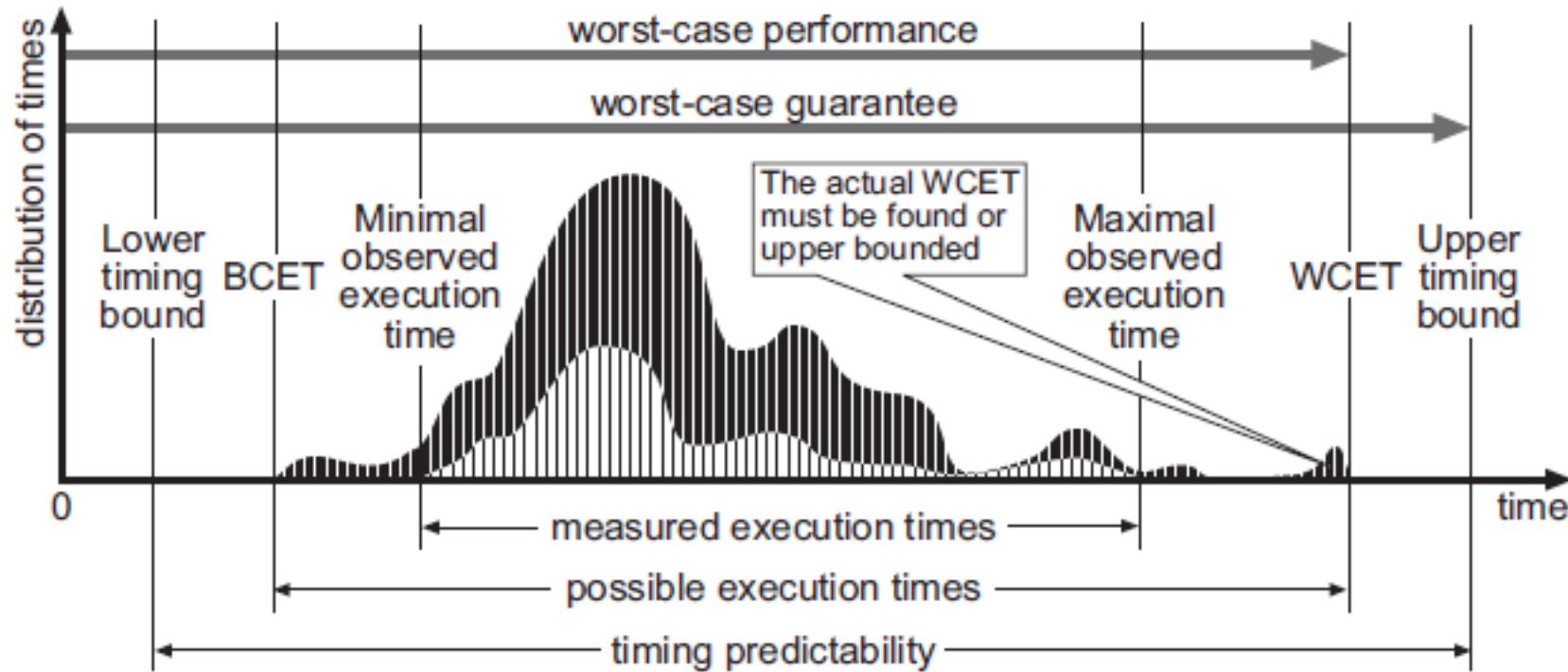
- Static probabilistic timing analysis
- Measurement-based probabilistic timing analysis

[Schedulability] Analysis with probabilities

- Schedulability
- Sensitivity
- Mixed criticality

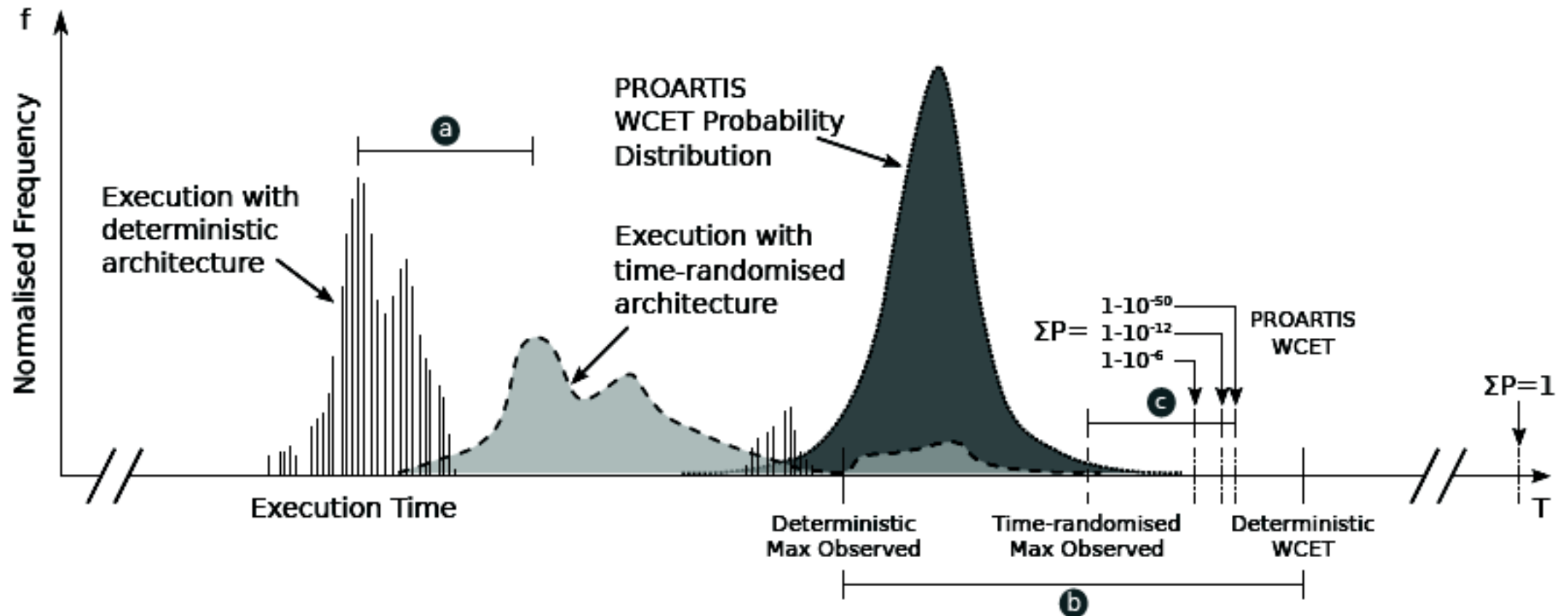
Modeling with Probabilities

Worst-Case Execution Time:



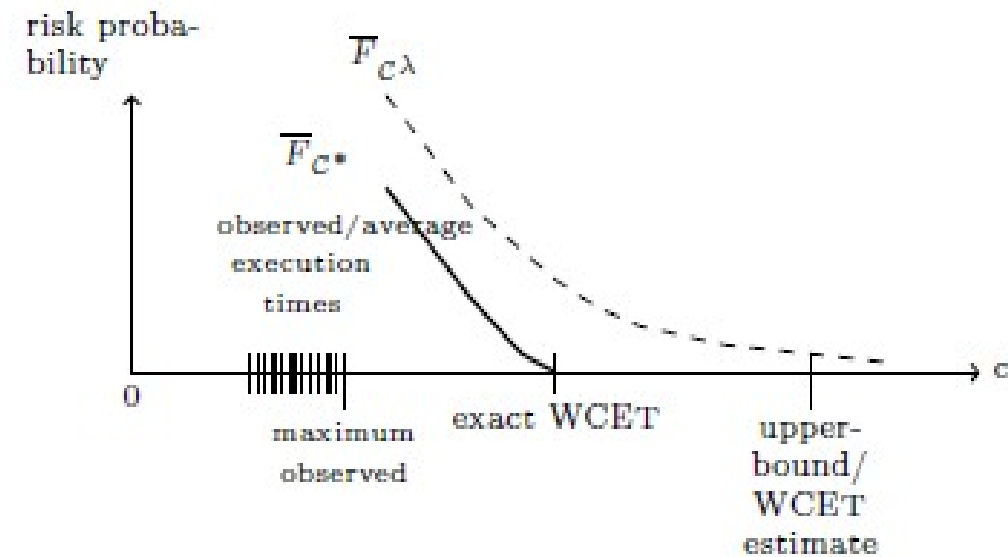
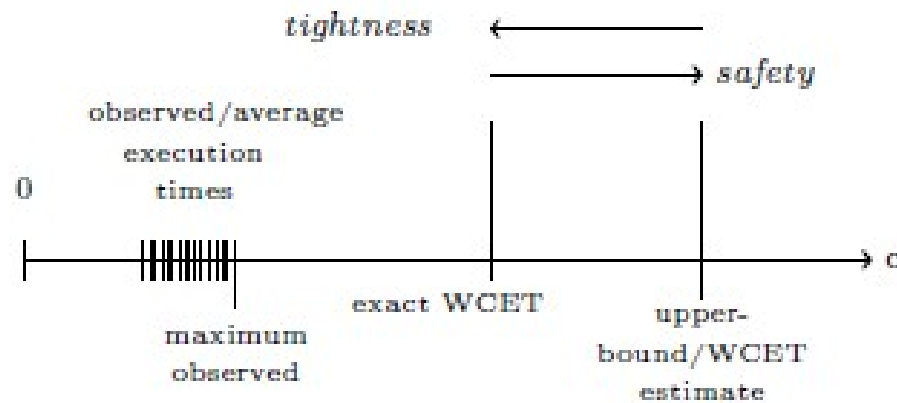
Modeling with Probabilities

Probabilistic Worst-Case Execution Time:



Modeling with Probabilities

Probabilistic Worst-Case Execution Time:



Open Problems

- Why the need for a pWCET? Isn't enough the WCET?
- pWCET: worst-case distribution or distribution of worst-cases?

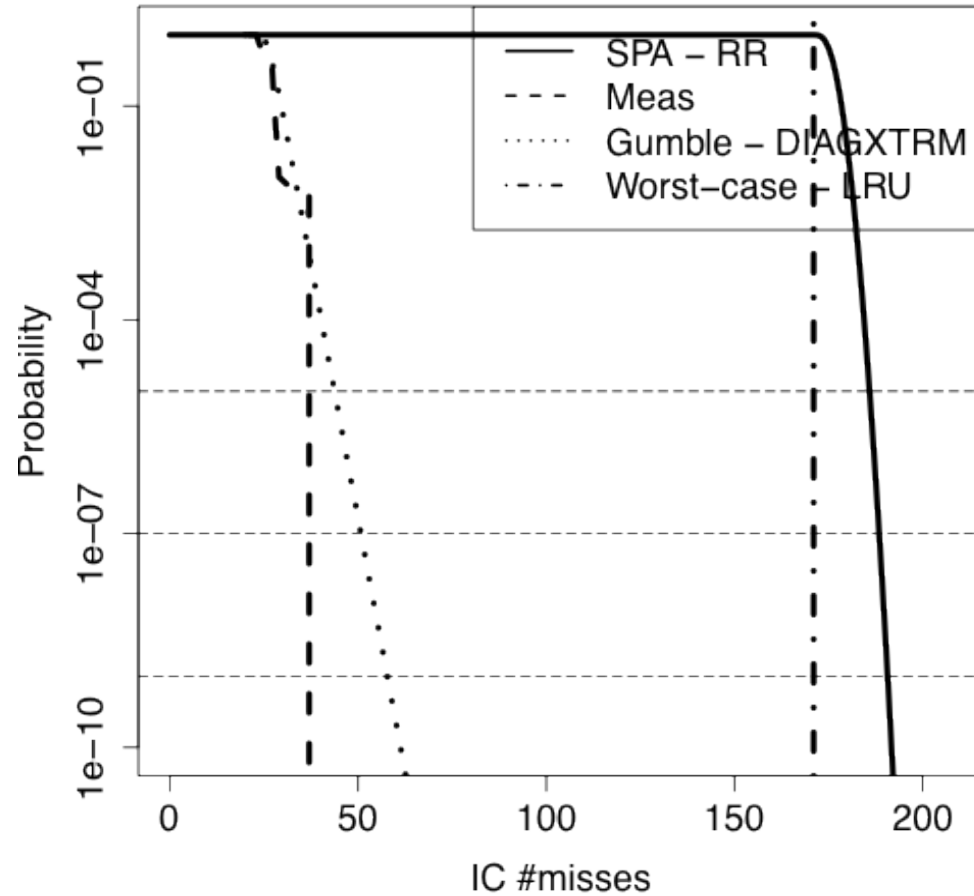
Modeling with probabilities...

Static Probabilistic Timing Analysis

- Based on time-randomized real-time systems – Random Replacement Caches
- Multiple works from 2011: Davis, Altmayer, Cucu-Grosjean

Well structured!

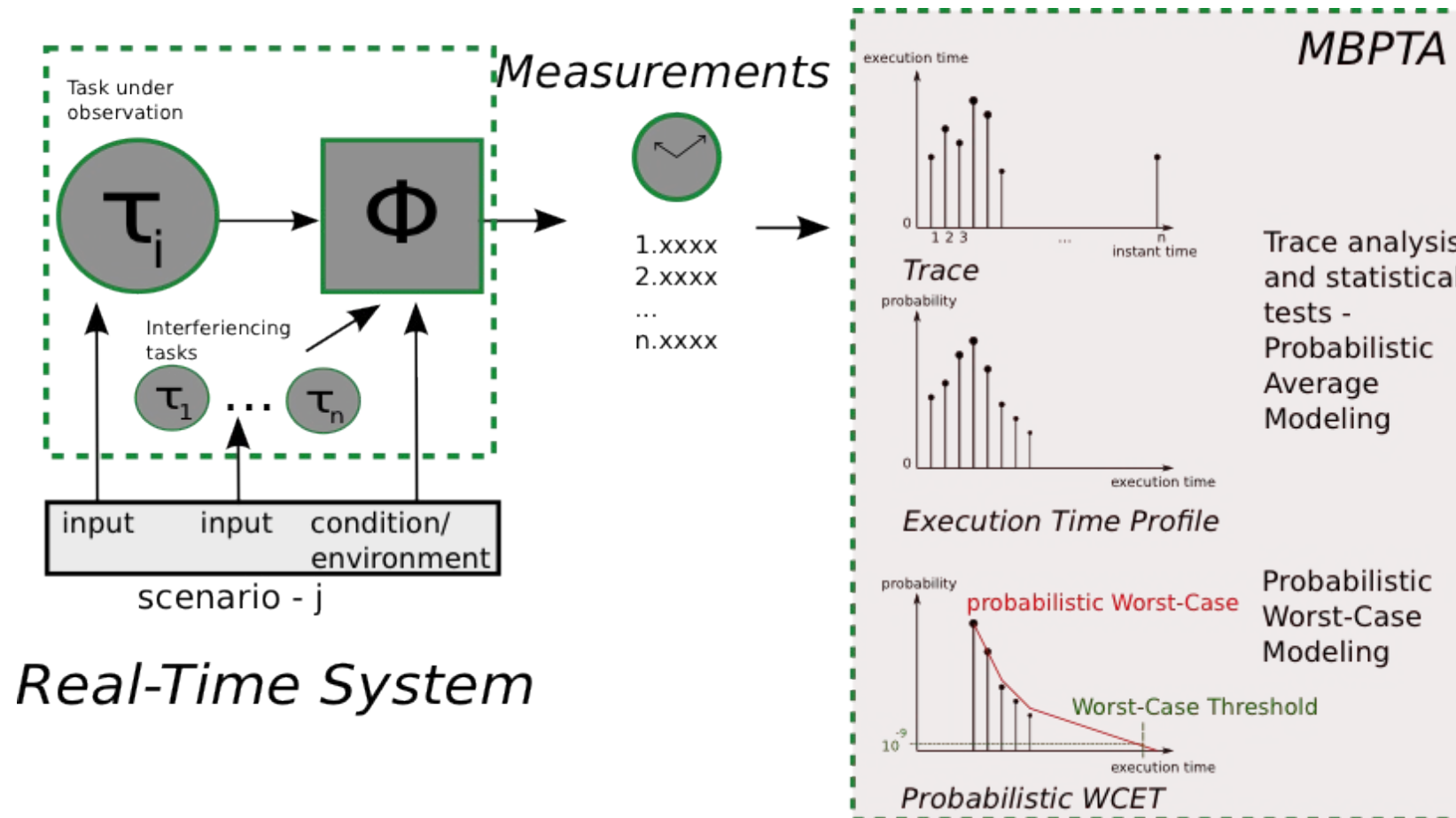
Random Replacement Cache



Measurement-Based Probabilistic Timing Analysis

- Measurements
- Statistical analysis + Extreme Value Theory (EVT)
- > pWCET estimates

Measurement-Based Probabilistic Timing Analysis



Measurement-Based Probabilistic Timing Analysis

1. EVT + Randomicity

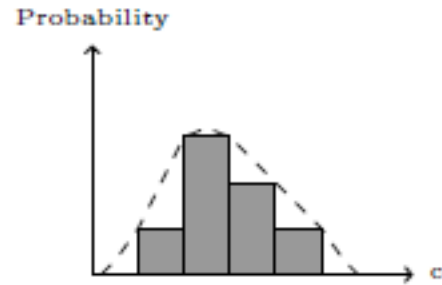
“intractability”, “control source of variability” →
“randomicity”

2. EVT + Statistical analysis

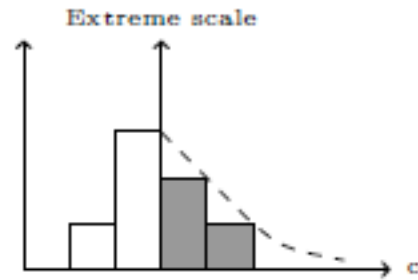
no control but just measurements → “coverage”,
“dominance”, etc..

BSC, INRIA, YORK, ONERA, etc. Who else would like to join?

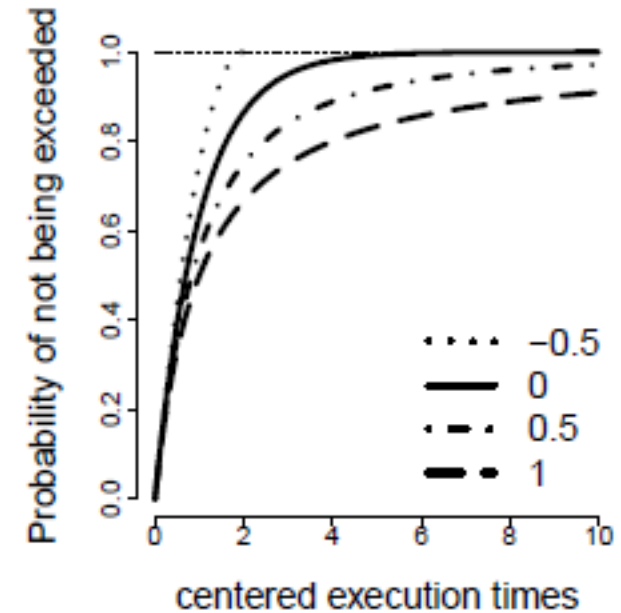
pWCET estimation with the EVT



(a) Distribution of execution times (dashed curve) from the frequency of their measurements (grey rectangles).



(b) Estimate of the right tail of the execution time distribution (dashed curve) from the frequency of extreme execution times (grey rectangles).



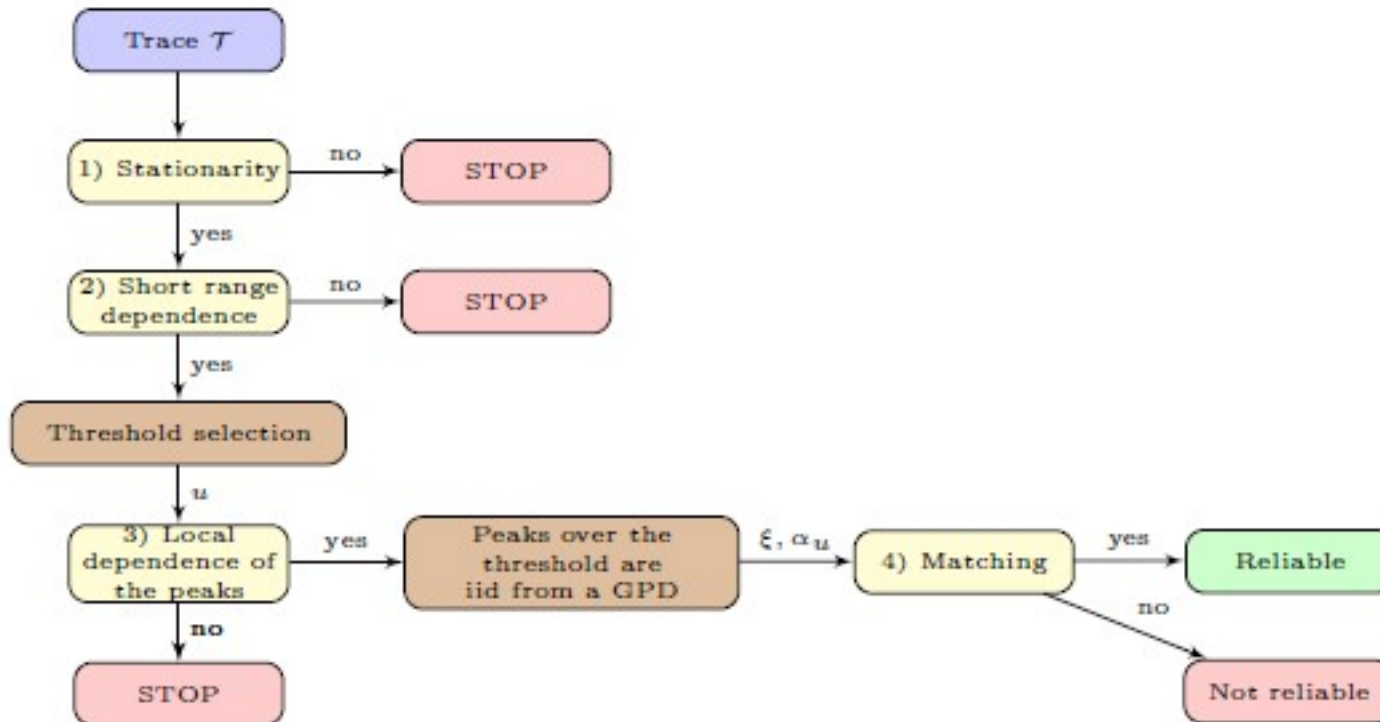
(c) GEV CDFs for different values of the shape parameter ξ .

Open Problems: The EVT

Not really a plug and play tool, for both non-time randomized and time randomized architectures

1. Worst-case?
2. Where are the guarantees from? Hypotheses
3. Block Maxima or Peak over Thresholds?
4. Parameter selection

Statistical analysis + EVT



DIAGXTRM:
1.composable,
2.correct,
3.reliable and
4.robust

Measurement-based probabilistic timing analysis: OPEN PROBLEMS

- 0) EVT Applicability: hypotheses, parameters, complexity, etc.
 - 1) Confidence
 - 2) Worst-case: Enumeration, scenarios/inputs
 - 3) Time analyzable architecture
 - 4) Fault modeling

Understanding the EVT for better MBPTA

EVT applicability

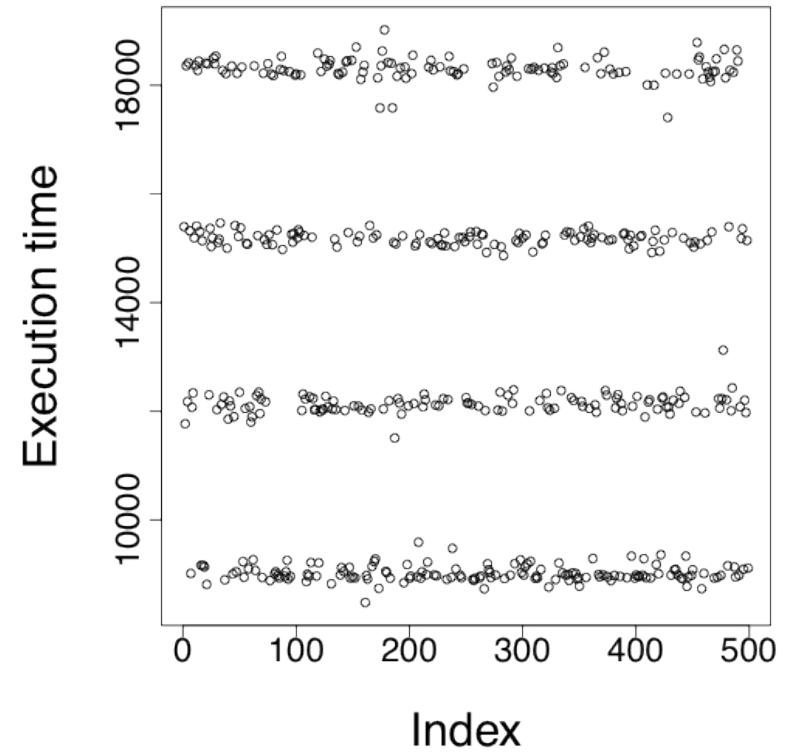
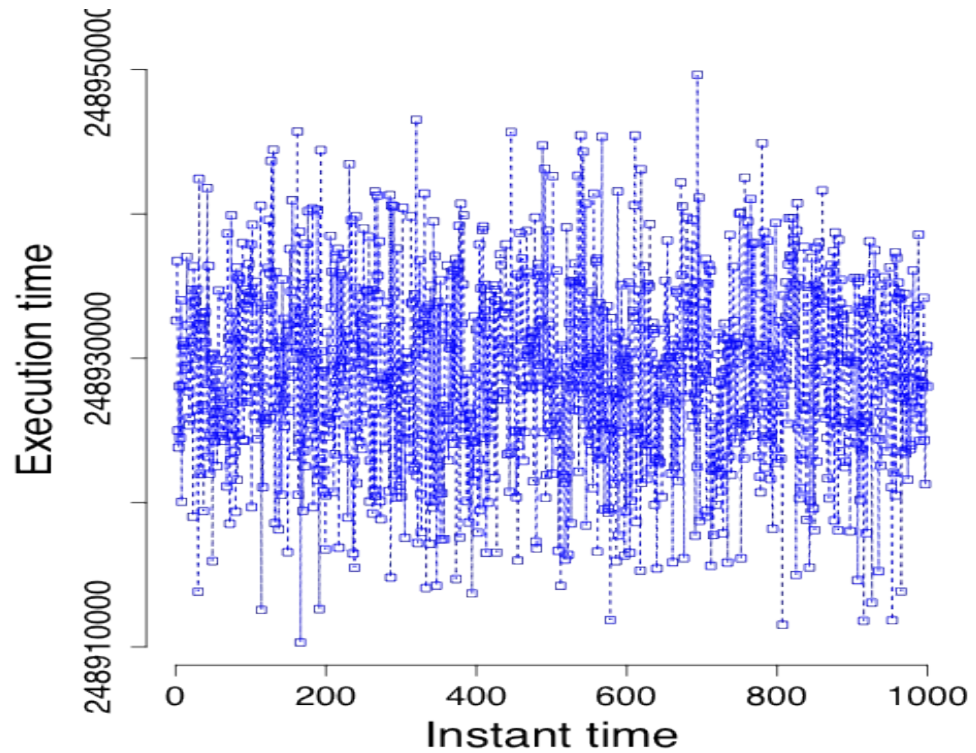
- Independence and Identical Distribution (iid) or Stationarity, Independence, Extremal independence and matching -> **STILL AN OPEN PROBLEM!**

- Trace analysis – average behavior, hypotheses, etc.
- Parameter to be selected – strong impact
- Multi-paths; discontinuities, frequency?

Understanding the EVT for better MBPTA

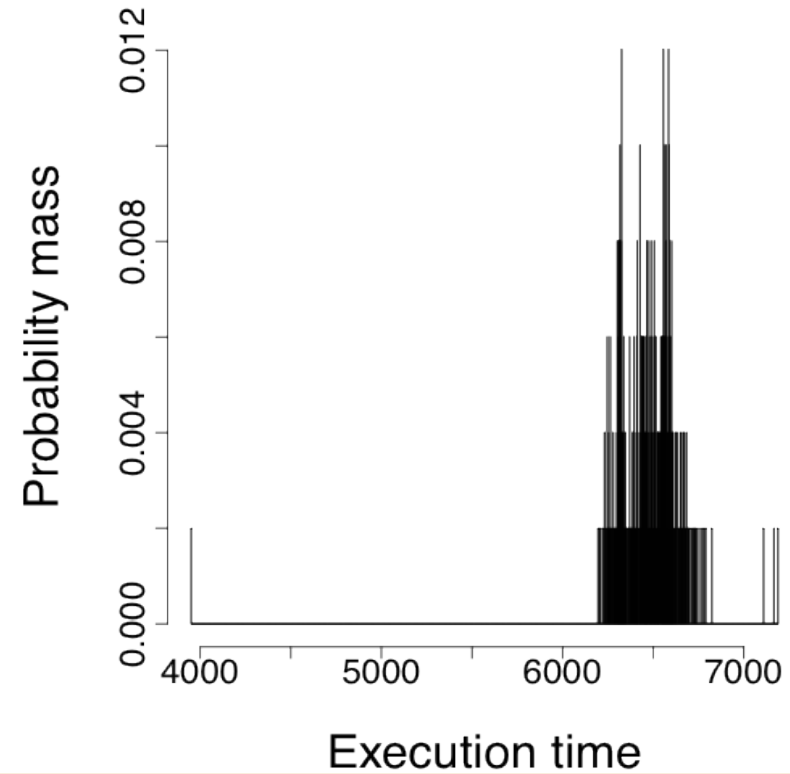
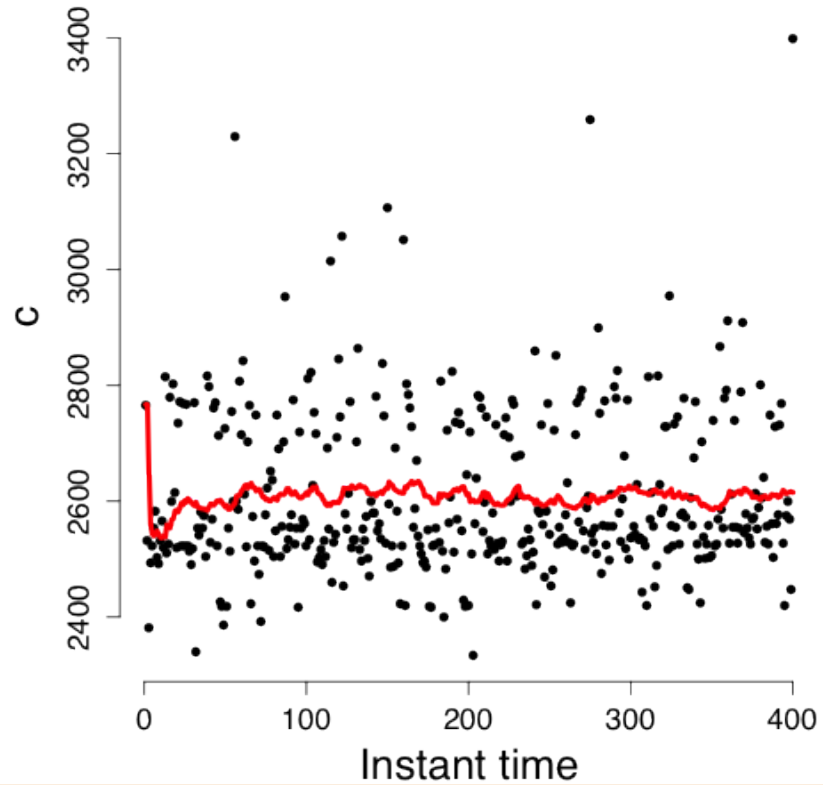
Variability

Non-time randomized systems



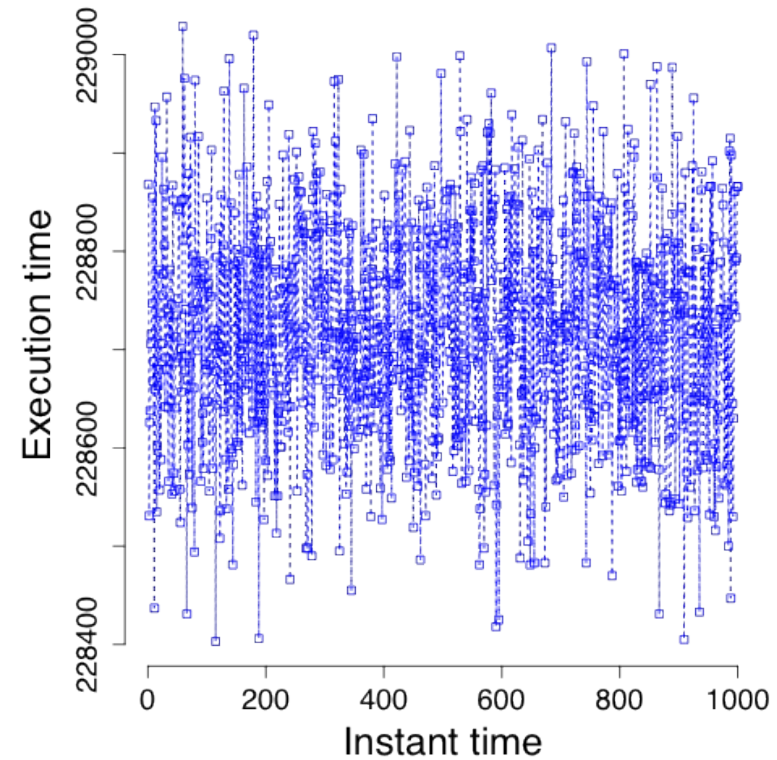
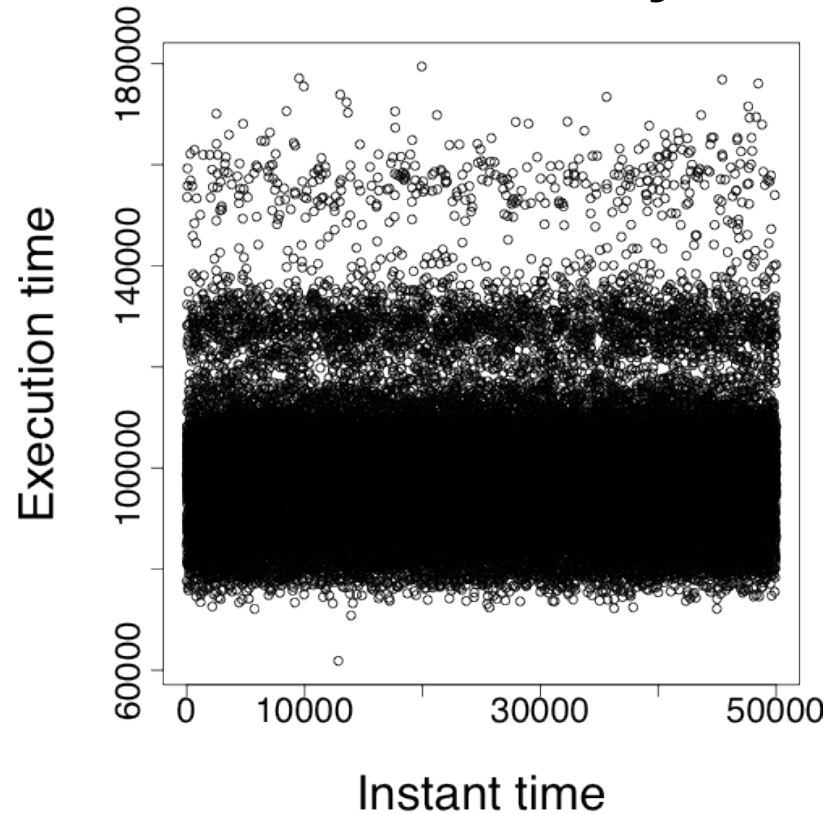
Variability and modeling

Non-time randomized systems



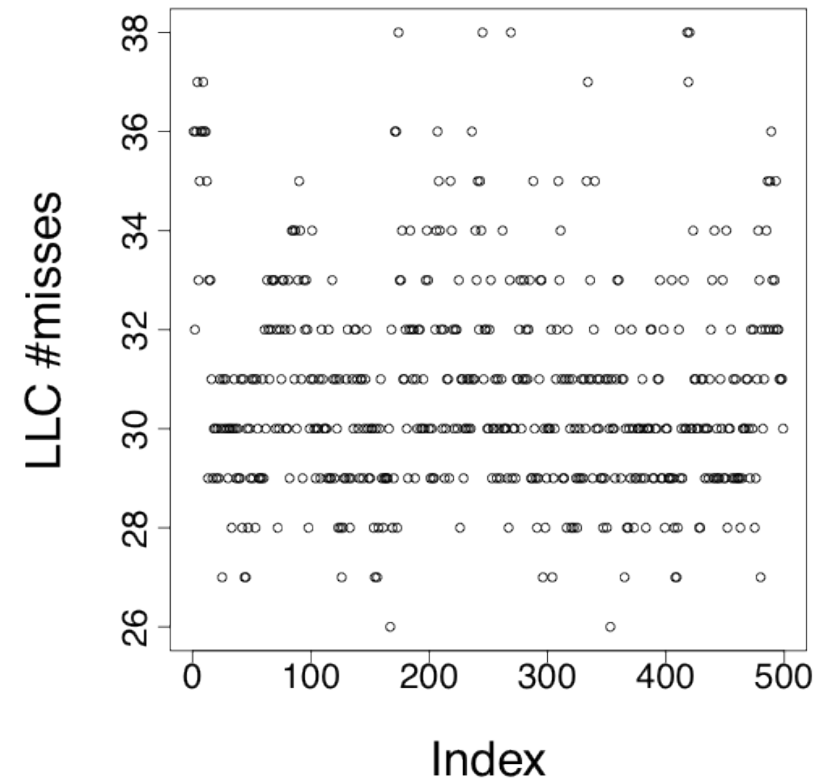
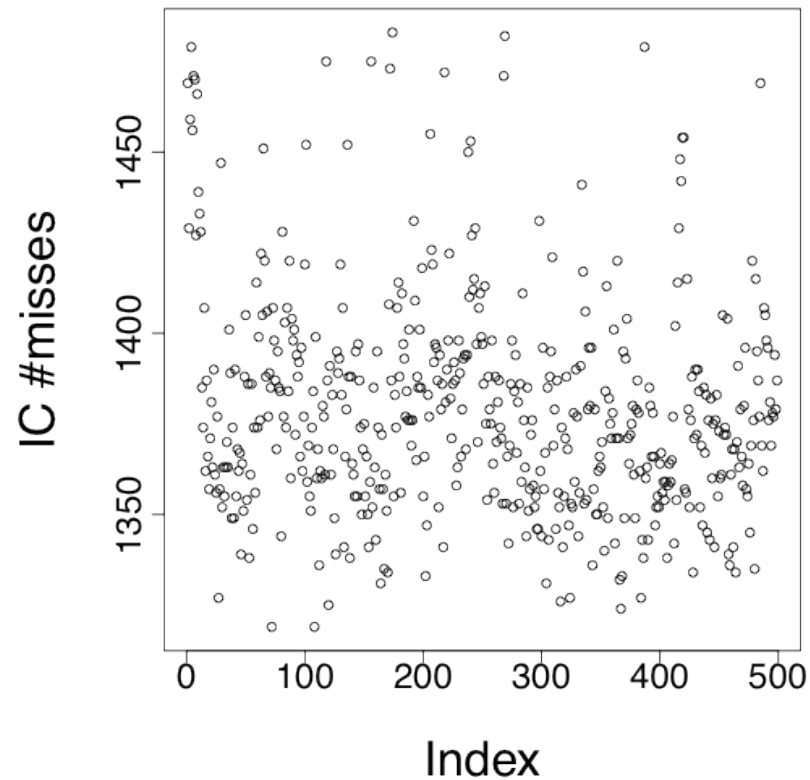
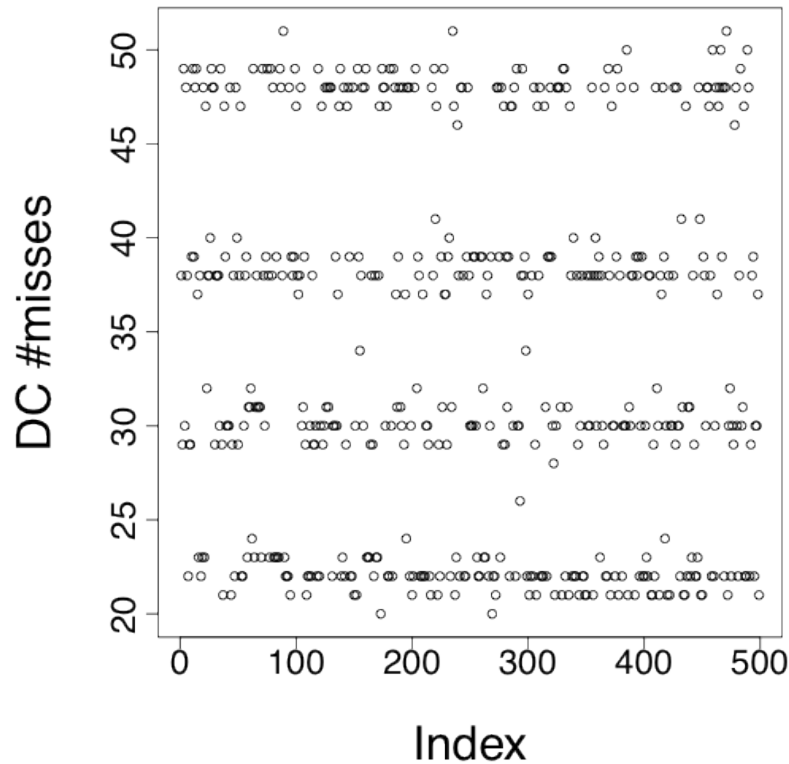
Variability and independence

Non-time randomized systems



Variability and cache

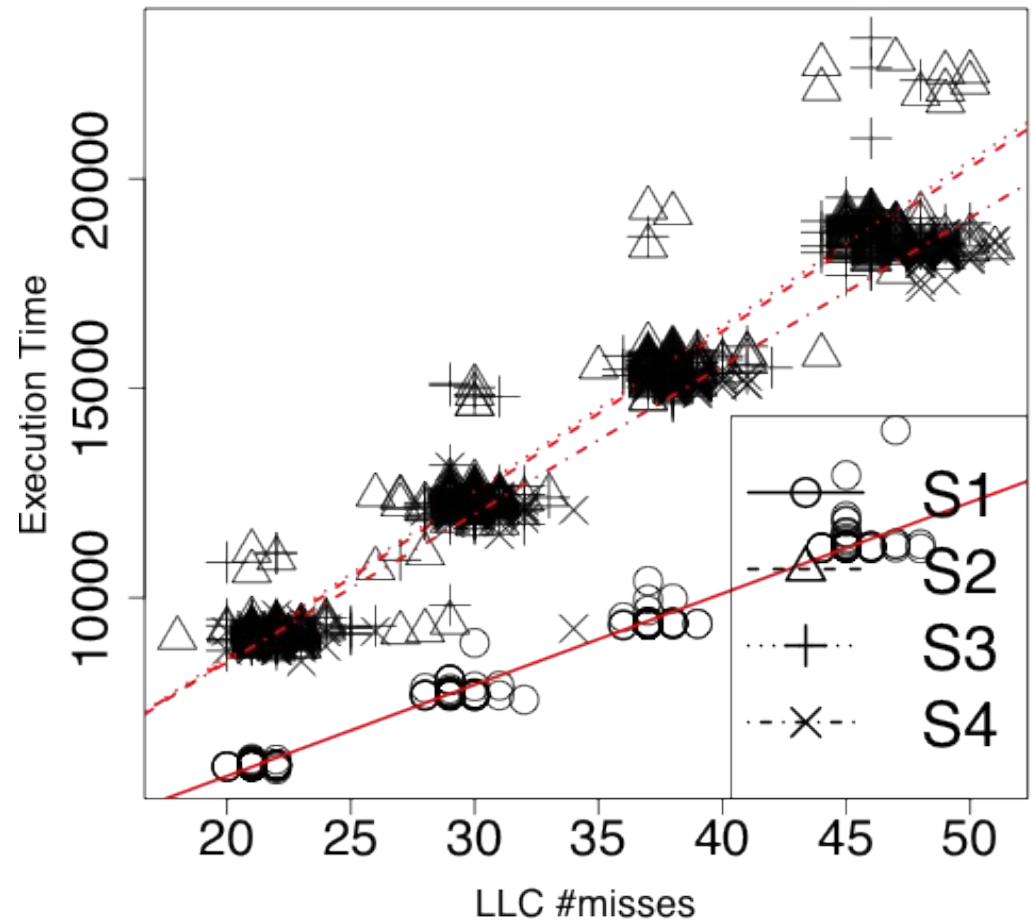
Non-time randomized systems



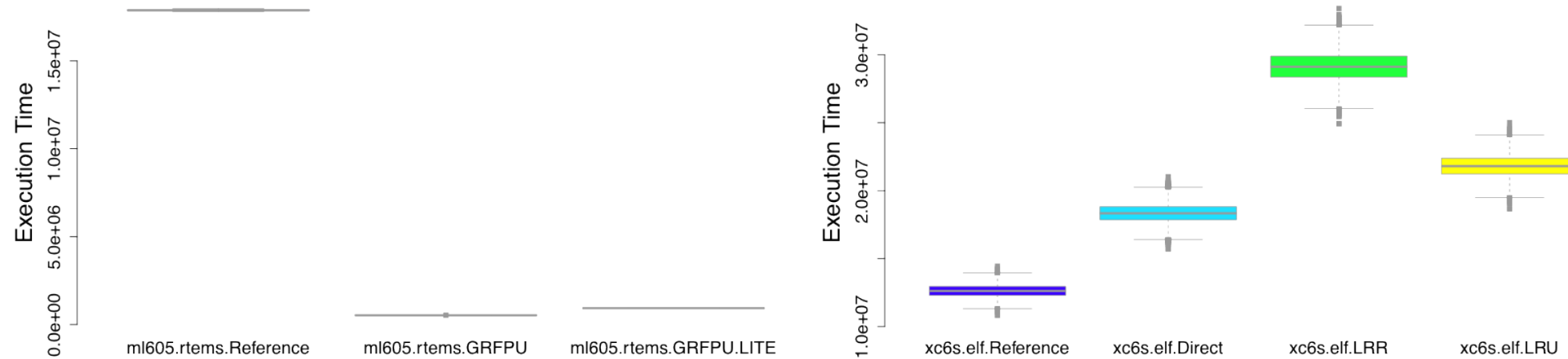
Cache impacts

Non-time randomized systems

Impact of cache on time execution
time: [linear] correlation



Cache importance



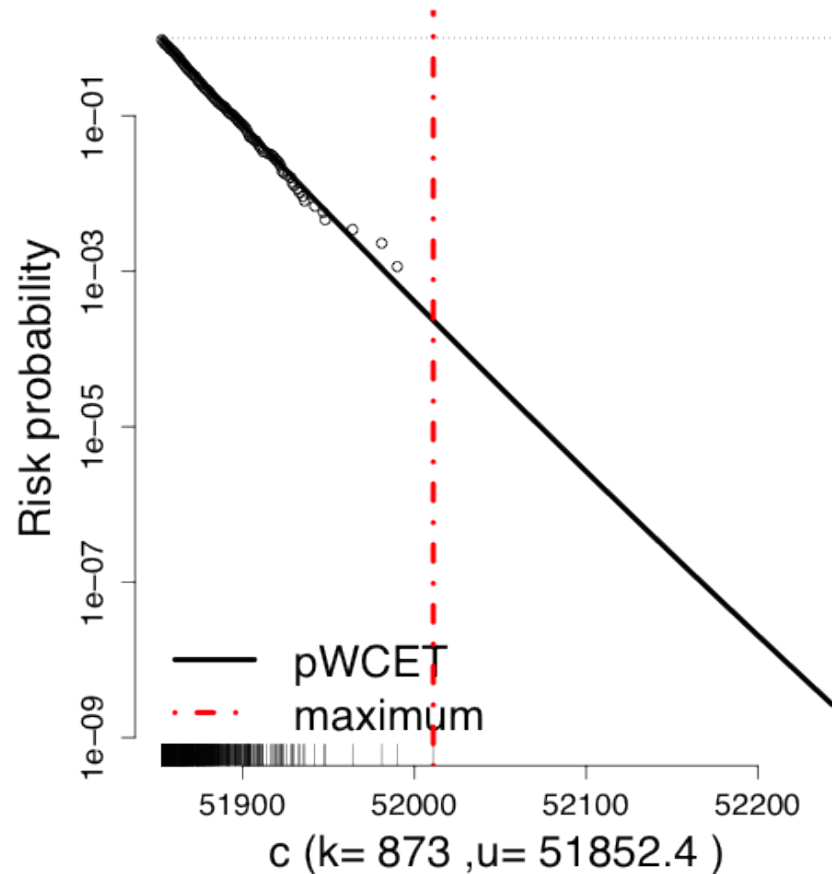
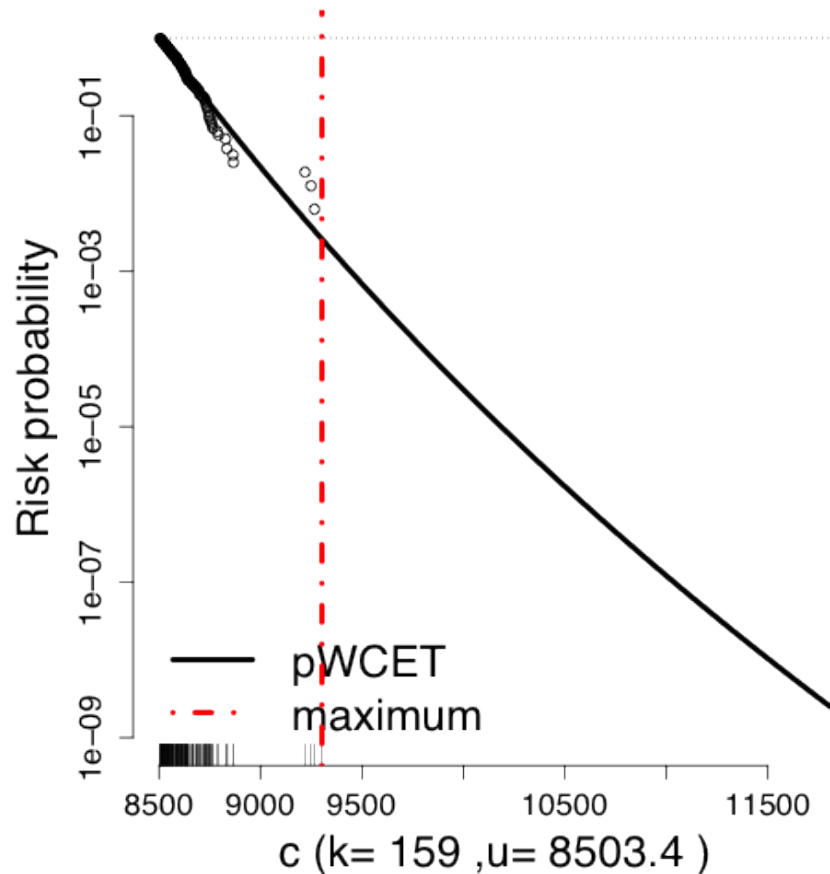
Instruction cache: random replacement
cache with better average performance

Dependence effect

$$cdf_{C^{ei}} \succcurlyeq cdf_{C^i}$$

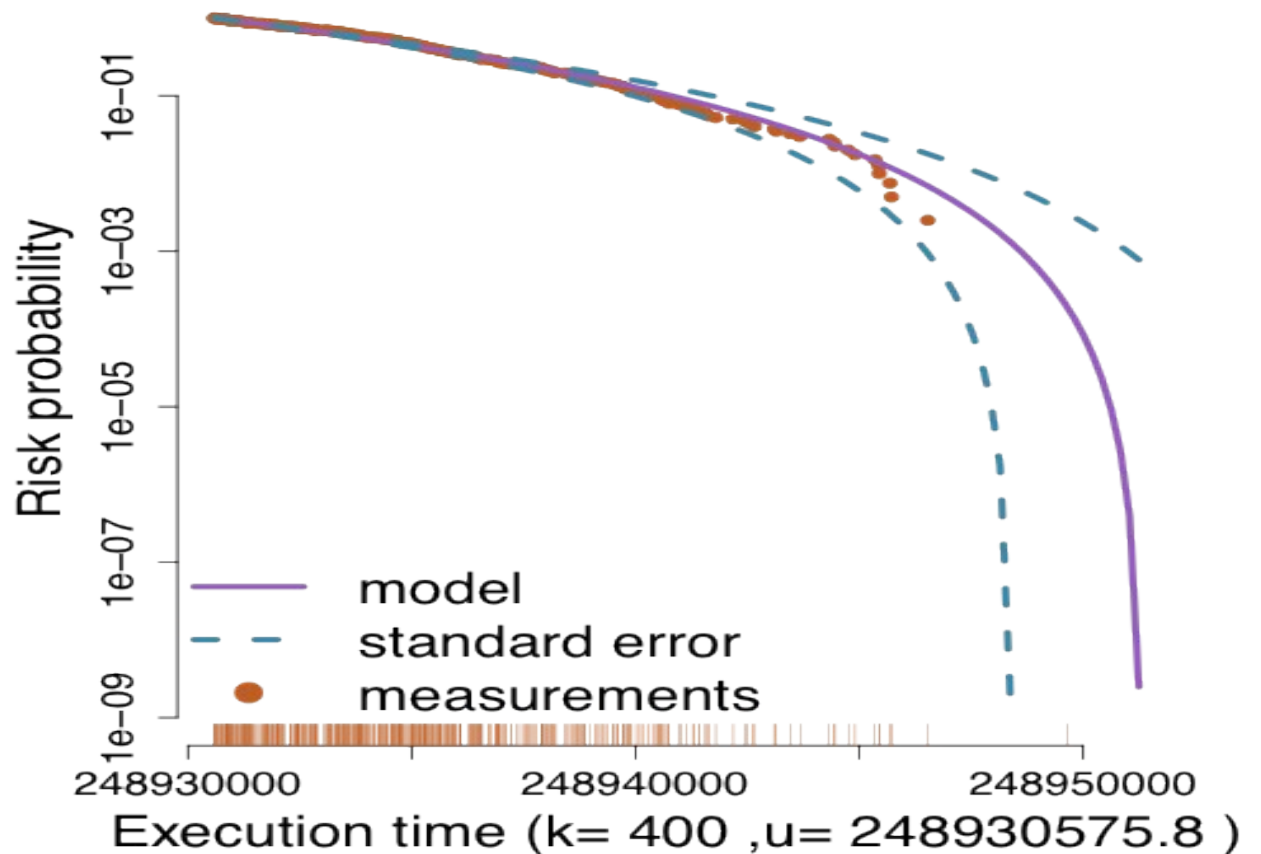
Dependence: more safety/pessimism

Best fitting: input measurements



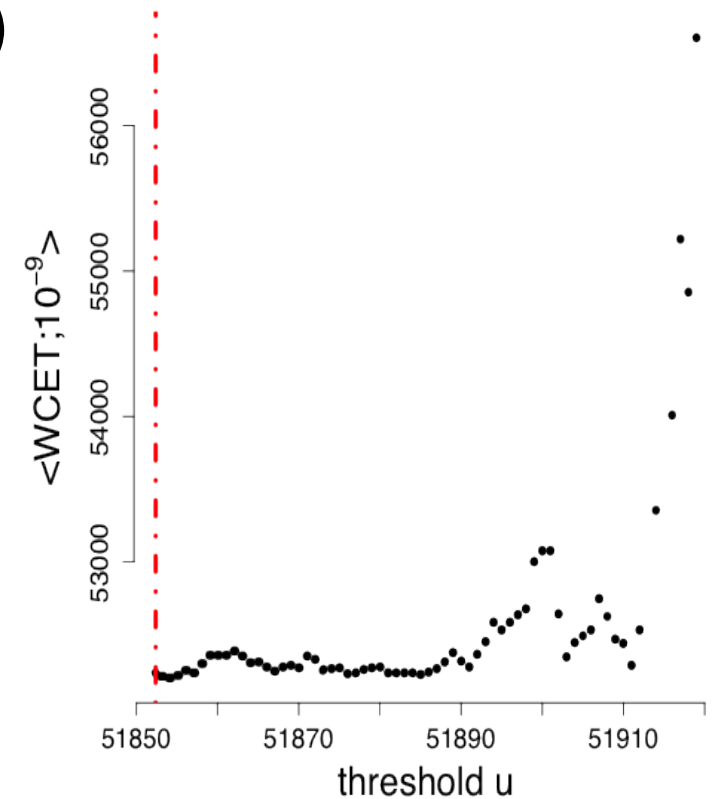
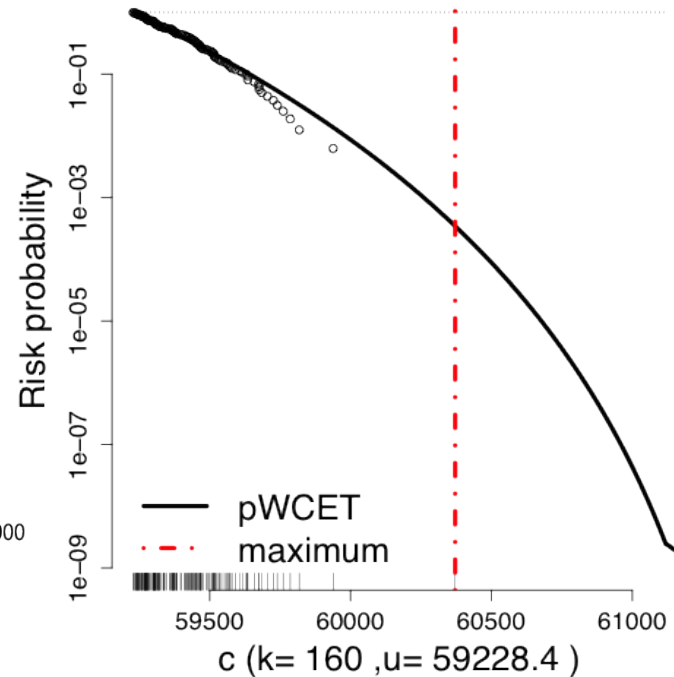
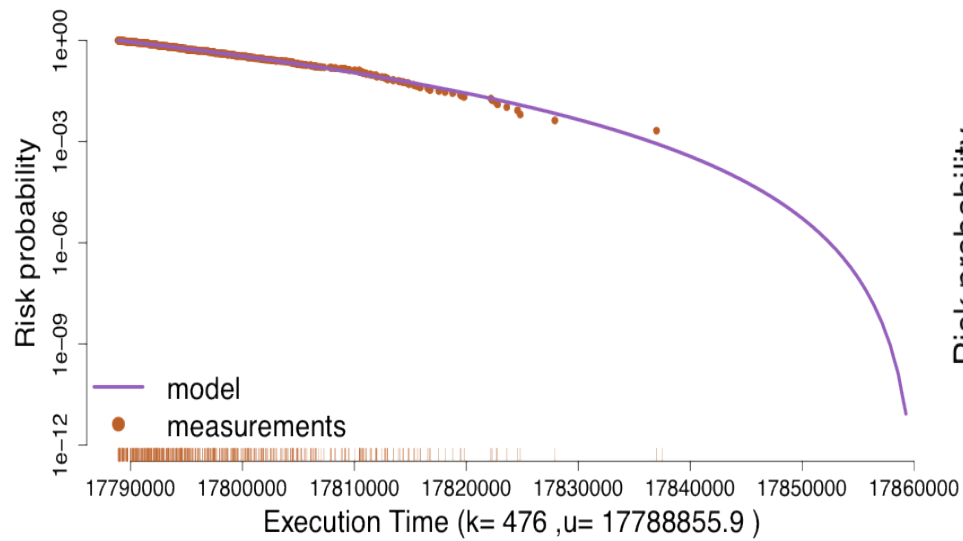
Best Fitting Evaluation

Standard Error:
EVT robustness



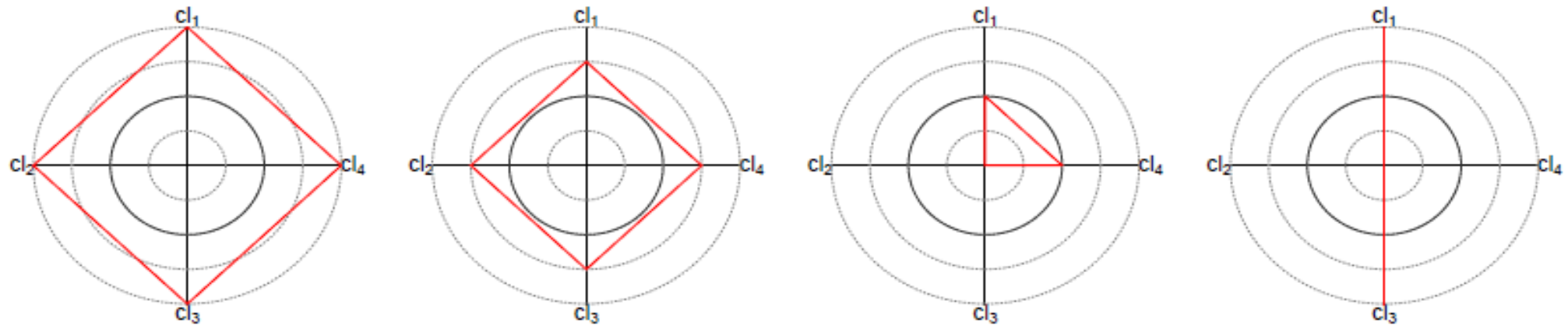
Parameters Selection

- Shape distribution: best fit (no constraints)
- Block size b or threshold u : select the best



Statistical confidence

From statistical tests to pWCET model confidence/reliability:
◦ Confidence and reliability, spider net, parameter effects

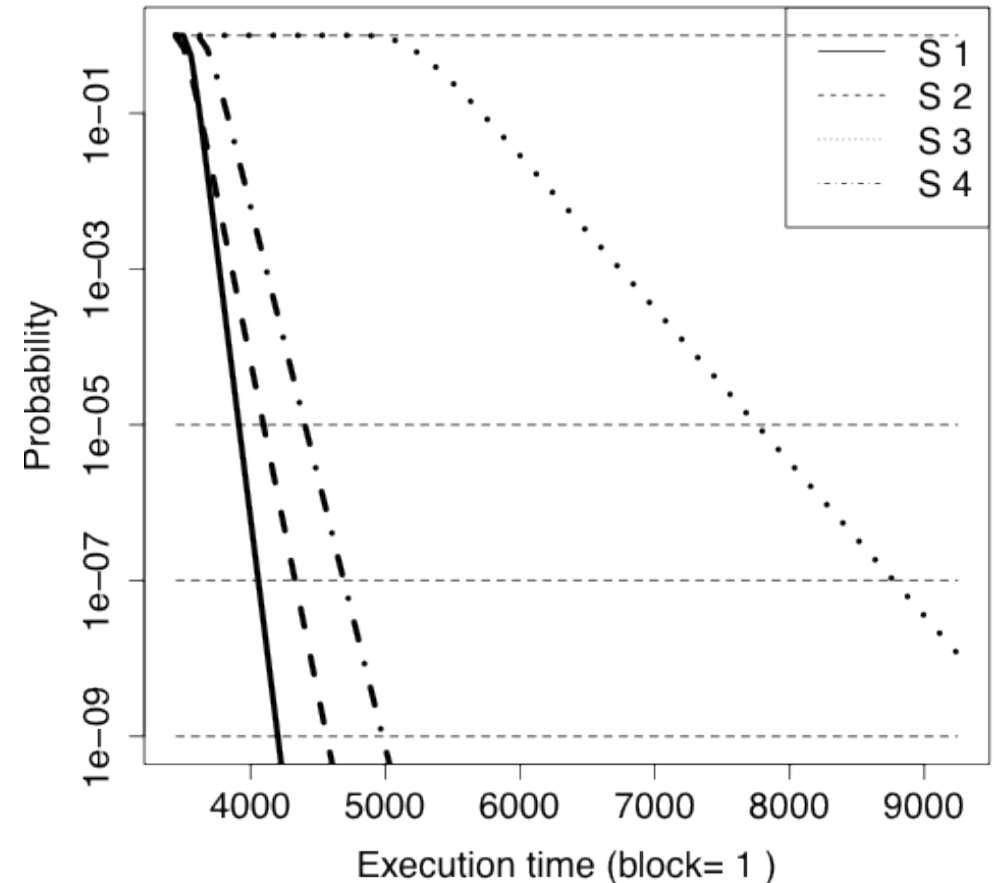


(a) Full confidence on all the hypotheses: full reliability
(b) High confidence on all the hypotheses: high reliability
(c) Low confidence on cl_1 and cl_4 , no confidence at all on cl_2 and cl_3 : no reliability
(d) Full confidence on cl_1 , $cl_1 = 4$, and no confidence at all on cl_2 , $cl_2 = 0$, and cl_4 , $cl_4 = 0$: no reliability

Worst-case problem

Worst-case guarantee:
multiple scenarios,
multiple conditions

- Guarantee the worst-case from all the scenarios
- Scenario dominance
- Multi-paths/multiple inputs



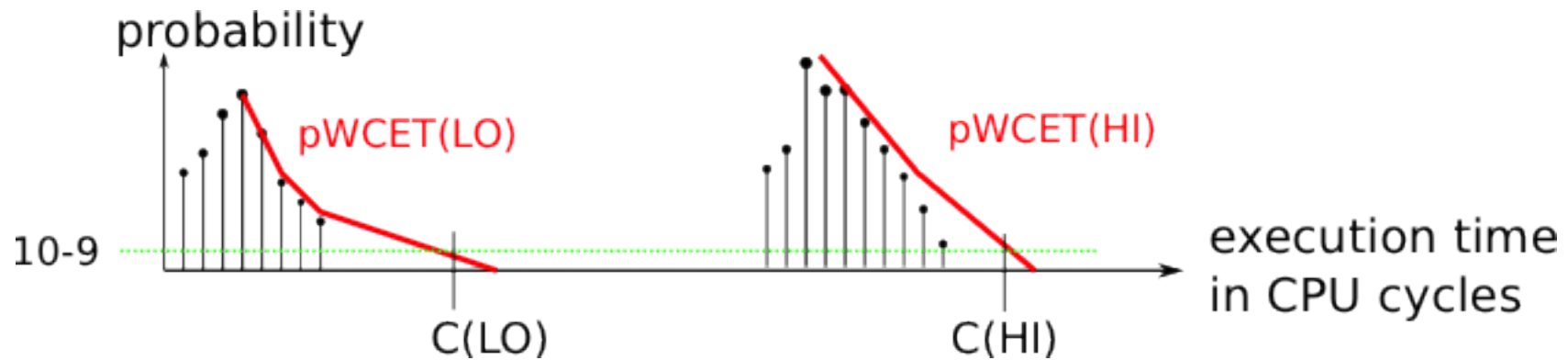
Time analyzable architecture

- What does it mean?
 - EVT applicability? + More control?
- What are the effects?
 - Worst-case condition
- Platform or system?
 - Timing analyzable platforms
 - Timing analyzable applications?

Fault modeling

Modeling faults with measurements:

- Traces of execution time: including fault effects
- Execution conditions



Open Problems

Probabilistic schedulability analysis

Schedulability with probabilities

- Diaz from 2002: Markov Chain, (shrink and “convolution”, Markov chain - backlog)
- EDF, FP with probabilities modeling WCET (pWCET) and Period (pPeriod): (e.g. Maxim 2013)
 - “convolution” + deadline miss ratio
- Probabilistic guarantees – shared resources (pDeadline)
- Formal approaches: Automata (probabilistic timing automata)?, Stochastic Petri Nets (e.g. Carnevali 2014), Markov Chain?
 - Deadline miss ratio

Main hp: Independence; with pWCETs it is obtained (Cucu-Grosjean 2013)

Probabilistic bounds

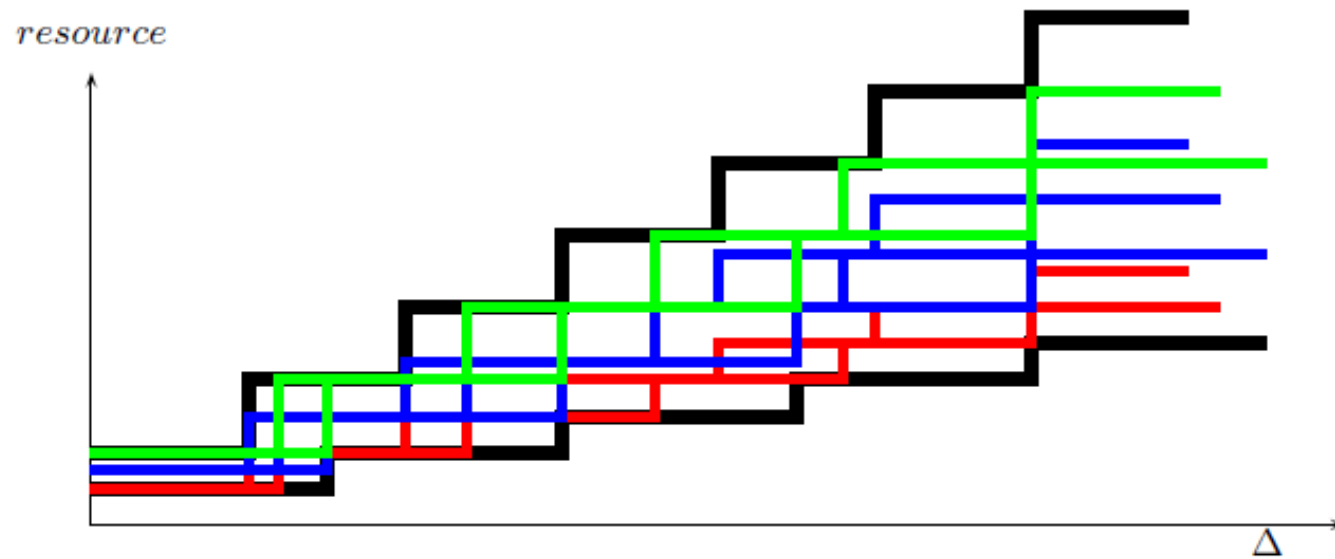
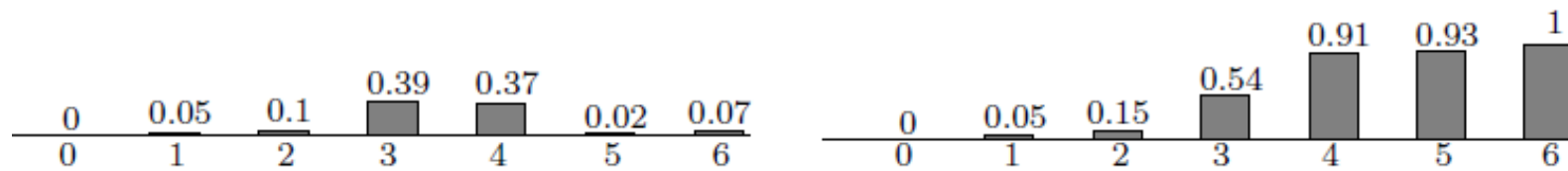
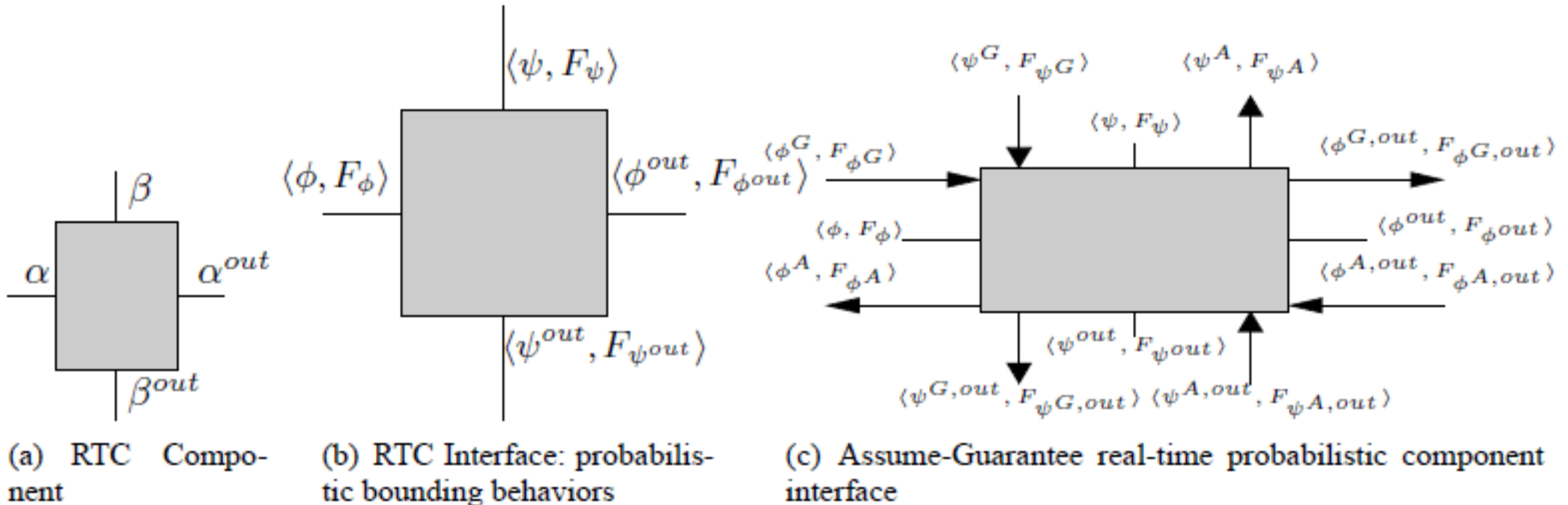


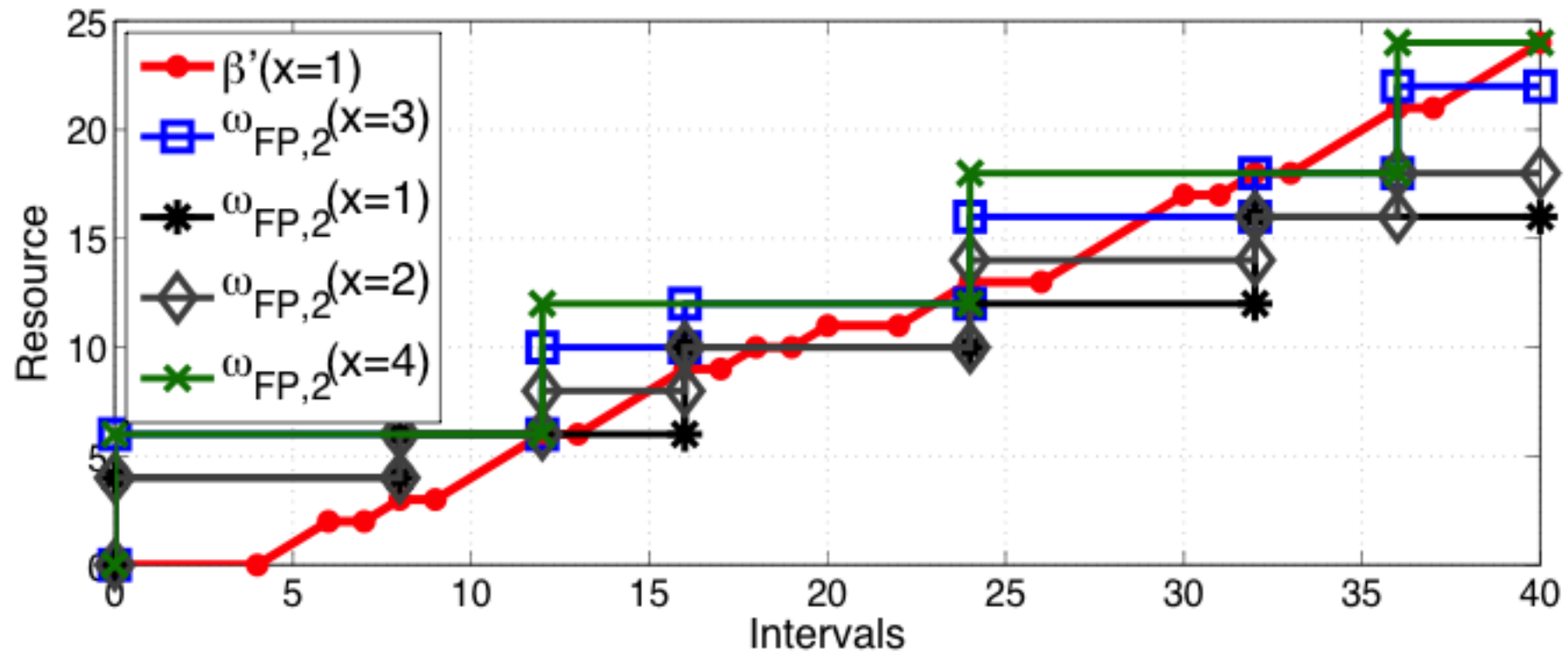
Fig. 6. Probabilistic curve: ordered multiple curves $\phi_i(\Delta, x)$.



Probabilistic components



Probabilistic schedulability



Open Problems

Probabilistic sensitivity analysis

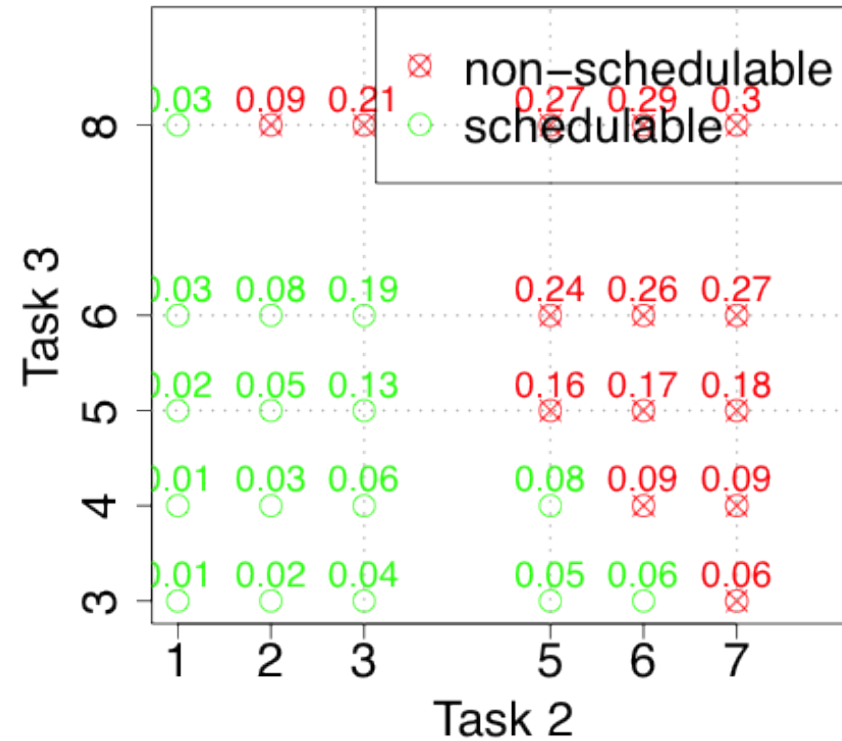
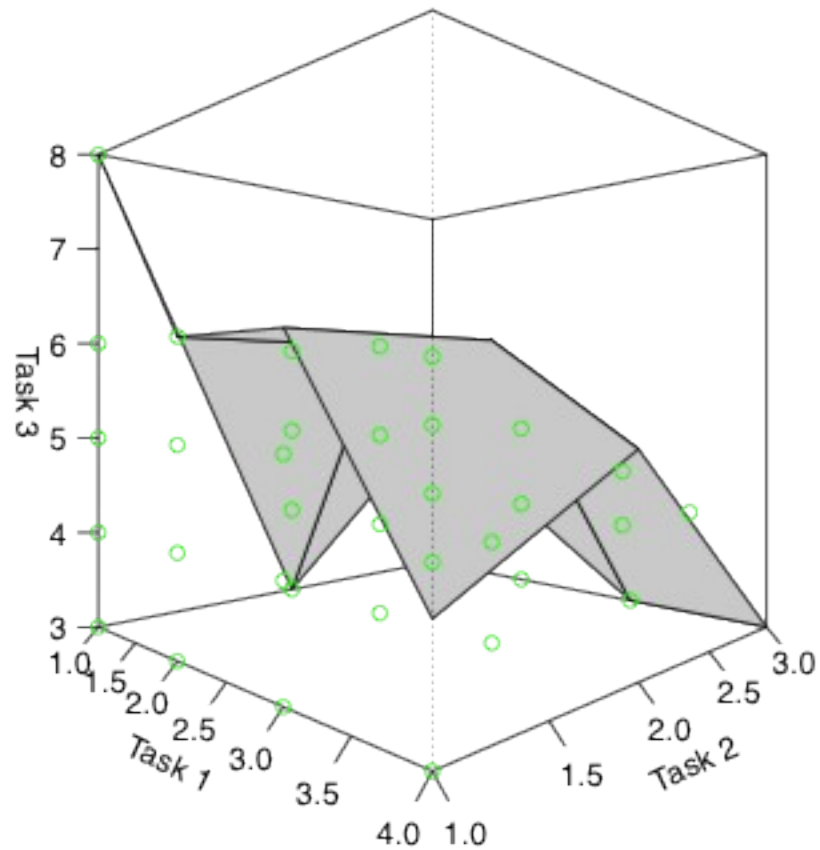
Sensitivity analysis with probabilities

What has been done:

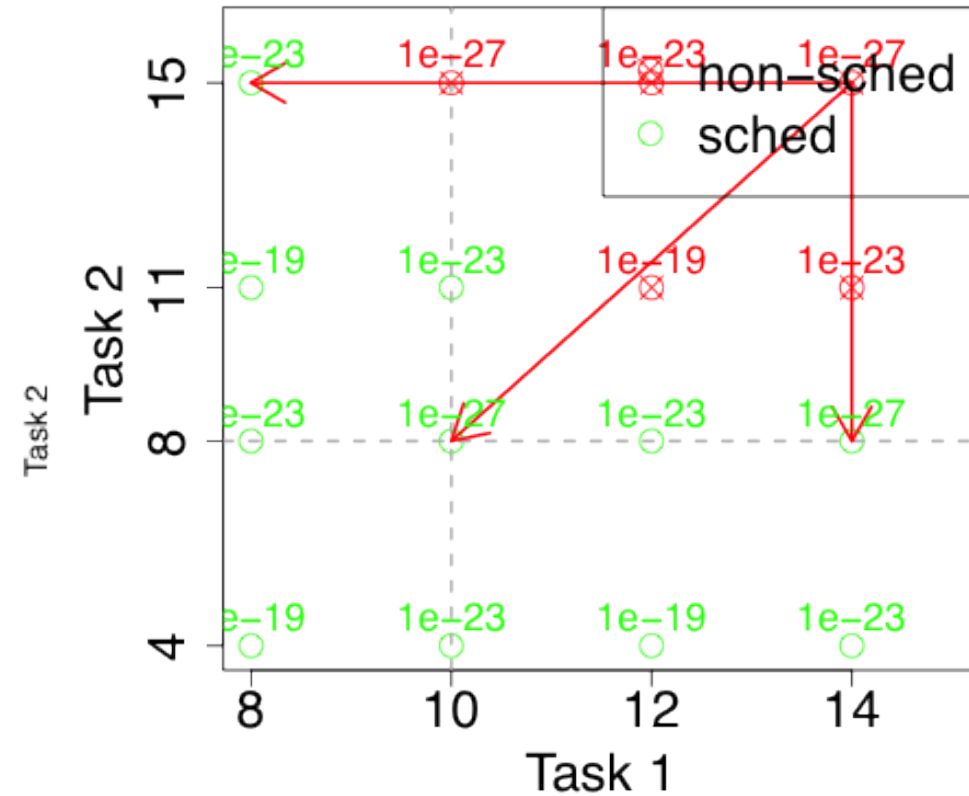
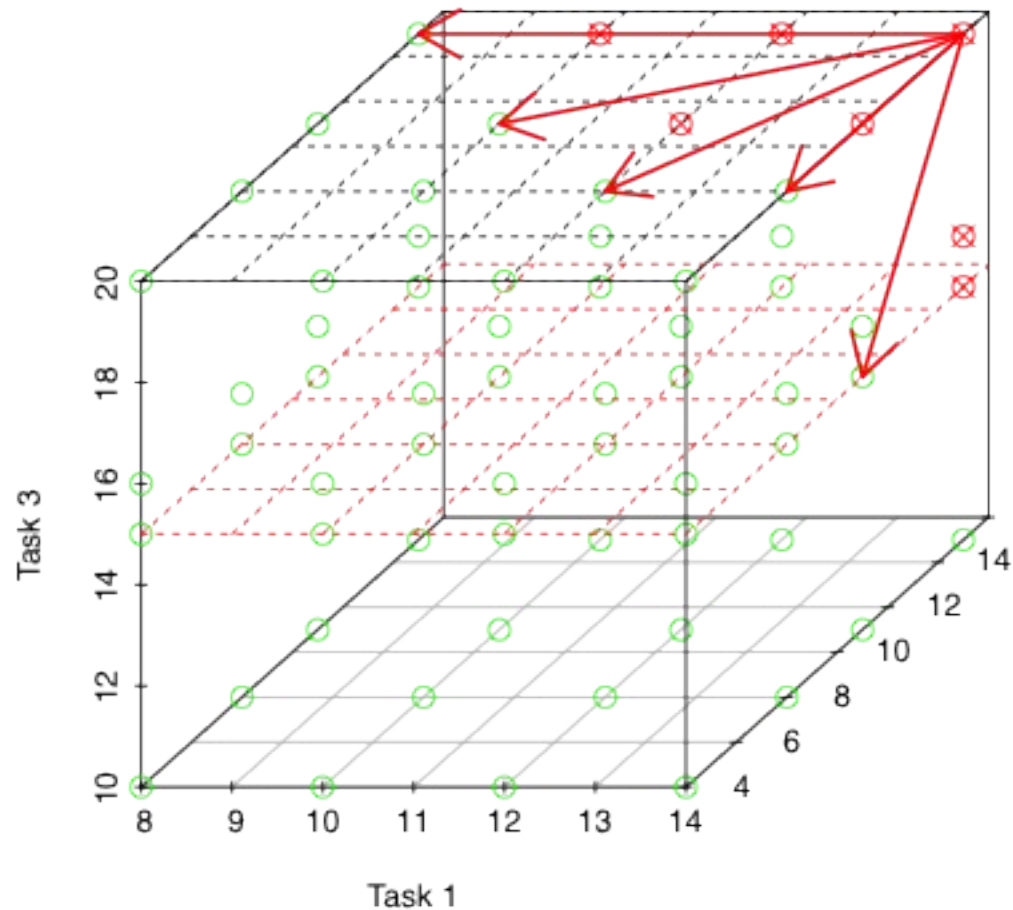
Workshop WMC 2015 – probabilistic C-Space

What else?

Sensitivity analysis with probabilities



Sensitivity analysis with probabilities



Open Problems

Probabilistic mixed-criticality

Mixed-criticality with probabilities

What has been done:

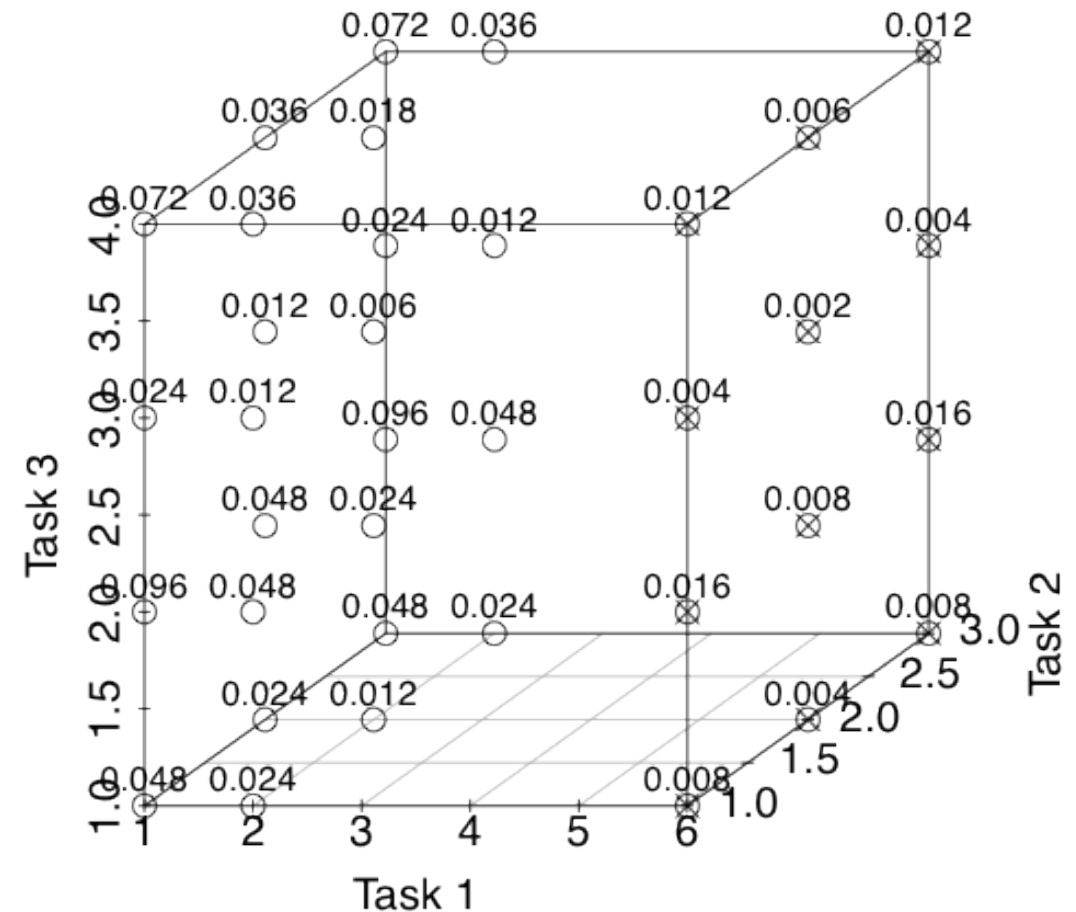
RTCSA 2015 - pWCET and more, WCET 2015 - WCET
and mixed criticality

What else?

Mixed-criticality with probabilities

$pWCET(hi)$, $pWCET(lo)$
 $WCET(lo, pWCET)$, $WCET(hi)$

Mean Time To Failure
 Independence



Thank you
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