A Framework For The Evaluation Of Measurement-based Timing Analyses

Benjamin Lesage, David Griffin, Frank Soboczenski, Iain Bate, Rob Davis

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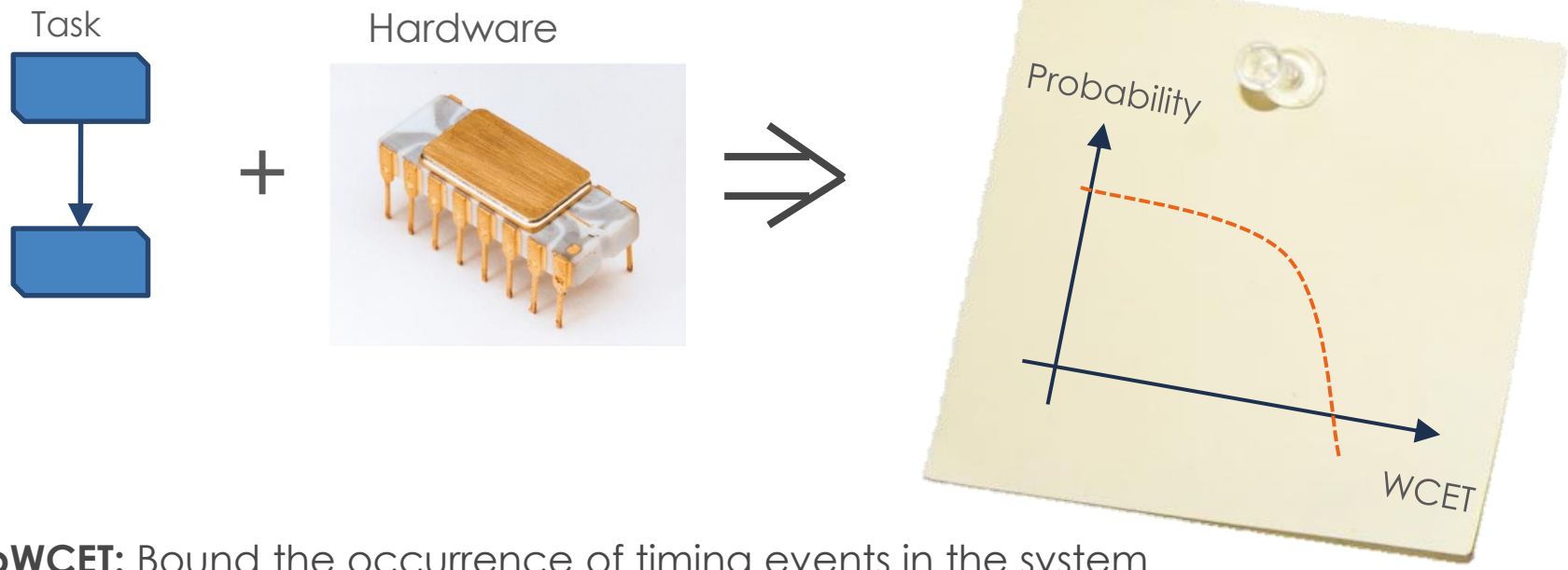
UNIVERSITY of York

PROXIMA

Context

pWCET estimation



- **pWCET:** Bound the occurrence of timing events in the system
  - WCET with attached exceedance probability
  - **Sound**: Upper-bound the actual execution time
  - **Tight**: Close to the actual execution time

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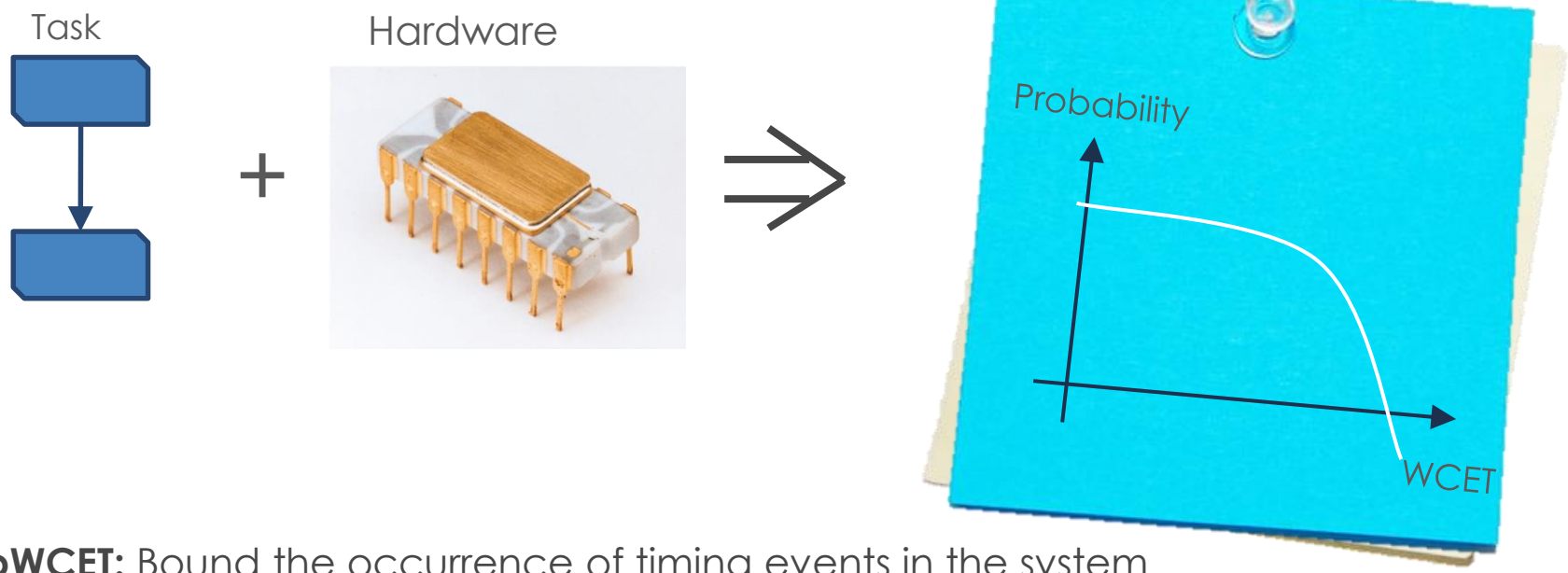

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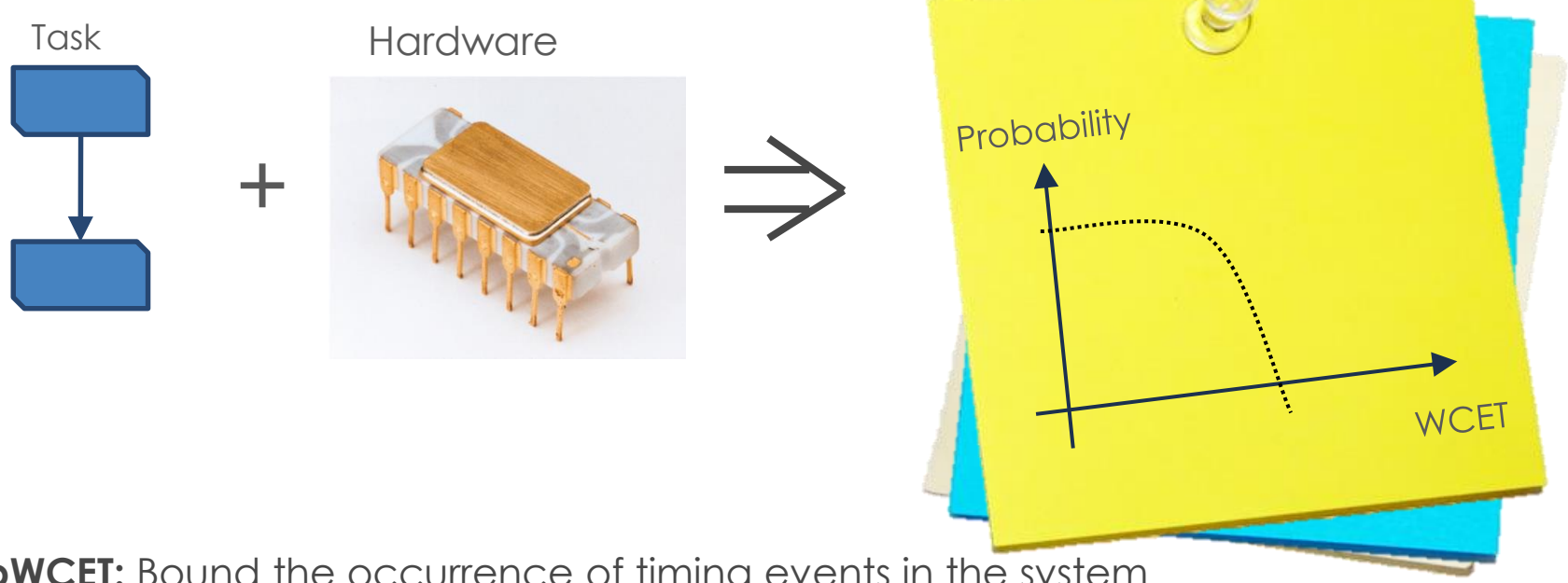

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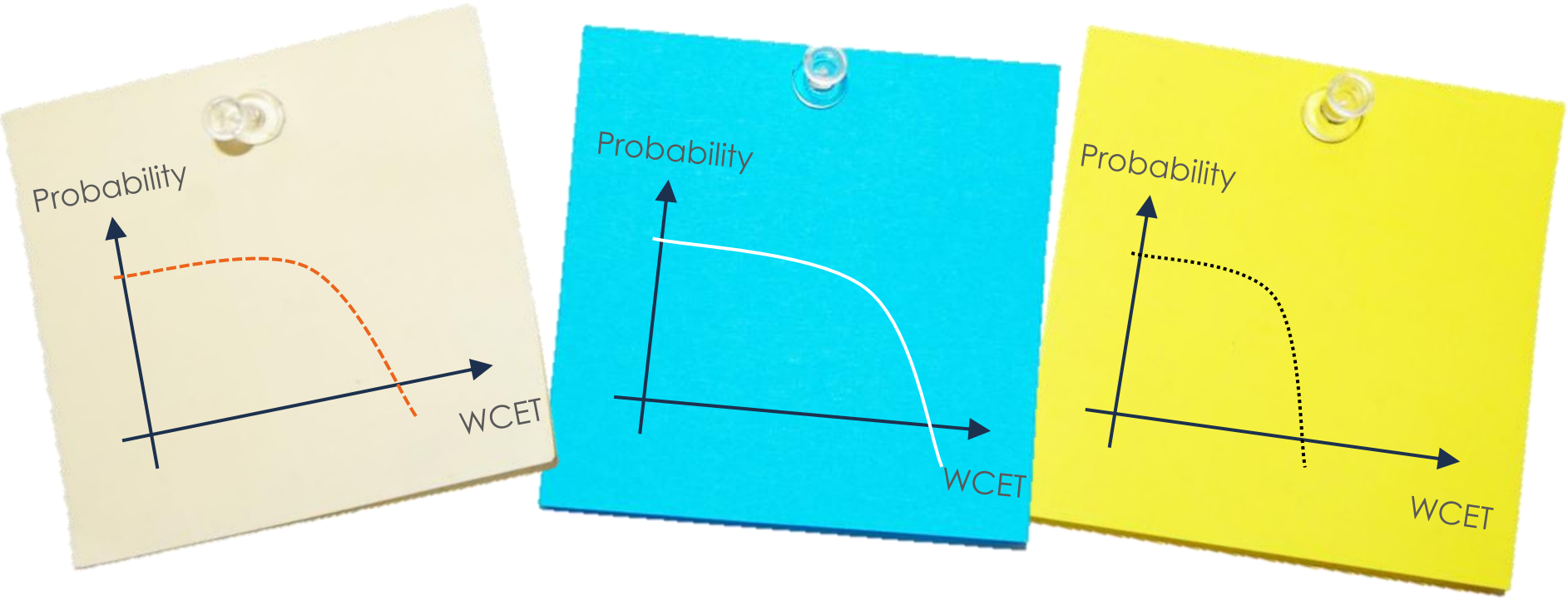
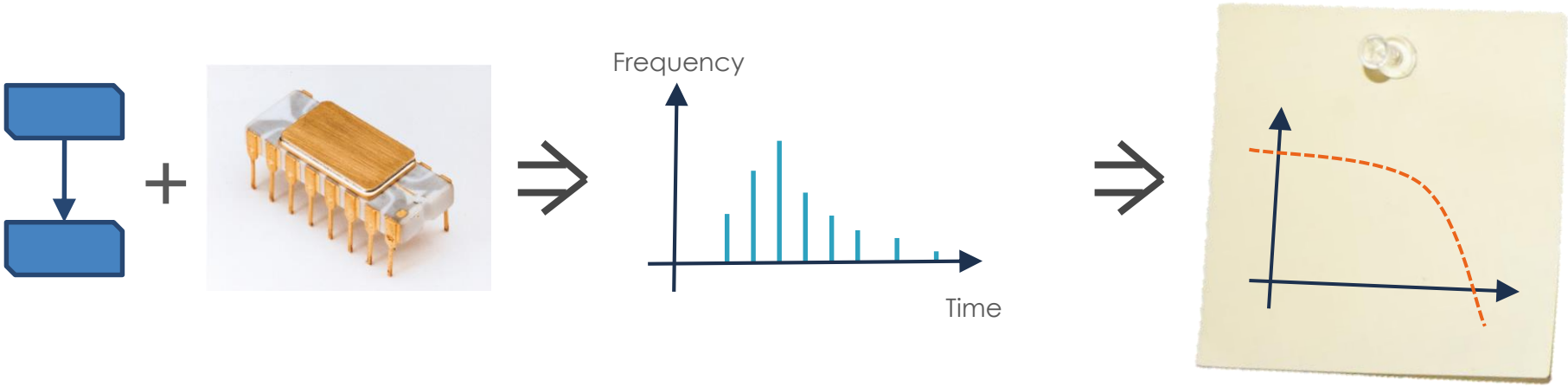


- **Sound** and **Tight** comparisons are difficult without a ground truth
  - Smaller estimates may be optimistic
  - Larger estimates may be pessimistic

Context

MBPTA – Measurement Based Probabilistic Timing Analysis [ECRTS 2012]

- **MBPTA**: derive a pWCET from runs of the analysed task
  - Predicts the tail of the pWCET using Extreme Value Theory
- Abstraction from the analysed platform and task
  - Sources of execution time variability must be bounded
  - Analysed samples must cover all paths in the application



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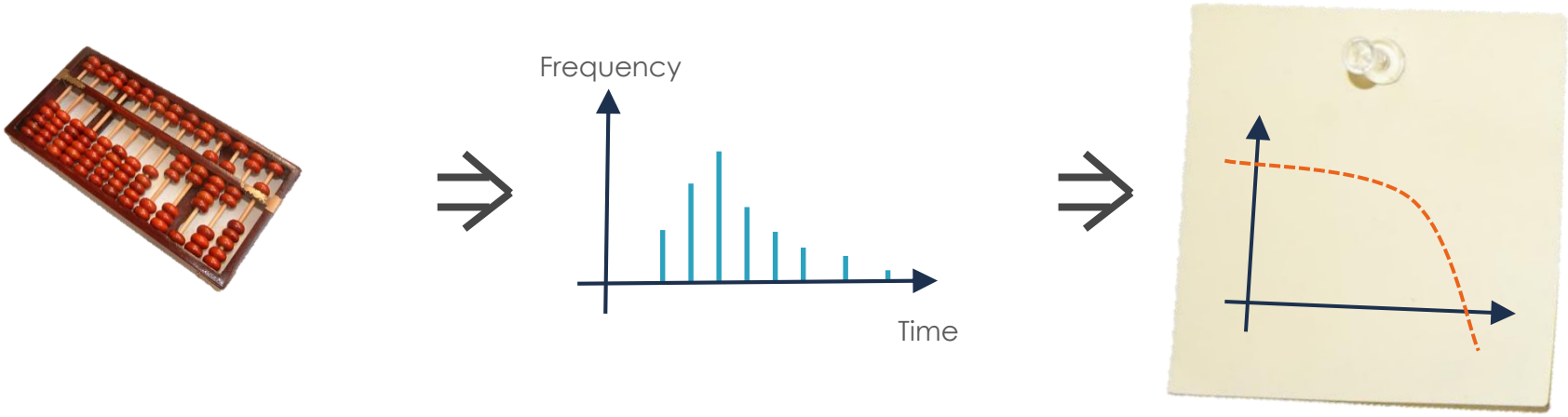

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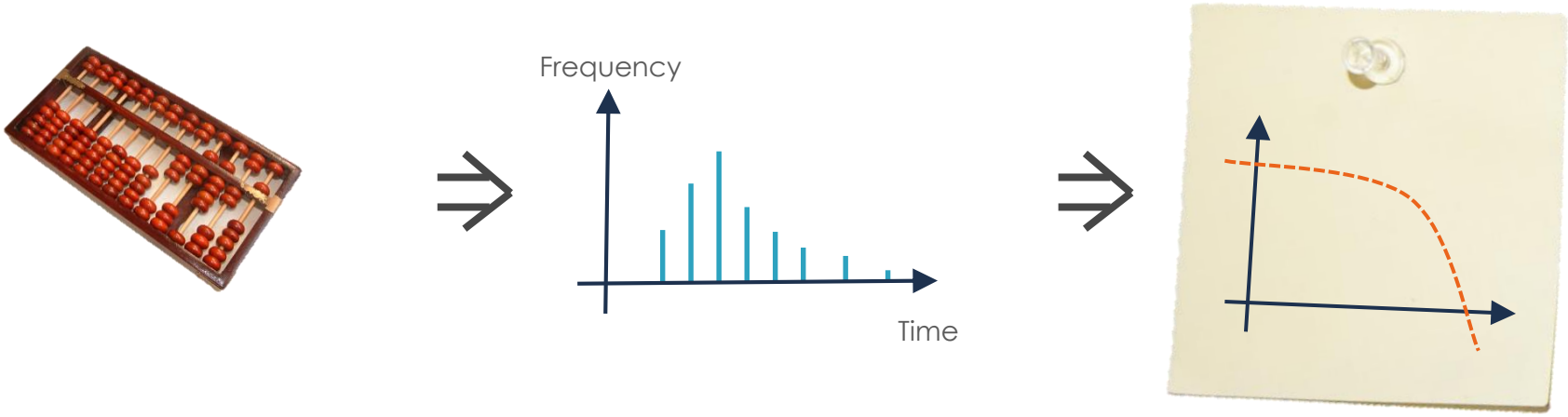
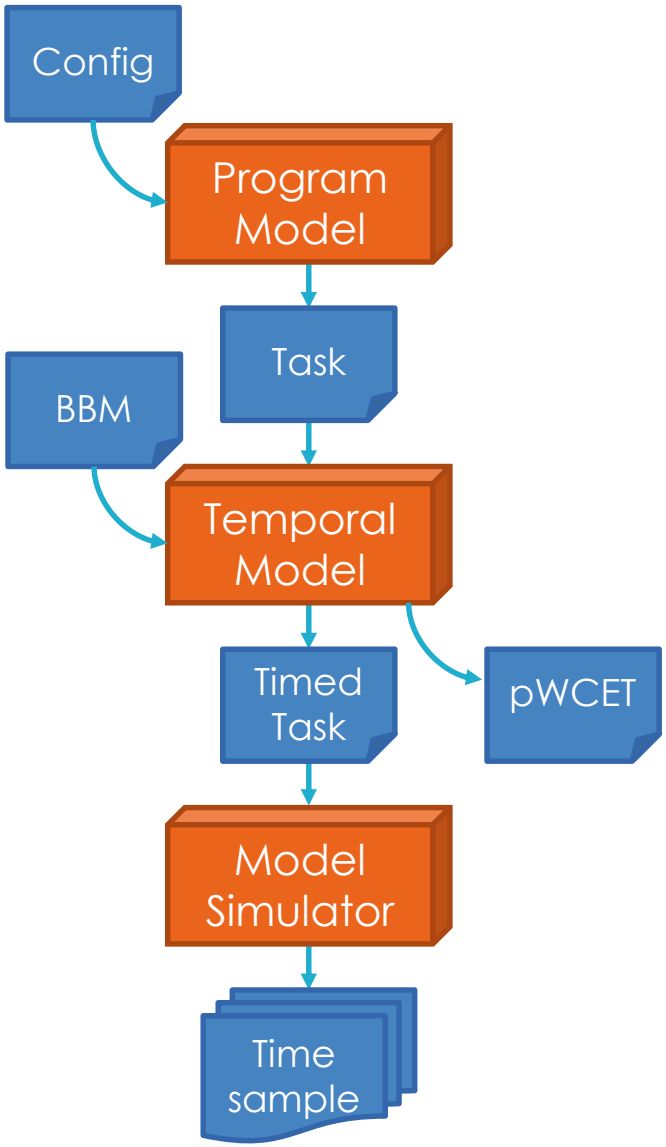


Framework for the evaluation of MBPTA

Overview



- **Program model:** Generate the structure of a task
  - Configured by the end-user
- **Temporal model**: Attach temporal information to blocks
  - Relies on **Basic Block Measurements**
  - Abstractions allow exact pWCET computation
- **Model simulator**: Collection of time samples
  - Controlled to satisfy coverage requirements
  - Samples fed to the Timing analysis

Outline

- Context
- Framework for the evaluation of MBPTA
  - Temporal Model
  - Task
  - Program Model
  - pWCET
  - BBM
- Evaluation
- Conclusion

Framework for the evaluation of MBPTA

Independent Block Model

- **Basic block**: sequence of instructions with a single entry/exit

- The behaviour of a block depends on the **platform P** and its **state s**

P(b ,s) = (t', s')

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Independent Block Model

- **Basic block**: sequence of instructions with a single entry/exit

- The behaviour of a block depends on the **platform P** and its **state s**

P(b ,s) = (t', s')

- Sources of execution time variability must be bounded
  - Through **probabilistic** or deterministic mechanisms
  - Contributes to the independence of blocks' behaviour
- Focus on path coverage requirement

Framework for the evaluation of MBPTA

Independent Block Model

- **Basic block**: sequence of instructions with a single entry/exit

- The behaviour of a block depends on the **platform P**
  - Captured by an Execution Time Profile: $\boldsymbol{ETP_b}$
  - Independent of the execution history
  - Akin to the output of low-level timing analyses
- **Path**: a finite sequence of basic blocks

  - The **execution time** of a path is the convolution of its components

$$\mathbf{pET}(\pi) = \bigotimes_{b \in \pi} ETP_b$$

Framework for the evaluation of MBPTA

Representing tasks

- **Task**: a finite set of paths
  - Represented as an **Abstract Syntax Tree** (AST)
  - Tree nodes map to syntactic structures in code
  - Leafs map to basic blocks in code

- Capture standard programming patterns
- Ease reasoning about WCET computation

- No arbitrary flow between blocks
- No support for flow constraints

Framework for the evaluation of MBPTA

Generating tasks

- Start from the root of the tree
- Randomly pick node type
  - Selection constrained by user
- Generate relevant node type parameters
- Generate subtree for all node children

Framework for the evaluation of MBPTA

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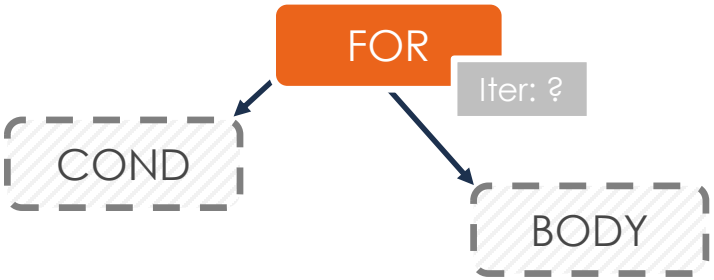

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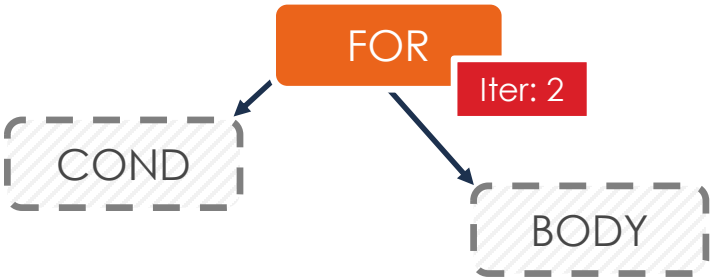

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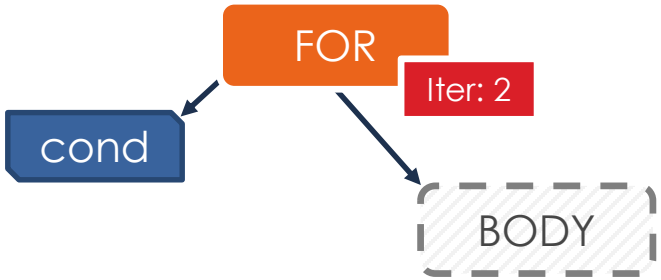

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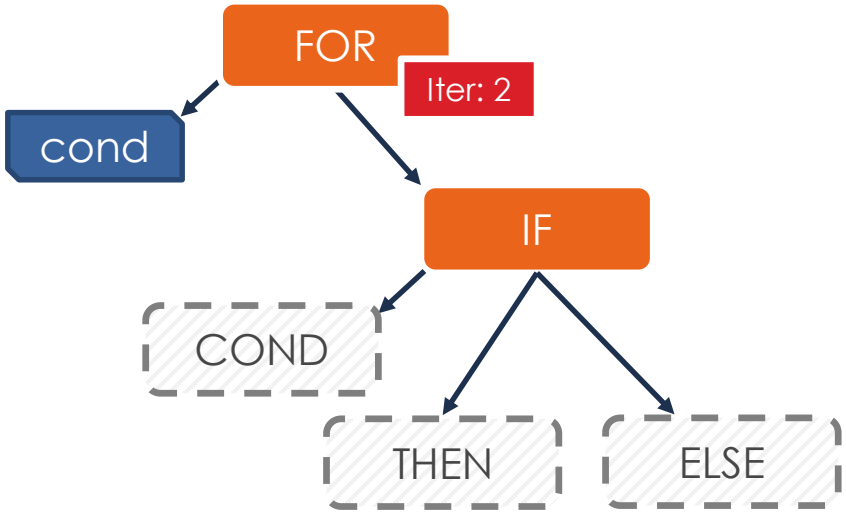

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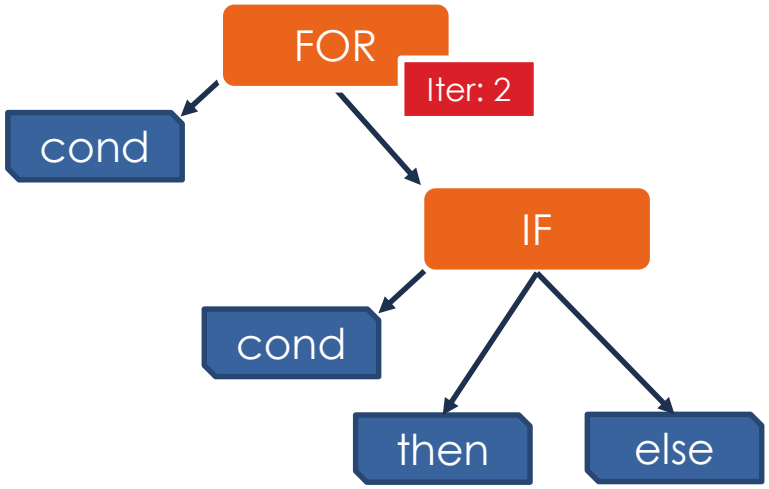

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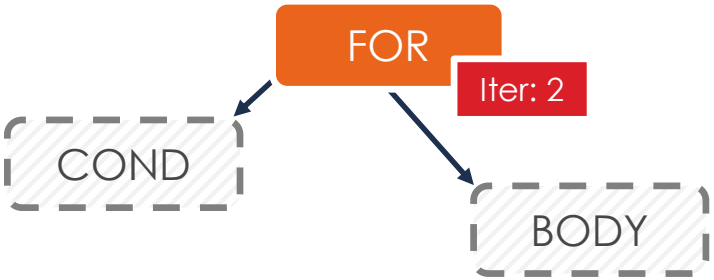
Framework for the evaluation of MBPTA

pWCET computation – An example



- The behaviour of a node is independent of the execution history
  - Both in timings and execution path

Framework for the evaluation of MBPTA

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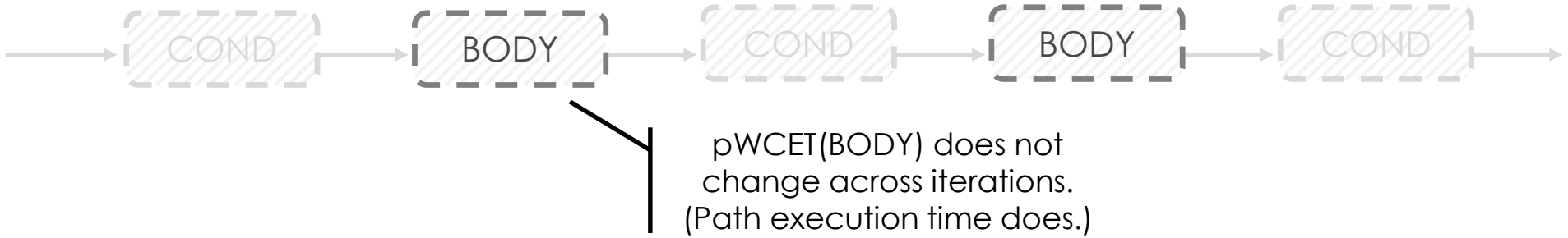

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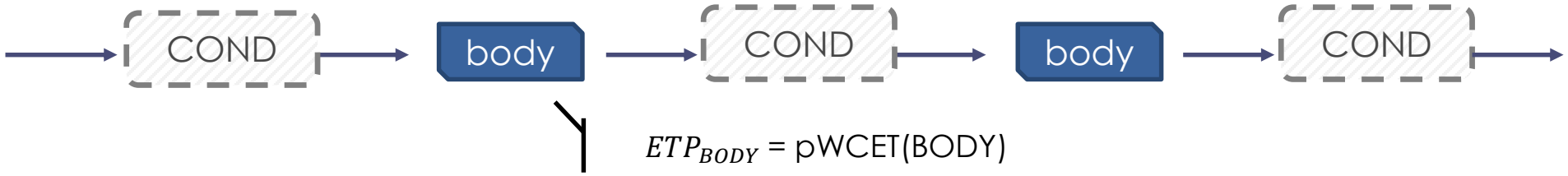

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Framework for the evaluation of MBPTA

pWCET computation – An example

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Framework for the evaluation of MBPTA

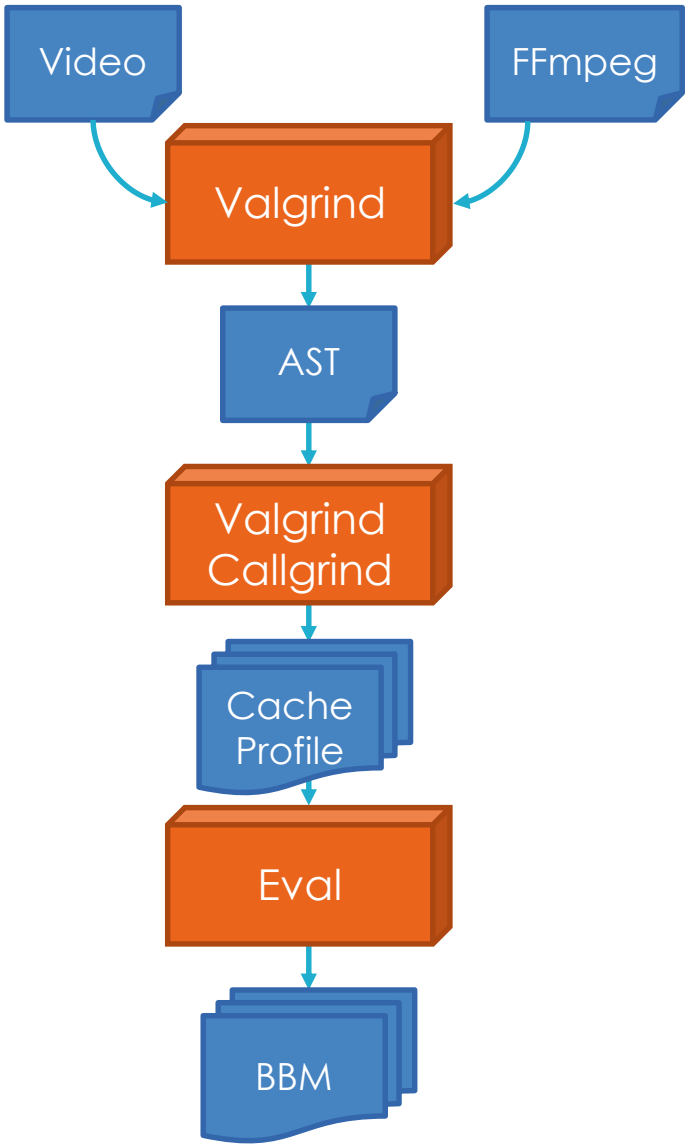
pWCET computation – An example

$$pWCET(LOOP) = pWCET(COND)^{iter+1} \otimes pWCET(BODY)^{iter}$$

- The behaviour of a node is independent of the execution history
  - Both in timings and execution path
- The pWCET of a node is a combination of its children
  - Similar to tree-based WCET computation
  - Relies on convolution (⊗) and envelope (⊔) operations

Framework for the evaluation of MBPTA

Gathering basic block measurements (BBM)



- Capture timings off a real application
  - Ensure representative low level timings
  - Assume independence of blocks
  - Assume covering observations
- Extract the structure of the application
  - **Valgrind** Instrumentation framework
  - Extract traces of memory accesses
- Collect cache hits/misses at the block level
  - **Callgrind** instrumentation tool
  - Simulate a randomised memory hierarchy
  - Satisfy architectural requirements of MBPTA
  - Capture probabilistic profiles
- Instrument **FFmpeg** h264 decoding primitive
  - Readily available input vectors
  - Vast array of basic block profiles

Evaluation

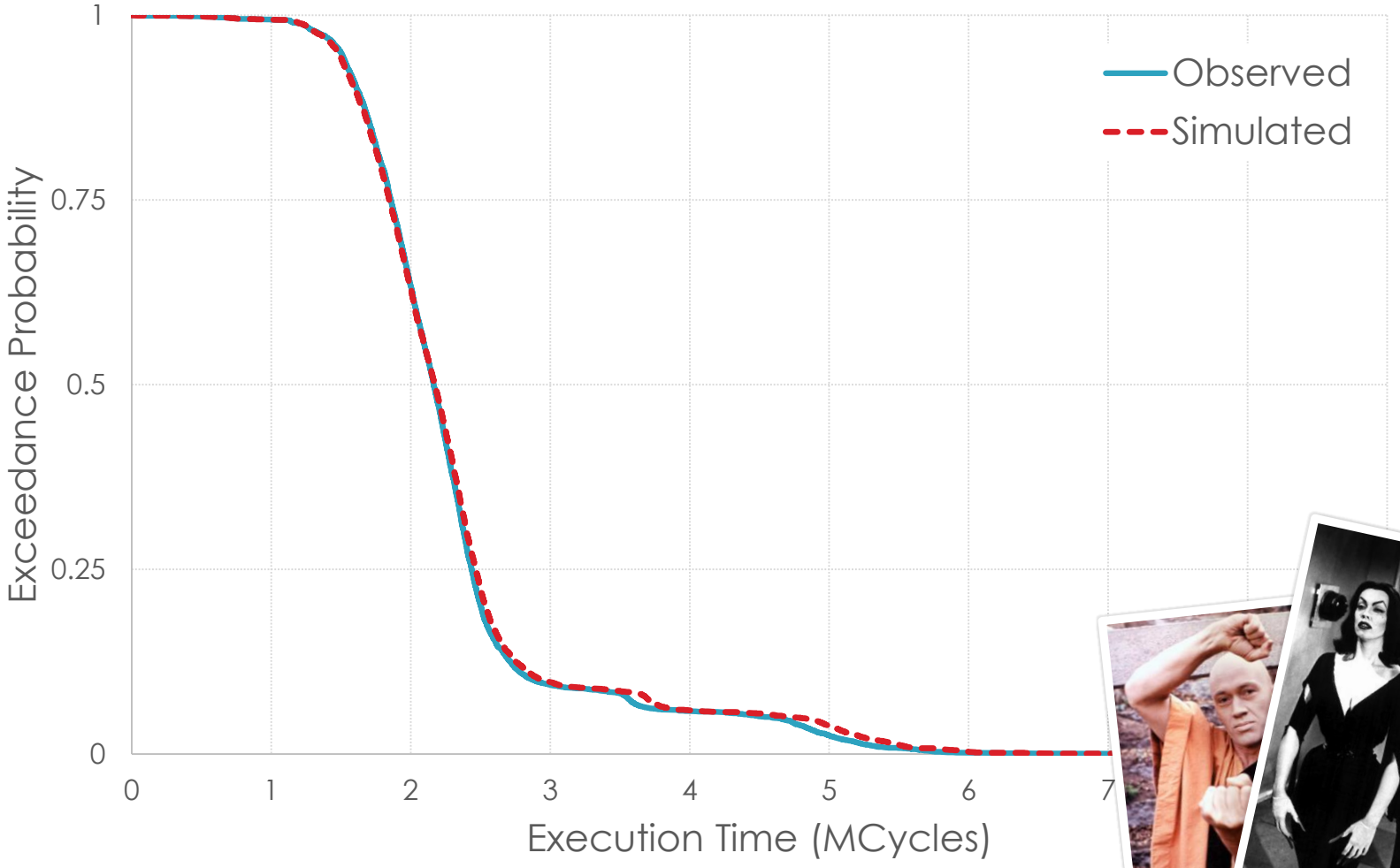
Realism – Experimental conditions

Does the framework produces realistic execution time traces ?

- Compare observed and simulated execution times
- **Observed**: Collect execution time and path for each run
  - Build BBM of blocks across all runs
  - Process ≈8000 frames per input vector
- **Simulated**: Simulate each observed path in the framework
  - Pick execution times in traversed BBM
  - Ignore dependencies between traversed blocks
- Input vectors from the archive.org movie database

Evaluation

Realism - PLAN



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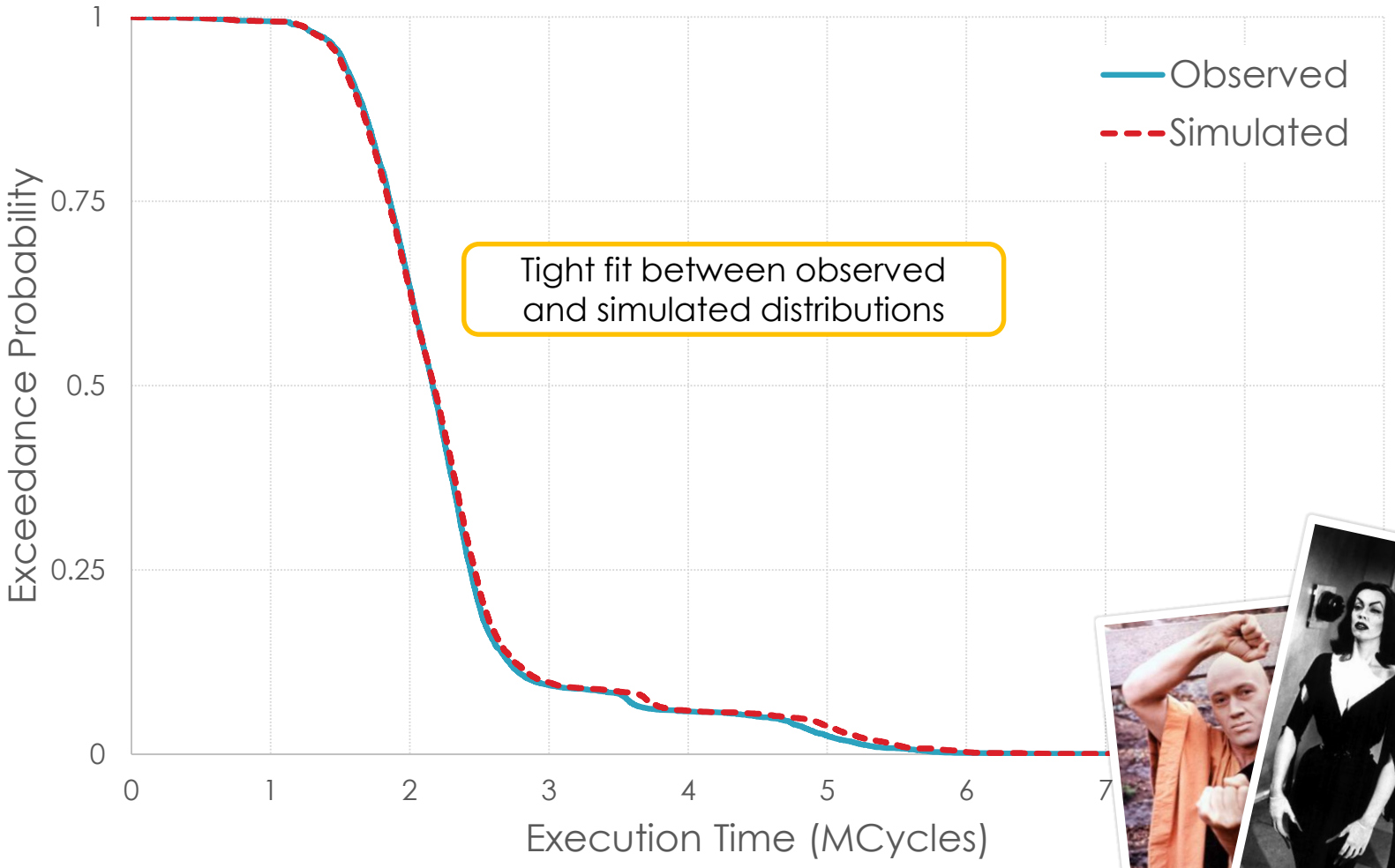

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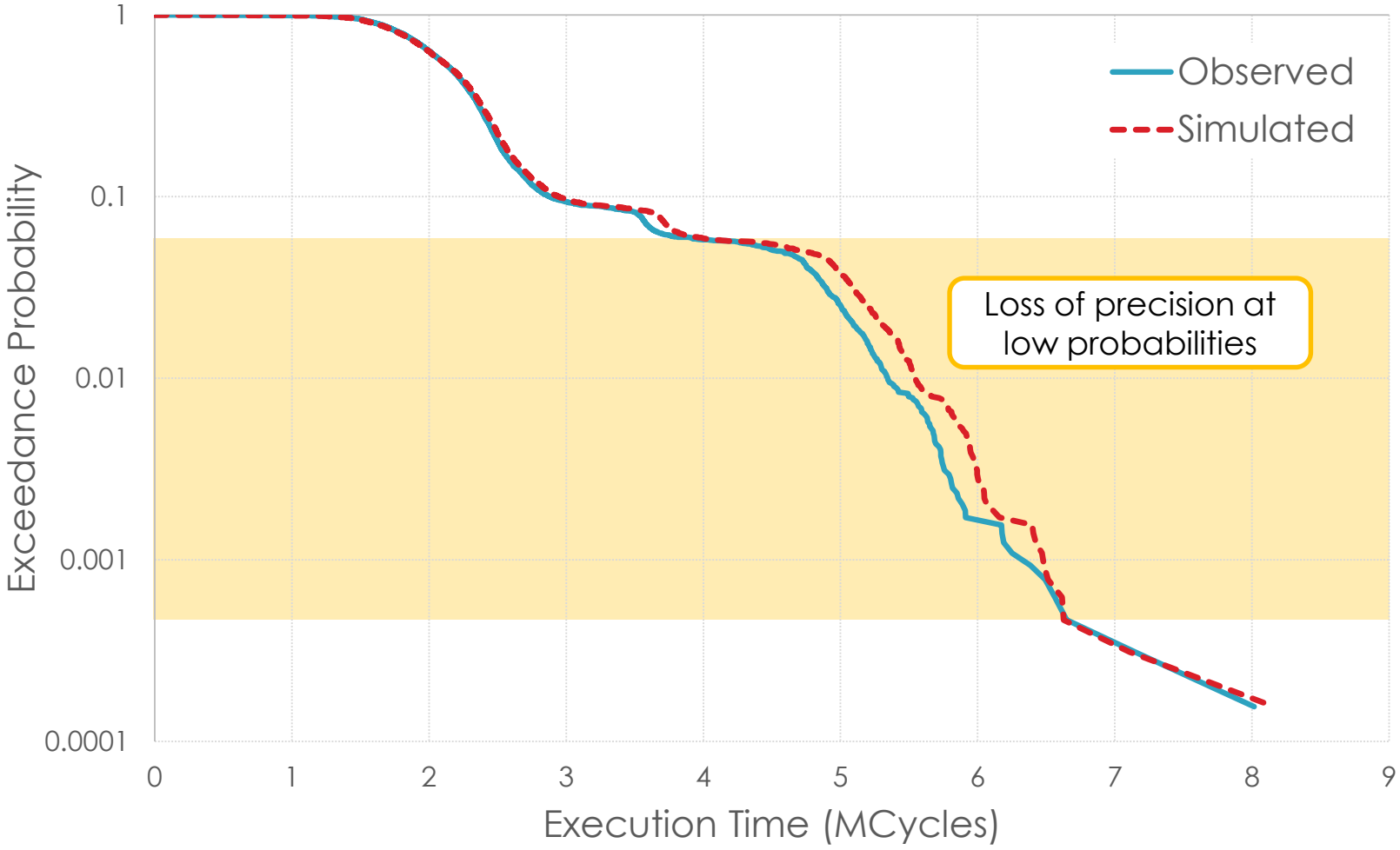

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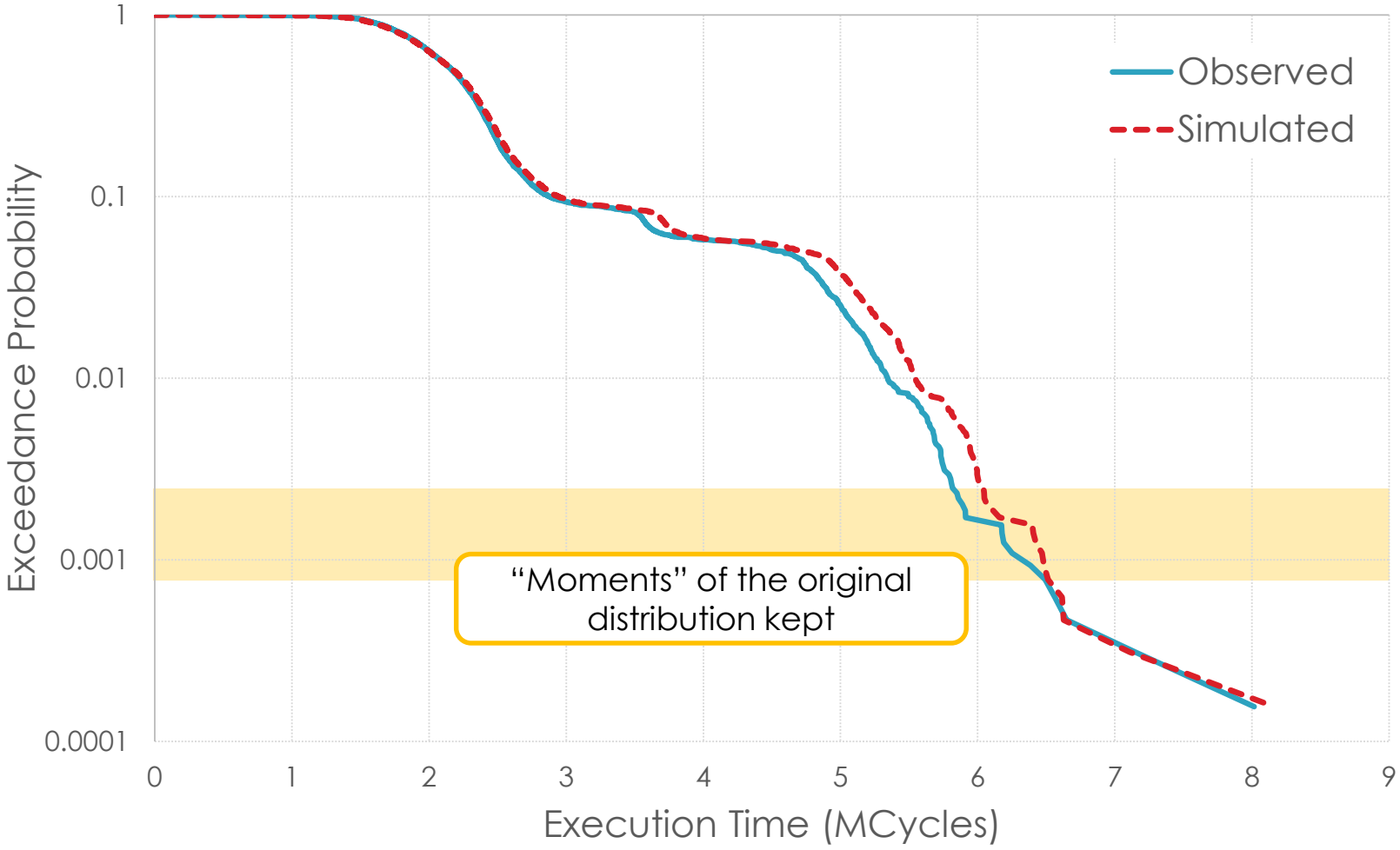

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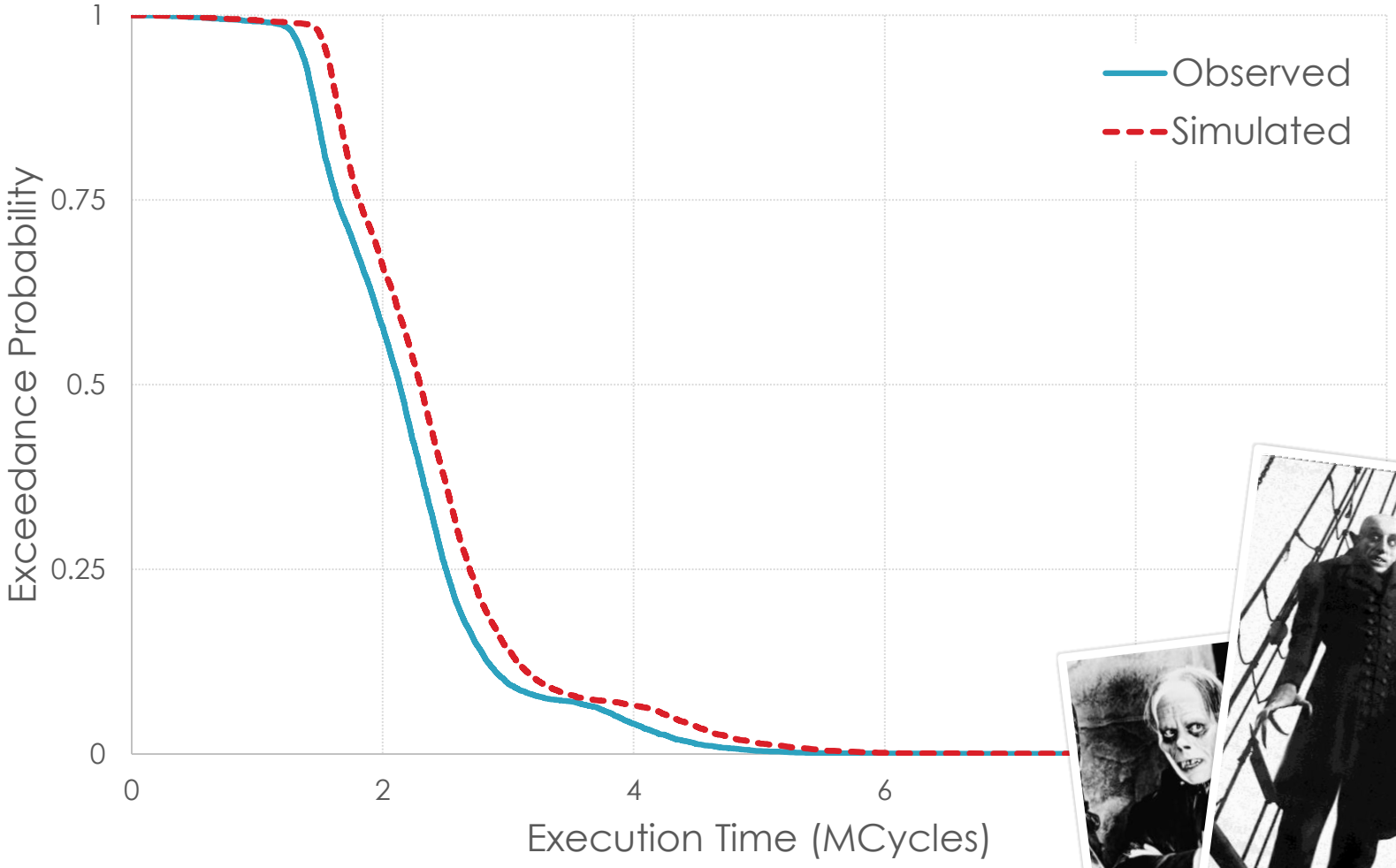

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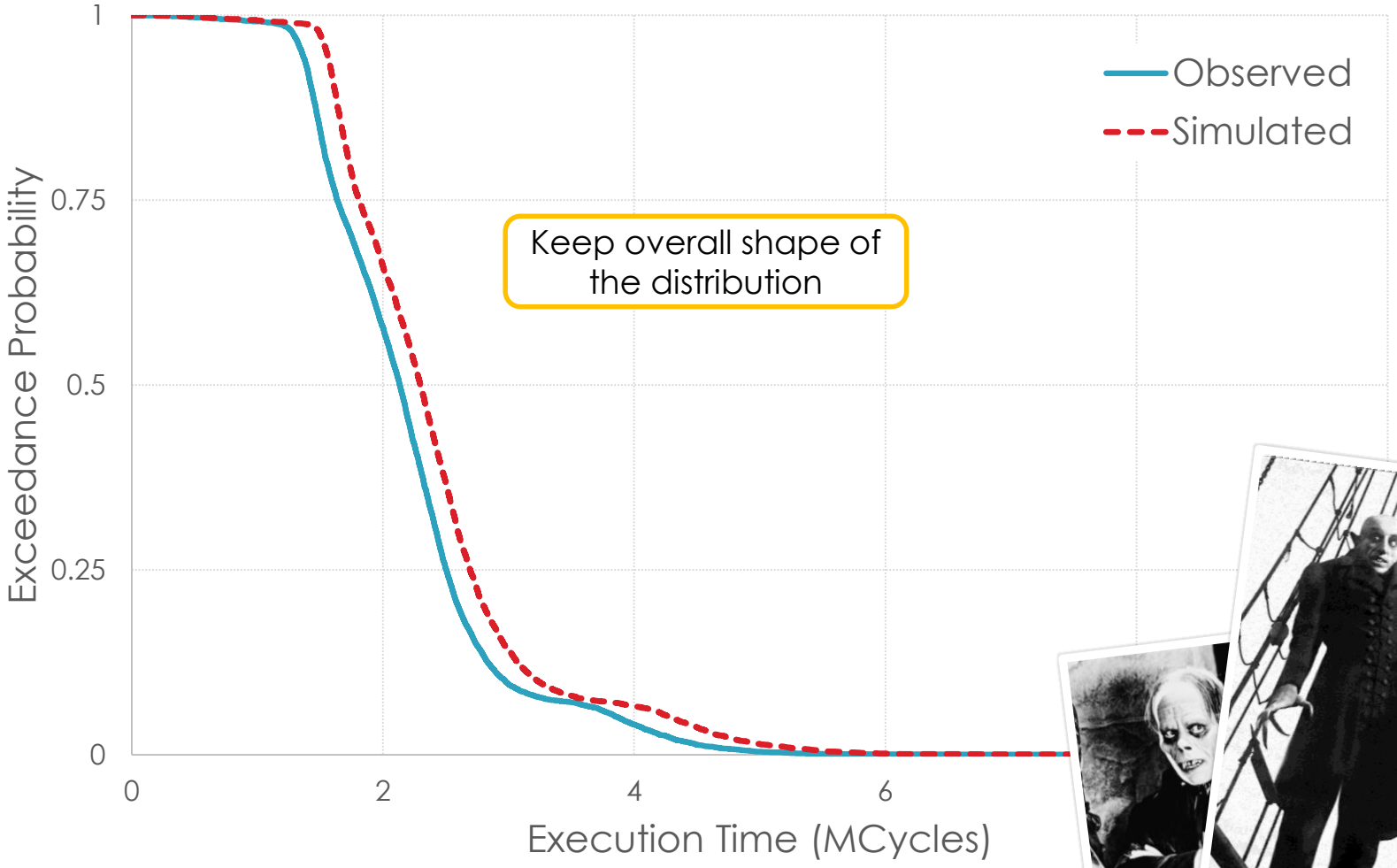

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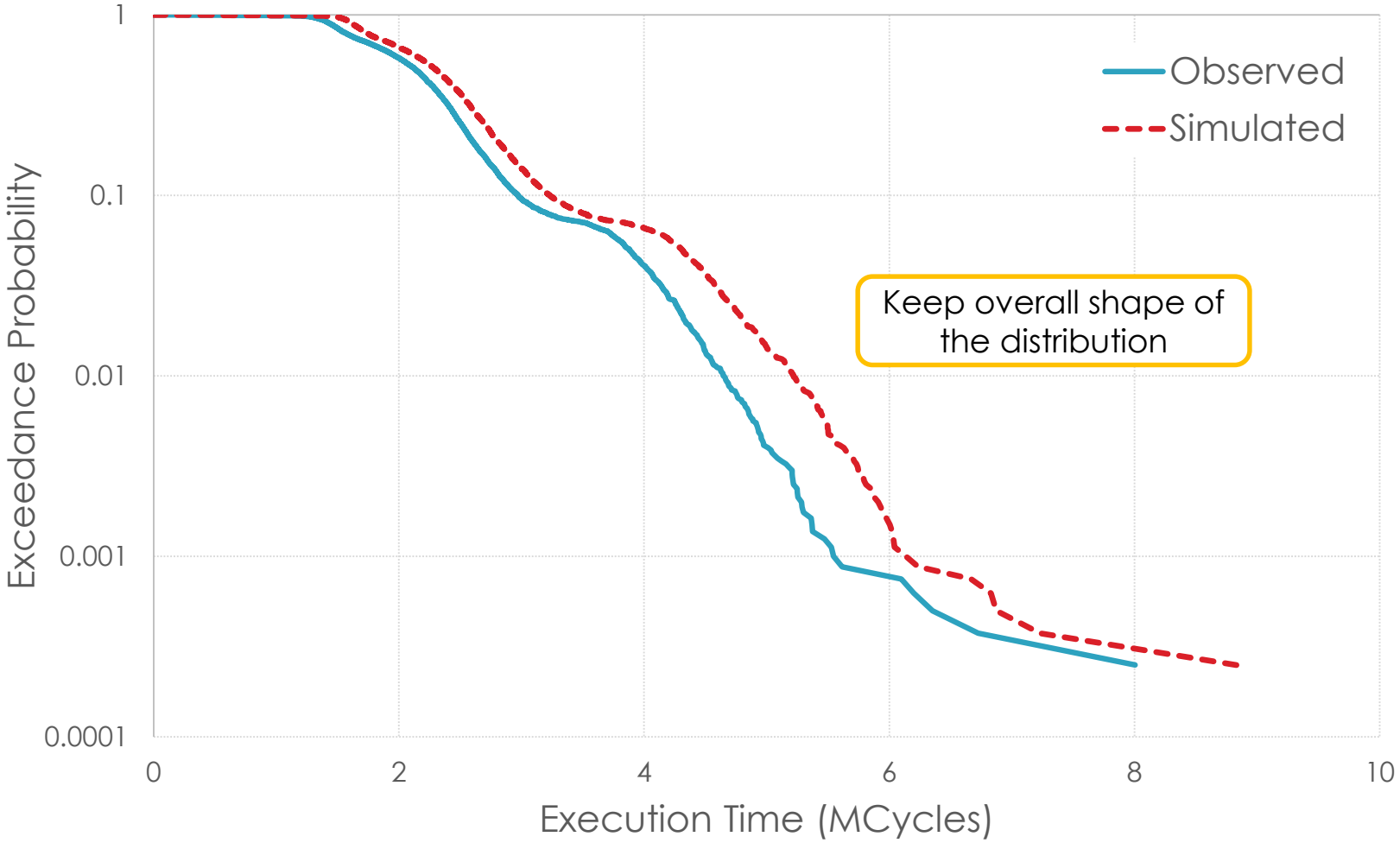


Evaluation

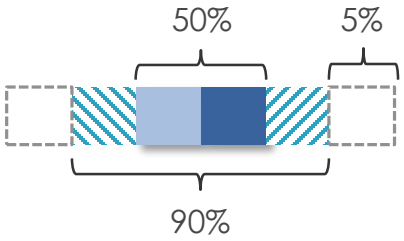
Robustness - Experimental conditions

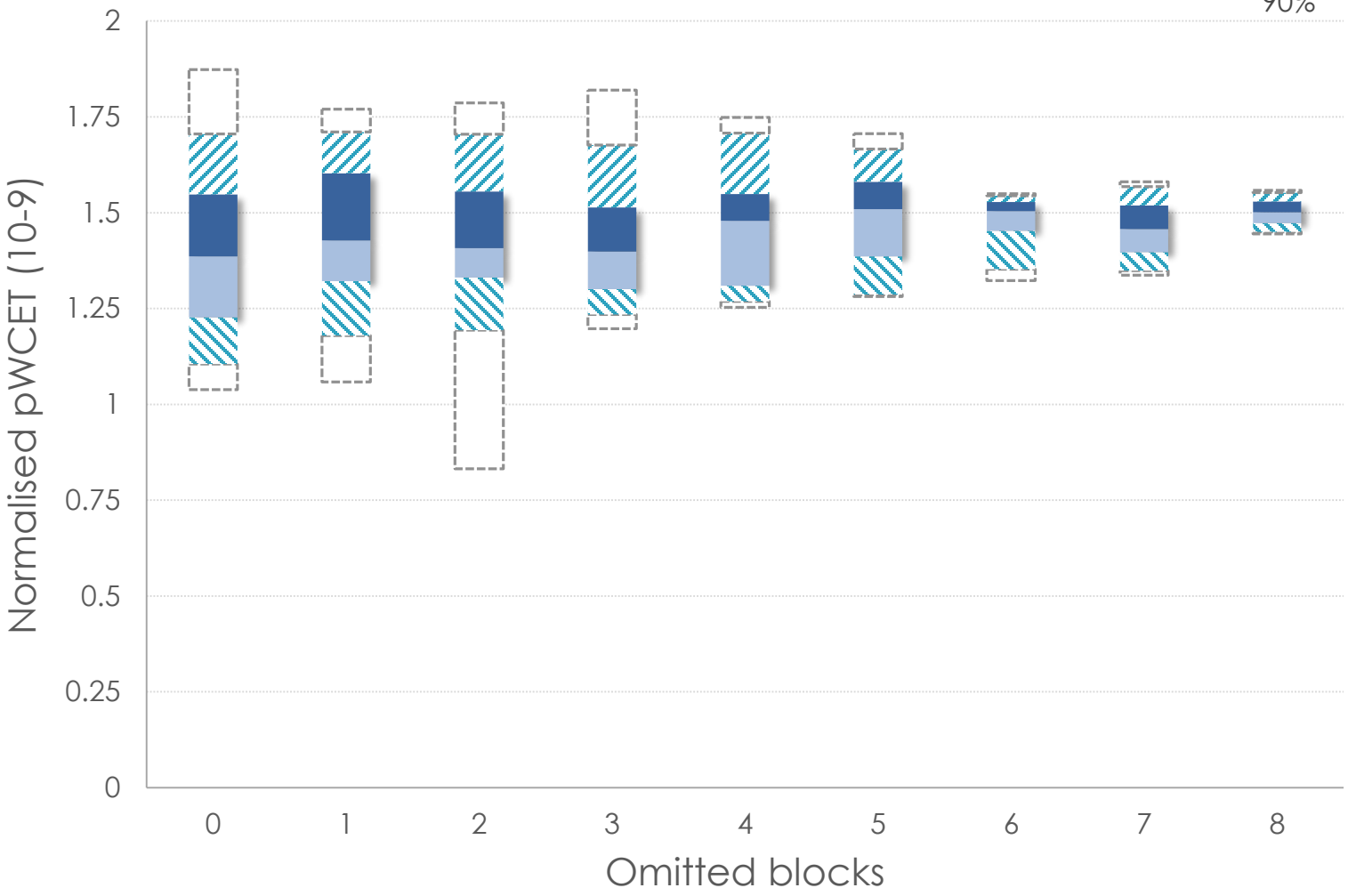
How robust is MBPTA in the absence of path coverage ?

- Compare predicted and exact pWCET
  - Metric: Normalised pWCET at 10^{-9} (over exact value)
- Control coverage of samples fed to the analysis
  - Enforce path coverage during simulations
  - Randomly ban nodes in the AST
  - Only ban non-dominating nodes
- 100 randomly generated tasks
  - Pick ETP in BBM database
  - 8000 runs per sample
  - Remove tasks with un-coverable path set
  - 2 samples per task/per experiment

Evaluation

Robustness - Results





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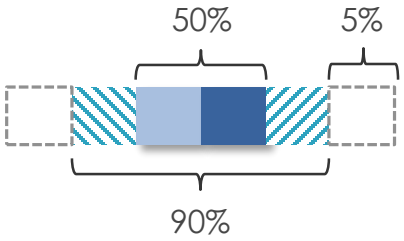

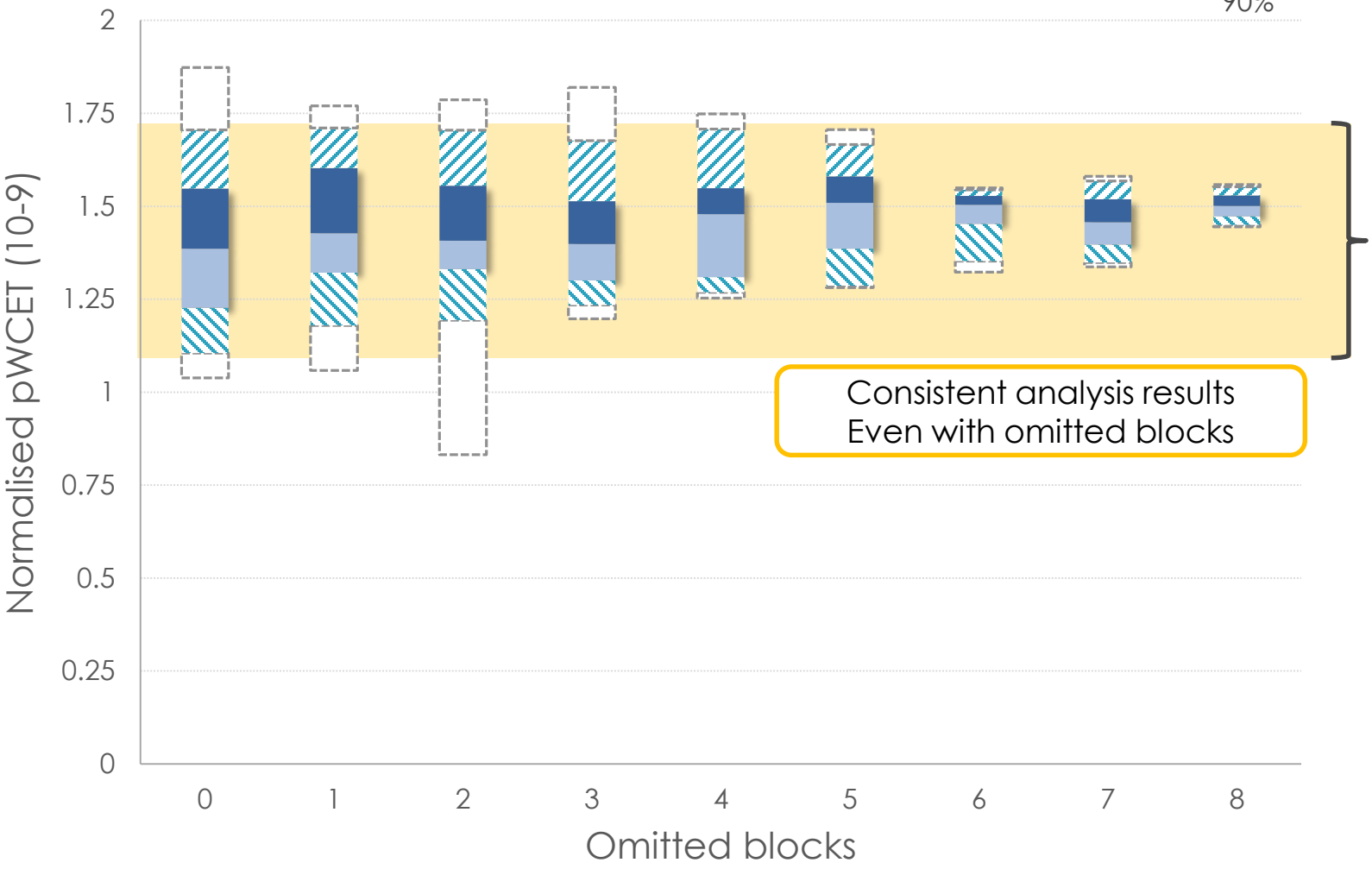

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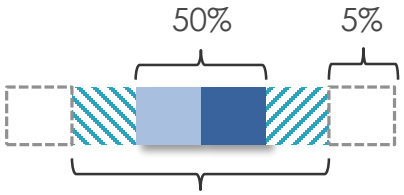

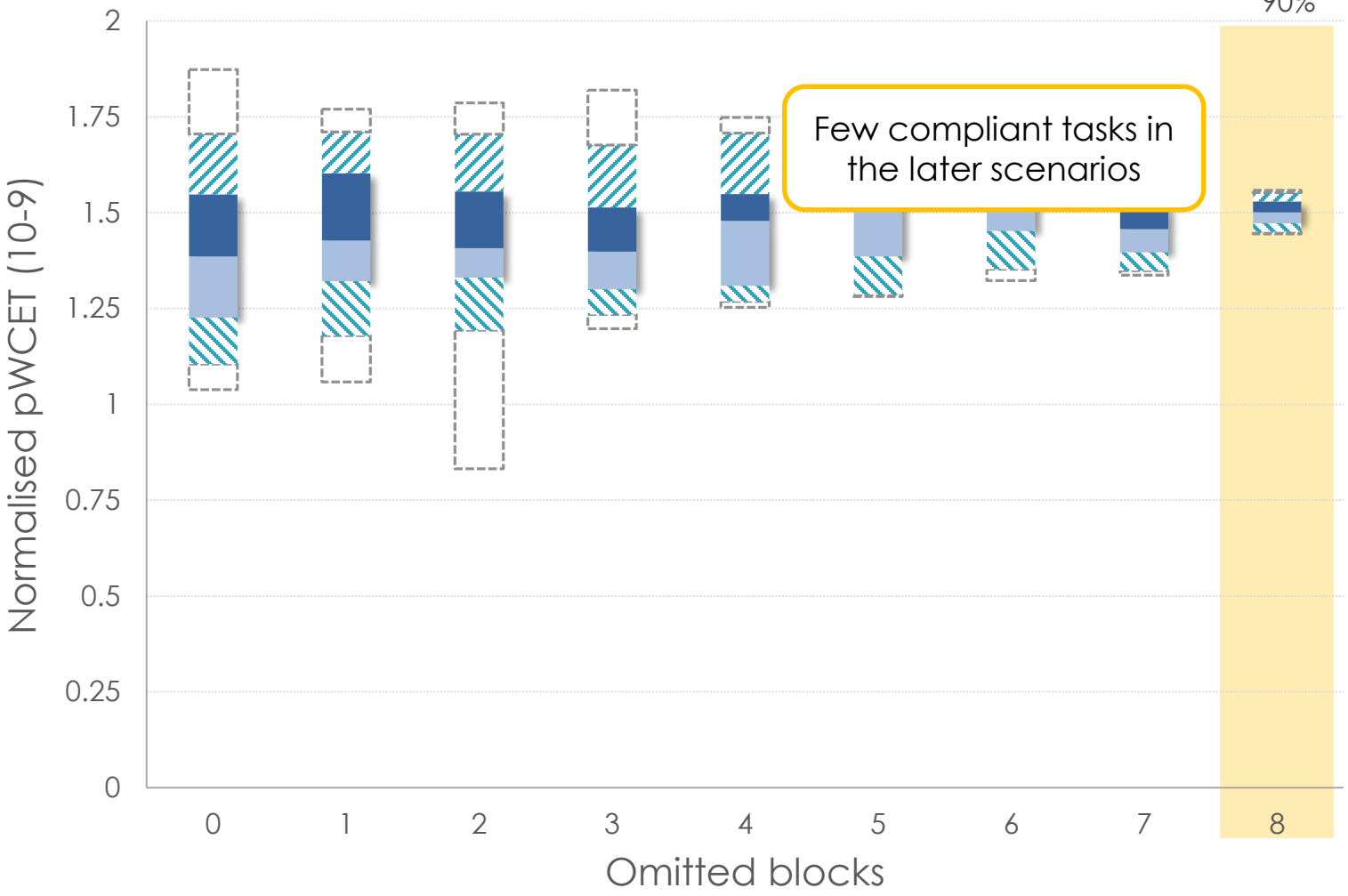

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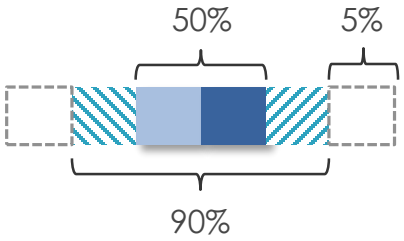

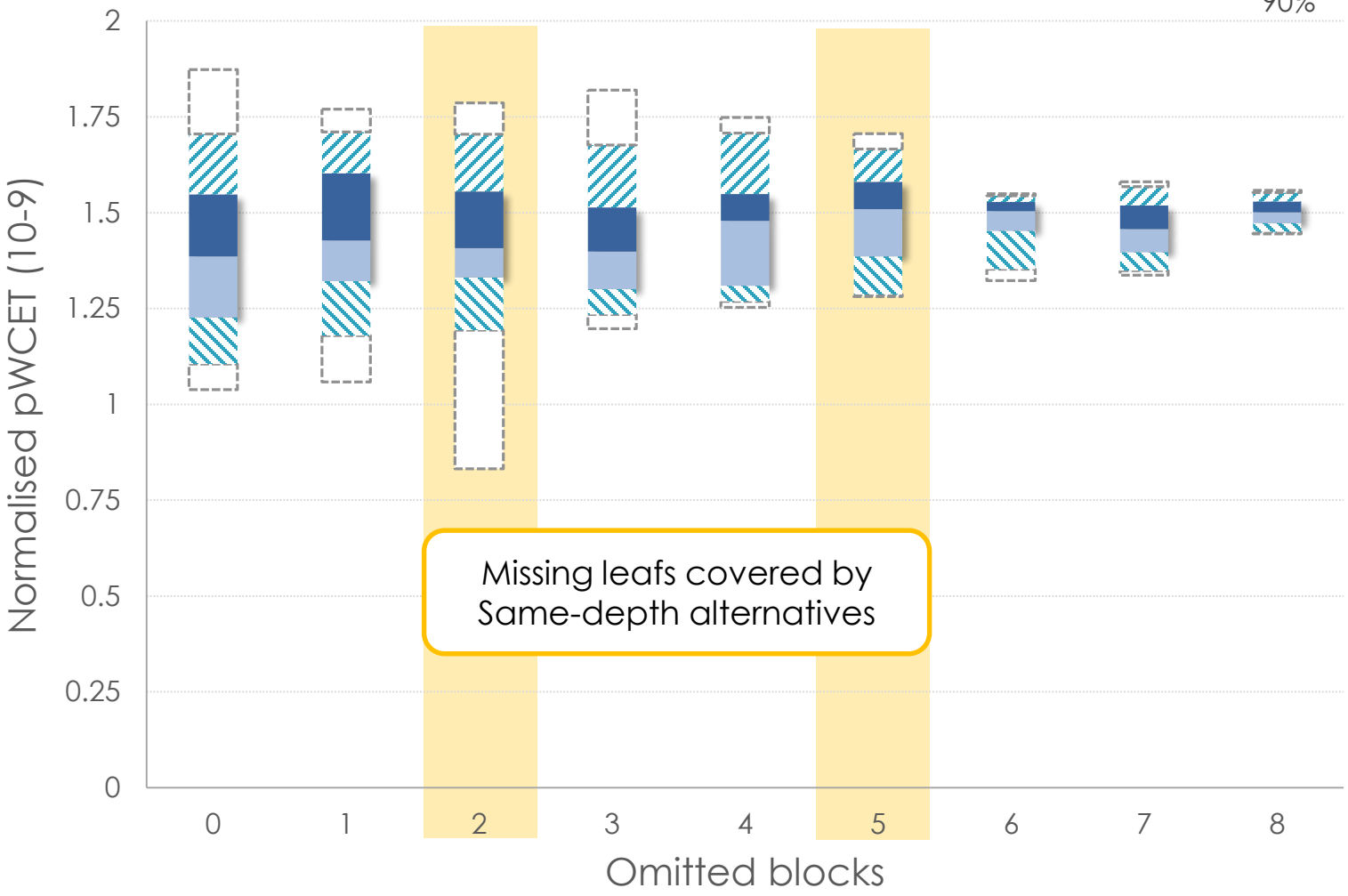

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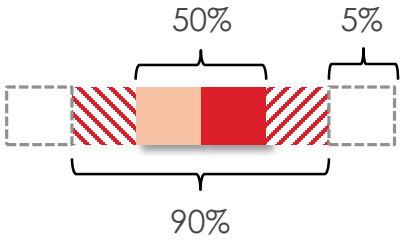

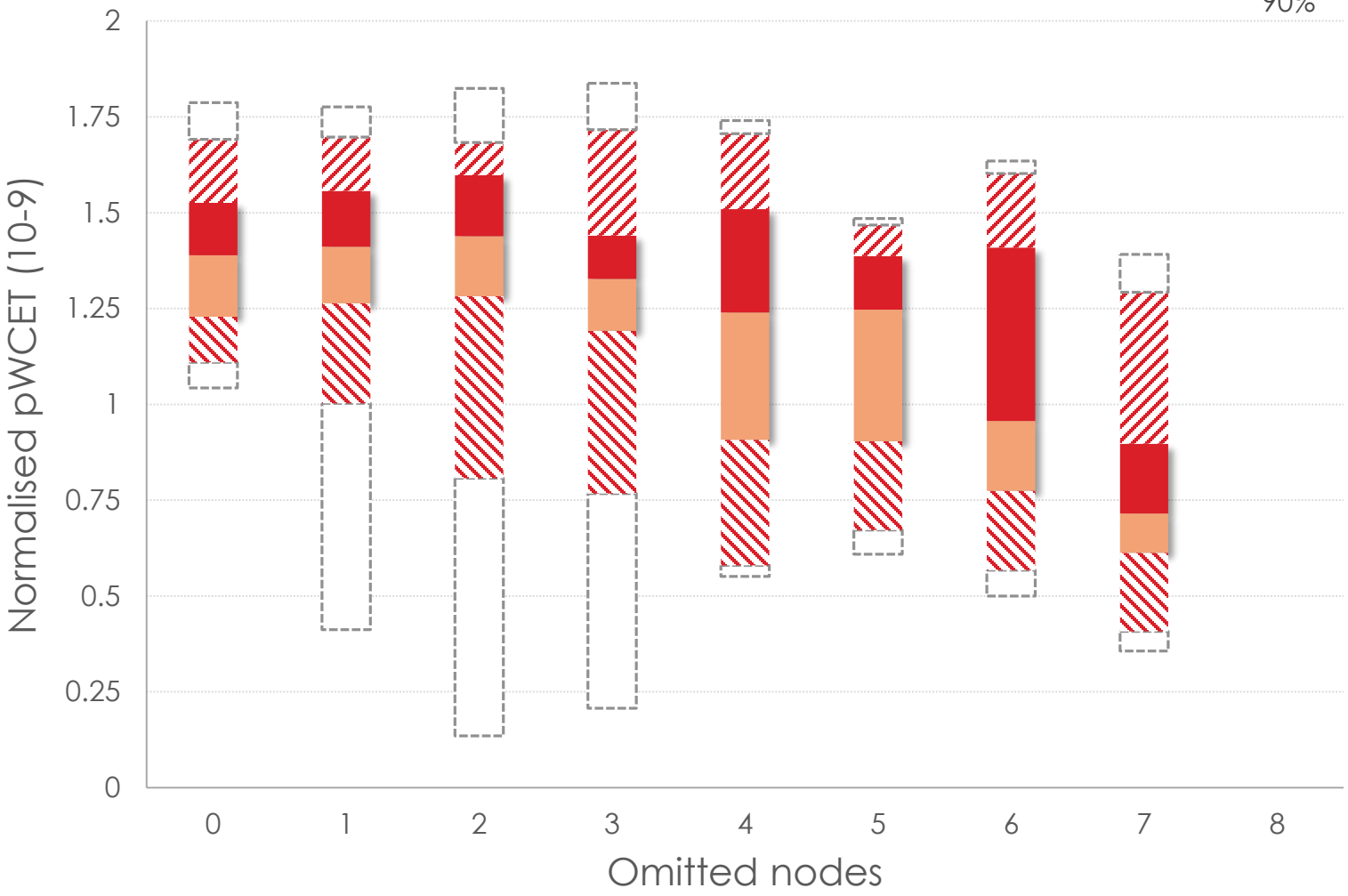

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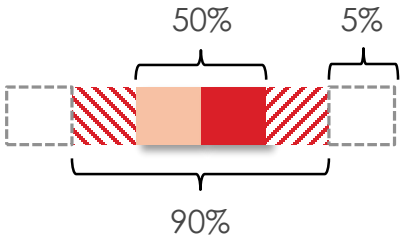

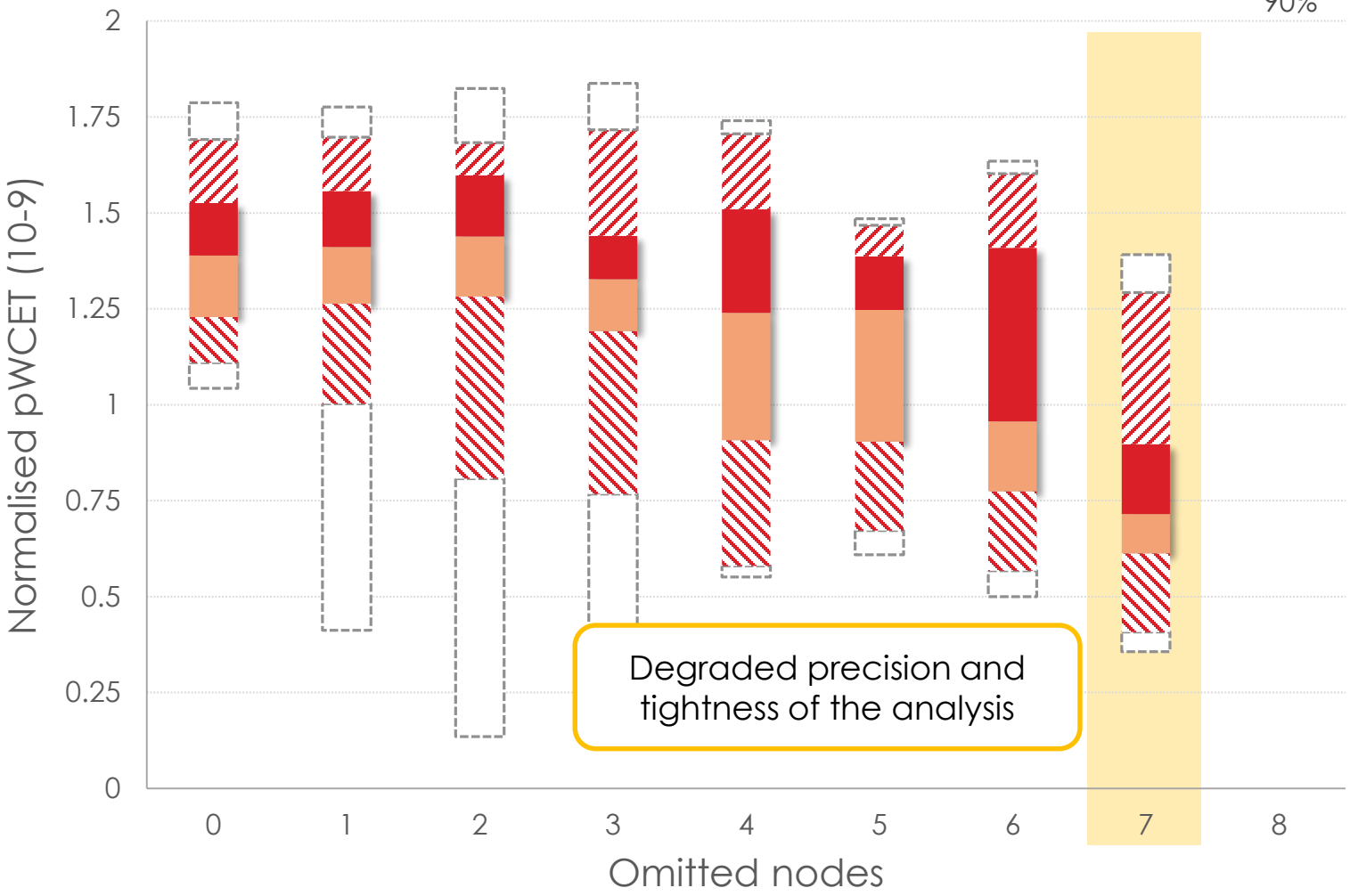

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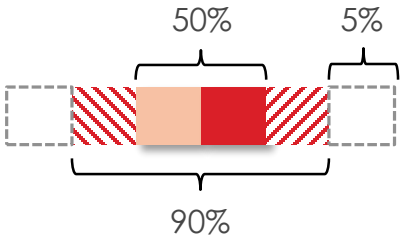

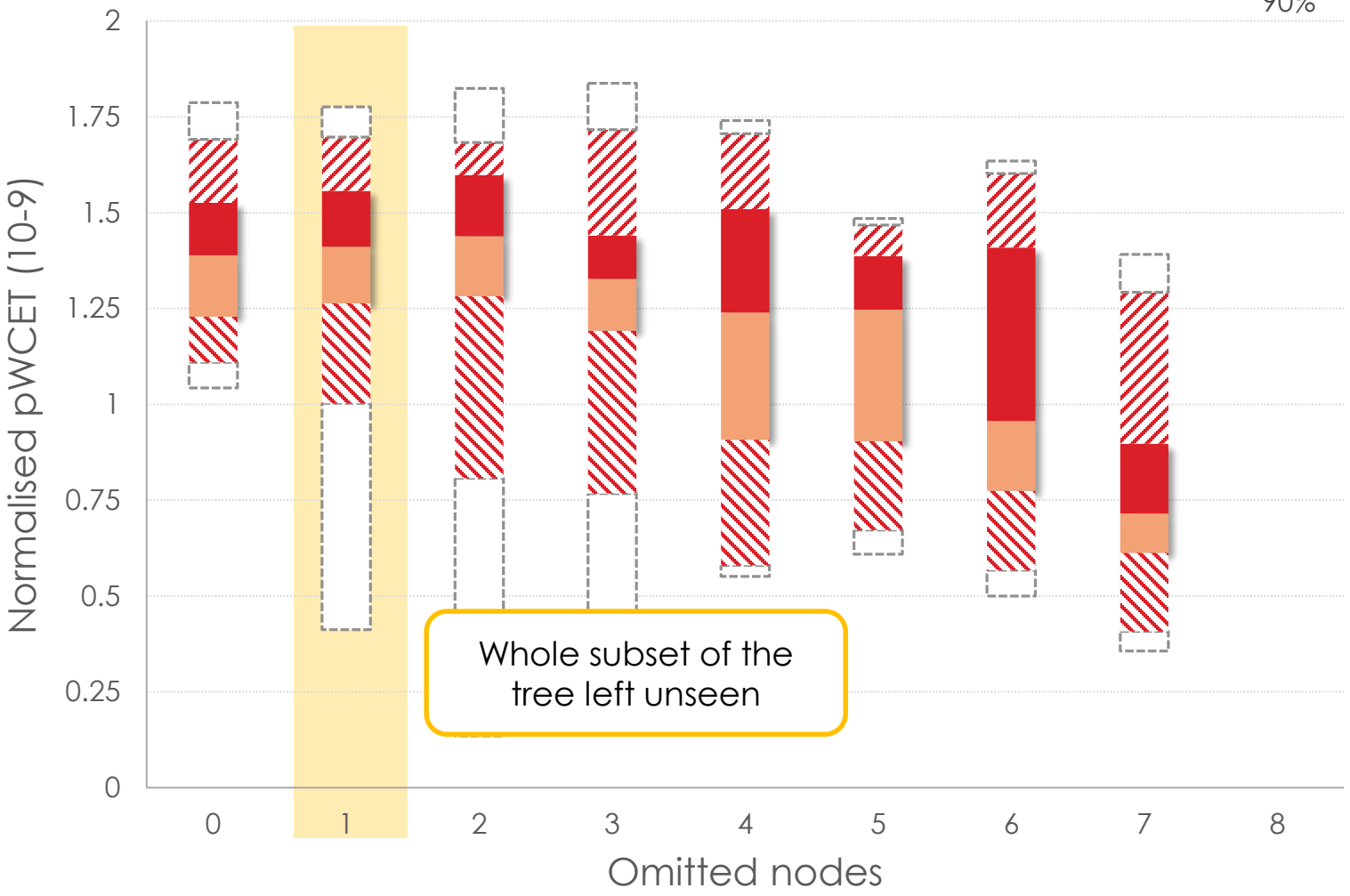

Conclusion

A framework for measurement-based timing analyses:

- Abstract the superfluous from the platform model
- Rely on observed timing data
- Build upon existing high-level timing analyses
- Detect problems, not their absence

On the robustness of MBPTA:

- Path coverage is an expensive requirement
- Biased samples can produce sound estimates

Future work

- Introduce (controlled) dependencies between blocks
- Introduce (controlled) dependencies between runs

Questions ?

- Intel 4004: http://www.intel.com.tr/content/www/tr/tr/history/museum-story-of-intel-4004.html
- Post'it: alegri / 4freephotos.com
- Abascus: HB / Wikimedia.org
- Torn paper: http://imgarcade.com

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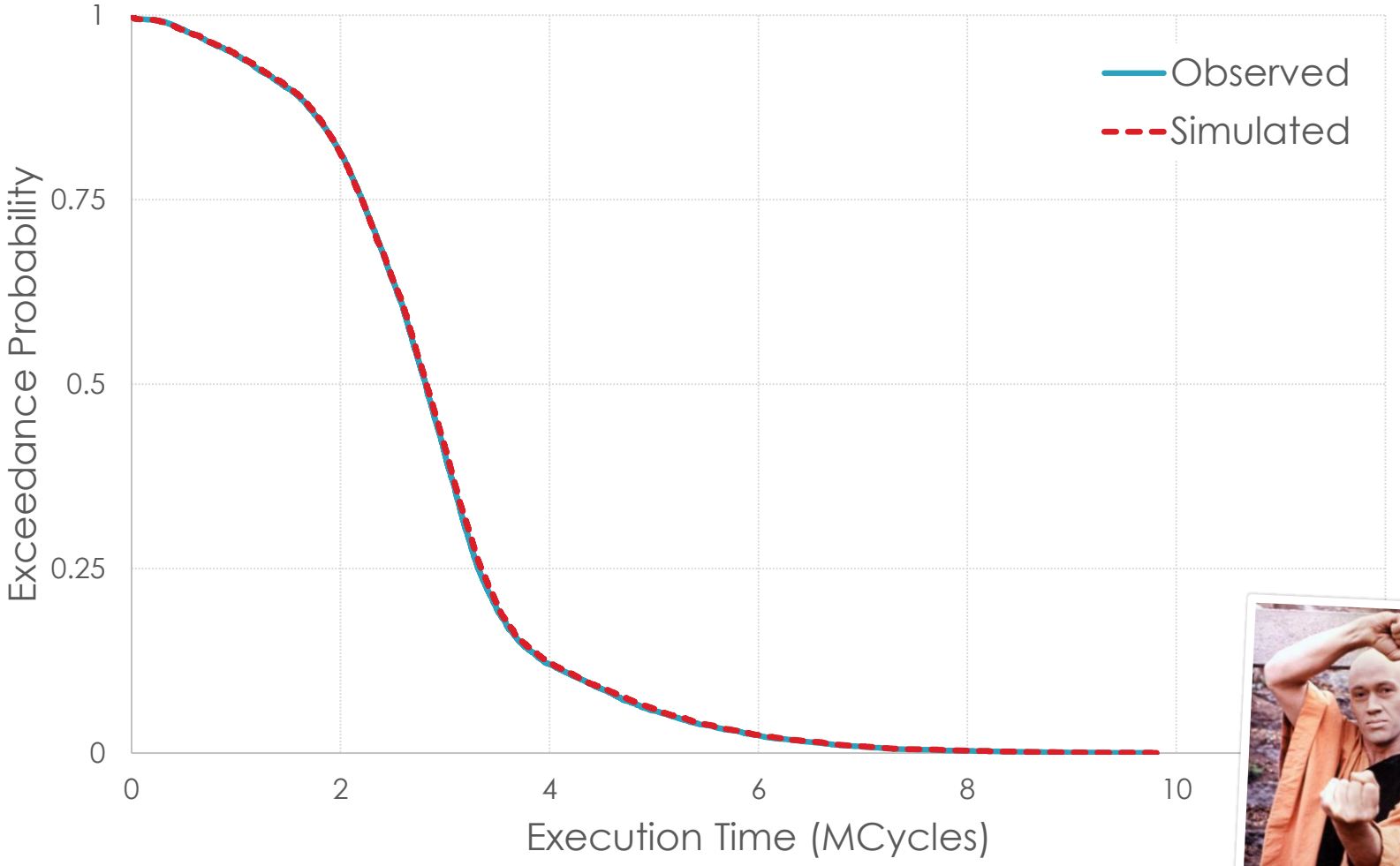

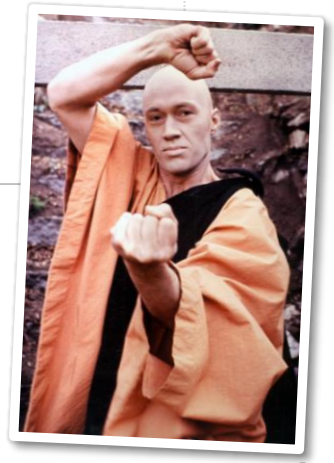

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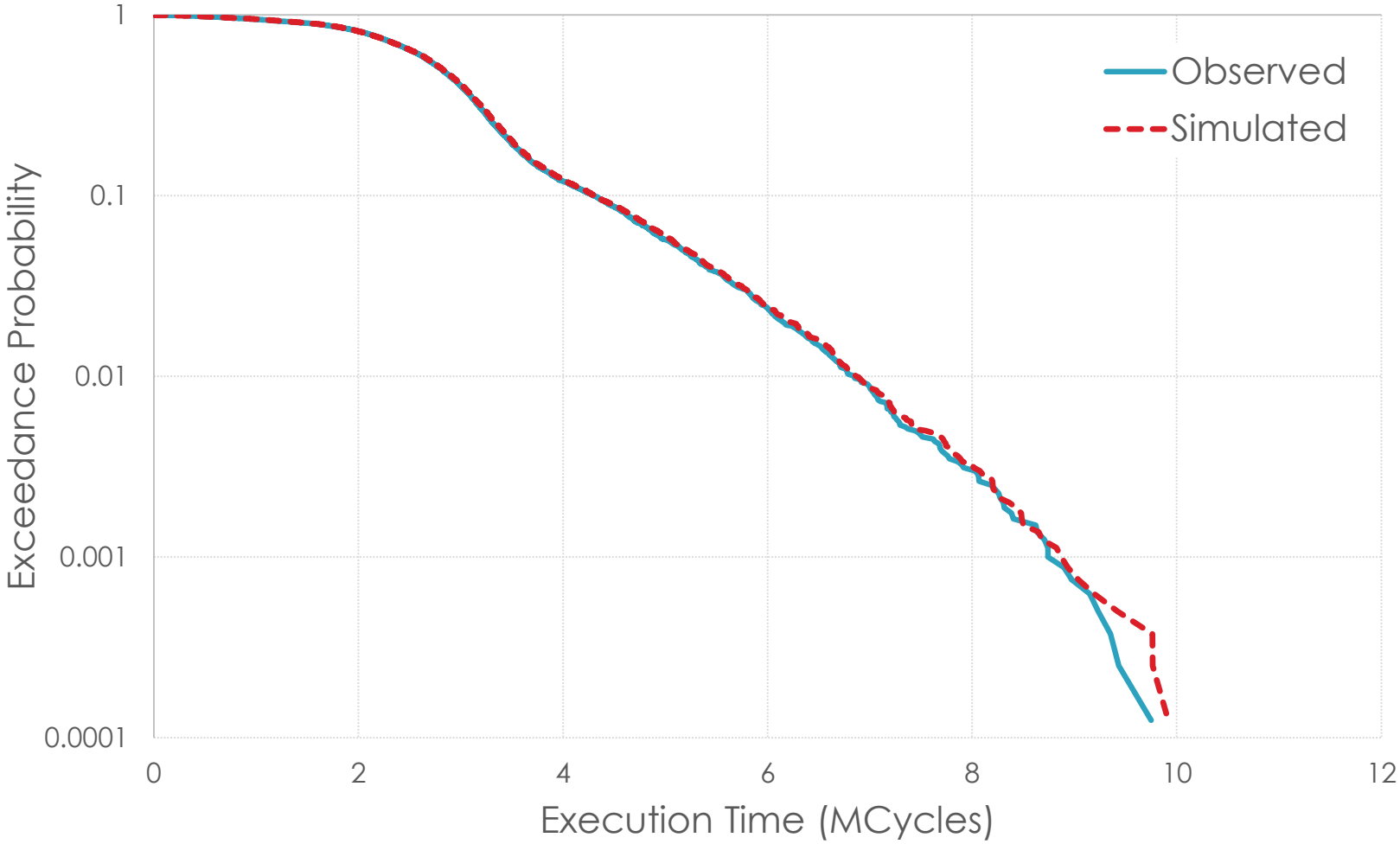

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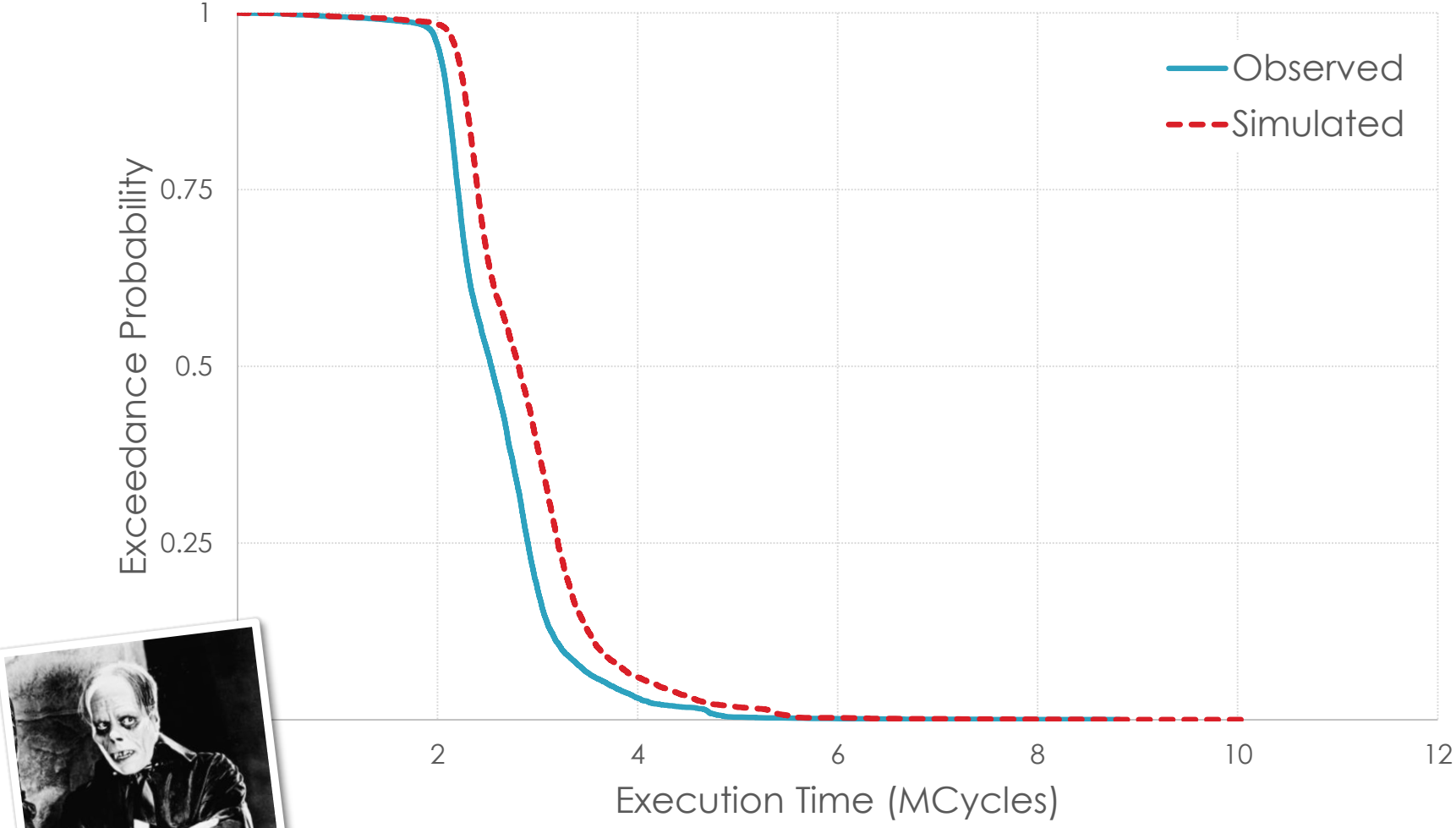

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