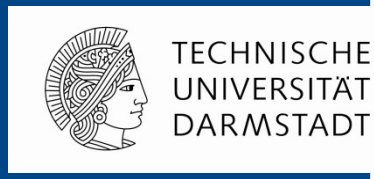
Continuous Non-Intrusive Hybrid WCET Estimation Using Waypoint Graphs

Boris Dreyer, Christian Hochberger, Alexander Lange,
Simon Wegener and Alexander Weiss



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GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

AbsInt

ACCEMIC accelerate your microcontroller design

TECHNISCHE UNIVERSITÄT DARMSTADT

UNIVERSITÄT ZU LÜBECK
INSTITUT FÜR SOFTWARETECHNIK UND PROGRAMMIERSPRACHEN

Agenda

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- **Motivation**
  - Measurement-based Execution Time Estimation
  - Program Flow Trace (PFT)
- **Waypoint based Worst Case Execution Time Estimation**
  - Waypoint Graph
  - Context Model
- **Evaluation**
  - TACLeBench
- **Conclusion**

Execution Time Estimation

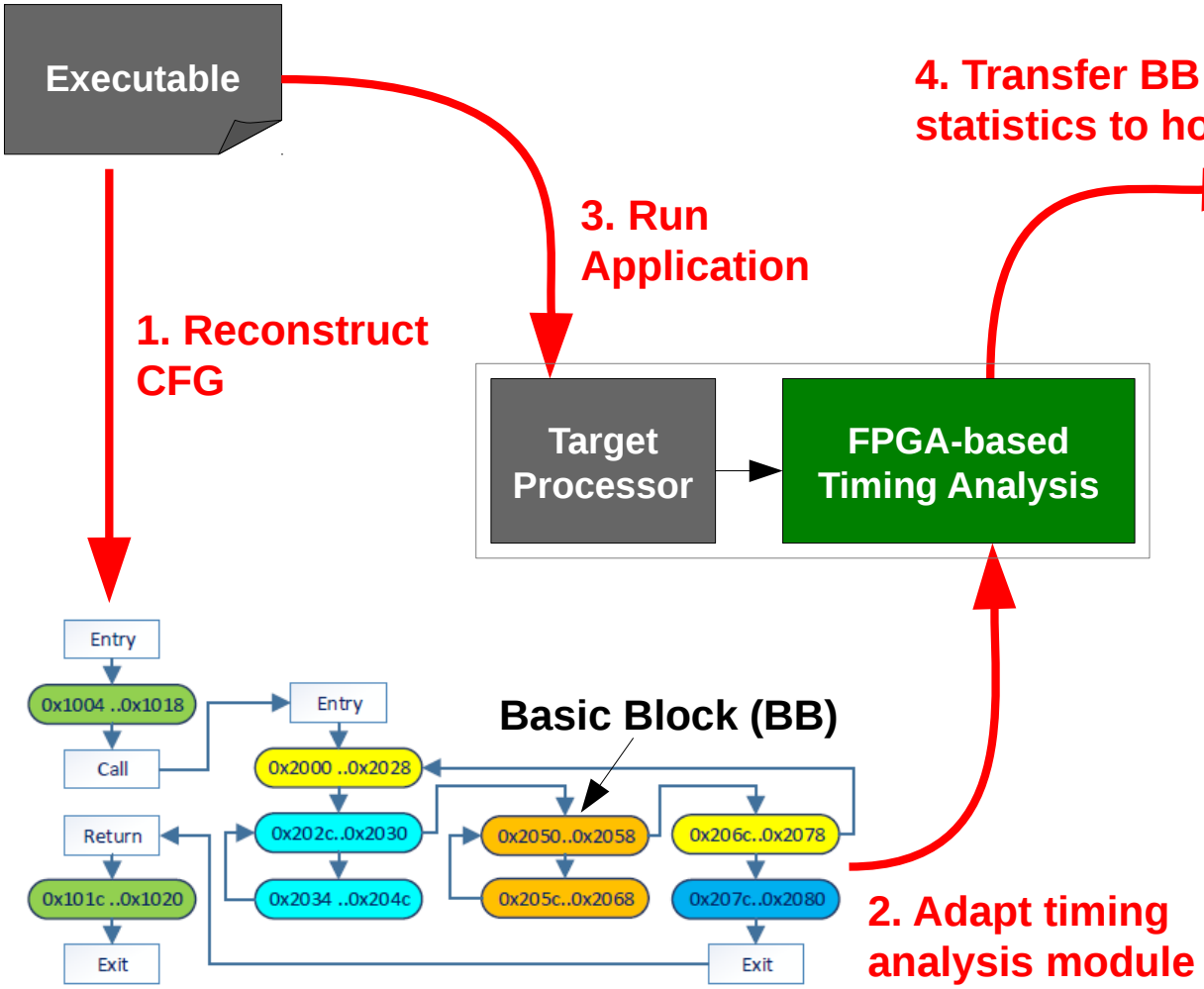
Boris Dreyer, Christian Hochberger, Simon Wegener, and Alexander Weiss.

Precise Continuous Non-Intrusive Measurement-Based Execution Time Estimation.

In Francisco J. Cazorla, editor, 15th International Workshop on Worst-Case Execution Time Analysis (WCET 2015), volume 47 of OpenAccess Series in Informatics (OASIcs), pages 45-54, Dagstuhl, Germany, 2015.

Schloss Dagstuhl—Leibniz-Zentrum für Informatik.

WCET Estimation – BB Approach



BB Address	Max First	Max Further
0x1004	8 us	0 us
0x2000	22 us	11 us
0x202c	16 us	8 us
0x2034	2 us	1 us
0x2050	12 us	8 us
0x205c	2 us	1 us
0x206c	8 us	4 us
0x207c	6 us	0 us
0x101c	6 us	0 us

Context Sensitive BB Statistics

WCET Estimation – BB Approach

BB Address	Max First	Max Further
0x1004	8 us	0 us
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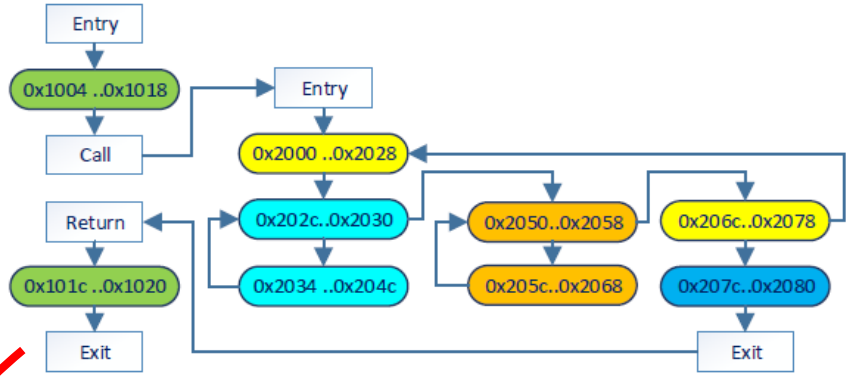
Context Sensitive BB Statistics

5. Annotate CFG



6. Find longest path (ILP based)

Overall execution time estimate
Our method: 191 us
Context insensitive: 258 us

Embedded Trace Units

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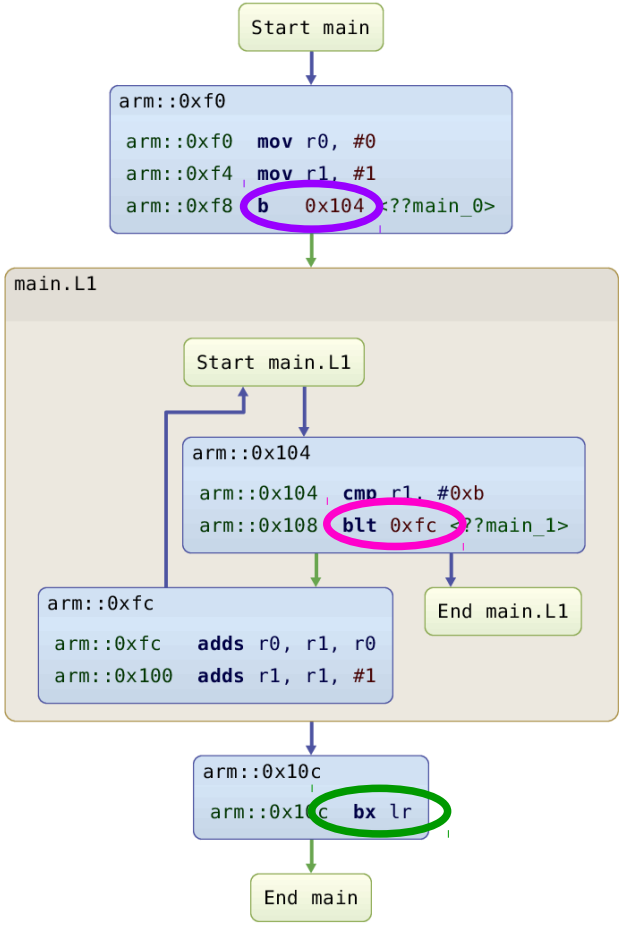
ARM Cortex A

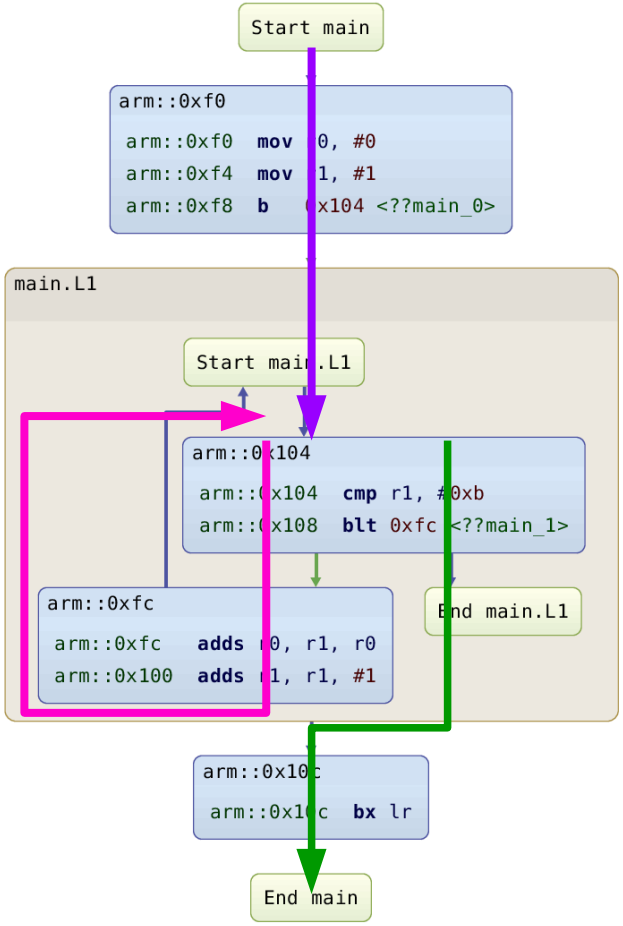
ETU type	Nexus 5001		ARM Coresight			
Implementation	Traditional branch messages	Branch history messages	ETMv3		ETMv4	PFT
Program Flow Observation Level	Branch	Branch	Instruction		Branch	Branch
Cycle count	Yes	No	No	Yes	Yes	Yes
Applicable for hybrid WCET measurement	Yes	No	No	Yes	Yes	Yes

Basic Block Graph



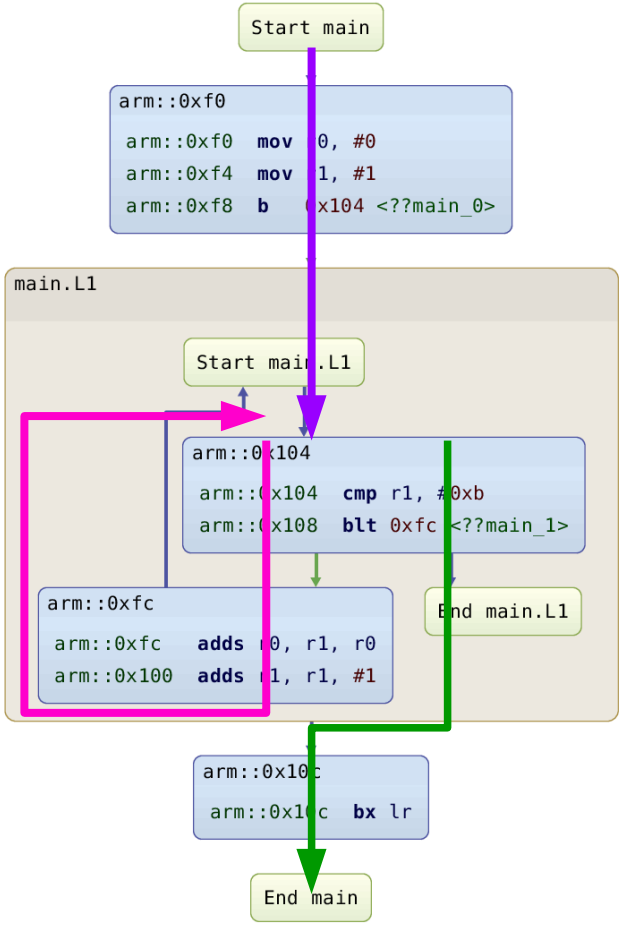
CFG

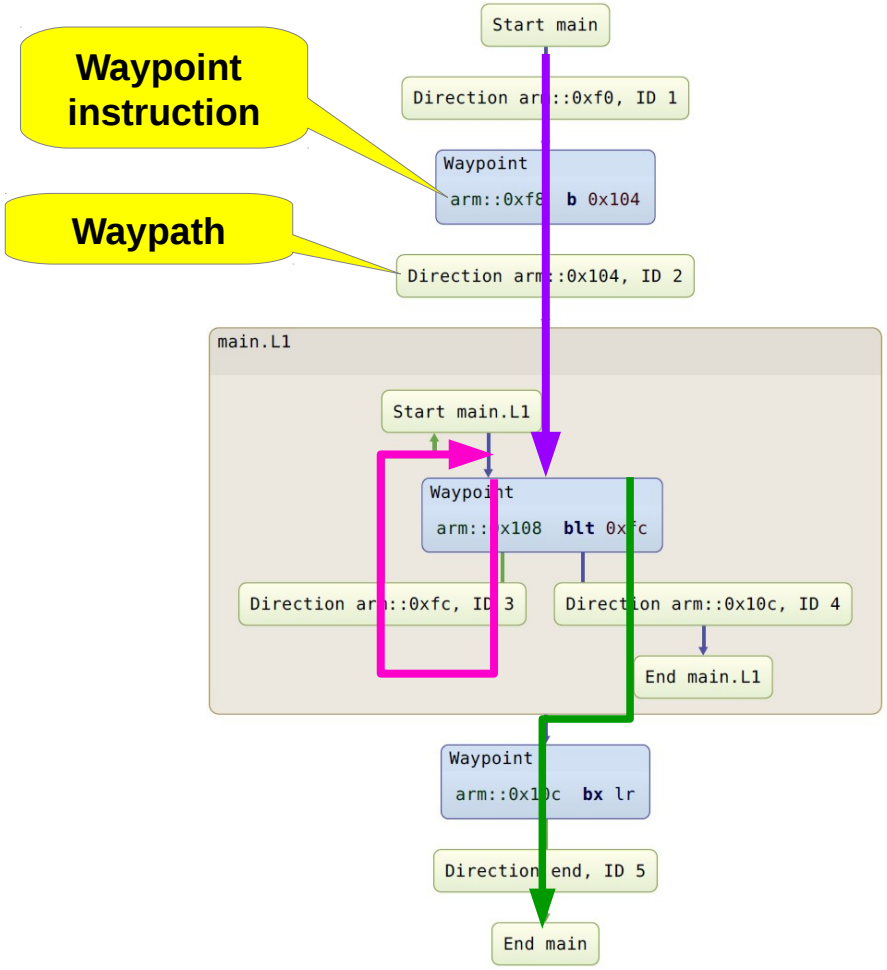
Basic Block Graph



CFG

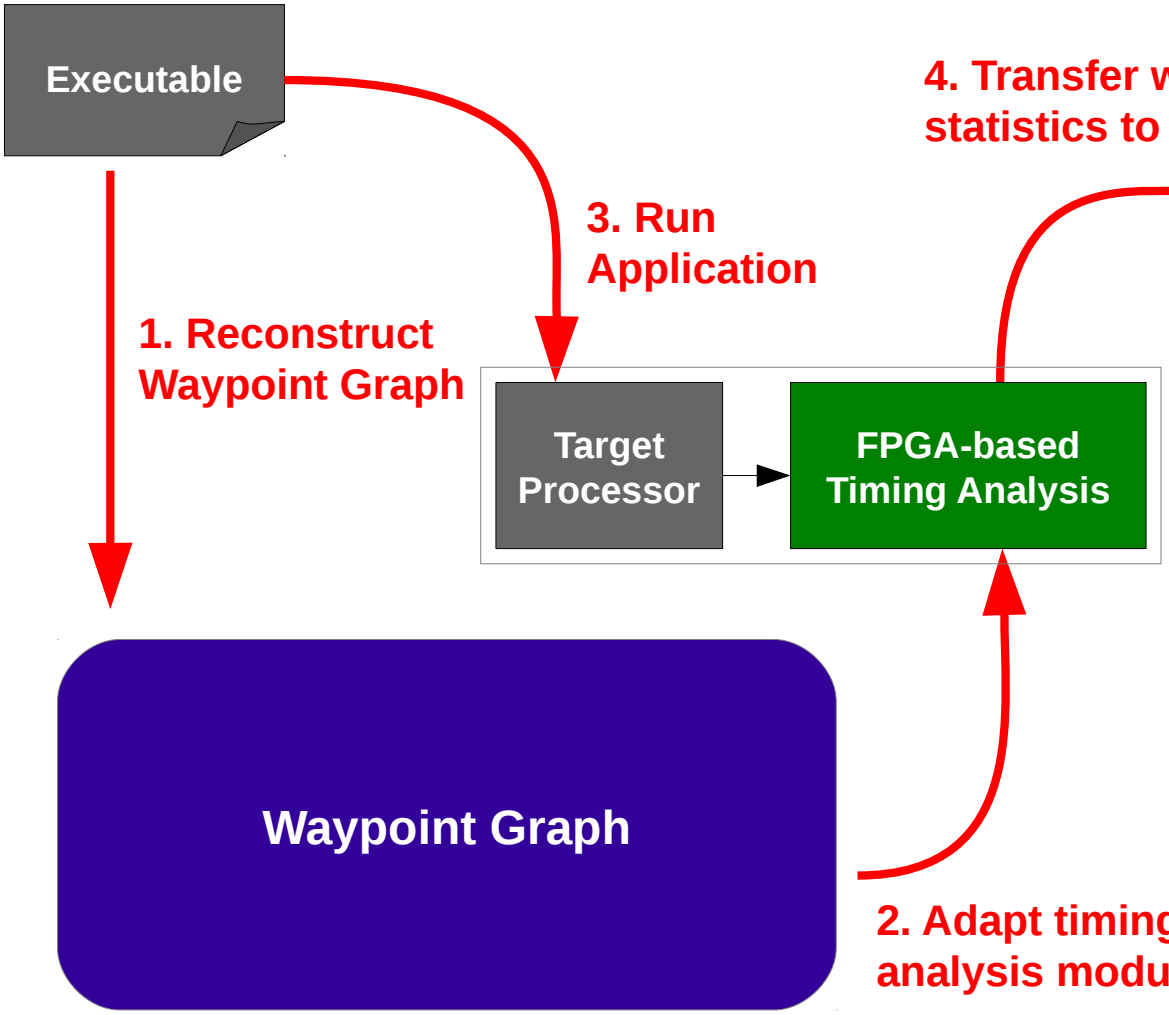
Basic Block Graph vs. Waypoint Graph





CFG **Maximization Equivalence** WPG

WCET Estimation Using Waypoint Graphs



Waypath ID	Max First	Max Further
0	8 us	0 us
1	22 us	11 us
2	16 us	8 us
3	2 us	1 us
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Context Sensitive Waypath Statistics

WCET Estimation Using Waypoint Graphs

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Context Sensitive Waypath Statistics

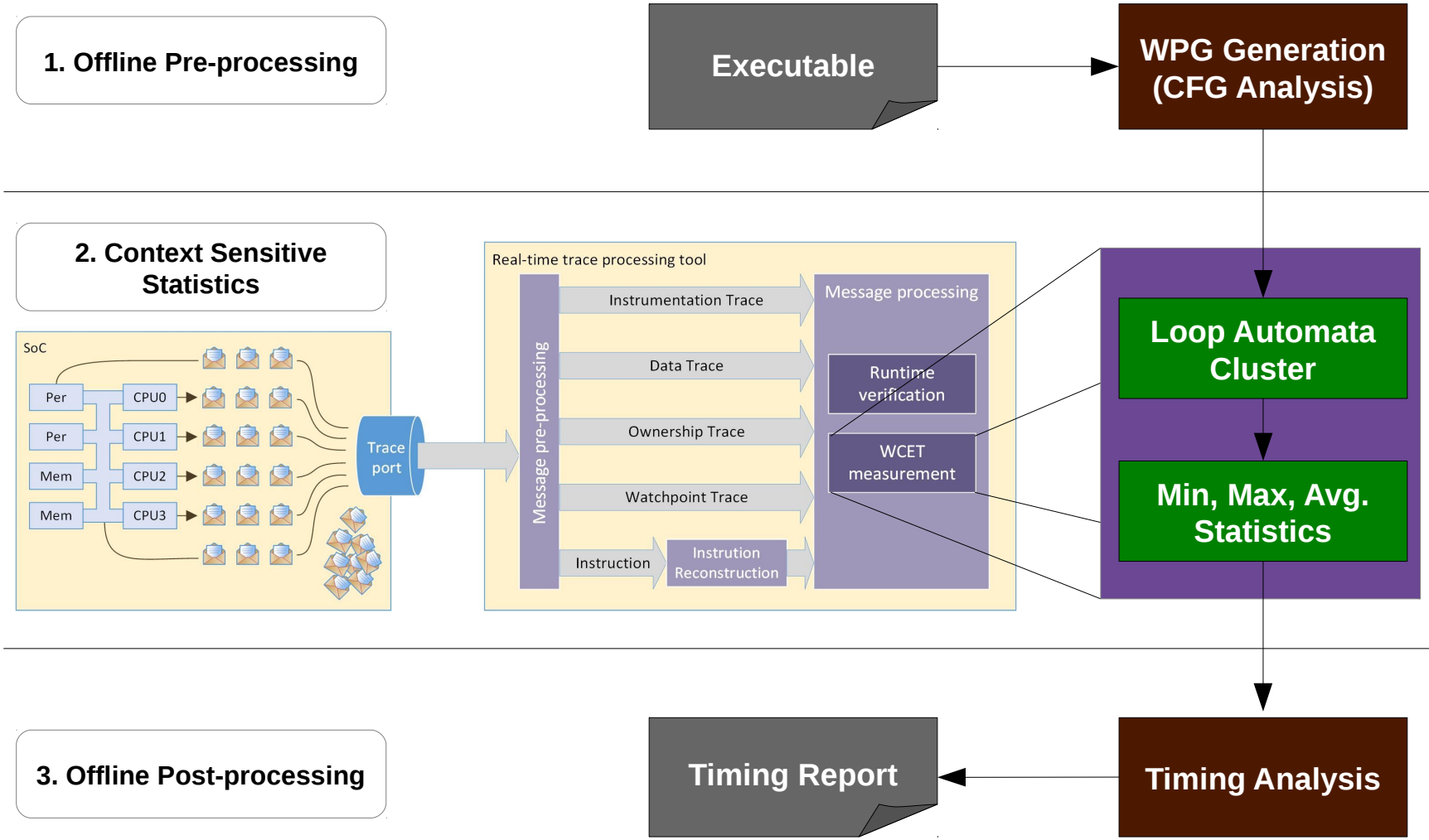
5. Annotate

Waypoint Graph

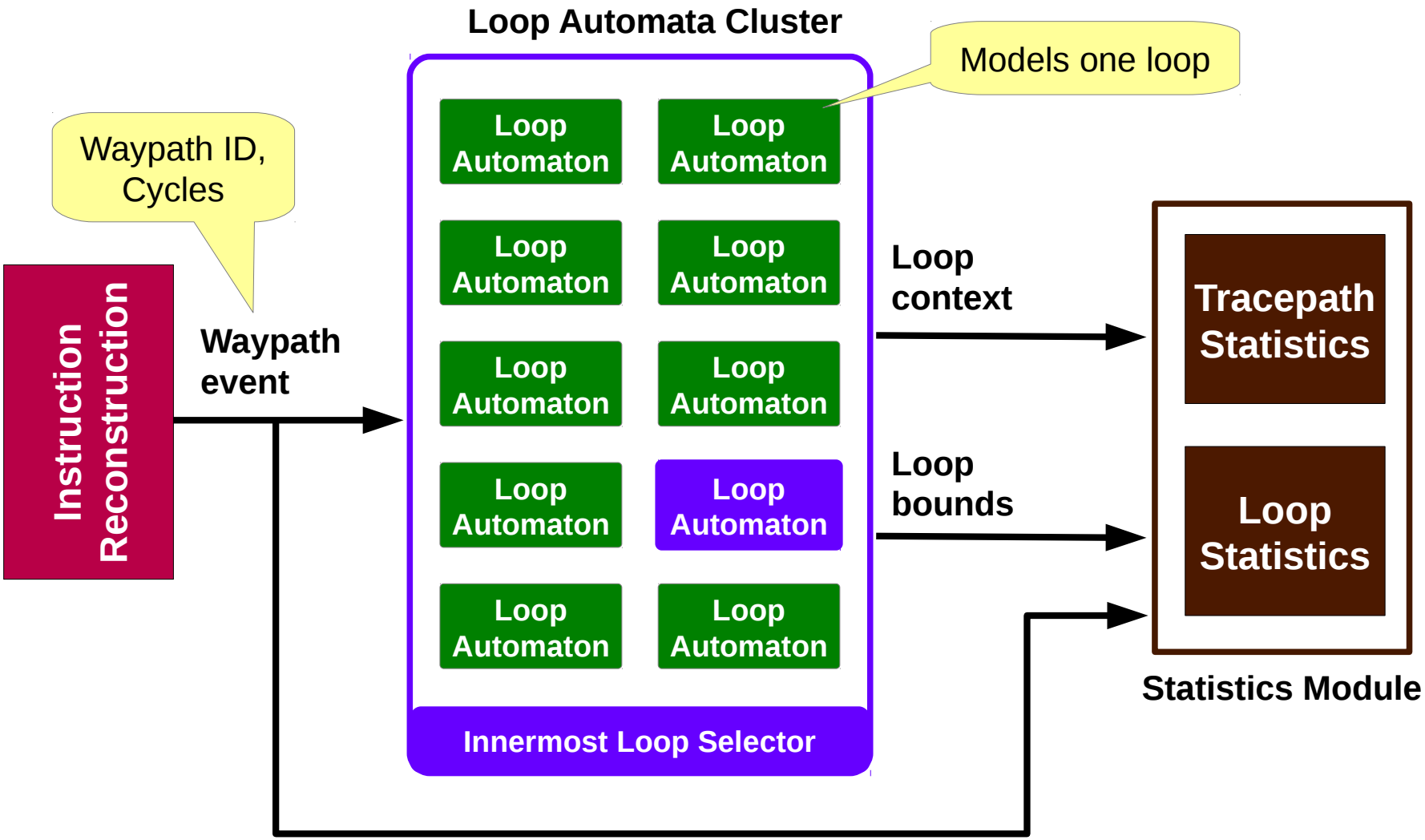
6. Find longest path (ILP based)

Overall execution time estimate

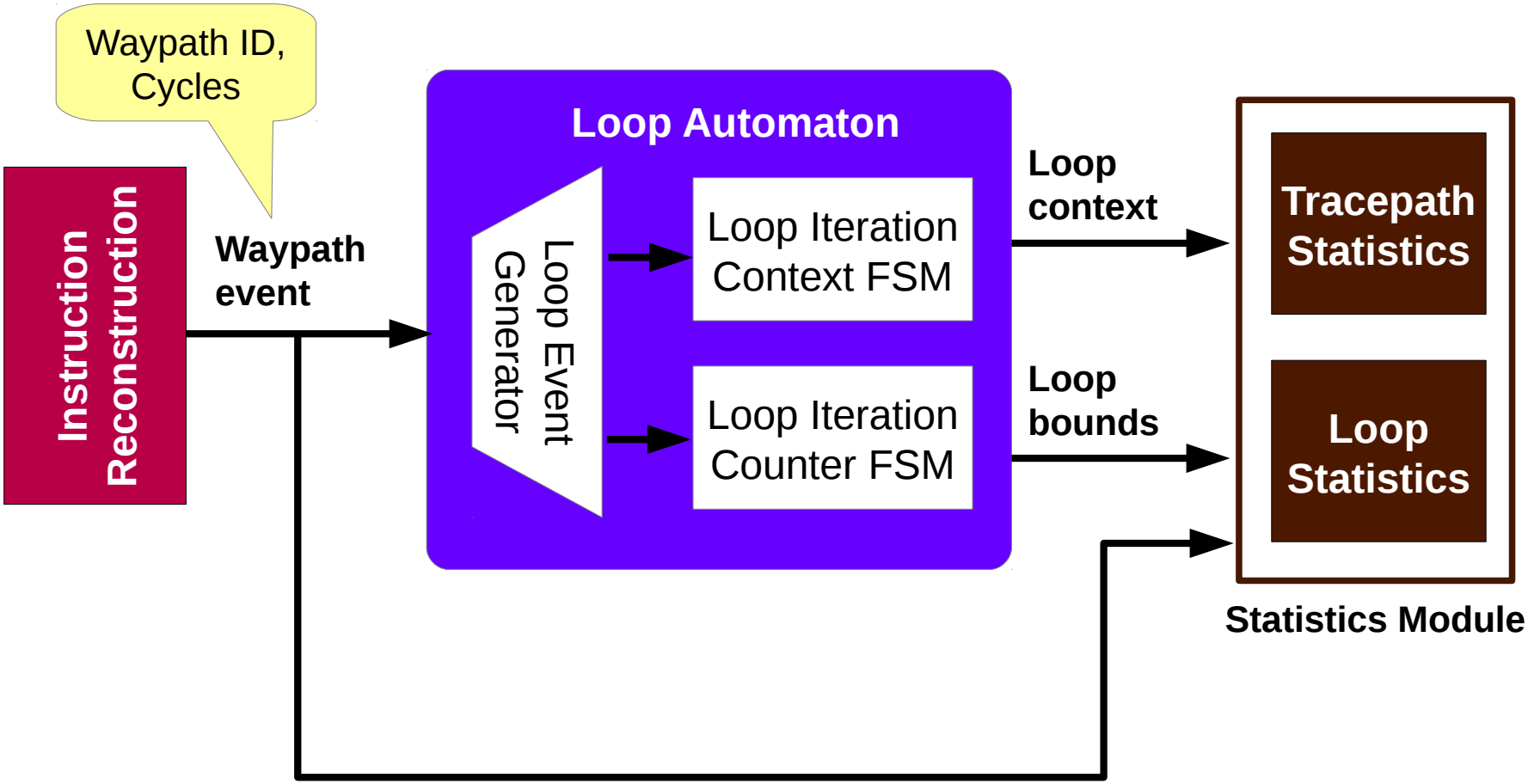
Execution Time Estimation - Architecture



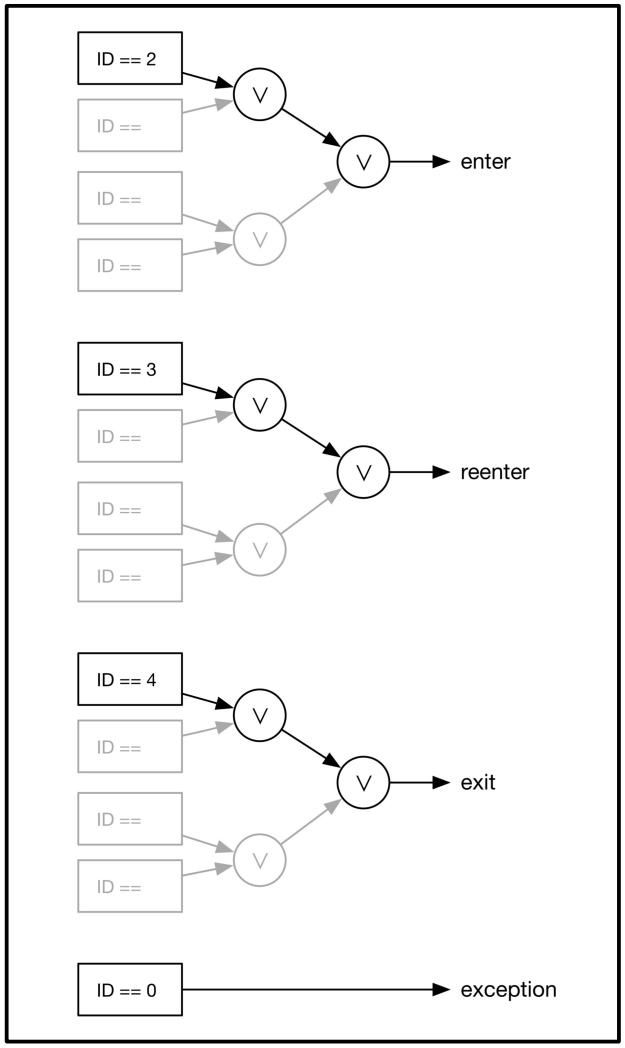
Loop Automata Cluster



Loop Automata



Loop Event Generator



Comparator Tree Set

Evaluation Setting

- **Xilinx Zynq XC7Z020-1CLG484C**
  - Dual-core ARM Cortex-A9 (666 MHz)
  - 32 kilobytes of L1 cache
  - 512 kilobytes of L2 cache (disabled)
  - SRAM data memory
- **DDR3 instruction memory (533 MHz)**
- **TACLeBench benchmark collection**
  - Executing each benchmark ten times
  - With and without L1 instruction cache enabled
- **Xilinx SDK 2016.1**

Context-Insensitive Overestimation (Ratio)

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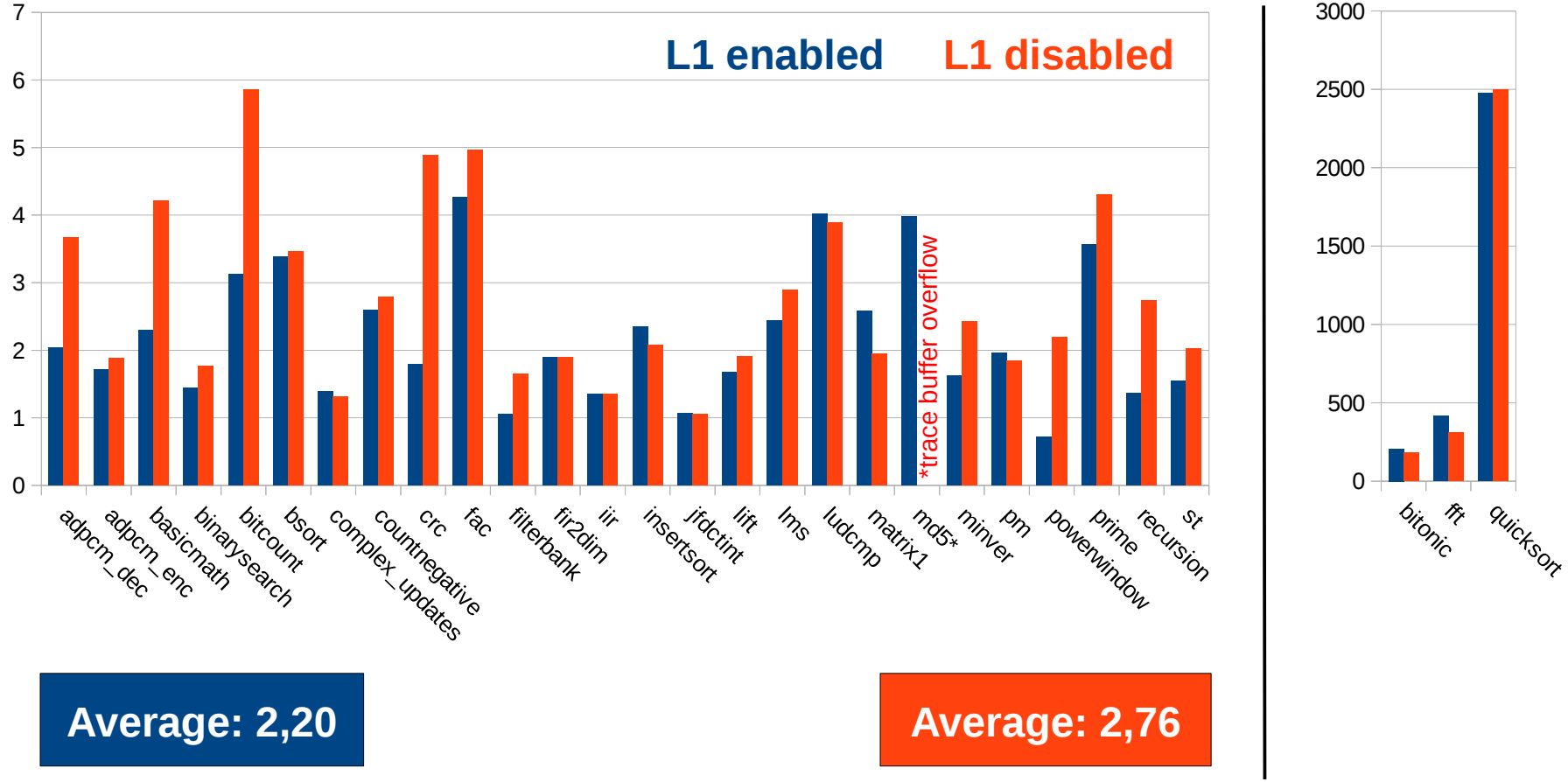
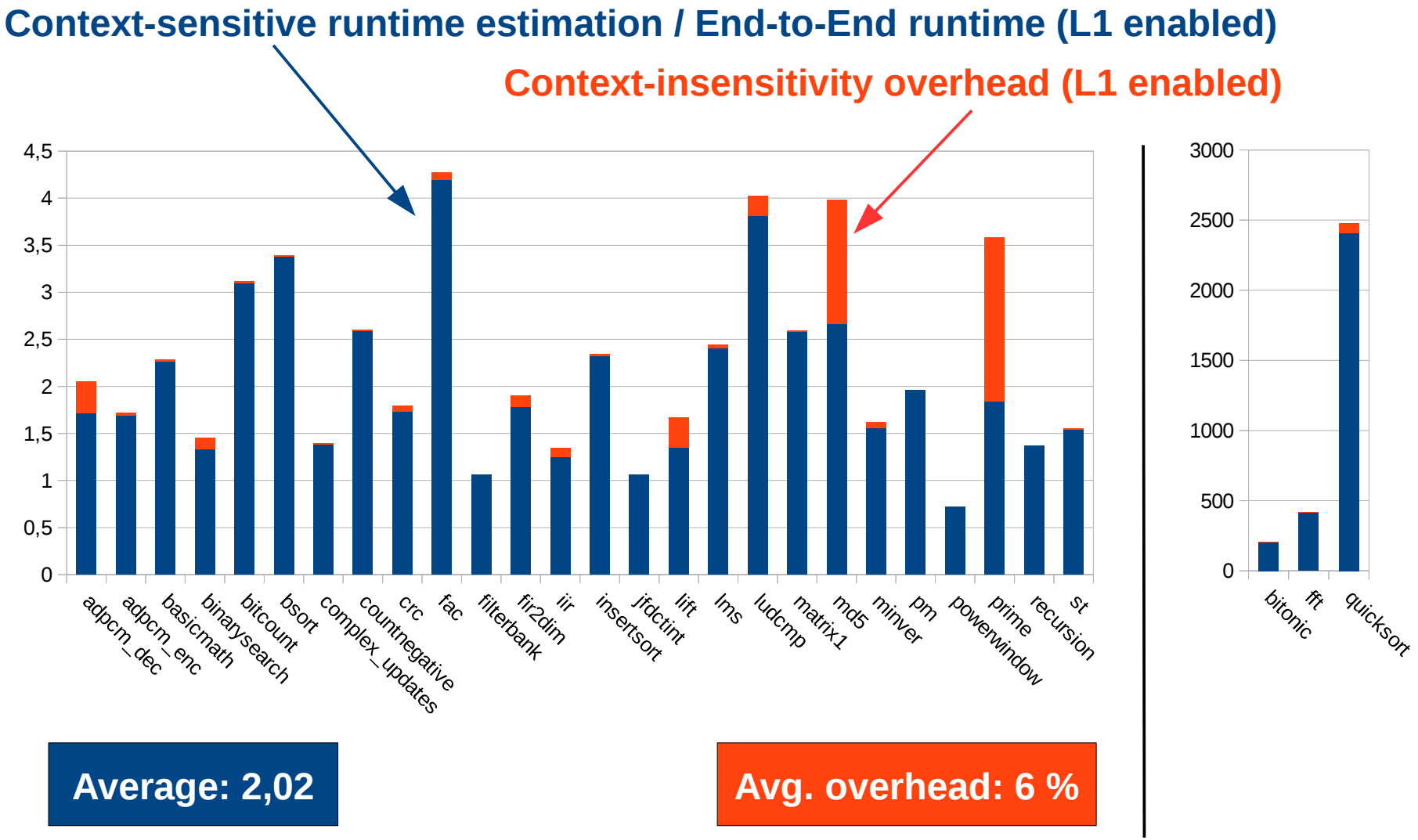
Context-insensitive runtime estimation / End-to-End runtime



Average: 2,20

Average: 2,76

Context-Sensitive Overestimation (Ratio)



Conclusion

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Continuous

- We perform direct online aggregation at runtime.

Non-intrusive

- We use the hardware support of modern SoCs.

Hybrid WCET Estimation Using Waypoint Graphs

- We measure waypath execution times online.
- We estimate the overall runtime offline.

Thank you!