3rd Italian Workshop on Embedded Systems

A HW/SW Unified Approach for Embedded Systems Monitoring

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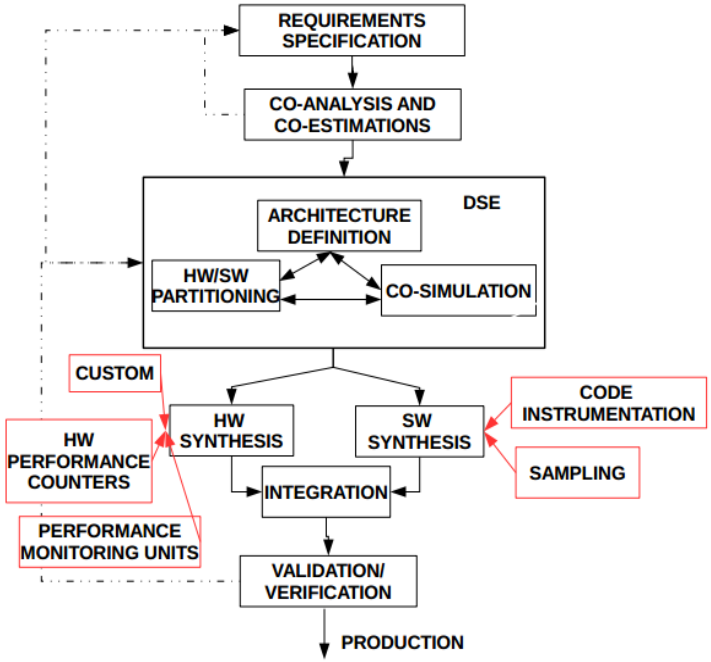
Overview

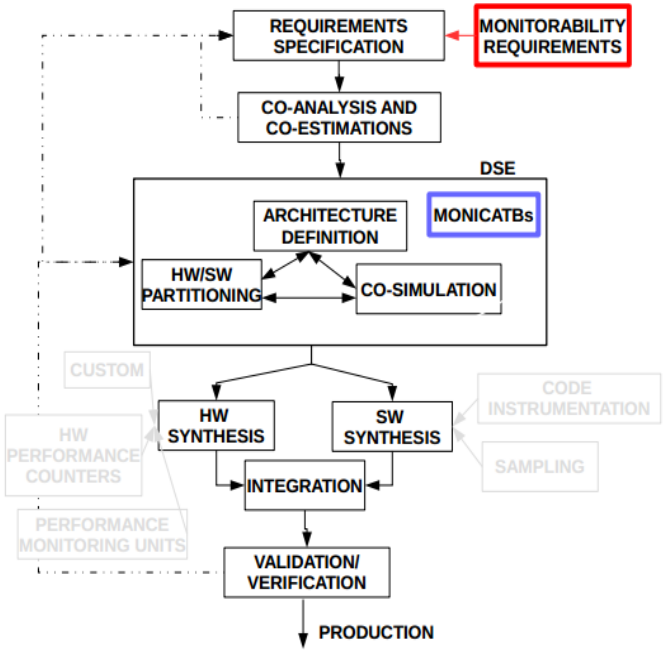
- Scenario
  - Embedded applications are characterized by increasingly stringent functional/non-functional requirements, leading to complex heterogeneous HW platforms.
- Problems
  - Platforms need to be characterized. On-chip monitoring systems support on this, but they are normally introduced at lower-levels of the design-flow, where it is costly to manage their impact.
- This work proposes a solution to this problem
  - Support the designer on the selection of on-chip monitoring systems since the initial steps of the design-flow (*system-level*) and the evaluation/estimation of their impact

Overview

The MONICA methodology

Goal: to consider monitorability requirements since the system-level of abstraction





Outline

- Context
- Motivations
- Contributions
  - MONICA methodology
  - AIPHS
- Validation
  - AIPHS
  - MONICA
- Conclusions and future works

Context

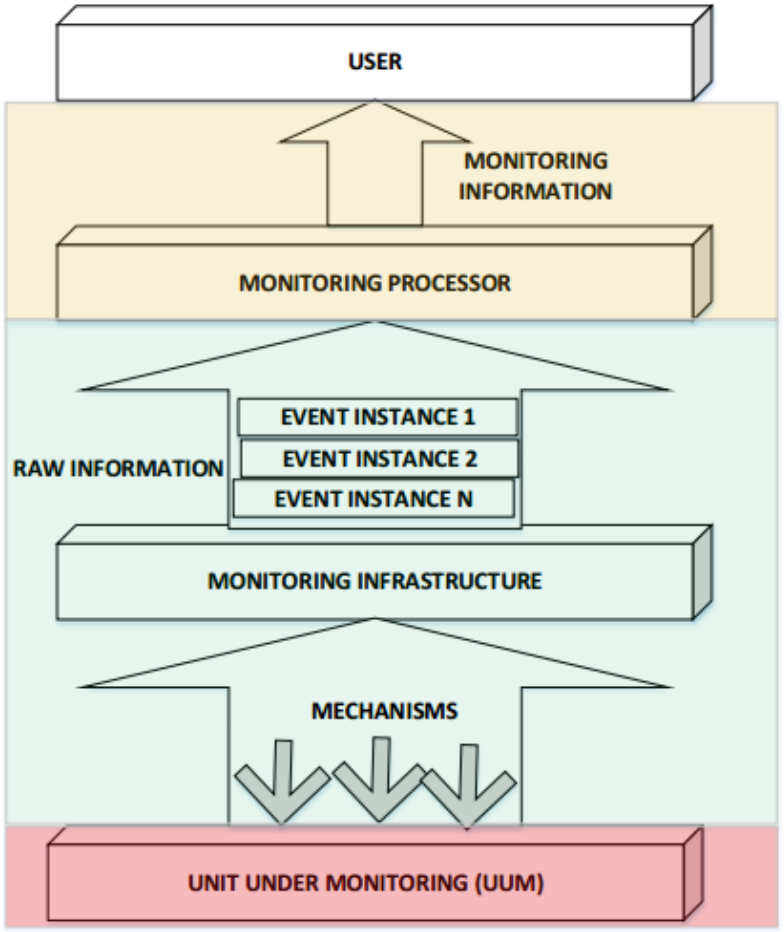
- During the development of digital electronic systems, requirements drive the design flow as main goals
  - Functional requirements (application behaviour)
  - Non-functional requirements (performance, power dissipation, etc.)

- The focus of this work is on dedicated/embedded digital electronic systems
  - Require the simultaneous optimization of several design metrics
  - Giving the set of functional requirements, the best HW/SW technologies to be adopted in the final implementation can be very different depending on non-functional requirements

Context

- Monitoring system
  - Unit under monitoring
  - Monitoring infrastructure
  - Monitoring processors
- Event Instance
  - It is referred to an event
  - ID, Timestamp, Information, Attribute

EI ID	EI TIMESTAMP	EI INFORMATION	EI ATTRIBUTE



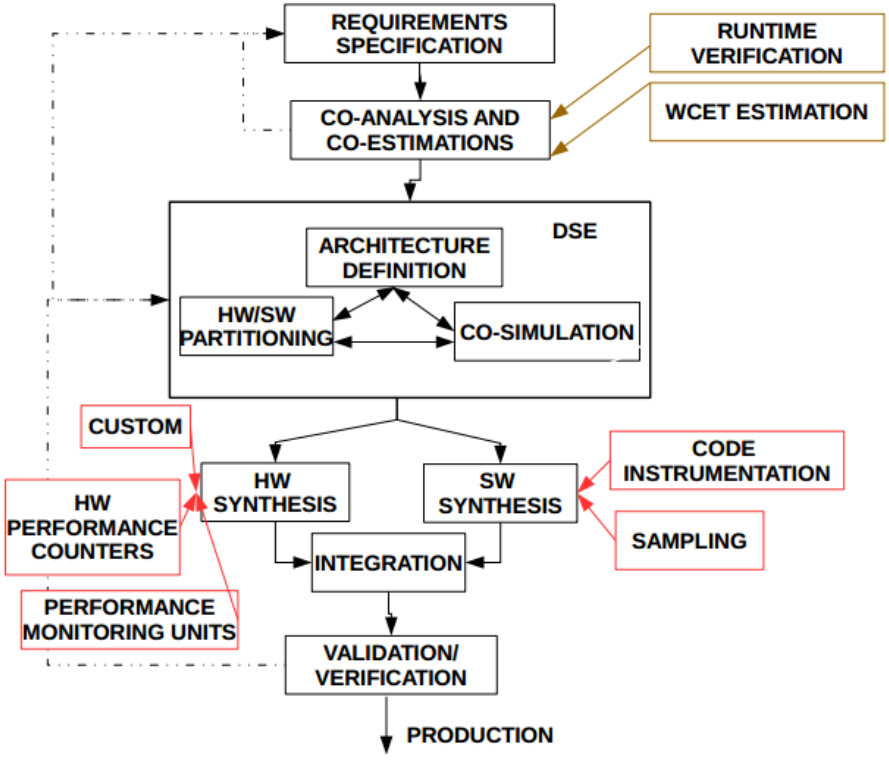
Context

Example: Measurement-Based WCET estimation

Concept	Example in measurement based WCET analysis
Monitoring action	Event instance at certain measurement points
Monitoring technique	Source-code instrumentation
Raw information	Event instances with two IDs and one timestamp
Event	Execution of annotations

Motivations

- What should be monitored
  - Target not considered
  - Strong impact on resources
- On-Chip monitoring systems
  - Introduced at lower-levels
  - Difficult to deal with their impact
    - Intrusiveness
    - Overhead
- Is it possible a meet-in-the-middle agreement?



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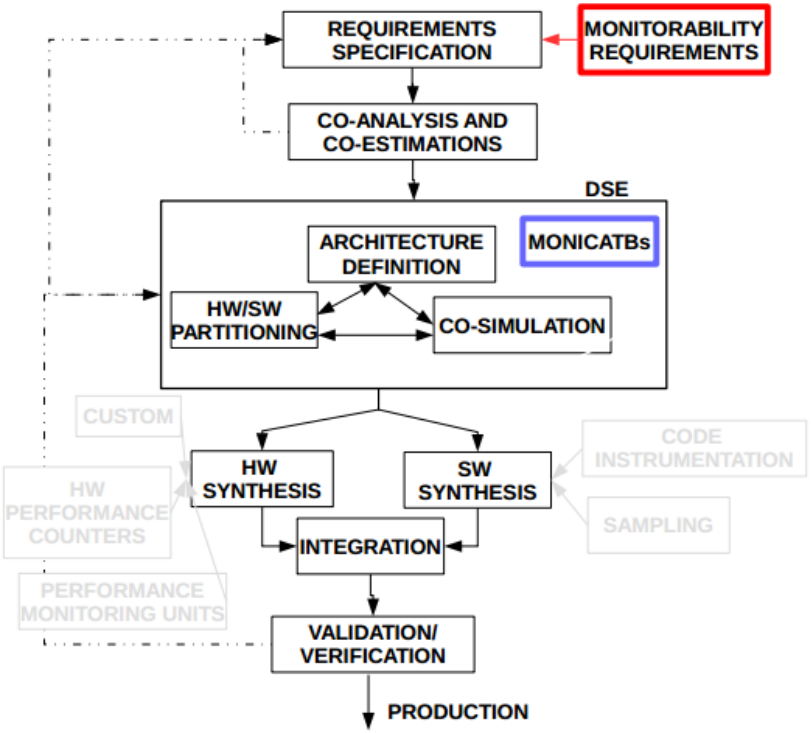
Contributions

To raise the abstraction level of on-chip monitoring systems integration

- Some work to be done to obtain "knobs", i.e. parameters, also called monitorability issues
- In a HW/SW co-design flow, this means to move on-chip monitoring actions at design-space exploration step

- Is it a sort of "*Design for Monitorability*"*?*



Contributions

Proposed actions

1) Quantitative parameters
2) Qualitative parameters
3) Reference architecture for on-chip monitoring systems
4) New characterization of existing on-chip monitoring systems
5) Metrics to evaluate the impact at system-level
6) Introduce methodology in a HW/SW co-design flow
7) Targeting of both SW and HW tasks
8) Making the methodology extendible
9) Proposing the methodology as a framework

Contributions

Proposed actions in the scientific literature

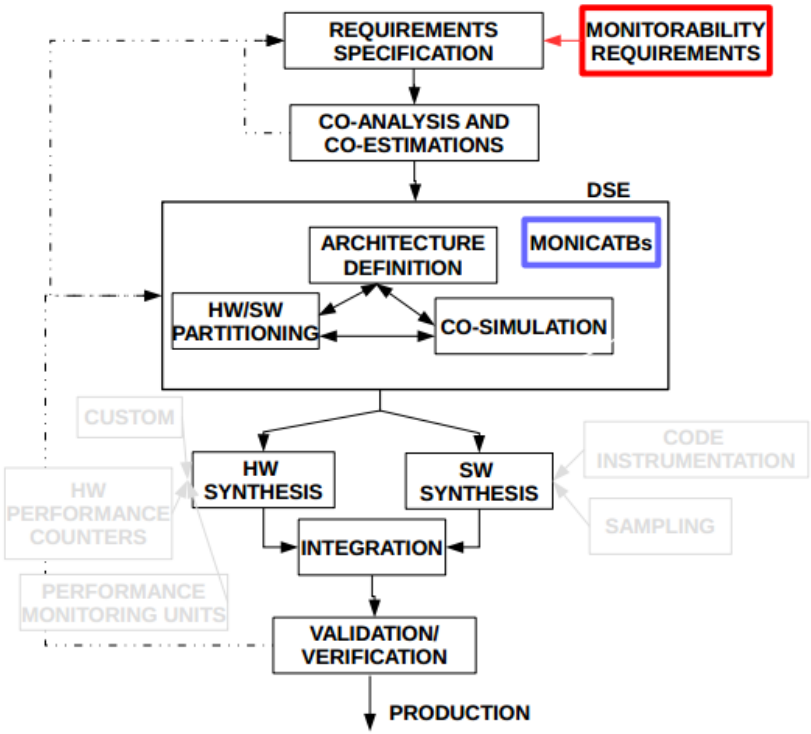
	Proposed solution	OWL [2005_Schulz]	Airwolf [2008_Tong]	ABACUS [2010_Matthews]	M1 [2013_Kornaros]	SOF [2015_Lee]	M2 [2015_Nelissen]	MONICA
	Year	2005	2008	2010	2013	2015	2015	2017
1	Definition of parameters for a quantitative approach							X
2	Definition of parameters for a qualitative approach				X	X		X
3	Proposal of a reference architecture for OCMSs				X		X	X
4	Characterization of existing monitoring solutions		X		X	X	X	X
5	Metrics to evaluate the impact at system-level							X
6	Insertion in an ESL flow							X
7	Targeting of both SW and HW Tasks					X		X
8	Extendible	X		X		X	X	X
9	Proposed as a framework	X		X		X		X

Contribution

MONICA methodology

- Acronym of on-chip **MONI**toring system **Ch**a**A**racterization

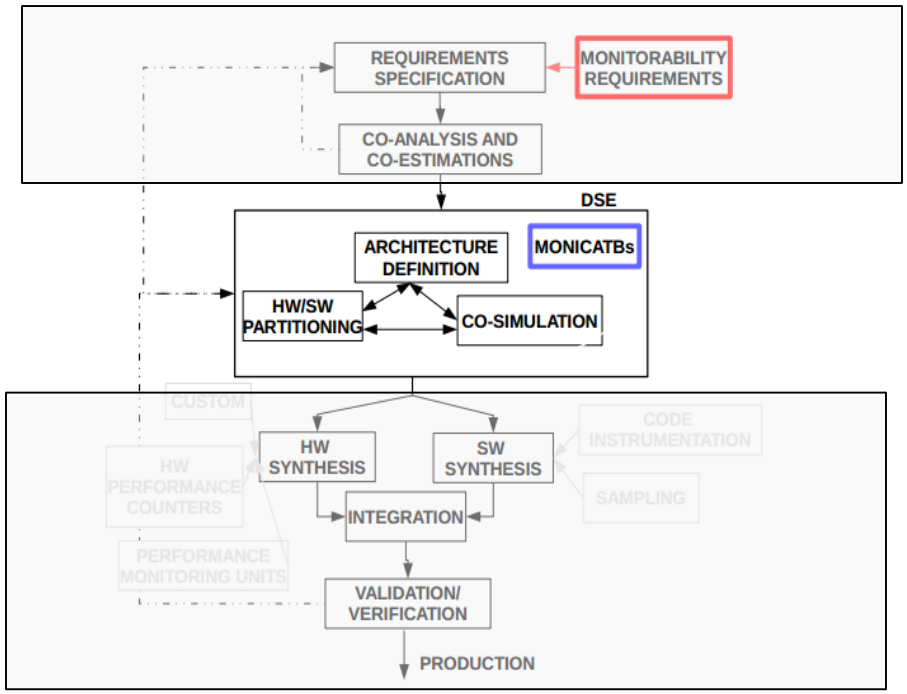
- Act on HW/SW partitioning
  - Act on cost functions
  - Act with a multi-level partitioning
    - Given the first assessed solution, a second-level partitioning considers the additional monitorability constraints

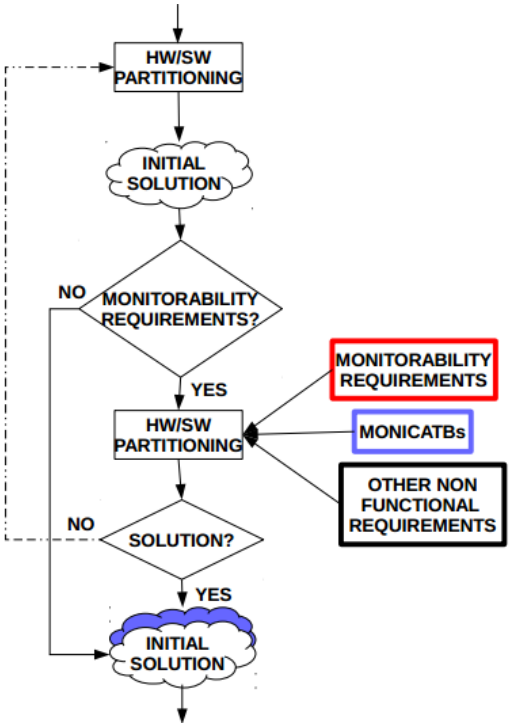


Contribution

MONICA methodology

Two-steps partitioning





Contribution

MONICA methodology

Quantitative

Parameter	Details
Efficiency	• Detection latency (DL) $DL = T_{WMI} + T_{MIO} + T_{WMP} + T_{MPO}$ • Performance Degradation
Cost	• Physical Cost (PC) • Power dissipation cost • Design Cost
Memory space	• Memory requirements for raw information and monitoring information storage.

Contribution

MONICA methodology

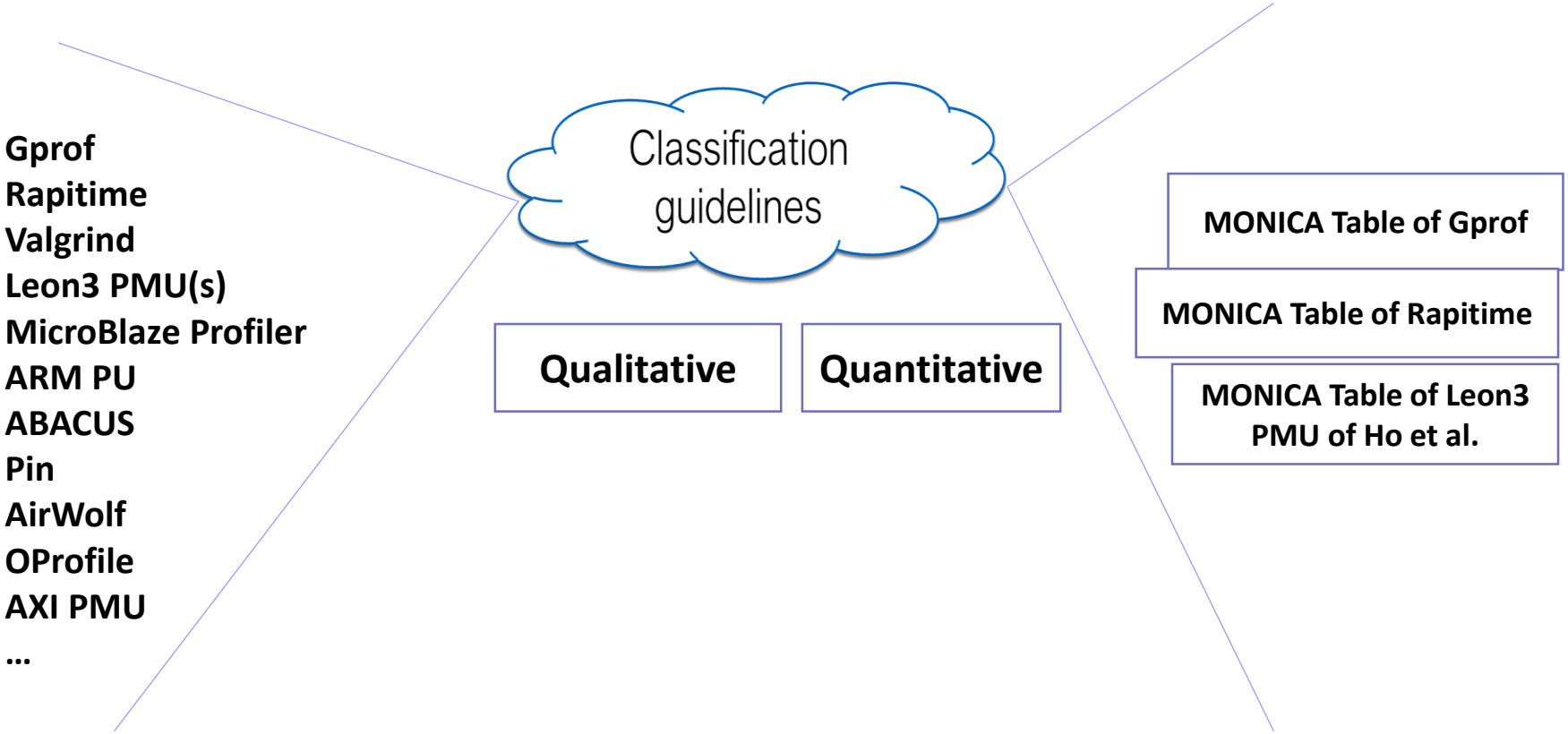
Qualitative

Parameter	Details
Type of Physical Implementation	• {CF, RCF, PF}.
SW Platform	• {bare-metal, OS}
Purpose	• {DBG, PF, QoS, PW, EN, TM, FT, RL, SEC}.
OCMS architecture	• N-S-M = {SW-SW-SW, SW-SW-HW, SW-HW-SW, SW-HW-HW, HW-HW-SW, HW-HW-HW}. • Monitoring technique: {SLCI, SBLCI, DBLCI, SLI, HPC, PMU, HTB, custom}
Multi-thread/Multi-core	• Multi-thread = {yes, no} • Multi-core = {yes, no}
Synchronization	• {Automatic, Custom}
Resource Sharing	• {SW task, PPs, instruction memory, data memory}.

Contribution

MONICA methodology

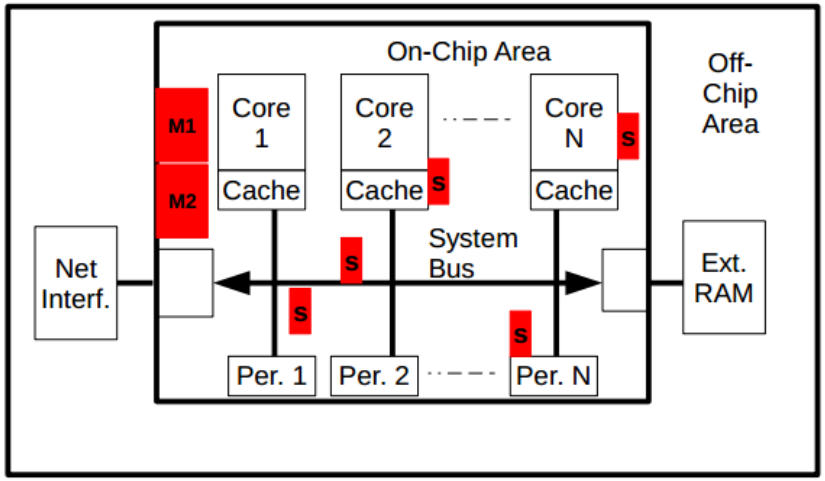
Creation of MONICA tables



Contribution

AIPHS

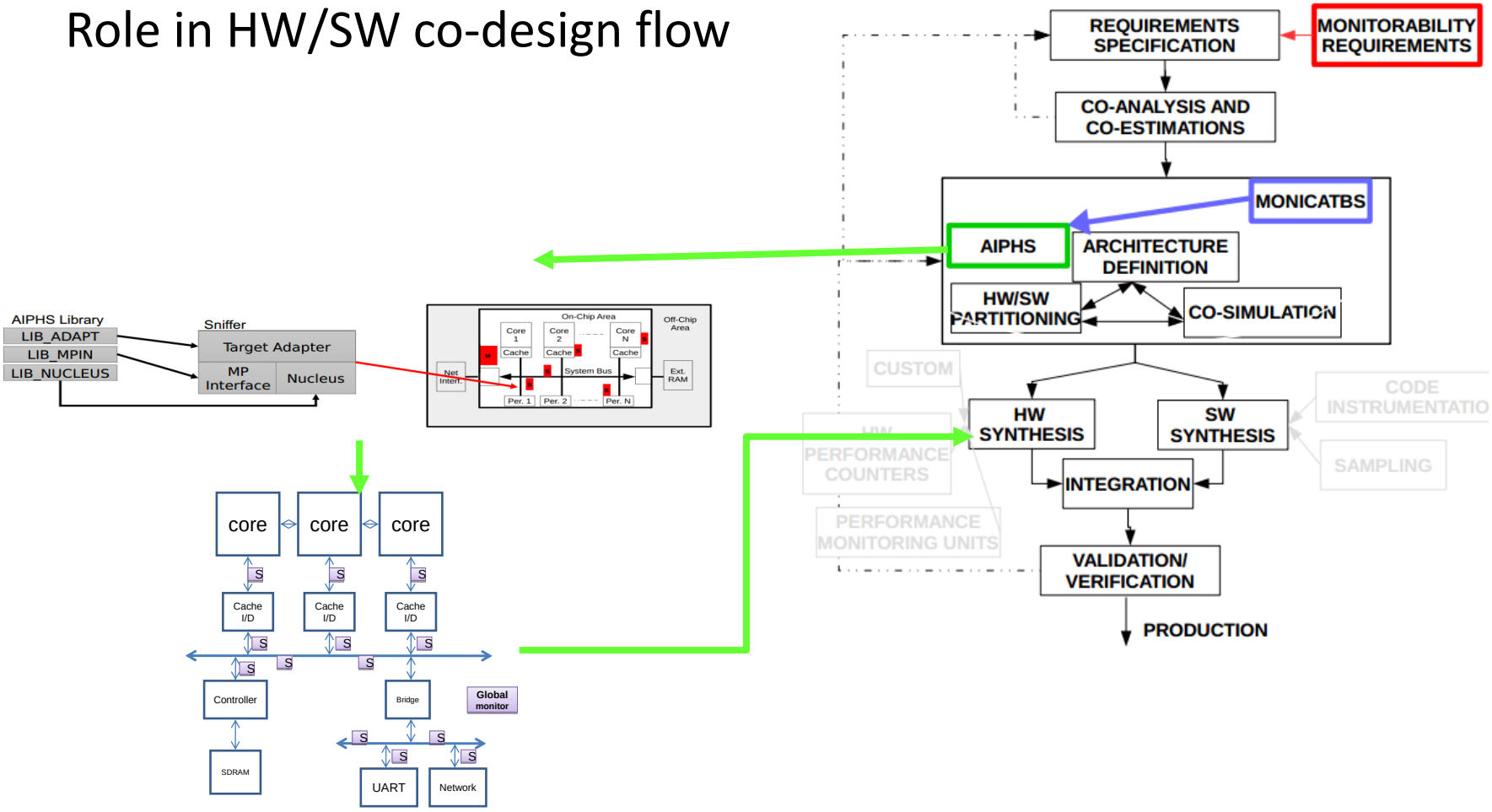
- Acronym of "AdaptIve Profiling HW Sub-system"
- Library of elements to develop HW on-chip monitoring systems
  - Strongly customizable on-chip monitoring architecture
  - APIs to interact with implemented on-chip monitoring systems both in bare-metal and Linux user-space applications



Contribution

AIPHS

Role in HW/SW co-design flow



Contribution

AIPHS Metrics

- Memory exploitation metrics
- HW communication metrics
- Overall execution time metrics
- Code coverage metrics

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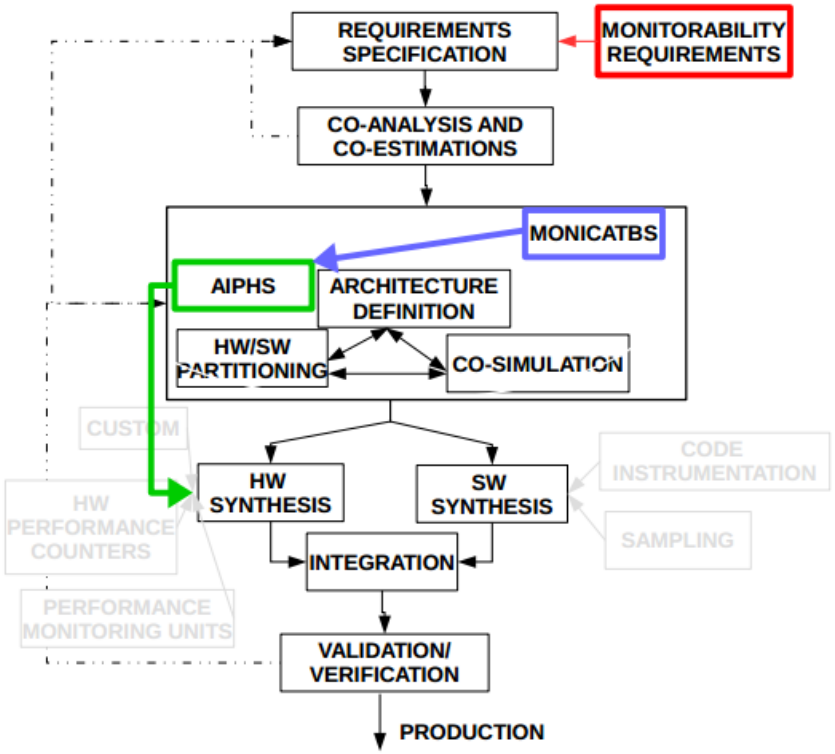
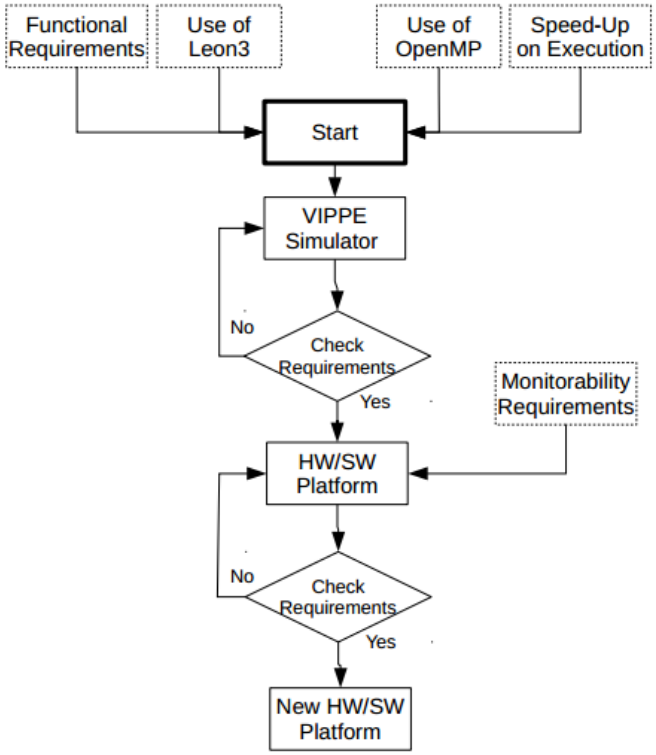
AIPHS Validation

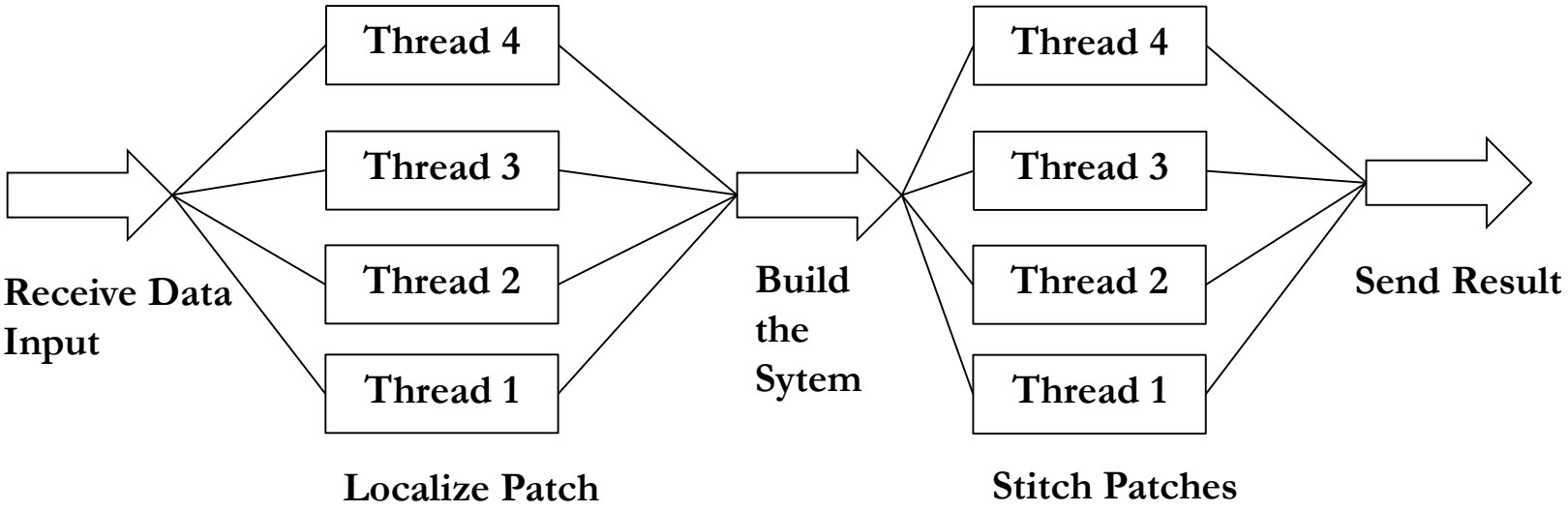
Indoor localization algorithm





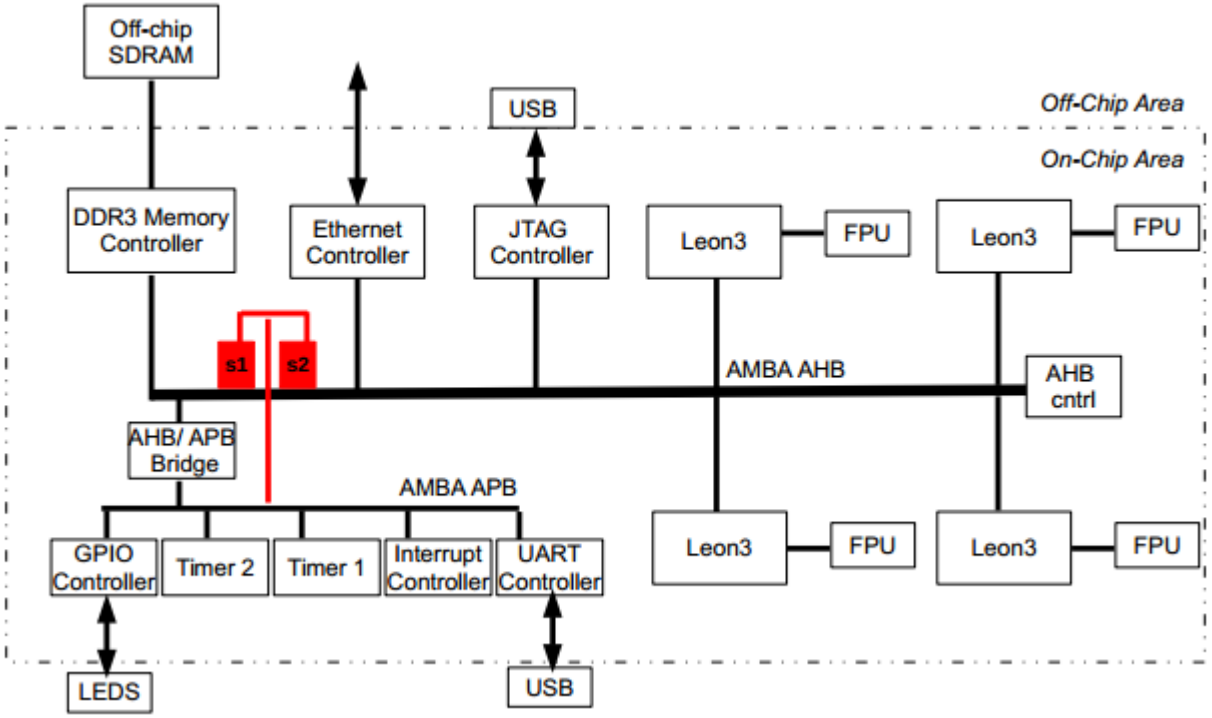
AIPHS Validation

Indoor localization algorithm



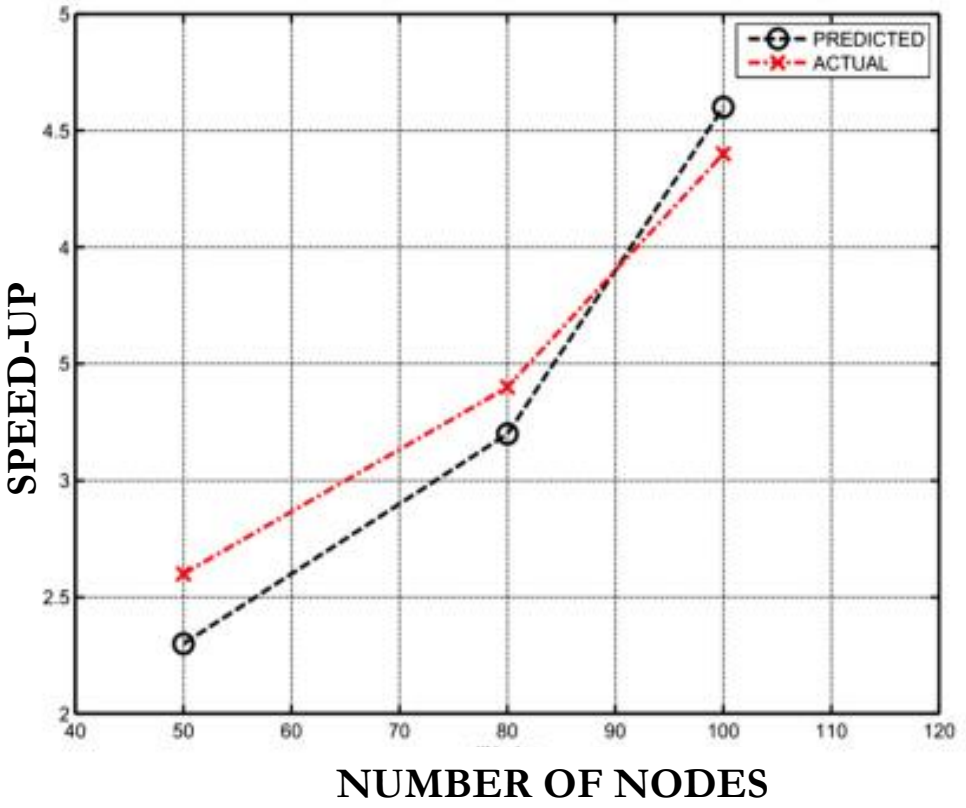
AIPHS Validation

HW architecture of the monitored system



AIPHS Validation

Predicted vs actual speed-up trend



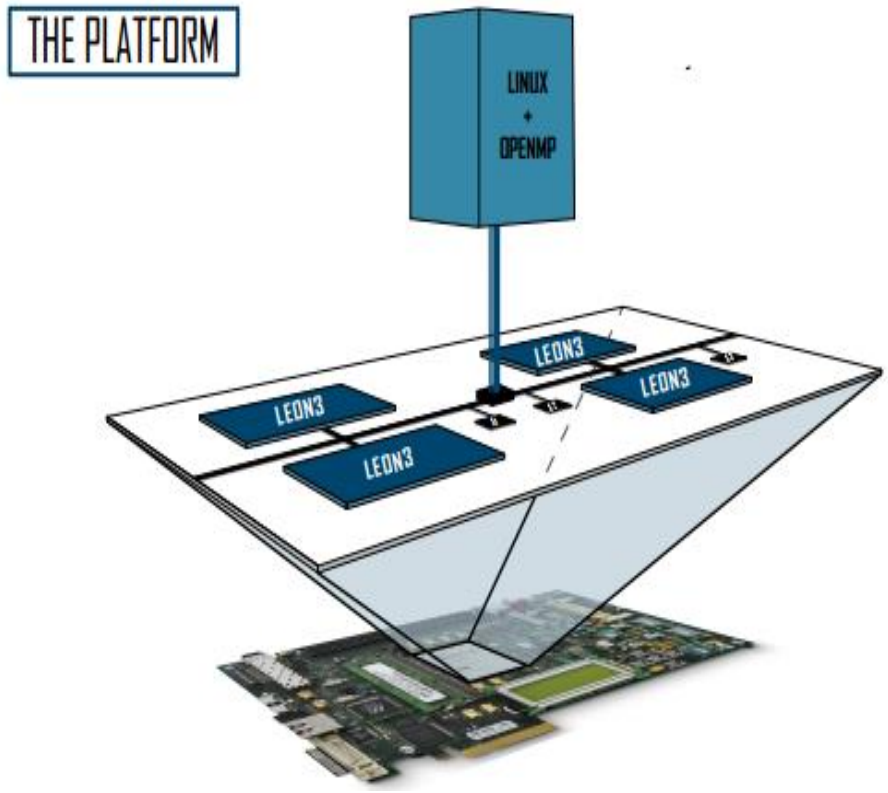
Usage of MONICA: F-OMP

Development of an OCMS able to offer a feedback about the use of OpenMP in embedded systems physically implemented on FPGA

- Parallel Coverage
- Workshare duration
- Load Balancing
- Work Scheduling
- Number of data cache / TLB misses
- False Sharing

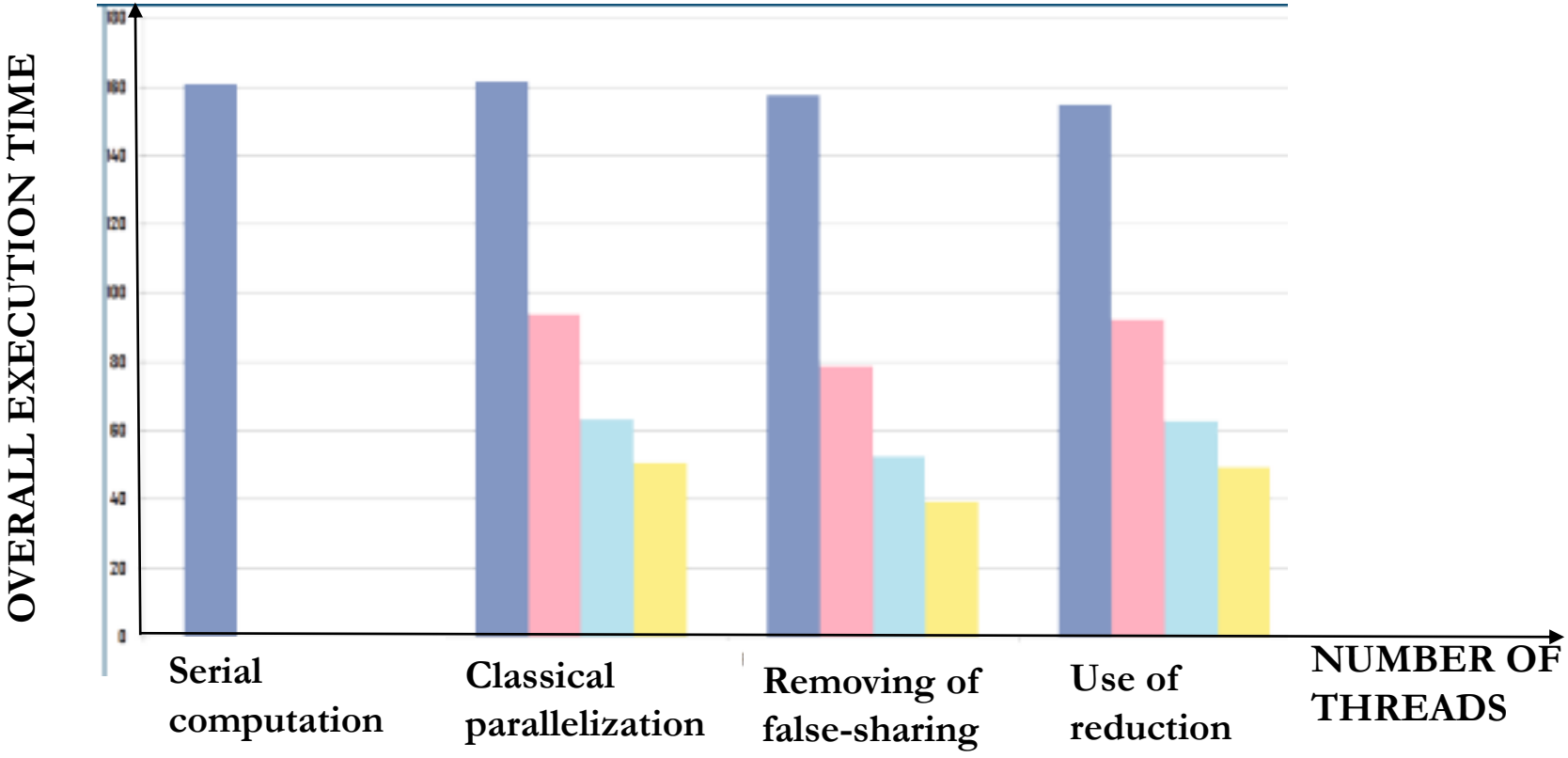
Usage of MONICA: F-OMP

HW architecture of the monitored system



Usage of MONICA: F-OMP

Application of feedbacks from F-OMP



Conclusions

The main contributions of the work:

- Proposal of MONICA methodology, to consider on-chip monitoring systems since the initial steps of the design-flow and evaluation/estimation of their impact, something that has never been proposed in literature
- Proposal of AIPHS library, to develop HW on-chip monitoring systems for architectures on reconfigurable logic
  - Validation through three use-cases
- Application of both MONICA and AIPHS to develop F-OMP, an on-chip monitoring system to offer feedback to speed-up the execution of applications that make use of OpenMP

Future Works

- Release of the tool to fill the MONICA table for each on-chip monitoring systems
- Introduction of MONICA methodology in an existing HW/SW co-design tool
- Integration of ABACUS into AIPHS
- Porting of F-OMP toward RISC-V architectures

Thank you

Any Questions?