GEMSCLAIM

Greener Mobile Systems By Cross Layer Integrated Energy Management

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Consortium:

- University of Innsbruck
- Queen's University Belfast
- RWTH Aachen University
- Politenica University of Timisoara

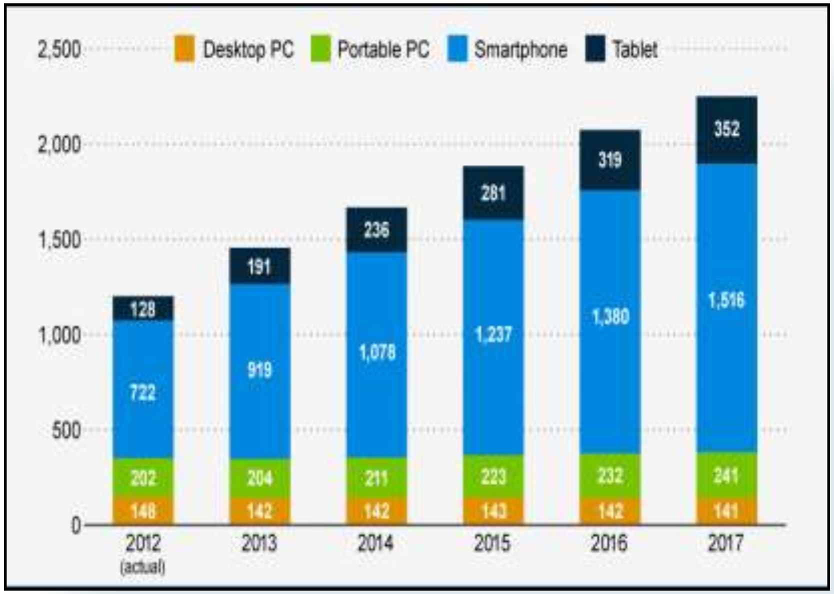
Start: September 1, 2012

End: August 31, 2015

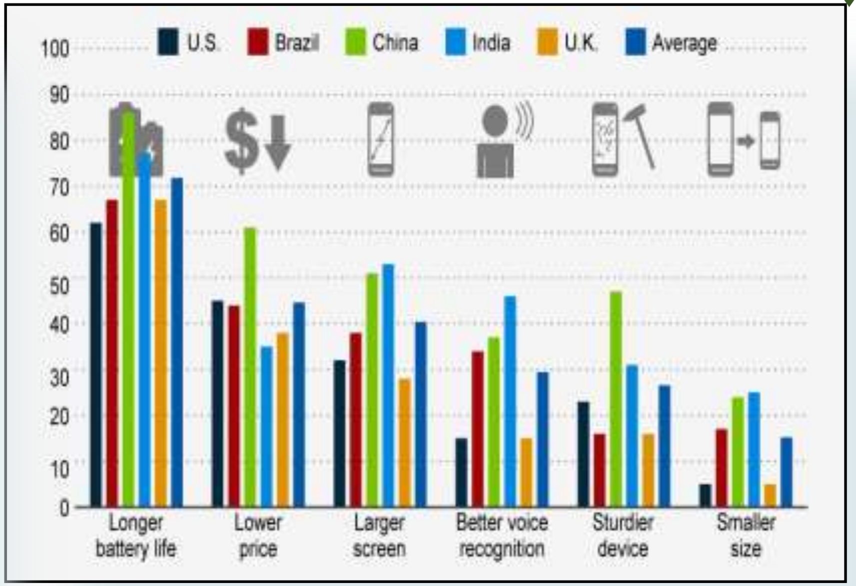
Chist-era Projects Seminar 2016, Bern, April 28, 2016

Scientific background

Smartphone sales (billions)



Improvements wanted by mobile device users (%)



- Mobile systems are becoming more energy demanding
- Longer battery life is the most desired user feature.
- Trade-off between energy and performance for mobile devices and many other computing systems: desktop computing, cloud computing, HPC
- Mobile devices are inherently heterogeneous
  - Risc-like application processor, DSP for baseband processing

Key challenges and potential impact

Cross layer energy management and optimization for mobile devices: HW/simulator, OS, compiler

- Energy-aware optimizing and parallelizing compiler
- Energy-proportional operating system
- Customizable HW modeling with energy monitoring facilities
  - simulator
  - FPGA

Potential impact

- control trade-off between energy optimization and performance
- additional 30 % energy savings for mobile terminals

Consortium and synergies

Cross-layer power optimization

universität innsbruck

Queen's University Belfast

Universitatea Politehnica Timişoara

RWTH AACHEN UNIVERSITY

MPSoC

Project Coordination

Physical prototyping
Continuous energy monitors & sensors

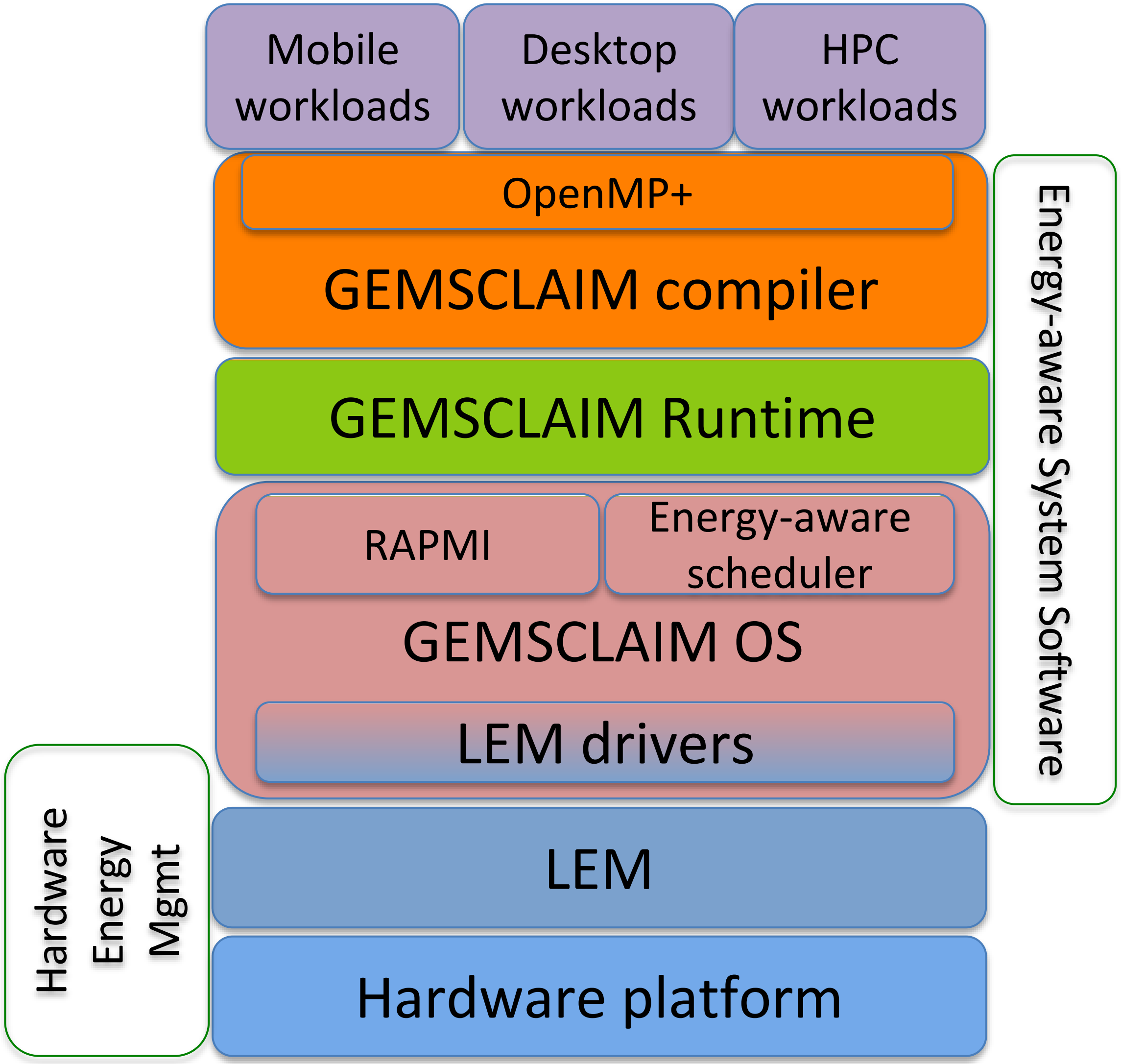
Virtual prototyping & hardware design
Instruction-level power modelling

Compiler/RTL/OS interface, Multi-objective optimisation
Energy accounting, abstractions, SLAs

OS-FPGA, OS-VP interface, lightweight RTL

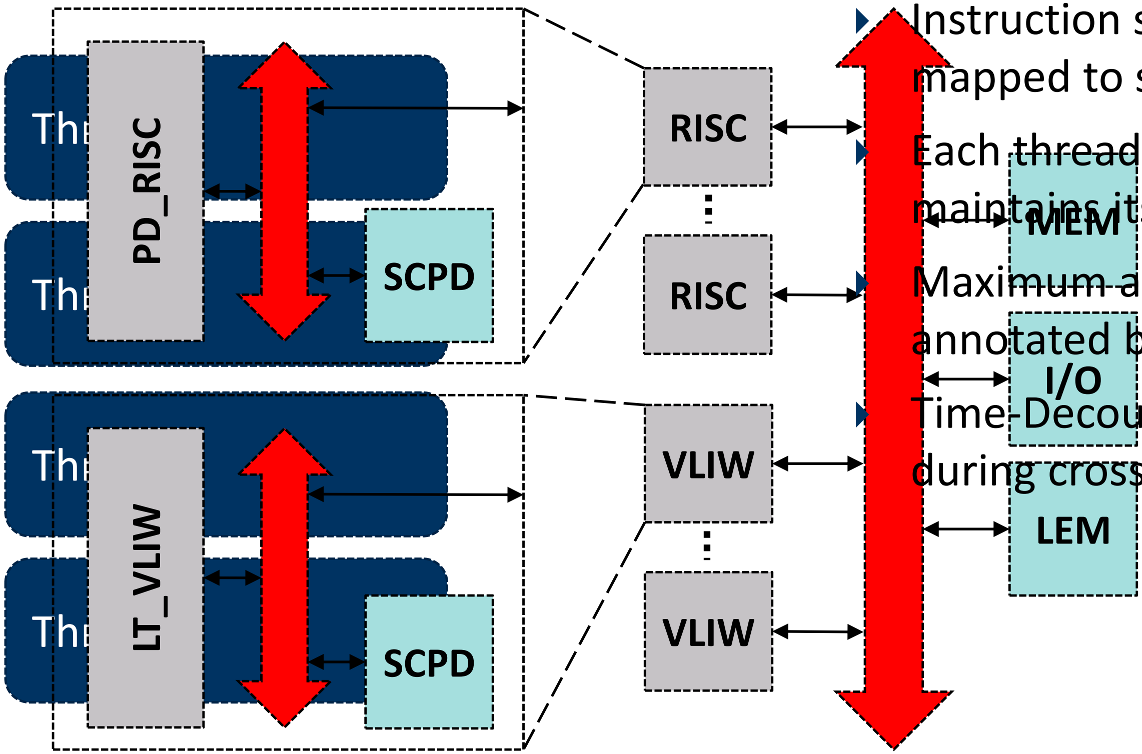
Energy-efficient programming and energy optimisation of mobile workloads at/across levels

GEMSCLAIM Software and Hardware Stack



Parallel SystemC Simulation

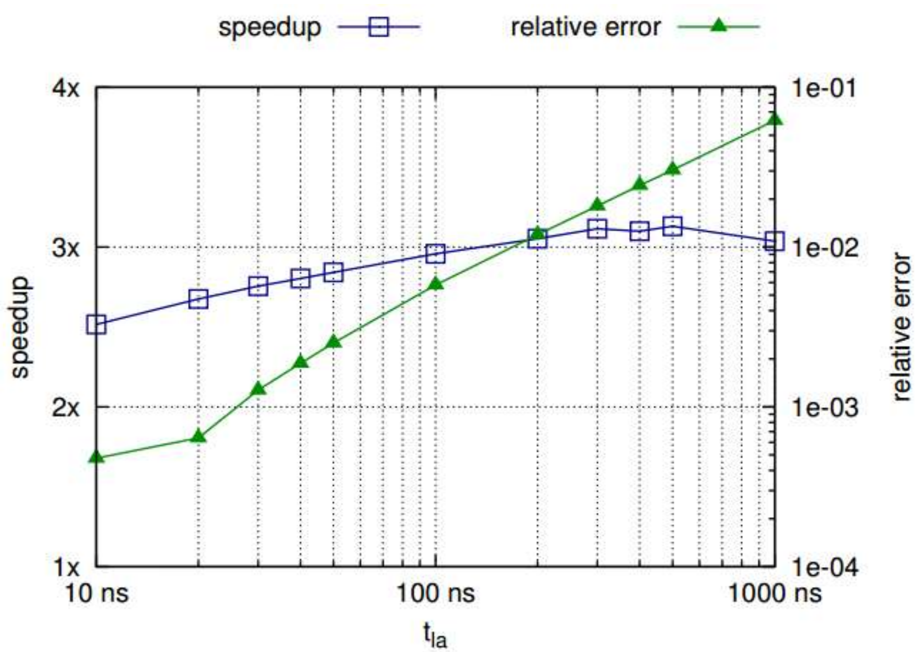
- Contemporary heterogeneous multi-core system
  - System parameters (number/type of cores, mem size…) statically configurable
- GEMSCLAIM simulator is based on SystemC
  - Exchanging reference SystemC with ICE’s SCOPE SystemC kernel enables parallel simulation



- Instruction set simulators are automatically mapped to simulation threads
- Each thread simulates on its own and maintains its own simulation time
- Maximum allowed time difference (t_{la}) is annotated by the system designer
- Time-Decoupling may induce a timing error during cross thread communication

Simulation speed vs. accuracy

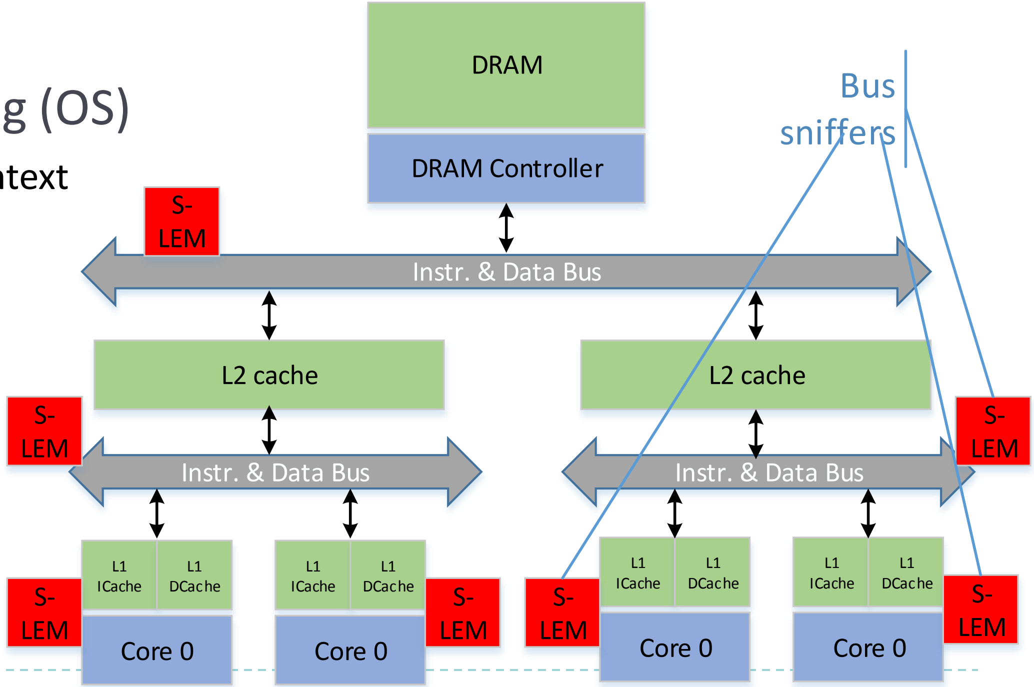
- Test setup (parallel simulator uses 4 threads):
  - 8 RISC + 8 VLIW system
  - Application: “ocean” from SPLASH-2 benchmark suite



- ➢ 3x speedup possible with ~1% error in timing
- ➢ Timing error increases linearly with time decoupling

FPGA prototype with PTEA

- Per Thread Energy Accounting (PTEA)
  - Per-core energy accounting (HW)
    - Shared resources
      - Monitor bus transactions
      - Account the energy of the transaction to the core which initiated it
      - Use the interconnect existing support to identify the source of the transaction
    - Local resources
  - Per-thread energy accounting (OS)
    - Energy counters part of thread context

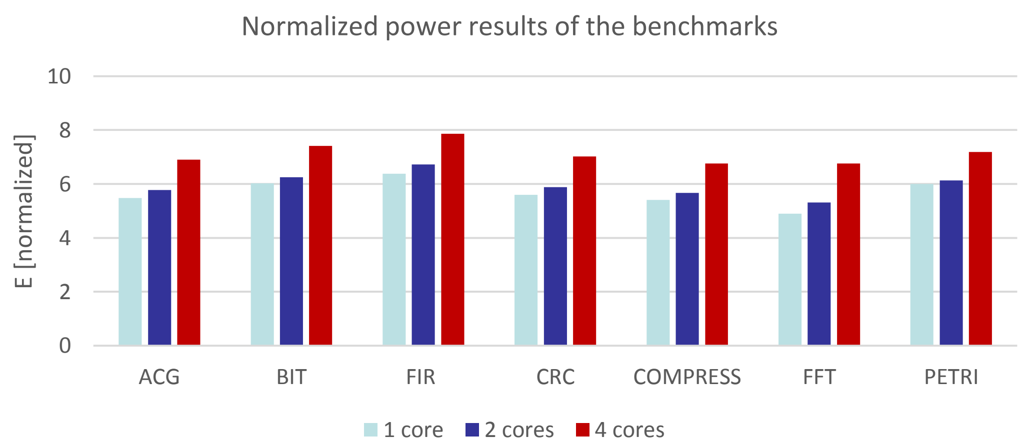


FPGA prototype with PTEA

- Platform
  - ZC 702 board with Xilinx Zynq 7020 device
    - PL – programmable logic
    - PS – processing system
- System
  - ARM Cortex A9 Dual Core processing system
    - ARM0 – used to configure and monitor LEM
  - Target reference design block
    - 4 processing cores (Microblaze), with local interrupt controller and local memory
    - LEM sensors: 2 sensors/core, 2 shared sensors/memory
  - Target design
    - 2 clusters of 4 cores blocks
    - 8 Microblaze cores, with local interrupt controller, local timer and local memory
    - 2 LEMs

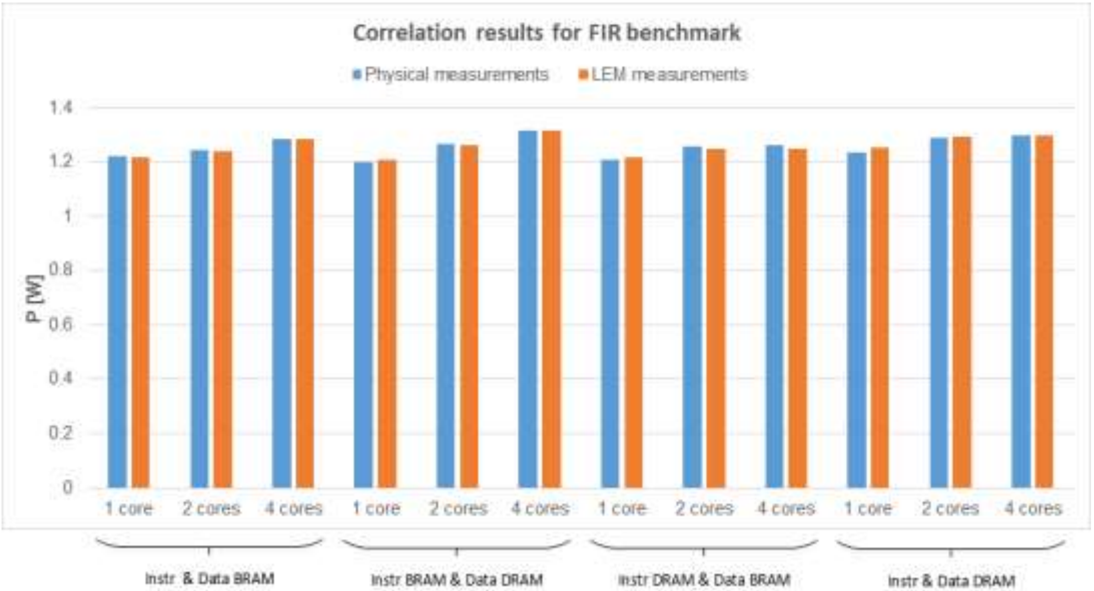
FPGA prototype with PTEA

- Calibrate and validate FPGA prototype
- WCET benchmarks
  - No OS / bare metal implementation
  - Small enough to be executed from BRAM too
  - Repeatable/ deterministic
  - 2-3 minutes/test x 2/3 tests x 2 boards
  - Normalized energy



FPGA prototype with PTEA

- Correlation results between power estimations of LEM and physical measurements: ~95%



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Energy-aware OS prototype

- GEMSCLAIM OS prototype
  - Heterogeneous Multi-processing support
  - SystemC simulation
  - FPGA prototype
- Portable Execution Supervisor
  - Execution controlling daemon on Linux systems
  - ARM big.LITTLE (ODROID-XU3)
    - Exynos 5 Octa
  - x86-64 (Intel servers)
- Energy-awareness
  - Account energy per-thread and on different HW components
  - Control execution for reducing energy consumption

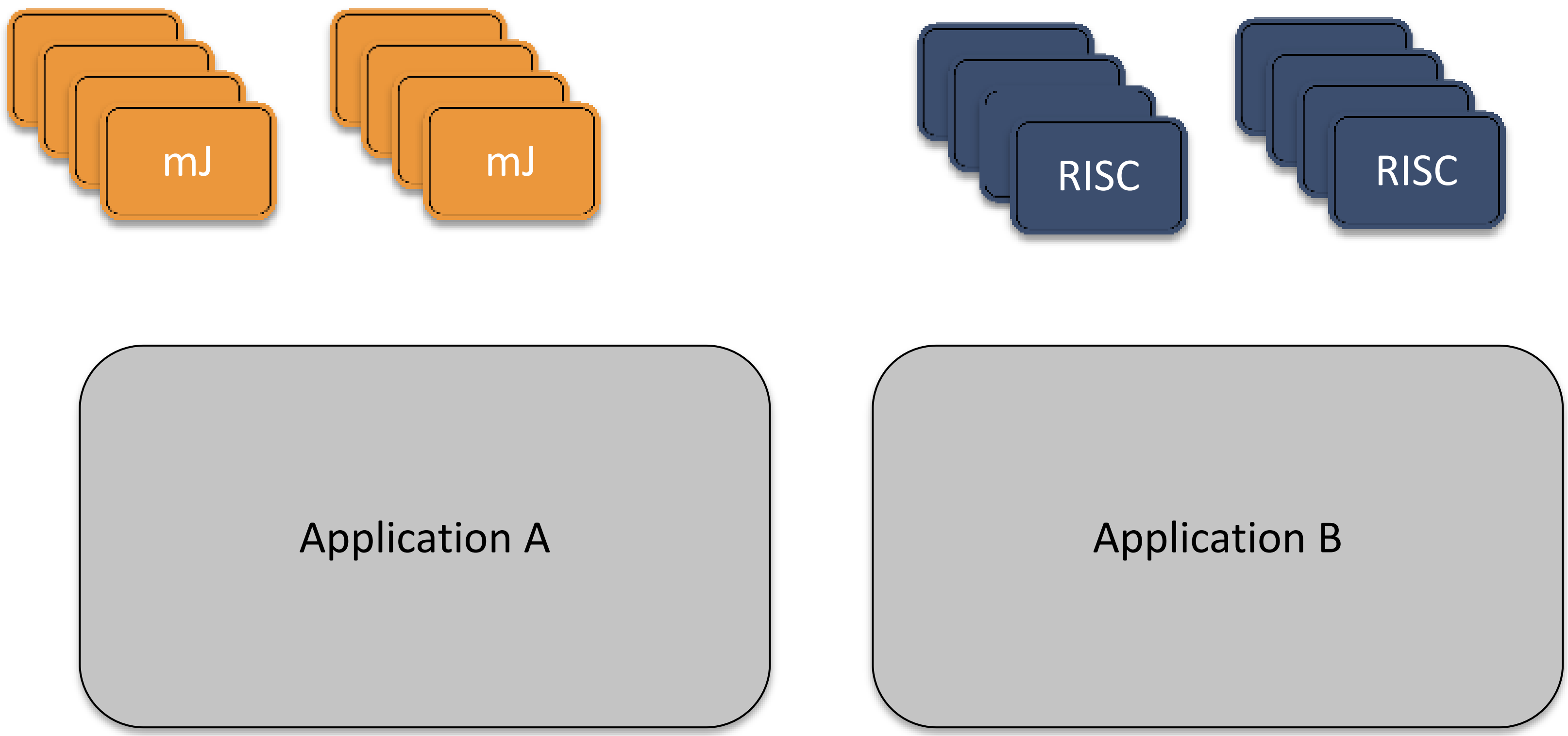
Resource Allocation and Power Management Interface (RAPMI)

- Ported on several platforms
- LEM (SystemC and FPGA)
  - CPU, Memory
  - Sampling period <1us
- ODROID board sensors
  - CPU, Memory, GPU
  - Sampling period ~262us
- Intel RAPL
  - Hardware counters
  - Sampling period ~1ms

Energy-aware scheduling

Energy slices (first-class resource)

Processor time slices (within energy budget)



Multi-objective energy-performance optimization

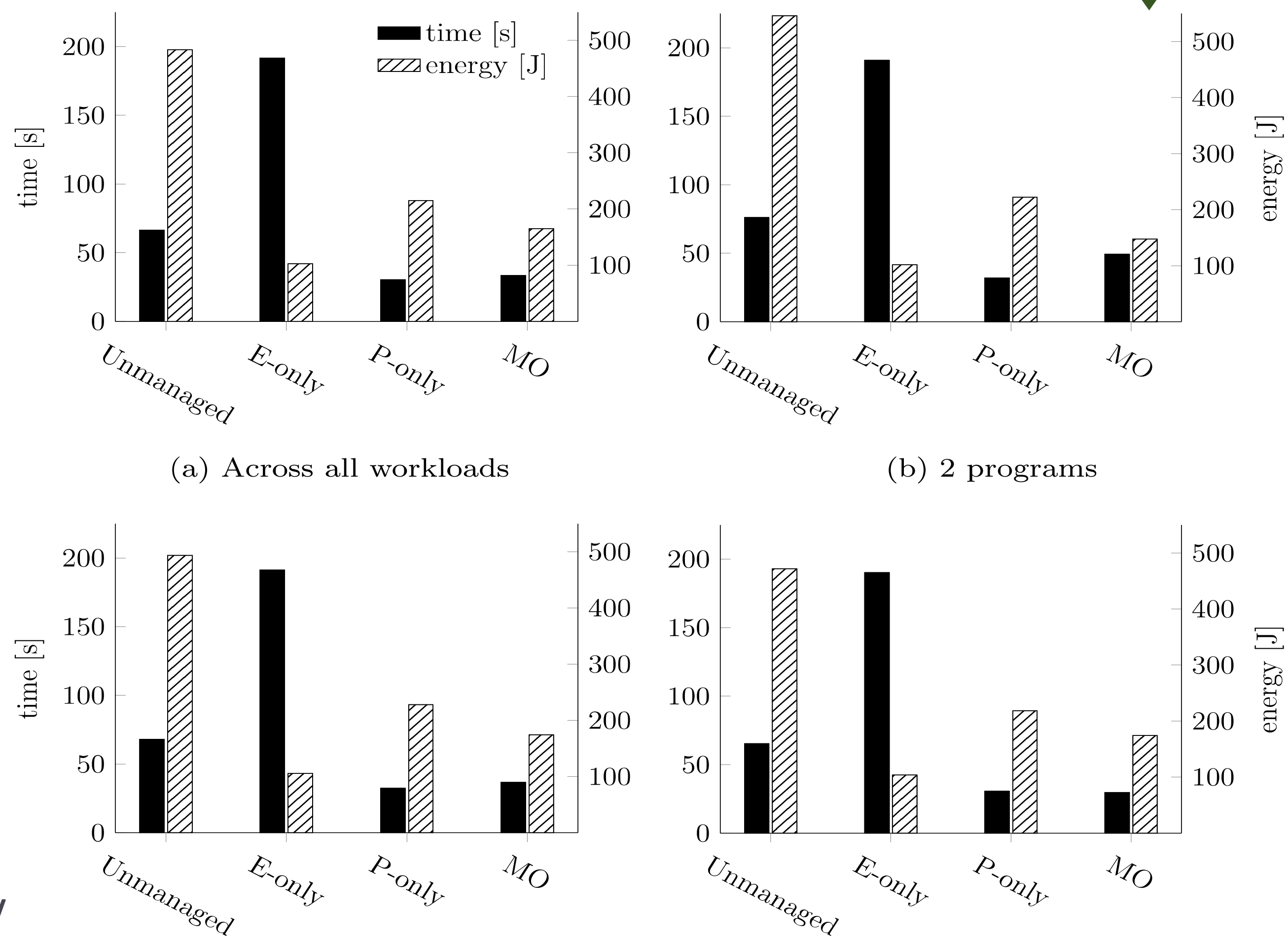
- Target combined energy-performance goals
  - Include SLA information from OpenMP+ extensions
  - Multi-program execution
- Monitor execution of the workload
  - Programs enter and exit
  - Periodically probe programs through the GEMSCLAIM runtime
    - *Scalability* (multi-threading)
      - Guide DCT
    - *Slowdown* (frequency throttling)
      - Decide DVFS

Prototype evaluation

- ODROID-XU3 platform
  - Power sensors
    - CPU and Memory
  - DVFS
  - ARM big.LITTLE heterogeneity
    - A15 and A7 cores
- Multi-program execution
  - Workload generator
    - MediaBench, BOTS, NAS, Rodinia
- Baseline
  - Unmanaged
- Optimizers
  - Energy only (E-only)
  - Performance (execution time) only (P-only)
  - Multi-objective Probing Guided Optimizer (MO)
    - EDP target

Results

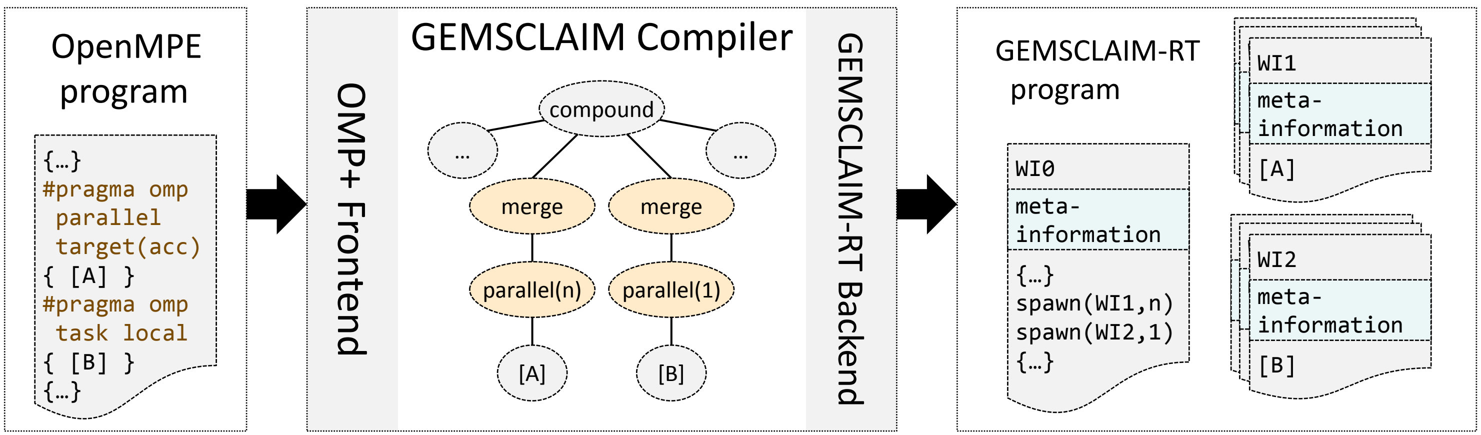
- MO
  - vs. Unmanaged
  - ~3x less energy
  - ~2x faster execution
  - vs. P-only
  - ~30% less energy
  - ~90% of performance
  - vs. E-only
  - ~6x faster execution
  - ~30% more energy



(a) Across all workloads
(b) 2 programs
(c) 4 programs
(d) 6 programs

Compiler and runtime system

- The GEMSCLAIM Compiler is a source-to-source C compiler
  - supports C programs annotated with OpenMPE
  - OpenMPE is an energy-aware extension to OpenMP



- Programs are divided into meaningful code regions
  - division either by manual annotation or automatically (e.g. based on parallel regions)
  - individually tunable and annotated with additional metadata
  - metadata is derived from analysis and/or user annotations

Compiler runtime system

- Compiler runtime available on all relevant platforms
  - GEMSCLAIM virtual platform & ARM boards (e.g. ODROID XU+E) & X86/64-Linux reference version
- Supports *upcalls* from OS/low-level layer
  - E.g. **`irt_set_dop(uint32)`** allows OS to control per-program degree of parallelism

  → More effective parallelism management than simple thread packing!
- Performs *downcalls* to OS/low-level layer
  - E.g. for application-level frequency scaling control

  → Can make use of information not available at the OS layer!

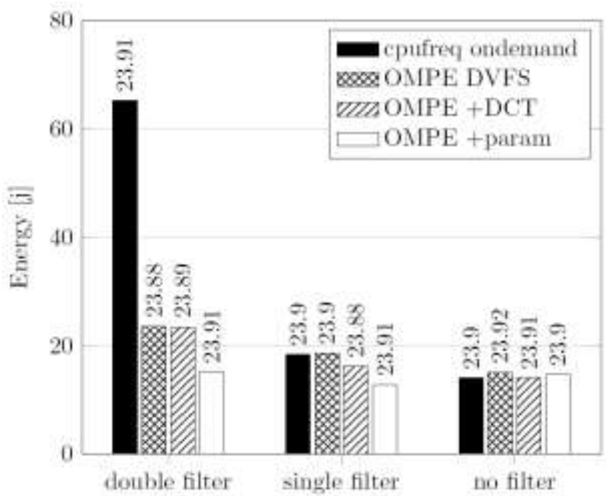
OpenMPE – OpenMP for energy

- Set of extensions published at IWOMP 2015 (*Application-level Energy Awareness for OpenMP*)
  - Region construct (handling code outside OpenMP regions)
  - Objective clause (defining multiple optimisation objectives and constraints)
  - Param clause (define tunable parameters for compiler optimisation)
- In addition to energy, power and time: *quality of service* constraints
  - Can be mapped to user-defined parameters
  - Example usage in video decoder:

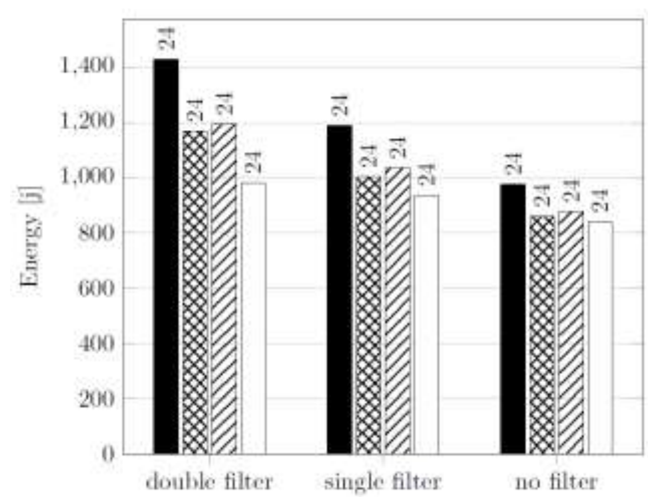
```
#pragma omp parallel for schedule(dynamic)
        objective(E : T<1/f_rate; Q<3) param(scaling, range(1:8:1))
for (int y=0; y<rows; y+=2*scaling)
    for (int x=0; x<cols_2; x+=scaling) {
        ...
        if(scaling > 1) { ... }
    }
```

e-optimizer

- Multi-objective optimization for OpenMPE programs
  - Dynamically searches best configuration for given goals and constraints
  - Combines random sampling (to prevent local minima) with multi-dimensional hill climbing (to quickly converge)
  - Up to 77% energy savings on mobile and 31% on desktop



Mobile platform, 704x576 resolution



Desktop platform, 1408x1152 resolution

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GEMSCLAIM Publications 2012 and 2013

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GEMSCLAIM Publications 2014

- M. Marcu, C. Cernazanu, Applications of Smart Metering and Home Appliances' Power Signatures, Proceedings of 2014 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Montevideo, Uruguay, May 2014
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- R.N. Vasiliu, M. Popa, M. Marcu, Wireless programmable thermostat using Raspberry Pi, Proceedings of 6th International Workshop on Soft Computing Applications (SOFA) Timisoara, Romania, Jul. 2014
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- On the Potential of Significance-Driven Execution for Energy-Aware HPC. Philipp Gschwandtner, Charalampos Chalios, Dimitrios S. Nikolopoulos, Hans Vandierendonck, Thomas Fahringer. EnA-HPC 2014 - Sep 1-2 Dresden, Germany.
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- Application-level Energy Awareness for OpenMP. Ferdinando Alessi, Peter Thoman, Giorgis Georgakoudis, Thomas Fahringer, and Dimitrios S. Nikolopoulos. Proceedings of the 11th International Workshop on OpenMP (IWOMP 2015). Vol. 9342 Springer International Publishing Switzerland, 2015
- Parallel SystemC Simulation for ESL Design using Flexible Time Decoupling. Jan Henrik Weinstock; Rainer Leupers; Gert Ascheid. International Conference on Embedded Computer Systems: Architectures, Modeling and Simulation (IC-SAMOS), IEEE Computer Society, 2015

GEMSCLAIM Publications 2015 (2)

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Important GEMSCLAIM project objectives

- Cross layer energy management and optimization for mobile devices: HW/simulator, OS, compiler
- Control trade-off between energy optimization and performance
- additional 30 % energy saving for mobile terminals

- GEMSCLAIM achieved all of that.

Conclusions and way forward

- Cross-layer energy management and optimization requires breaking barriers between layers
  - Common abstractions, metrics
  - Synergetic optimization approaches
- Measuring energy consumption remains challenging
  - Machine-specific, intrusive, coarse-grain
  - Hybrid modelling & measurement approaches are the only viable
- Software needs to evolve to break the energy wall
  - Energy optimization should become explicit
  - Sensitivity of energy to software structures is not well understood
- *GEMSCLAIM provides promising solutions for these challenges in a holistic approach, demonstrated on a physical HW/SW substrate*

Sustainability and Valorisation

- Joint FETHPC proposal accepted: H2020 FETHPC AllScale
- Part of the SW under Apache 2.0 license (open source)
- Parts of the GEMSCLAIM OS Runtime are used in current research projects (FP7 NanoStreams) and are a foundation for future research proposals under the Horizon 2020 research programme
- Parallel simulation technology developed in GEMSCLAIM will be used for upcoming industry collaboration projects.
- The GEMSCLAIM VP will be used as a basis for future research projects proposed in the context of Horizon-2020 Research Programme of the EU.

www.gemsclaim.eu