Whole-Systems Energy Transparency

ENTRA

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The energy consumption of computing has a significant environmental impact

Energy consumption and the environmental impact of computing technologies have become a major global concern. The growth of energy consumption in cloud computing and internet traffic is not sustainable with energy efficiency levels at their current level. Some studies estimate that these activities will account for up to 18% of global energy consumption by 2030 at current rates of growth, and would represent a major contribution to greenhouse gases.

Battery life in mobile and embedded systems

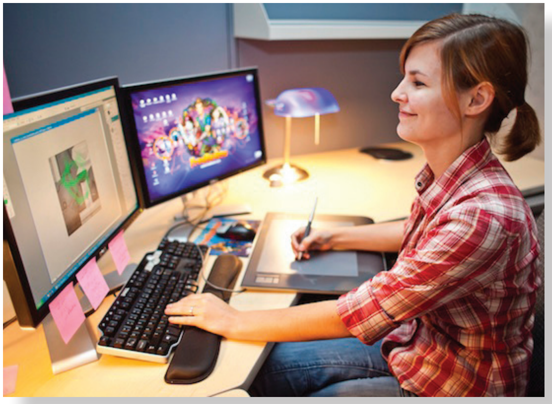
Optimizing energy consumption of battery-powered devices is an increasingly vital requirement. There are now billions of mobile computers such as phones, tablets and laptops in use, while a multiplicity of tiny embedded computers such as implantable medical devices run on batteries that cannot be replaced or recharged.

The gains are in optimizing the software

Surprisingly, more energy savings can be achieved by improving software technologies than by improving the underlying hardware. Even with current hardware, much of the potential for energy saving is wasted by inefficient software. While hardware can be designed to save a modest amount of energy, the potential for savings are far greater at the higher levels of abstraction in the system. The greatest savings will come from understanding how to develop software where energy efficiency is a verifiable design goal - in short to make software development energy-aware.

Energy transparency as the foundation for energy-aware system design

The ENTRA project emphasizes the importance of energy transparency from hardware to software as a foundation for energy-aware system design. Energy transparency enables a deeper understanding of how algorithms and coding affect the energy consumption of a computation when executed on hardware. It is a key prerequisite for informed design space exploration and helps system designers to find the optimal tradeoff between performance, accuracy and energy consumption of a computation.



The ENTRA project promotes energy efficiency to a first-class software design goal

The ENTRA project develops tools for the production of "greener" software, resulting in systems that make a certifiably more efficient use of their available resources: primarily energy, but also execution time, memory, disk space, and so on. The project will facilitate predictions of energy consumption to be made early in the software design phase, thus enabling the development of greener IT products.

Key techniques enabling energy transparency

The two main techniques for enabling energy transparency are advanced program analysis and modeling of energy consumption in computer systems. Program analysis yields information about the energy usage of a program while it is still under development, and before it is actually executed on hardware. Energy modeling provides knowledge on how energy is consumed during a computation. Such models can be established at different levels of abstraction, ranging from low-level machine instructions to higher-level code blocks and procedures. The final energy models, irrespective of their level of abstraction, provide information that feeds into static analysis algorithms for resource usage.

Verification of energy budgets

Energy-aware design is fully realized when the energy usage of a system can be verified during development. This means that a system will be delivered with an energy certificate stating that its energy consumption or power dissipation is guaranteed to remain within stated bounds, or that the battery will have a minimum specified lifetime, and so on.

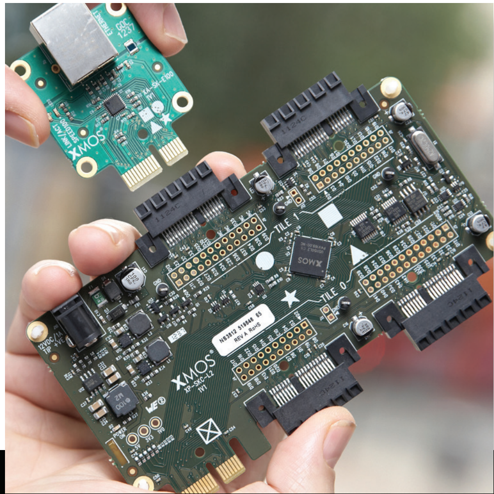
> "Energy-aware design is fully realized when the energy usage of a system can be verified during development.

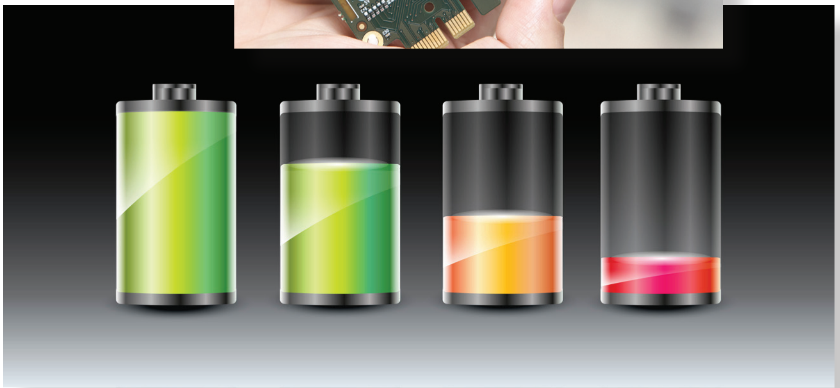
Trading off energy efficiency and performance

The ENTRA project will also study applications where energy consumption is tunable. That means that one can design software that can choose how much energy it will consume. Lower energy consumption might come at the cost of lower performance or quality. For instance, generating low quality video or audio, with lower energy costs, might be satisfactory in some situations, or one could reduce energy usage by running less urgent computations more slowly.

“The ENTRA project develops tools that facilitate the production of “greener” software.

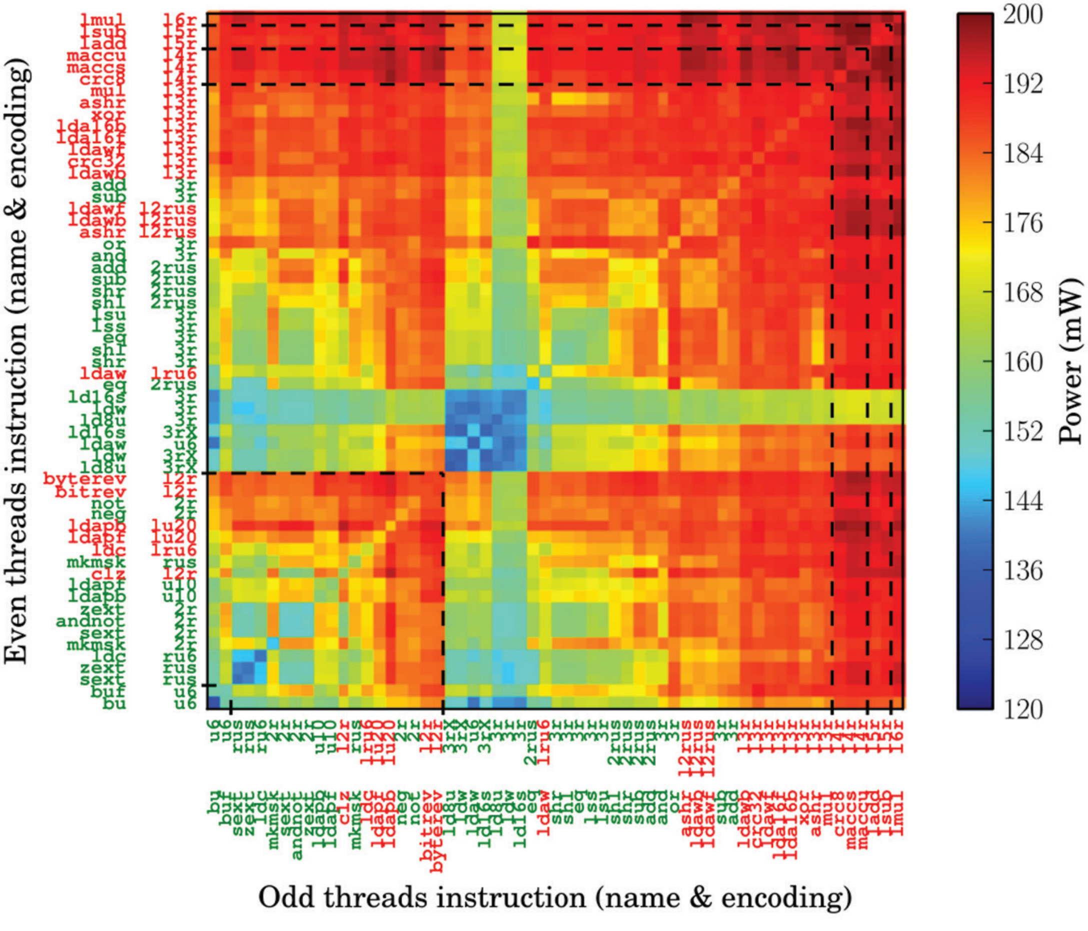
“Energy transparency will enable energy-aware optimizations.





The ENTRA project vision

It is the vision of the ENTRA project to enable energy-efficient system design, especially energy-efficient software engineering, through resource usage analysis, verification and optimization, both during code development and at runtime, based on whole-system energy transparency.



ABOUT ENTRA

ENTRA is a 3-year research project funded by the EU 7th Framework Programme Future and Emerging Technologies (FET). The project runs from the 1st October 2012 to the 30th September 2015.

The consortium consists of 4 partners

- Roskilde University, Denmark (Coordinator)
- University of Bristol, UK
- IMDEA Software Institute, Spain
- XMOS Ltd, UK

ENTRA is one of seven projects in the FET MINECC proactive area, Minimising Energy Consumption of Computing to the Limit.

www.entraproject.eu

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SEVENTH FRAMEWORK PROGRAMME

Energy-aware tools

Work Package 1. The concrete outcome of the ENTRA project will consist of prototype tools for energy analysis, verification and optimization. The tools will target the XC language and will be demonstrated on the project case studies.

Energy-aware Software Development

Work Package 1. How will energy transparency affect the conventional software engineering life-cycle when developing energy-efficient software products? The results and experiments of the project will be summarised as recommendations applicable at each of the stages of software development (from design to implementation, deployment and maintenance) obtained by using the modeling, analysis, verification and optimization techniques.

> The consortium has expertise in formal modeling and verification of designs, including designs of industrial complexity, at different levels of abstraction.

Energy Modeling (Low level)

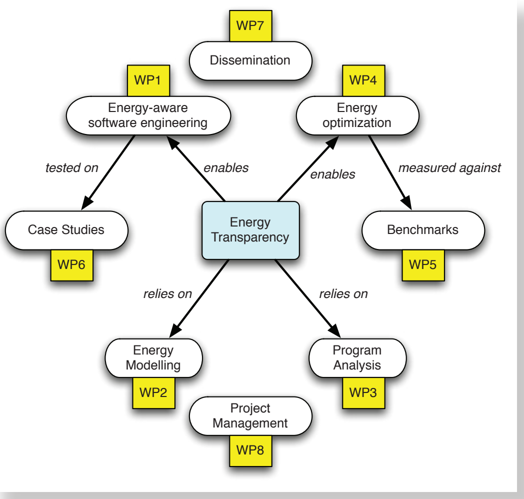
Work Package 2. Instruction Set Architecture (ISA) models are currently being established for the xCORE, initially associating instructions with average values. A significant advancement of the state of the art with respect to modeling takes advantage of the fact that formal analysis can also be performed on the basis of cost functions, rather than just cost values. Such cost functions can capture dependencies that influence the energy consumption of an instruction (such as operand values or execution history).

Energy Modeling (High level)

Work Package 2. The modeling of energy usage at higher levels is achieved using semantic mapping techniques on the one hand and dynamic profiling on the other. Explicit interpretive models of higher-level languages and execution models (including parallelism) are used to lift low-level energy models to more abstract structures. LLVM is also being studied as the target of intermediate level energy models that can be mapped to a both higher and lower level models.

Common Assertion Language

Work Package 2. The project is defining a common assertion language for expressing energy and timing properties in languages used by the embedded software design. This language will allow the expression of complex specifications including energy consumption functions that depend on data properties (such as data size), other environmental properties (such as clock frequency and voltage) and inter-module contracts. The assertion language will be multi-purpose, used for analysis, optimization, verification and debugging of embedded systems, allowing (energy) information flow between different components of the integrated tool set.



Resource analysis

Work Package 3. Advanced techniques for time complexity analysis and Worst Case Execution Time (WCET) analysis are being adapted to energy, with extensions for inferring upper and lower bounds on energy use. Handling multi-core applications is essential due to the important role of parallelism in energy consumption.

Verification and certification of energy properties

Work Package 3. The ENTRA vision for energy-aware development leads to automatic techniques supporting rich specifications about a program's energy, timing and precision properties. These can be verified using analysis information during development, leading to the possibility of certification of energy usage when software is delivered. This is a radical departure from current practice in which energy usage is only known by testing, with no guarantee about worst cases.

Program transformations for energy optimization

Work Package 4. Energy transparency will enable energy-aware optimizations. Later work in the ENTRA project will explore specialization and parallelization techniques to derive energy-efficient transformation of programs. Online analysis tools will support the integration of manual and automatic techniques, allowing the developer to explore the design space to achieve energy-efficient implementations.

Dynamic program optimizations

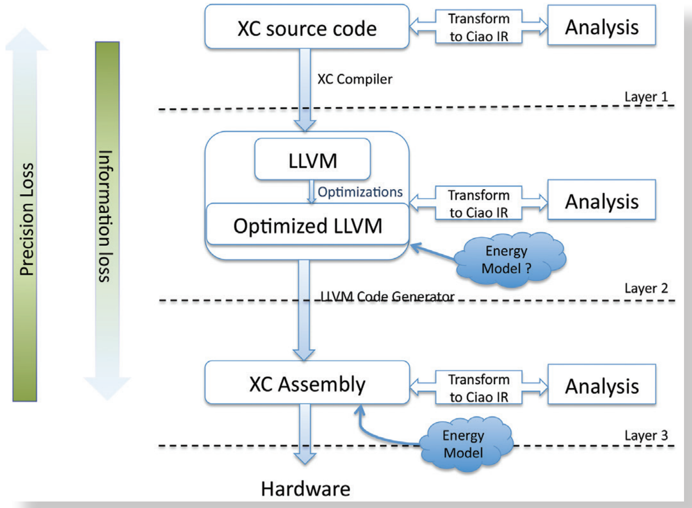
Work Package 4. Energy transparency will allow a radical re-interpretation and extension of techniques available in the literature, such as techniques for trading off energy usage against precision or speed of computation, and run-time scheduling which takes account of global energy consumption of a set of energy consuming tasks. In the final stages of the project we will explore integration of dynamic transformations such as auto-tuning and code perforation with advanced energy models also developed in the project.

Benchmarking and Optimality

Work Package 5. A new notion of optimality has been defined and explored, based on the idea of the minimal energy achievable by optimal utilization of existing hardware. This provides a pragmatic and realistic approach to benchmarking and is adaptable to all platforms.

Case Studies

Work Package 6. The main target languages used for experiments in the ENTRA project are the XC language and xCORE assembler developed by XMOS Ltd. The xCORE is a scalable multicore, can run different cores at different speeds, and is event-driven at architecture-level, enabling power-efficient implementations. The case studies being studied include an audio equalizer, an I2S audio transport controller and an Analogue to Digital Converter.



Roskilde University

The PLIS group at Roskilde University investigates foundations, tools and languages for the development of adaptable, reliable, human-oriented computer systems. The group's research covers theoretical foundations, languages, tools and semantic models together with application areas. Static analysis and program transformation are particular areas of expertise.

University of Bristol

The University of Bristol is the lead university in the Cadence Academic Network in Europe on Advanced Design Verification Methodology. It has unique expertise in formally modeling and analyzing designs of industrial complexity at various levels of abstraction from software down to silicon. It is well connected to the large cluster of semiconductor design companies in the local area. Bristol University also hosts the Energy-Aware Computing (EACO) initiative - a platform to engage with industry to promote the ENTRA project and its research results, and a route to exploitation.

IMDEA Software Institute

The IMDEA Software Institute has ample expertise in areas related to the project such as static analysis (including resource usage analysis), verification, parallelization and programming languages design and implementation. IMDEA has also experience in transferring static analysis and verification tools and techniques to industry.

XMOS Ltd.

XMOS is an SME with a revolutionary event-driven multi-core processor family (xCORE) for embedded systems, along with tools for ensuring that hard timing constraints can be met. The xCORE processor is suitable for a wide range of demanding embedded applications and is being used today by a rapidly expanding set of customers in consumer, audio, industrial and automotive applications.

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