Inferring Component Energy Consumption from On-Chip Counters

Background and Motivation

The environmental footprint of modern information and communication technology (ICT) has grown to alarming levels. Data centers, personal computing devices, and networked systems collectively consume a rapidly increasing share of global electricity, contributing significantly to greenhouse gas emissions. Reducing the energy demand of software and hardware systems is therefore a critical challenge—for both environmental sustainability and economic efficiency.

A major obstacle to improving software energy efficiency is the difficulty of obtaining reliable, fine-grained energy measurements on heterogeneous hardware platforms. While some processors expose detailed energy telemetry—such as Intel's Running Average Power Limit (RAPL) interface or AMD's equivalent sensors—many components (e.g., storage devices, memory subsystems, cooling hardware, and network interfaces) do not provide dedicated energy counters. This lack of observability limits our ability to build accurate energy models and to understand the true environmental cost of software systems.

Goal of the Thesis

This thesis aims to investigate whether on-chip energy counters can be used as a basis for inferring system-wide energy consumption, including components for which no direct measurements are available. The core idea is to leverage the CPU, whose energy usage can be measured via RAPL and it's sub-domains like Package/PSYS, as a controlled "energy probe" to characterize other hardware subsystems.

Research Approach

The student will design and implement a methodology that includes:

1. **Background Research**

2. **Controlled Load Generation:**
   Use the CPU to generate reproducible workloads (e.g., I/O-intensive tasks, network operations, memory-intensive microbenchmarks) that individually stress specific hardware components.

3. **Energy Inference Modeling:**
   Measure the CPU's and whole system energy consumption during these tasks and derive empirical models or regression curves that estimate the energy usage of:
   - Storage devices (SSD/HDD reads/writes)
   - Memory operations
   - Network transmit/receive paths
   - Cooling components (fan control)
   - Other peripheral subsystems

4. **Validation:**
   Where possible, compare inferred energy values with external measurements (e.g., power meters, PMCs, IPMI sensors) to evaluate accuracy.

Expected Contributions

The thesis will contribute to:

- A novel methodology for deriving subsystem-level energy estimates using system wide energy metrics by deduction from CPU energy counters.
- A better understanding of cross-component energy interactions in modern computing platforms.
- Improved tools and models for evaluating the environmental impact of software systems on otherwise unmeasurable hardware.
- Practical implications for sustainable computing, environmentally aware software design, and lifecycle carbon assessment.
- Ideally the thesis will lead to a paper.

Supervision & Environment

This thesis will be carried out in collaboration with **Green Coding Solutions**, a company specializing in sustainable software engineering, energy-aware tooling, and methodologies for measuring and reducing the environmental footprint of digital systems. Green Coding Solutions develops open-source tools, energy-profiling frameworks, and best-practice guidelines for environmentally responsible software development, and works closely with industry and research partners to advance sustainable ICT practices.

The student will be embedded in a research environment that combines academic supervision with practical insights from Green Coding Solutions' ongoing projects. This includes access to energy-measurement tooling, benchmarking infrastructure, and domain expertise in Green Software Engineering. Students will receive comprehensive guidance in systems performance analysis, energy profiling, experimental methodology, and scientific writing, as well as the opportunity to contribute to open-source software and real-world sustainability initiatives.

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