Technology Strategy Board
Driving Innovation

Knowledge Transfer Network

Industrial Mathematics

How low can you go?

ANALYSIS OF ERRORS IN NEXT GENERATION DIGITAL CIRCUITS

ARM Holdings plc / University of Edinburgh

The need

Reducing energy consumption is an ongoing concern for electronic devices such as laptops and mobile phones. Lowering the supply voltage of digital circuits extends battery life, but risks arithmetic processing errors that would normally cause circuits to fail. ARM's Razor Technology detects and corrects these errors to avoid catastrophic failure, allowing circuits to be operated safely at sub-critical supply voltages.
Razor adapts supply voltage to maintain a constant small error rate as the workload and environmental factors change. The present proof-of-concept Razor CPU operates correctly when the supply is lowered to the critical voltage. Further insights are still required regarding the theoretical limits and improvements in control algorithms for achieving optimal performance.

The outcomes

As a result of our investigations we have quantified the scope for further reduction in energy consumption and proposed a proportional-integral-differential (PID) control strategy for adapting the supply voltage to achieve maximum energy efficiency over a range of workloads, clock frequencies and sampling times. Energy efficiency in digital circuit design is challenging the received wisdom: accepting and correcting a small number of errors is more energy-efficient than designing in a safety margin for zero error rate.

The contribution of this work includes: defining the optimization problem for further energy reduction; setting up the measurement system to estimate the potential amount of energy saving; testing the sensitivity of the critical voltage under different measuring time windows; testing the impacts of different workloads on error occurrence; investigating control algorithms for energy-efficient real-time operation.

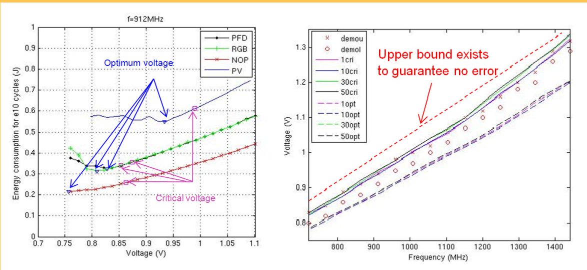
Through this internship project, the student acquired a better understanding of an engineer's approach to problem solving, and gained more experience in processor design and testing, numerical analysis and optimization.

"The KTN helped us find a great student in Rui, whose diligence and tenacity helped us both gain a deeper understanding of the Razor control loop problem, and techniques we can use to attack it."

Danny Kershaw, ARM

Technical summary

Through a combination of board-level measurement and analysis, we obtained greater understanding of the underlying issues. Data were collected from ARM's proof-of-concept Razor-aware CPU for different workloads and clock frequencies. Next, an off-line analysis was performed in Matlab software to determine the critical voltage, below which errors start to appear, and to identify the optimum voltage from an energy-efficiency point of view. The optimum voltage is determined by modelling the trade-off between the energy consumed in error correction against the energy saved from operating at a lower supply voltage. Typical results can be observed in the lower left figure, showing the difference between the critical and optimum voltages in terms of energy consumption.



At different frequencies, measurements for typical workloads generally suggest that a 9-18% energy reduction is possible by tuning the supply from the critical to the optimum voltage. The figure to the right illustrates that the measurement sensitivity is dependent on the observation duration. By plotting results for looping the fixed workload by 10, 30 and 50 times, we see that: (1) Even at 50 times workload the critical voltage is substantially lower than the upper bound. (2) With the current proportional controller, the proof-of-concept Razor-aware CPU is not achieving optimum energy efficiency which indicates room for improvement through better controller design.

Further, we analyzed the detected error characteristics under different voltages and workloads. The apparent randomness of circuit error observation suggests a model-free online control strategy for voltage adaption. An adaptive PID control algorithm based on Actor-Critic learning is proposed, which can be applied to tune the operating point to the critical or the optimum voltage for energy saving with affordable complexity.

"The internship has given me a great opportunity to get in touch with some real engineering problems on a fairly developed project in ARM Ltd R&D Group. It is exciting to work in an industrial team and apply my specific knowledge to meet their needs."

Rui Wang, University of Edinburgh

"This has been a very exciting project where Rui's existing expertise in energy efficient wireless systems has been successfully applied to the problem of improving the energy efficiency of the Razor processor. I believe that there is significant scope for further academic and industry work on this interesting topic."

John Thompson, University of Edinburgh

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EPSRC
Engineering and Physical Sciences Research Council

Project Details

Partners

ARM Holdings
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Project investment

£15,000

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