LEARNABLE, SCALABLE, ENERGY EFFICIENT ANALOG-TO-DIGITAL INTERFACES AND THEIR AUTOMATED DESIGN

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Technology Description

Engineers in Prof. Xuan "Silvia" Zhang's laboratory have developed a unifying design and optimization paradigm to automate the design of analog-to-digital interfaces and create scalable, general purpose analog and mixed signal (AMS) blocks that employ machine learning to adapt and support an assortment of analog sensor inputs.

Currently, analog-to-digital converters (ADCs) employ hand-crafted AMS circuits to connect raw sensor data to computational logic. These traditional ADCs are labor-intensive to design and have idiosyncratic architectures that cannot adapt to the range of quantization schemes necessary for emerging high performing applications. To overcome these problems, this new fullstack design flow and development toolchain infuses intelligent optimization directly into the hardware, making the design process more efficient and the resulting hardware more robust and flexible. The invention employs deep learning methods to create a hardware substrate that is robust, error tolerant and amenable to automated synthesis and compilation. The resulting ADC can support both linear uniform quantization and reconfigurable high-resolution nonlinear quantization with high conversion speed and low conversion energy.

Overall, these generic, flexible AMS blocks are the key missing link in an end-to-end vertically integrated solution for intelligent electronic platforms that combine sensing, processing and learning. The technology could enable future intelligent analog-to-information interfaces for near-sensor analytics and processing.

Stage of Research:

- **Proof-of-concept:** The inventors performed SPICE simulation and modeling using their automated design approach "NeuADC". Their results leverage the mixed-signal resistive random-access memory (RRAM) crossbar architecture and validate the competitive performance of NeuADC and its ability to support multiple reconfigurable quantization schemes.
- **Near Sensor Conversion**: The inventors used NeuADC to extract Histogram of Oriented Gradients ("HOG", a popular algorithm in human recognition) feature in analog domain. The SPICE simulation for energy efficiency showed NeuADC HOG was >1000X better than a conventional FPGA-based HOC and 5.5X better than digital ASIC HOG.
- **In Memory Computing**: The inventors developed NeuralPeriph – a novel neural approximation method to synthesize computational circuits integrated seamlessly with the crossbar architecture. The design incorporates both computation and quantitization and is 9.2X more energy efficient

than conventional peripherals with 8X more computational throughput.

Applications

- **AMS circuits –** ADC and other AMS circuits with flexible front-end input for intelligent electronics platforms; end-user applications include Internet of Things (IoT), bio-sensing, imaging and autonomous robotics
- **Electronic design automation** for ADC and other AMS circuits

Key Advantages

- **Automated design** with synthesis tool and neural network-based training of the circuit
    - design process is transformed such that a neural network implementation can be synthesized and the resulting neural network-based ADC has flexible blocks that can be trained to quantitize for optimizing different applications
    - the entire synthesis process can be automated
    - shortens design cycle, increasing productivity and improving yield
- **Flexible AMS blocks -** learnable, scalable and portable
    - framework supports different quantization schemes (traditional monotonic and non-traditional)
    - can be trained to "discover" the optimal scheme
    - compatible with non-volatile memory such as RRAM and ReRAM
    - improves end-to-end performance and efficiency
- **Energy efficient –** saves power in backend image signal processing (e.g., no need for Gamma correction in the digital domain)

Publications:

- Cao, W., Ke, L., Chakrabarti, A., & Zhang, X. (2019). Neural Network-Inspired Analog-to-Digital Conversion to Achieve Super-Resolution with Low-Precision RRAM Devices. arXiv preprint arXiv:1911.12815.
- Weidong Cao, Xin He, Ayan Chakrabarti and Xuan Zhang. NeuADC: Neural Network-Inspired RRAM-Based Synthesizable Analog-to-Digital Conversion with Reconfigurable Quantization Support, Design, Automation & Test in Europe Conference & Exhibition (DATE), IEEE, 2019.
- Cao, W, Ke, L, Chakrabarti, A, and Zhang, X (2019) Neural Network-Inspired Analog-to-Digital Conversion to Achieve Super-Resolution with Low-Precision RRAM Devices, International Conference On Computer Aided Design, Westminster, CO, 2019.

Patents: U.S. Patent Application Pending

Website: Zhang Lab