Special Issue on Approximate Computing: Challenges, Methodologies, Algorithms, and Architectures for Dependable and Secure Systems

(Article begins on next page)

19 April 2024

Guest Editorial: Special Issue on Approximate Computing: Challenges, methodologies, algorithms and, architectures for Dependable and Secure Systems

Alberto Bosio, *Member, IEEE,* Mario Barbareschi, *Member, IEEE,* Alessandro Savino, *Senior Member, IEEE,* Jie Han, *Senior Member, IEEE,* Jrgen Teich, *Fellow, IEEE*

T HE current trend in energy resources shapes how computing systems will address new challenges in the following years. As a matter of fact, following the current trend, by 2040, computers will require more energy than the world's resources can generate. In the very upcoming future, by 2025, data centers alone will consume 20% of all available electricity. A similar trend already impacts the communications side where, for example, energy consumption in mobile broadband networks and mobile terminals is comparable to data centers. These trends can only accelerate by broadening the spectrum of possible mobile applications to the Internet of Things (IoT), which will connect 50 billion devices through wireless connections to the cloud infrastructure within a few years.

In such a scenario, classical approaches to computer system design are no longer adequate to address the problems highlighted, and new ones need to be introduced. More than ten years ago, the scientific literature demonstrated that the Approximate Computing (AxC) paradigm could pave the way to ease the power requirements and reduce the impact of the computation on the energy budget. When coupled with error-resilient applications, AxC achieves significant gains in overhead reduction (i.e., energy and latency) at the cost of a slight (i.e., still acceptable for applications) precision reduction of output. On precise computations, an accuracy degradation can often be controlled and limited in the output space of the application executed on the AxC computing system.

So far, many AxC techniques and CAD tools have been developed targeting different abstraction layers: Circuit, Architecture, and Software. However, in the past four years, AxC has just moved from its infancy to the mainstream, also becoming attractive to the computer industry. Widely adopted Machine Learning algorithms already deeply leverage AxC techniques, i.e., the TinyML trend, and hardware manufacturers started exploiting AxC in their designs (i.e., NVIDIA GPU Volta architecture). Finally, new application domains started to use AxC, such as Testing, Dependability, Safety, and Security. In particular, Dependable systems design often requires power- and area-hungry solutions, such as redundant schemes. The ability of AxC methodology to provide smaller designs is nowadays a new possibility for functional safety experts to exploit fault tolerance and general design optimization with more tools.

Similar considerations can be drawn when dealing with robustness in the security domain. Recent works already point out that AxC techniques, deployed in selected parts of the systems, make the system less prone to external attacks by increasing the data's noise or changing the application's power signature.

The Special issue on "Approximate Computing: challenges, methodologies, algorithms and architectures for Dependable and Secure Systems" met its original goal of collecting scientific contributions that covered connections between the AxC paradigm and the dependability and security of digital designs.

This special issue comprises three highly rated research papers covering a significant part of the original call for paper.

The first paper in the Special Issue by Martin H. et al. extends the classical association of approximate computing with results that show a trade-off between result accuracy and computational efficiency, offering its application in the world of hardware trustworthiness with encouraging results.

The second paper, by Cai M. et al., proposes a design flow combining concepts of timing speculation and approximate storage to achieve a dependable operation of STT-MRAM devices. The STT-MRAM technology is considered a promising candidate for non-volatile memory (NVM), i.e., for caches and implementing embedded NVM.

In the third paper, Liu B. et al., authors proposed a low-power precision reconfigurable tensor multiplication unit (TMU) with approximate computing technologies, applying the multiplication unit to a CNN-based keywords speech recognition. The architecture is configured to use approximate encoding and addition and a lower voltage for the approximate circuits to improve energy efficiency. Results will prove the need for AxC techniques when a system's energy efficiency is the final goal.

These articles provide a snapshot of state of the art and hopefully can also suggest opportunities and challenges of this vital research theme. Enjoy reading!

Alberto Bosio received the Ph.D. in Computer Engineering from Politecnico di Torino, Italy, in 2006. He is a Full Professor at École Centrale de Lyon, Institute of Nanotechnology in France. His research interests include Approximate Computing, In-Memory Computing, Test and Diagnosis of Digital circuits and systems, and Reliability. He co-authored four books, four

patents, 54 journals, and over 164 conference papers. He is the vice-chair of the eTTTC and a member of the IEEE.

Mario Barbareschi is a Tenured Assistant Professor of Computer Systems at the Department of Electrical Engineering and Information Technologies of the University of Naples Federico II. He received the Ph.D. in Computer and Automation Engineering in 2015 from the University of Naples Federico II. His research interests include Hardware Security and Trust, Approximate Computing, emerging technologies, and embedded systems design based on FPGA technology. He has authored more than 60 peer-reviewed papers published in leading journals and international conferences.

Alessandro Savino is an Associate Professor in the Department of Control and Computer Engineering at Politecnico di Torino (Italy). He holds a Ph.D. (2009) from the Politecnico di Torino, Italy. He has been part of the program and organizing committee of several IEEE and INSTICC conferences and as a reviewer of IEEE conferences and journals. He co-authored more than 80 book chapters, journals, and conference papers. His research interests include Approximate Computing, Reliability Analysis, Safety-Critical Systems, Software-Based Self-Test, Operating Systems, Imaging algorithms, Machine Learning, and Audio manipulation.

Jie Han received the B.Sc. degree in electronic engineering from Tsinghua University, Beijing, China, and the Ph.D. degree from the Delft University of Technology, The Netherlands. He is currently a Professor and Director of Computer Engineering in the Department of Electrical and Computer Engineering at the University of Alberta, Edmonton, AB, Canada. His research interests include approximate computing, stochastic computing, brain-inspired learning systems, and neural networks.

Jrgen Teich is with Friedrich-Alexander-Universitt Erlangen-Nrnberg (FAU), Germany, where he has been directing the Chair for Hardware/Software Co-Design, since 2003. He received the M.S. degree (Dipl.-Ing.; with honors) from the University of Kaiserslautern, Germany in 1989 and the Ph.D. degree (Dr.-Ing.; summa cum laude) from the University of Saarland, Saarbrcken, Germany, in 1993. His research focuses on electronic design automation of embedded systems with an emphasis on hardware/software co-design, reconfigurable computing, and multi-core systems.