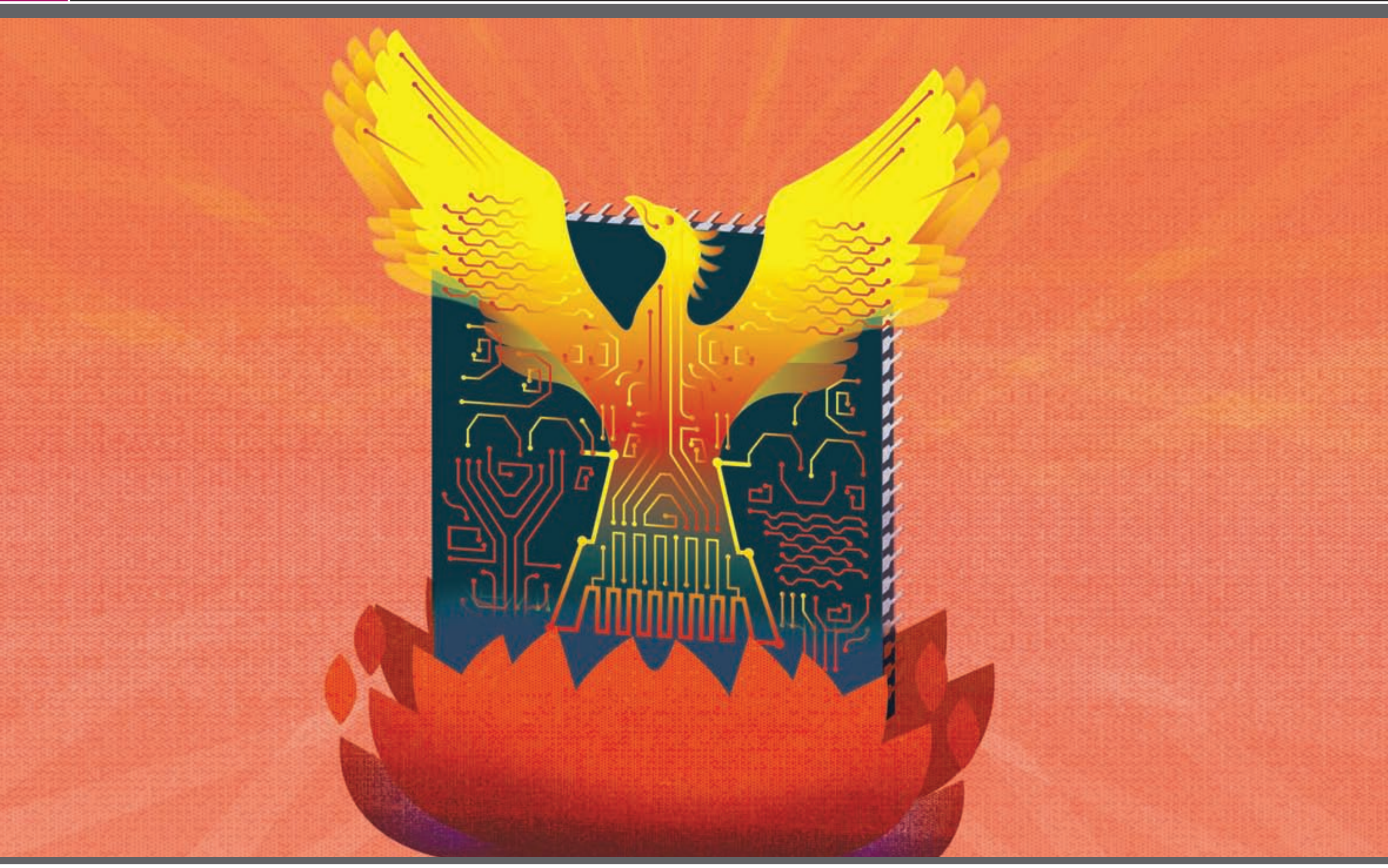

The End of Moore's Law

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These days, you can hardly attend an electronics, computing, or semiconductor conference, read a related technical magazine or publication, or even listen to a science or technology program without encountering the topic of the impending end of Moore's law within the next 10 to 15 years. Even Gordon Moore himself, who admittedly had also incorrectly predicted an untimely end of his law in the past, is now yet another voice articulating the many compelling reasons that it's real this time around. Within this context, several initiatives have emerged addressing the era following the demise of Moore's law as their primary goal. These include, for example, the IEEE Rebooting Computing Initiative and the new IEEE International Conference on Rebooting Computing.

While the subject has benefited from many approaches, each with a different emphasis, we thought it would be appropriate and helpful to readers of *Computing in Science & Engineering* to dedicate a special issue to this topic. In so doing, our goal wasn't simply to add to what has already been written or to delve into more detail in any one particular aspect but rather to give an overarching, holistic view from researchers whom we consider to be among the thought leaders in the field. These recognized experts cover the history, the varied and fundamental reasons for the universal convergence on the validity of today's prediction of this upcoming inflection point, and the principles that guide current options to continue

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exponential scaling of computing performance, albeit along different trajectories than had so successfully been predicted by Moore's law for over 50 years.

We start with a vision that combines a philosophical as well as practical outlook from Stan Williams of Hewlett Packard Labs. He boldly argues that "the end of Moore's law might be the best thing that has happened in computing since the beginning of Moore's law." Williams goes on to posit that continued exponential growth will be based on "[opening] up the von Neumann bottleneck." This is essentially done, he says, through a "memory-driven computing platform enabled by photonic interconnect."

Neuromorphic computing is a bio-inspired approach for post-Moore's law computing. Kwabena Boahen of Stanford University delves into this topic, masterfully explaining the principles at the core of neuromorphic computing, an approach that seeks not to reproduce brain function but rather to generate a brain-inspired computing paradigm that triggers a leap over the Moore's law wall. At the heart of this approach is the combination of analog with digital methods, drawing on the best of current technology and the remarkably efficient methods—as well as we understand them—in which the brain functions. He lays out a five-point plan for implementing a vision that's well on its way to realization.

Insofar as Moore's law has been one of the driving forces of economic productivity and innovation for many years, we felt that it was important to include an economic perspective as well. This is provided by University of Texas at Austin's economist Kenneth Flamm, who has written extensively on the topic. Flamm provides the societal, political, and economic context that spawned Moore's law 50 years ago through a "tide of massive national investment in information technology." Through facts and figures, combined with fundamental principles of economics, he argues for the need "of a new partnership capable of successfully creating the technological foundations of a 21st century successor to Moore's famous law."

A complete treatment of Moore's law and the prospects for continued growth in computing performance wouldn't be complete without the perspective of two practitioners who are among those who have heroically led the law's success to date, and who will continue to lead and steer this curve as it goes through the inflection point and emerges in a new embodiment. One of these experts is Thomas Theis of Columbia University, formerly of the Semiconductor Research Corporation and IBM Watson Research Center. The second expert is Paolo Gargini, retired (Fellow) from Intel, who has led, as chairman, the International Technology Roadmap for Semiconductors (ITRS and ITRS 2.0). The ITRS/ITRS 2.0 teams concluded their work and Gargini went on to create, within IEEE and in collaboration with other IEEE volunteers, the new International Roadmap for Devices and Systems (IRDS), which continues and expands the indispensable roadmapping that will lead research into the beyond-Moore era with sustained exponential growth.

Theis explains and argues for the key role that will be played by the "introduction of new devices, new 3D integration processes, and new architectures for computing." His physics-based treatment makes the case that progress will result from the multiplicative effects that will extend growth by combining different devices and approaches in a complementary fashion. Theis's treatment provides a vision of a creative dimension of progress resulting from what we could call technology grafting, an approach that has heretofore not been effectively exploited in this realm.

Gargini is somewhat of a recognized patriarch in the field of roadmapping of semiconductor devices and integrated circuits. His treatment is not only thorough but also offers insights into how Moore's law managed to be sustained for over 50 years. Building on this deep understanding not only of the technology but of its drivers, context, and scientific fundamentals, Gargini shares with us the key principles that will guide the roadmap beyond the current inflection point. His distillation of the past and future principles that together must guide the future to ensure success should be a must-read for all engaged in creating the new computing paradigms that will extend Moore's law's exponential growth.

We hope this special issue provides readers with a unique mix of perspectives that allows them to develop a deeper understanding of the issues surrounding Moore's law and the prospects for continued exponential growth in the coming era of computing. The field is indeed too large for a thorough treatment of all its aspects within one special issue. Nevertheless, we believe that the insights that can be gained by including different perspectives on technology, science, engineering, and economics from those who are recognized leaders in their disciplines should complement and possibly even extend other treatments of the subject. If it leads to more innovative contributors being inspired to join the field, offering new approaches and initiatives, we will have proudly achieved our goal here. For additional overviews of some of the key enabling technologies for future computing, see *Computer* magazine's special issues on the topic (December 2015 and September 2016).

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