

The idea drove a wave of technology that transformed society so that today, people carry cell phones that are little supercomputers. But the Moore's Law era — which lasted far longer than Moore himself expected — is coming to an end.

The speed of laptops and desktops has plateaued while the power required to run systems is rising sharply. And industry can't continue cramming more transistors onto chips indefinitely.

Major change is about a decade away, says Rob Leland, director of Sandia National Laboratories' Computing and Information Sciences (CIS) Research Foundation and Computing Research Center.

"We need a new type of computing device, new materials, new designs, and it's not at all clear what that should be," Leland says. "It has to be something that's not only substantially better than what we can do now, but which also can improve exponentially, because we don't want to jump to a new device technology that is also static."

The CIS Research Foundation is taking on a moon-shot goal: Develop the computers of the future.

Sandia is well positioned for the challenge because of its broad supercomputer experience, from architecture to algorithms to leadership in high-performance computing.

"We think that by combining capabilities in microelectronics and computer architecture, Sandia can help



Computing engineer Kathye Chavez inspects a component board in one of the many cabinets that make up Sandia's Red Sky supercomputer.

initiate the jump to the next technology curve sooner and with less risk," Leland says.

An 'epic effort'

Advances in electronic computing technology have played a crucial role in assuring national security for six decades. This began with early work to discover feasible designs for the hydrogen bomb, exploit encryption, calculate ballistics tables for conventional artillery and predict risks to society associated with weather and climate. The effort continues today with work to engineer a safe, secure and reliable nuclear stockpile and to solve "needle in haystack" data analytic problems.



Microsystems and Engineering Sciences Applications (MESA) microlab and microfab facilities opened early in 2006. The complex is designed to bring together experts in microelectronics and computer architecture.

The plateauing of Moore's Law is driving the energy costs of modern scientific computers ever higher, to the point that if current trends hold, future supercomputers would become impractical due to their enormous energy consumption. Leland says resolving the challenge will require new computer architecture that reduces energy costs, which are principally associated with patterns of moving data within the system and thus can be improved. And eventually, it will require new technology at the transistor device level that uses less energy.

Sandia can make important contributions in the physics and architecture of future computing and in components "that would be assembled into a new system that would require a new software ecosystem, and that would require new approaches to applications," Leland says. "So essentially the whole stack, the whole set of technologies that layer on top of one another,

will have to be redone to some degree, perhaps radically in some cases."

And with scientific, manufacturing and economic hurdles to work through, "it'll be an epic effort," he says.

Sandia won't develop the next generation alone but can play a key role because of its leadership in computer architecture and thanks to MESA, the Microsystems and Engineering Sciences Applications complex, which does multidisciplinary microsystems R&D and fabricates chips to test ideas.

"It doesn't really help us if we have a new device that we then can't engineer into a system," Leland says. "It's really the combination of the microelectronics capability, the computer architecture capability and all the different layers that come with that. For example, that would require new operating systems, new tools and algorithms, and so on."

MESA integrates disciplines throughout the Labs. It can invent, test and scale new information technologies and is at the heart of Sandia's work on exascale, quantum and other emerging technologies post Moore's Law, says Gil Herrera, director of Microsystems Science, Technology and Components, who runs MESA. Exascale computing aims to achieve a billion billion operations a second without excessive energy use, while quantum technology seeks to find ways





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Erik DeBenedictis

to use the interaction of atoms and particles to process information in new and highly efficient ways.

“At MESA, we can explore beyond-Moore technologies using approaches that are scalable to high-volume manufacturing,” Herrera says. “MESA is a magnet that attracts researchers from across Sandia, from universities and industry interested in meeting the challenges posed by the end of Moore’s Law. We have the flexibility to investigate different materials, devices, architectures and concepts.”

Different systems for different tasks

Sandia, in response to a call from the U.S. Department of Energy for ideas for major new experimental science facilities, has proposed a Center for Heterogeneous Processing and Packaging, or CHIP², an acronym meant to invoke a computer chip. The center would advance microsystems research, particularly for the nuclear weapons program; expand cybersecurity efforts in providing trusted microelectronics; and increase computing research and development. Leland says the center is 10 to 15 years away, but would keep DOE at the forefront of technology and attract a new generation of talent.

As a national laboratory, Sandia is able to take an independent, critical look at how proposed future technologies work, when they might be feasible and what risks each entails, says Erik DeBenedictis, who works in the Advanced Device Technologies Department. He also credited Sandia’s unique position to strong electronics research built on its nuclear mission and to MESA.

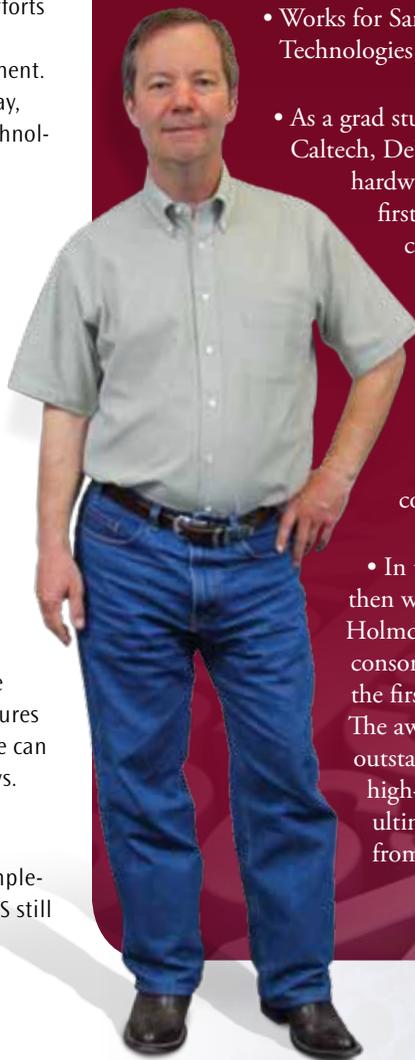
“We have a fab that allows us to actually experiment with these devices by making them and seeing how well they work. ... We can explore the designs, we can explore the materials, we can explore the architectures and the function. And if they look good, we can transfer the technology to industry,” he says.

The integrated circuit technology behind today’s computing is called CMOS, for complementary metal oxide semiconductor. CMOS still

DeBenedictis joined Sandia after his startup company failed. His first day of work was Sept. 10, 2001 — the day before 9/11. “I came to Sandia to earn a living after suffering a setback. I had no idea that on my second day on the job, national security work would experience a big boost.”

STATS

- Bachelor of science in electrical engineering from Caltech
- Master of science in electrical engineering (computer engineering) from Carnegie Mellon
- Ph.D. in computer science from Caltech



- Works for Sandia’s Advanced Device Technologies Department.
- As a grad student and post doc at Caltech, DeBenedictis worked on the hardware that turned into the first hypercube multiprocessor computer. Later dubbed the “Cosmic Cube,” it ran for more than a decade after he left the university and was copied over and over. It’s considered the ancestor of most of today’s supercomputers.
- In the 1980s, DeBenedictis, then working for Bell Labs in Holmdel, N.J., was part of a consortium competing for the first Gordon Bell award. The award, which recognizes outstanding achievement in high-performance computing, ultimately went to a team from Sandia.