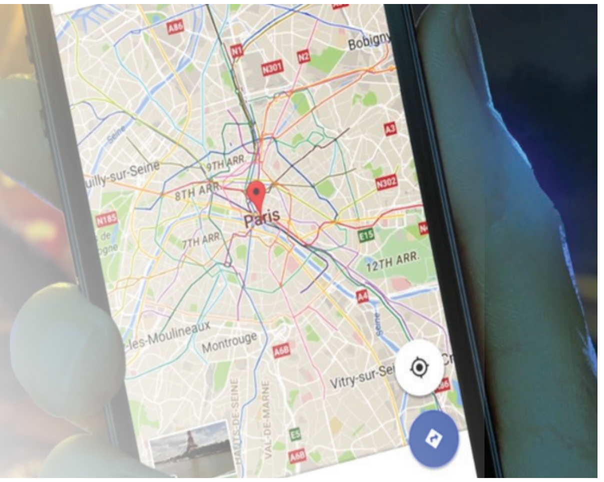
DARPA

VERY LARGE SCALE INTEGRATION (VLSI)

Advancing National Security Through Fundamental Research

VERY LARGE SCALE INTEGRATION (VLSI)



THE NEED AND OPPORTUNITY

Nothing could be more iconic of high technology than integrated circuits, the electronic brains in everything from military satellites to musical birthday cards.

One of DARPA's earliest investments in the advancement of IC technology was an ambitious effort called the Very Large Scale Integrated Circuits (VLSI) program. During the 1970s and 1980s, VLSI development brought together multidisciplinary research communities with the challenge to deliver significant advances in microelectronics fabrication, computer architecture, and system design. These R&D commitments helped overcome early barriers to the transistor-scaling trends described by Gordon Moore in a seminal 1965 paper. In it, he articulated what would become known as Moore's Law – at an exponential pace, computer power would dramatically increase as the relative cost of computing declined. DARPA's VLSI program helped propel the field of computing, furthering U.S. military capabilities and enhancing national security, all the while helping to usher in a new era of commercial microelectronics applications.

Among the resulting technologies from the VLSI program were Reduced Instruction Set Computing (RISC) processors, which have provided the computational power undergirding everything from supercomputers and NASA's Mars Pathfinder mission to a panoply of mobile devices. Also, the development of RISC processors enabled the performance of graphics hardware to essentially double every 18 months over many years. Although Moore's Law focused on the inverse relationship between an increasing number of transistors and cost, performance improvements became synonymous with transistor scaling and a prime motivator for continued scaling.

The VLSI program underscored the value of collaboration across the U.S. electronics community as well as the role DARPA could play in opening doors for further innovation. To foster the pursuit of new chip designs, DARPA established the Metal Oxide Silicon Implementation Service (MOSIS) in January 1981. MOSIS provided a fast-turnaround, low-cost capability to fabricate limited batches of custom microelectronic devices. The service accelerated innovation by opening opportunities to researchers who otherwise would not have had direct access to microelectronics fabrication facilities.

While the U.S. accelerated the pace of microelectronics innovation throughout the 1970s and early 1980s, Japan took the lead in advanced semiconductor manufacturing toward the end of the 1980s. In a bid to regain dominance in manufacturing, in 1987 DARPA and the U.S. semiconductor industry established the Semiconductor Manufacturing Technology (SEMATECH) consortium. In the decades that followed, the consortium fostered stronger community engagement among manufacturers and suppliers, and significantly enhanced R&D of next-generation production tools and equipment. By 1992, the United States was responsible for 82% of semiconductor production yields, which is in part attributable to this cross-community effort.

During the late 1980s and early 1990s, new and evolving military and commercial applications, including advanced weapons systems, networks, and the Global Positioning System (GPS), continued to drive the need for powerful, low-cost microelectronics. The persistent transistor scaling needed to make this happen required that innovation in semiconductor materials, device integration schemes, and other technical areas continue unabated.

THE DARPA SOLUTION

During this time, DARPA funded the Advanced Lithography Program that furthered the state of the art in the microlithography processes underlying chip making. Working with partners in academia and industry, the program advanced the development of new lens materials and photoresists capable of pushing past technical barriers that had previously limited the technology to 248-nanometer (nm) lithography and of supporting new-generation technology produced with 193-nm lithography. The resulting advances in miniaturization and circuit density had a dramatic effect on the semiconductor industry. The new lithography capabilities quickly became mainstream and industry players used them for advanced commercial and military microelectronics.

Building on the exploration of new materials and integration schemes from the early 1990s, DARPA in 1995 launched the Advanced Microelectronics program to develop transistors beyond the 25-nm-size threshold. The research efforts completed under the program led to FinFETs (fin field-effect transistors) based on a novel 3-D transistor design characterized by protruding fin-like silicon structures, which allow multiple gates to operate on a single transistor. Today, leading chipmakers continue to use FinFET technology to scale transistors down to 7 nm.

While Moore's predictions in the 1960s helped chart the course for transistor scaling over the subsequent six decades, it was the ingenuity and dedication of industry, academia, and government researchers—DARPA among them—that brought Moore's Law to life. DARPA's investments have helped industry and the Department of Defense (DoD) overcome the ongoing challenges of transistor scaling through the discovery of new materials that circumvent current limitations and can deliver performance and efficiency requirements that the future will demand. This has only been possible by fostering an environment for collaboration around novel design schemes and architectures, and by opening pathways for experimentation in the manufacturing and production of microelectronics.

THE IMPACT

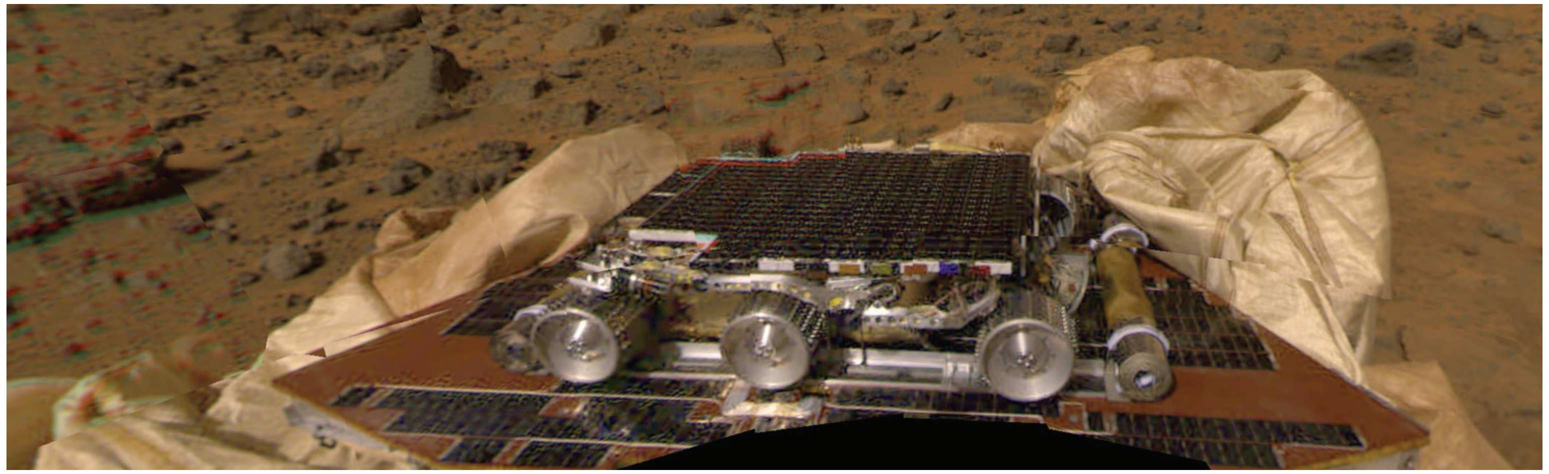
Because of the intertwined history of commercial and defense support for the semiconductor industry through programs like VLSI, MOSIS, and SEMATECH, the U.S. has enjoyed the distinct advantage of global leadership in microelectronics innovation. A beneficiary of this dominance has been the consumer electronics industry. This crucial commercial sector has been able to leverage value from innovations, such as GPS, with heritage in the DoD. In turn, military systems have been able to combine the power of leading-edge commercial processors alongside purpose-built integrated circuits.

Even so, the U.S. electronics development and manufacturing community today is facing a trio of challenges that threaten the health of the industry, as well as our military capabilities:

First, the cost of integrated-circuit design is skyrocketing, which is hampering innovation. Only large, global, multinational entities backed by massive commercial demand can innovate and compete in today's electronics landscape. This severely limits the complexity of circuits that cash-strapped startups and DoD designers can pursue and produce.

Second, foreign investment is distorting the market and driving technology and commercial development outside of the United States. Today, most microelectronic chips are made outside of the U.S. China's plan to invest $150 billion in its manufacturing capabilities is luring foreign interest. Even by 2015, China already had begun building 26 new 300-mm semiconductor foundries and had launched 1,300 fabless startups. These global economic forces are placing a premium on semiconductor innovation as the pathway for staying ahead.

Third, the continued trend toward anchoring computational solutions in generalization and abstraction, which resides primarily in software, is stifling potential gains in hardware. The rising



This is one of the first pictures taken by a camera aboard the Mars Pathfinder lander after its touchdown on July 4, 1997. In the foreground is the rover, named Sojourner, atop a solar panel of the lander. (Photo courtesy of NASA/JPL)

Shown in this 2007 photo is the IBM Blue Gene/P supercomputer installation at Argonne National Laboratory in Lemont, Illinois. (Photo courtesy Argonne National Laboratory)

cost of managing the complexity of a modern electronics system – from manufacturing and designing circuits to programming – has led to increased layers of abstraction. Coupled with the predictable benefits of continued transistor scaling, this has created an ecosystem where only generalized, multipurpose electronic hardware can be economically successful, and much of the value has moved closer to the application higher up the software stack. As a result, hardware has become closer to a commodity, relegating much of the potential gains in performance to specialized hardware for only select situations.

LOOKING AHEAD

The rising cost to design integrated circuits, increasing foreign investments, and the commodification of hardware places the domestic microelectronics community at risk. To take on these challenges, DARPA will build on the long tradition of successful government-industry partnerships to foster the environments needed for the next wave of U.S. semiconductor innovation.

Emblematic of this commitment is DARPA's five-year, $1.5 billion Electronics Resurgence Initiative (ERI), which is nurturing research and development all of the way from novel materials and device concepts to new design tools, computational strategies, and system architectures. Announced in 2017, ERI is helping to establish the technical foundations that will empower electronics innovators to continue achieving technological advances even as traditional silicon scaling no longer can map onto Moore's Law.

DARPA®

www.darpa.mil