Semiconductors thus form the basis of most of the key technologies that have underpinned the microelectronic and **personal computer** revolutions. But scientists have constantly speculated over whether semiconductor technology can continue to develop at the same pace in future. The massively increasing cost of developing new microprocessor and memory devices (a new chip plant may cost as much as U.S.$2 billion) has led some commentators to suggest that technical barriers are now being approached that will make it uneconomical for Moore's law to continue. Others have argued that leaps of innovation will continue to clear technical obstacles and that, like the automobile industry before it, the semiconductor industry will develop not by producing more powerful products at lower cost, but by producing a more diverse range of chips for a wider range of products.

Another question is whether the semiconductor industry that grew up in California's **Silicon Valley** can continue to maintain a technical lead over (indeed, perhaps even survive) foreign competition. Some fear that the battle is already lost. U.S. producers saw their market share of general-purpose memory chips decline from 100 percent in 1975 to just 5 percent a decade later and alleged that unfair trade practices by the Japanese were responsible. But other important factors also played a role, such as the economic trend toward globalization; increasing environmental regulations, driving producers from Western countries to less-regulated nations (chip manufacture is a notoriously environmentally unfriendly process); and the increasing competitiveness of Pacific nations. Also, as some commentators have pointed out, what has been bad for U.S. producers has been very good indeed for U.S. consumers, continually driving down the cost of personal computers and peripherals.

Semiconductors are the most ordinary and, at the same time, the most extraordinary of materials. Silicon semiconductors, derived from sand, have made possible an industry estimated to be worth at least U.S.$120 billion in annual sales that employs hundreds of thousands of people worldwide. More important, they have given the world microprocessors, personal computers, fiber optic telecommunications, and the Internet. They are undoubtedly one of humankind's most significant inventions.

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—*Chris Woodford*

Sendmail

Sendmail is a mail transfer agent and a de facto standard for the **Internet**; it was running in around 76 percent of the mail servers in 1999. Sendmail receives incoming **electronic mail** from external or local machines and delivers it to the intended recipient. By interpreting the address in the e-mail header, Sendmail can decide how to route the messages.

Sendmail was written at the University of California Berkeley by Eric Allman (1956–) as part of the BSD **Unix** release. Sendmail was first distributed as *delivermail* in 1979 with 4.0 and 4.1 BSD Unix. Commercial versions of Sendmail have been spun off the original public domain version. The Sendmail Consortium oversees the development of the new open source variants. Over the years, other programmers as well as companies like **Sun Microsystems** and **Hewlett-Packard** have contributed to the sendmail code.

In 1980, the addressing conventions of the Internet were undergoing changes. The new addressing scheme is the one used today, in which domain names are attached to the computer name. This greatly increased the number of possible addresses, but made delivery of e-mail very difficult, since old and new addresses coexisted for some time and different versions of mailing programs were available. Sendmail was designed to be compatible with **AT&T**'s Unix mail programs, the **ARPANET** mail system, and others in use at the time.

When the user wants to send an e-mail, the e-mail interface program calls sendmail, which temporarily stores the message. Sendmail then starts an SMTP (Simple Mail Transfer Protocol) transfer with the appropriate network computer. The Simple Mail Transfer Protocol was defined for use in the ARPANET and plays the same role for e-mail that File Transfer Protocol (**FTP**) plays for file transfer, or **Telnet** for remote log-in. If any errors are detected during transmission with the SMTP protocol, a message is returned to the user describing the problem encountered.

The evolution of Sendmail into a commercial product provides an instructive example of the general approach followed by Internet software pioneers. A commercial version of the program offers some important enhancements that are attractive for small or medium-sized businesses. However, the program is fully downward compatible with older, public domain versions of the program, which are available at no charge. After some time, the public domain version either catches up with the commercial version or the commercial version is put into the public domain. Either way, a new commercial version becomes immediately available and again offers increased functionality. A de facto standard can be maintained in this way, since only the larger businesses pay for the product and many programmers contribute to the public domain version.

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—*Raúl Rojas*

Shannon, Claude

1916–2001

U.S. Mathematician and Scientist

Claude Shannon is best remembered for his work on information and communications theory, which led to a scientific approach to communications engineering problems. He also was among the first to discover the connection between Boolean logic and circuits, setting the basis for the creation of the **digital computer**.

After finishing his B.S. degree at the University of Michigan in Ann Arbor, Shannon won a research assistantship at the Massachusetts Institute of Technology (MIT) running **Vannevar Bush**'s (1890–1974) pioneering **analog computer**, the Differential Analyzer. Shannon's job at MIT was to figure out how to put on the machine differential equations to be solved, and after the solution, to set the Analyzer up for the next problem. An important part of his responsibility was to return the machine to working order when it broke down.

The analog computer was mechanical and had spinning disks and integrators. There was also a complicated control circuit with relays. Shannon became interested in understanding the nature of the relay. Having studied **Boolean algebra** while at the University of Michigan, he soon realized that there was an isomorphic relationship between AND and OR logical expressions, and series and parallel relay circuits. Shannon sought to interleave the topology of the switching circuits—the way the contacts are connected up—with the Boolean algebra expressions. He recognized that a series circuit can be described by AND in logic, and a parallel circuit can be described by OR. Building on these relationships, Shannon set up a number of postulates and reached important conclusions.

Shannon wrote his M.S. thesis, "A Symbolic Analysis of Relay and Switching Circuits," describing his research. His paper was published in 1938 and won him the Alfred Nobel prize given by the combined engineering societies. Others who worked with relay circuits were aware of how the circuits worked, but they didn't have the Boolean algebra system to describe the circuitry. Shannon's work made it possible