Remembering Gordon Moore, whose famous law defined Silicon Valley for the next six decades

Yan Borodovsky
Retired Intel Senior Fellow, Director of Advanced Lithography, TMG, PTD

Photo courtesy of the Gordon and Betty Moore Foundation.
Gordon Moore and his wife, Betty Moore.

On March 24, 2023, several years short of becoming a centenarian, Gordon Moore passed away. An avalanche of "In Memoriam" followed, commemorating Gordon's monumental achievements: Starting Fairchild Semiconductor and running R&D, where technology for integrated semiconductor circuit manufacturing was invented; starting and building Intel, the first profitable Silicon Valley semiconductor company, and taking it as its CEO and chairman to the zenith of the Silicon Valley innovation and manufacturing ecosystem; and generously sharing his resulting financial success through the Gordon and Betty Moore Foundation. Gordon and Betty, his wife of 57 years, were recognized as California's most generous philanthropists in 2017.

Yet in the minds of those who are not technical professionals, Gordon's name is and will always be associated with the so-called "Moore's law," which, in simplified terms, is the prediction that the number of transistors that can fit on a chip doubles every two years.

As we all know, there is more to it, much more. Gordon's main observation in his original 1965 paper while still at Fairchild was that while the number of transistors in a given area will grow exponentially from year to year, the corresponding cost per transistor will drop exponentially over the same period, thus providing ever-increasing integrated circuit (IC) functionality from year to year for approximately the same cost on a predictable cadence. It is the monumental promise of this observation that became known as Moore's law, providing the underpinning of a business model for innumerable semiconductor startups and mature companies developing IC memories, IC controllers, microprocessors, system-on-chip, and a host of other semiconductor ICs all over the world, allowing the production of ever-more capable electronics and electronically driven products at affordable cost.

From its founding by Gordon Moore and Robert Noyce in 1968, Intel was at the forefront of realizing Gordon's vision, and I was very lucky to have an insider's view on how it was done for my 28 years there.

As a lithography staff engineer hired in 1987 by Youssef El-Mansy, Intel's VP and Portland Technology Development (PTD) director, and throughout my career there until my retirement in 2015, I was both witness to and participant in Intel's planning and execution on triple targets demanded by Moore's law: node-to-node 2x transistor logic area density growth at roughly 0.5x cost per transistor, produced on the all-important two-year node-to-node cadence.

Delivery on such targets for every technology generation (node) involved multiyear efforts by various groups within Intel's Technology and Manufacturing Group (TMG). To ensure TMG's ability to deliver to the furthest horizon and in predictable fashion to all targets required by Moore's law, Sunlin Chou, TMG SVP and GM, set up the Technology R&D Pipeline. Within the pipeline, funds were allocated to various universities and consortia for identifying and demonstrating the most promising approaches to transistor architecture and various IC technology approaches targeting capabilities that were three or four generations of technology beyond what was being produced in the leading-edge manufacturing at a given time. External research results and recommendations were passed for verification and comparative assessment to the internal TMG Pathfinding research organization, originally set up by El-Mansy. The focus was on researching and selecting technology solutions for one or two generations ahead of the node targeted for manufacturing as well as recommendations for technology solutions to be adopted for development by PTD, the organization responsible for the final phase of technology development for a given node. To ensure no yield loss between the PTD product development lines and multiple high-volume factories starting to manufacture new generations of products, Copy Exactly was implemented throughout TMG to ensure a flawless manufacturing handshake between R&D and high volume manufacturing (HVM). All of this allowed Intel to maintain a two-year node-to-node HVM cadence while overall node development, from early R&D Pipeline phases through the first year of manufacturing, lasted close to seven years.

It is universally understood in the semiconductor industry that adherence to the three tenets of Moore's law allowed continuous synchronization of schedules and performance targets. To a large degree, multigenerational roadmaps shared by IC manufacturers and tooling and material suppliers ensured that throughout every stage of the six- to seven-year research and development cycle, adequate resources existed to support the needed phase of R&D and eventually manufacturing. Commitment to the Moore's law cadence was in most cases instrumental in important decision-making regarding choices of technology solutions. If a proposed technical approach, while seemingly superior technically, was viewed as excessively risky to an HVM technology node introduction date, it was saved for development for future nodes while less risky, yet adequate, solutions were developed and adopted. Industry development and adoption of immersion lithography at a wavelength of 193 nm when inserting EUV at 13.5 nm, which was viewed by most as an excessive risk to the 32 nm IC node, is a case in point.

The ability to innovate as well as make hard decisions that can literally make or break a company, well in advance of knowledge required to be fully confident in the outcome, led to a company culture and structure that, under Gordon, favored meritocracy above all. Gordon himself was a meritocracy shining star: bachelor's degree from UC Berkeley; PhD from

Caltech (both in chemistry), handpicked by William Shockley—"the man who brought silicon to Silicon Valley"—to work with the future Nobel laureate in his 1956 startup; one of the "traitorous eight" who left Shockley's company to form Fairchild Semiconductor; Intel co-founder, who became its chairman and CEO, and led it to become the preeminent semiconductor company in the world. A simple look at Gordon's hires—starting with his first Intel employee, András István Gróf (we know him by his Americanized name, Andy Grove)—reveals uniquely talented, brilliant engineers and exceptional managers. Andy's first Intel employee hire was Sunlin Chou, with whom he worked under Gordon at Fairchild R&D. Chou had El-Mansy run Intel's Process Technology Development. Each was a true titan in his own way.

Led by Gordon, the company created a genuine meritocracy. Intel based its company structure and culture on coaching and promoting to positions of influence and authority based on one's critical contributions, whether they were a stream of inventions leading to solid technical solutions or demonstrated managerial ability to make hard decisions on a predetermined committed schedule. It is that culture of meritocracy that bred true diversity within Intel and led to its intellectual and commercial success.

I consider myself to be exceptionally lucky to have been hired and to have worked for the company co-founded by Gordon Moore. Best people, best time of my life—I could not ask for anything more. Thank you, Gordon, Sunlin, and Youssef.