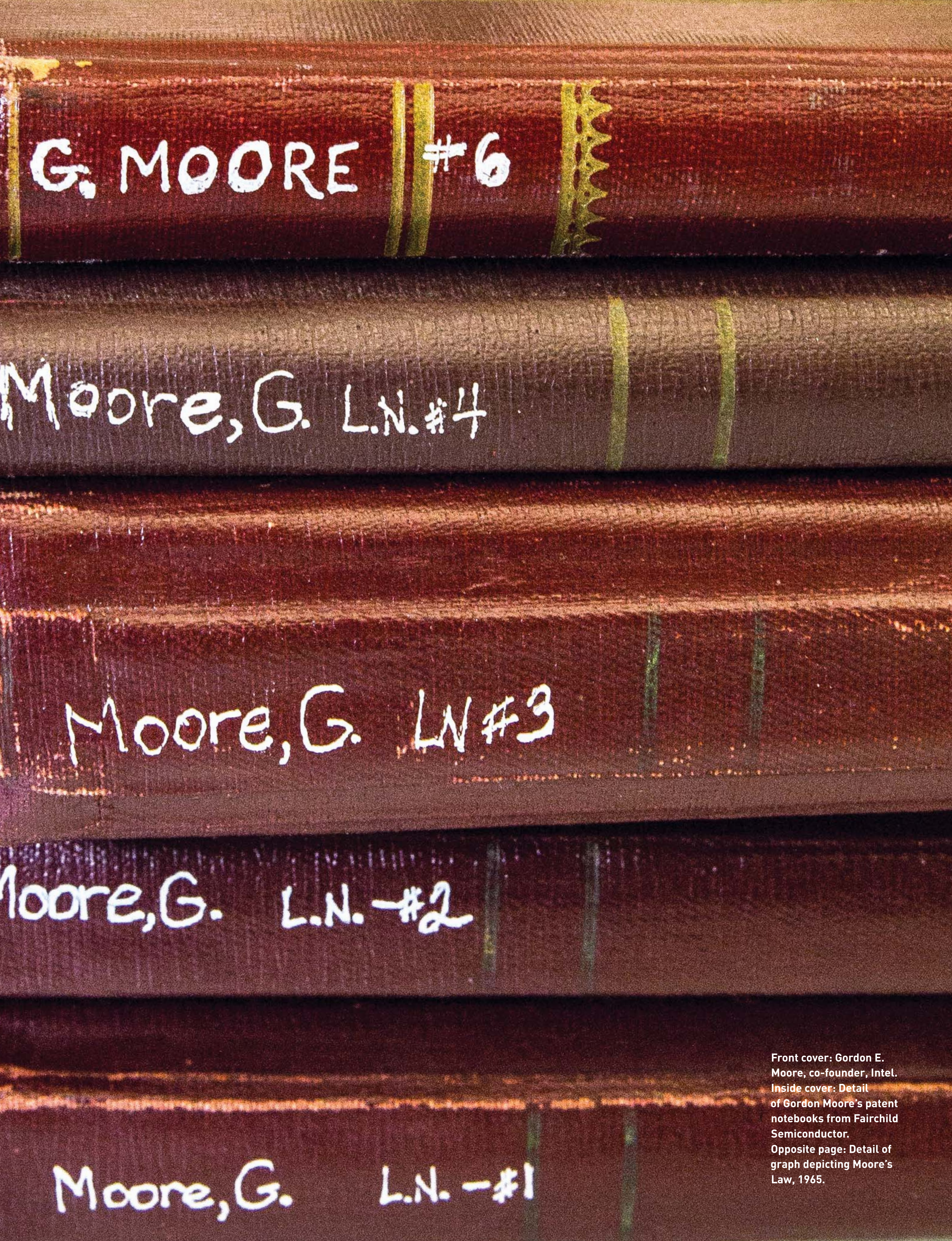
2015

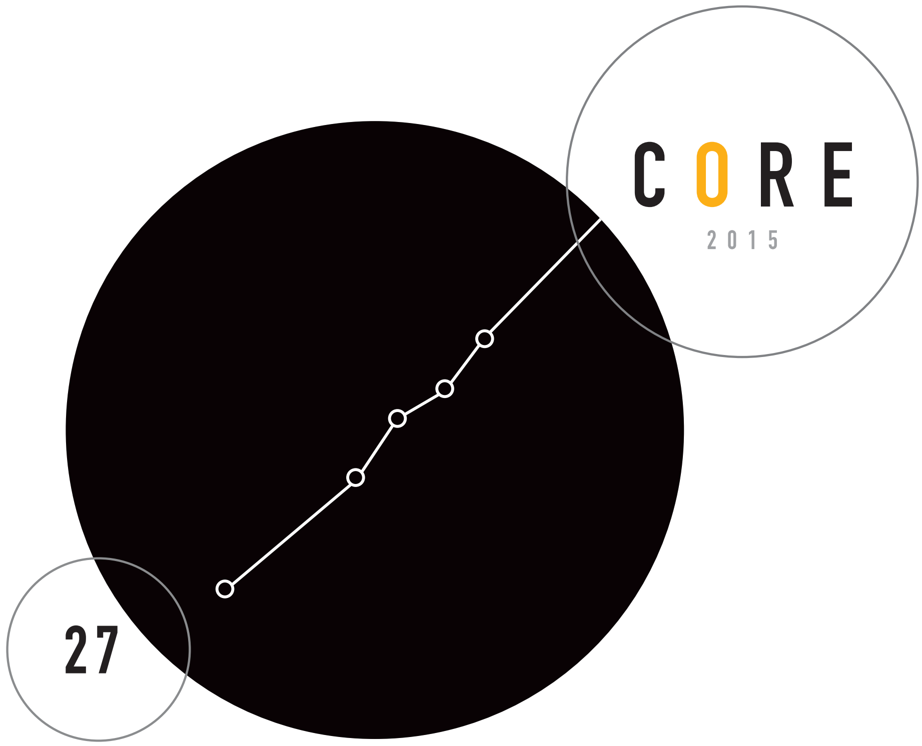
CORE

A Publication of
the Computer
History Museum

Moore's Law @ 50
In the (Photoshop) Mix
One of a Kind: Evelyn Berezin



Front cover: Gordon E. Moore, co-founder, Intel.
Inside cover: Detail of Gordon Moore's patent notebooks from Fairchild Semiconductor.
Opposite page: Detail of graph depicting Moore's Law, 1965.



MOORE'S LAW@50

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CEO'S LETTER

BUILDING ON OUR FOUNDATION

The Computer History Museum's work in the history of computing is built on three pillars. First is the history itself—the people and teams behind the breakthroughs, the problems they were trying to solve or the opportunities they saw, the technologies they invented, and the outcomes they achieved. In addition, we study and present our views on the considerable impact of all of that work—technological, economic, and societal. Finally, we study and convene interesting conversations on the implications of computing for our future.

In this year's *Core* magazine, we put that recipe on display in an insightful and fascinating way—by celebrating the 50th anniversary of Moore's Law, the famous postulate that forms the foundation of our electronic age, first published by the legendary Gordon Moore in 1965. We examine the history, legacy, and future of Moore's Law with articles from four remarkable authors and experts in the computing field today. If you aren't familiar with Moore's Law by now, you will learn a great deal about it in this issue. And if you believe you *do* know all about it, be prepared for some surprises.

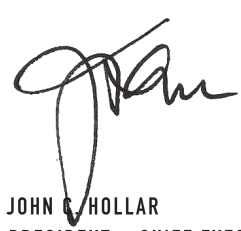
We begin with an essay from best-selling author Walter Isaacson, who defines Moore's Law in the context of the Museum's work preserving and interpreting the history of computing. Next, in anticipation of the spring 2015 release of Gordon Moore's authorized biography by Arnold Thackray, David Brock, and Rachel Jones, we offer a significant article from Brock examining how the law came to be. Steven Levy, another friend and frequent contributor to the Museum, weighs in with a classic impact story: the rise and growth of Google, a phenomenon absolutely enabled by Moore's Law. Finally, the implications story comes from investor and author Steve Jurvetson, who peers into the future to speculate on both the upward curve of Moore's Law and what may happen when the curve comes to an end.

We also look back at the Museum's very busy 2014—our *Fearless Genius* exhibit, our *Revolutionaries* speaker series, the growth of our education programs, and some notable additions to our collection. These are just a few of the features you'll discover inside.

Many of you will find it difficult to believe that 50 years have now passed since Moore published his famous essay, "Cramming More Components onto Integrated Circuits." We are honored to celebrate that anniversary with this issue of *Core* and to look behind the scenes with these talented writers.

Finally, I am delighted to recognize the generosity of Museum friends Jack and Casey Carsten. Their support not only has made this magazine possible but also has enabled us to expand distribution four-fold in 2015. My sincere thanks to them, and my best wishes to all of you. Enjoy!

Yours sincerely,



JOHN C. HOLLAR
PRESIDENT & CHIEF EXECUTIVE OFFICER

BY JENNIFER DE LA CRUZ
ORAL HISTORY & MEDIA MANAGER

EXHIBITS

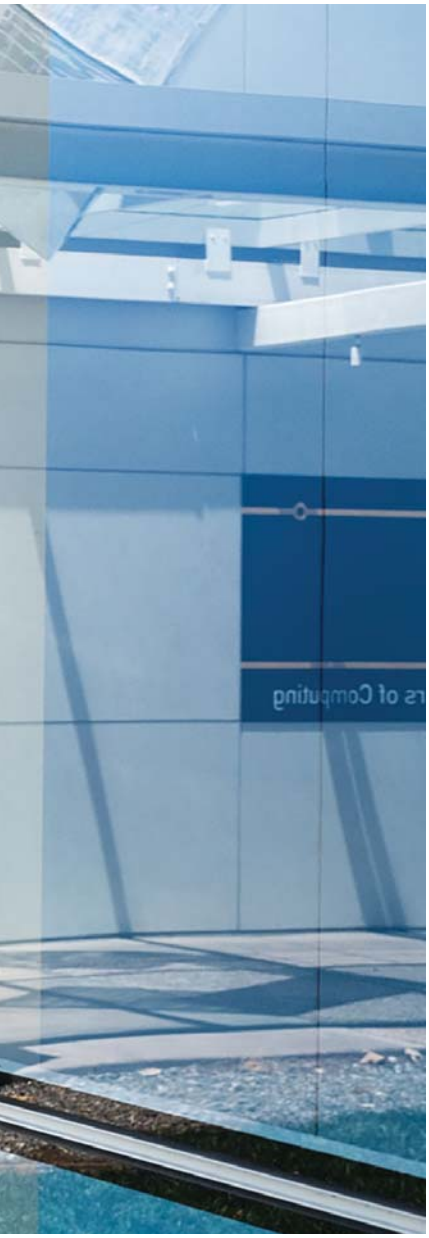
STAY FEARLESS, SILICON VALLEY!

BEHIND THE SCENES OF OUR *FEARLESS GENIUS* PHOTO EXHIBIT

Inspiration can happen in the blink of an eye—or with the click of a camera. Such was the case for the Museum's 2014 summer exhibit, *Fearless Genius: The Digital Revolution in Silicon Valley, 1985–2000*.

In early May 2014, the EG Conference (a play on the meaning "for example") was about to commence. EG, as it is commonly referred to, was founded and is presided over by Museum Trustee Michael Hawley. It was at this conference where Hawley first introduced Museum President and CEO John Hollar to documentary photographer Doug Menuez.

While Menuez has photographed events such as the AIDS crisis and the Ethiopian famine for publications like the Washington Post, *LIFE* magazine, and Newsweek,



Fearless Genius: The Digital Revolution in Silicon Valley, 1985–2000 opened on July 9, 2014.

it was a different project that first sparked the interest of Hawley, and now Hollar. Menuez had embarked on a 15-year project dubbed “Fearless Genius.” The project began in 1985 and took him deep inside the lairs of top secret laboratories, behind the closed doors of powerful boardrooms, and into the messy cubicles that make up the mecca of high tech: Silicon Valley.

“Fearless Genius” comprises never-before-seen photographs of some of the Valley’s leading innovators including Steve Jobs, Charles Geschke and John Warnock, Susan Kare, and Russell Preston Brown. Equally represented amid the tech giants are photographs showcasing the everyday men and women who toiled to turn the digital dream into reality. The photographs highlight a rarely seen aspect of the high tech world: humanity. It was apparent that “Fearless Genius” would be a perfect match for the Museum.

Back at the Museum, discussions ensued about exhibiting a selection of Menuez’s photographs. Vice President of Collections and Exhibitions Kirsten Tashev was immediately captivated by the photographs’ intimate

nature, recalling that it felt as if you were actually there—peering behind the curtains at product launches, lurking around the tables in cluttered break rooms, and hovering above boardrooms filled with high-powered executives. Each photograph told a story that was expertly captured by Menuez's gentle, yet discerning eye and written prose. It was truly a unique collection. Tashev was on board and was quickly joined by the Museum's Development team, who would take on the task of seeking out a sponsor.

And so, an exhibit was born.

It was the start of June before I knew anything of what had transpired in the preceding month. When Tashev approached me about curating an upcoming exhibit of 50 silver gelatin prints by Menuez in partnership with Media Director Jon Plutte, who would turn exhibit designer for the project, the Museum had not only procured a sponsor but also decided on a space for the exhibit as well as an opening date. Micron Technologies, an established company hailing from Boise, Idaho, with a long history in semiconductor memory devices, was interested in building its presence in the Valley, and so they would be the sponsor. With the customary exhibit spaces already occupied with shows, the Museum's lobby would serve as gallery for the exhibit; and due to the tricky intricacies that invariably come with juggling multiple schedules, the opening date would be a fast-approaching July 9. To recap, the exhibit would open in one month in a space that had never exhibited anything more than a few temporary display cases, backed by an eager sponsor looking to reemerge into the Silicon Valley locale. Did I want to do it? Of course! After all, we're in Silicon Valley—land of the can-do start-up—let's do it!

Plutte immediately began designing the space and researching vendors that could provide a temporary but secure wall and lighting system, before deciding upon Bay Area production and design company DaVinci Fusion. The ambitious design called for 25 4x10-foot partial walls to line a majority of the Museum's facade of glass windows, elevator bank, K-beam support near the Cloud Café, and finally more walls would go up on either side of the Orientation Theater.

Because walls would soon be covering a bulk of the Museum's street-facing windows (32 feet wide by 10 feet high), Plutte and I advocated for eye-popping window graphics that would not only promote the show, but also camouflage the starkness of the walls from the front of the building. We worked with San Francisco-based studio1500 on the graphic design for the windows and finally decided upon a puzzle-like design that would create both interest and depth on an otherwise flat space. The back of the walls would be painted a bright blue, while the window graphics would be printed on complementary yellow strips of vinyl.

Despite our tight schedule, Plutte and I both wanted to incorporate some type of media activity for visitors and decided upon quick read (QR) codes. We would have various "stops" throughout the exhibit where visitors could use their smartphones to scan QR codes and hear Menuez talk about selected photographs. We chose seven different photographs and we were, luckily, able to get Menuez to record a unique message for each stop.

Tashev came through with another interactive activity for visitors to the exhibit: a talkback board. Visitors would be invited to share their thoughts on two different prompts related to the exhibit: "What do you want the next Fearless Genius to invent?" and "Where were you during the digital revolution, 1985–2000?"

Everything was moving quickly, but smoothly. By the week of June 30, we had finalized the graphic design for a large wall panel that would display Menuez's artist statement, 50 image captions, seven QR code labels, and the front window design. The photographs were due to arrive at the Museum in two days from Florida, where they had been shipped from Menuez's studio in Red Hook, New York, to be framed.

Monday, July 7, marked the first day of installation. A skilled team of designers, fabricators, and technicians from DaVinci Fusion began putting up the walls and installing special light fixtures. By the end of the day the lobby had been transformed into a gallery! On day two, we were ready to hang the photographs and incorporate all of the final finishing touches. In the afternoon, we were excited to receive our first visitors to the exhibit—none other than Menuez and his wife, Tereza. Menuez walked through the nearly finished exhibit, taking pictures and marveling about what an amazing job the Museum had done to pull off this exhibit in such a short amount of time.

At 10:00 a.m. on Wednesday, July 9, visitors were ushered into the Museum's lobby where they were greeted by our newest exhibit, *Fearless Genius: The Digital Revolution in Silicon Valley, 1985–2000*. The lobby echoed with personal stories about Silicon Valley and questions about the people in the photographs. Visitors even took impromptu "selfies" with a large photograph of Steve Jobs, mirroring his pose as he explained 10-year technology development cycles. At the opening reception later that night, Hollar sat down with Menuez in a special question-and-answer session where Menuez shared his hopes for the future of Silicon Valley, saying that he hopes we can get back to the idealism that drew him here 15 years ago during his first meeting with Steve Jobs, a core belief that technology cannot only change the world but also make it better.

Fearless Genius opened on Wednesday, July 9 and closed on September 7, 2014. It was a fast show in every way, but that does not lessen its impact. Throughout the two-month run of the exhibit, 21,047 visitors filled the lobby, reminiscing by photographs and learning new stories about the high tech industry. Young children scribbled drawings and mused about what the next fearless genius should invent. (Popular answers included talking animals, faster transportation, better translation tools, and of course, machines that could do your homework.) If *Fearless Genius* taught us anything, it's that anything is possible—whether it's pulling off an exhibit in one month, inventing faster means of transportation, or even an app that can do your homework. Stay fearless, Silicon Valley! ○

IN THE (PHOTOSHOP) MIX

MUSEUM'S MEDIA TEAM DOCUMENTS THE MAKING OF NEW ADOBE PRODDUCT

There are not many chances for a do-over in life. How many times have you said to yourself "I wish I'd <*bought Apple stock in 1983*>"—fill in with yours. Interestingly, Adobe has recently had the opportunity to do just that. The catalyst for this is a combination of two factors: the rise of tablets as a major computing device and the ambition of Adobe Senior Principal Scientist Jeff Chien.

Tablets have become the main computing device of the 21st century, projected to eclipse the numbers of both laptops and desktop computers,[1] making them an obvious target for software development. Since tablet users take pictures—a lot of pictures—there is a great need for photo management and image editing on tablets; and although tablets are convenient and portable, a major problem with them is their lack of processing power. This is where Jeff Chien comes into the story.

Chien is a senior principal scientist at Adobe and a Photoshop Hall of Fame member. He has been working on Photoshop for over 20 years, helping develop important functions for the program such as the Healing Brush and Content-Aware Fill. He also has a background in networking and saw an opportunity to advance Photoshop by using Adobe's existing network-based Creative Cloud system to enhance its capability on tablets. "Why," he thought, "don't we use the power of our network-based systems to help tablets process those portions of images?" Adobe's Principal Product Manager for Digital Imaging Bryan O'Neil Hughes puts it like this: "He had a neat idea. Jeff being Jeff showed it to someone kind of high-up. They loved it and someone knocked on my door and said someone high-up loves it … We're going to need to figure out what the story is here." The story ended up being a new project dubbed "Orion." And so began a new direction in Photoshop's development that would ultimately culminate with the release of a new product known as Photoshop Mix.

This is all very cool and interesting, but why would this story be in an issue of *Core* magazine for the Museum?

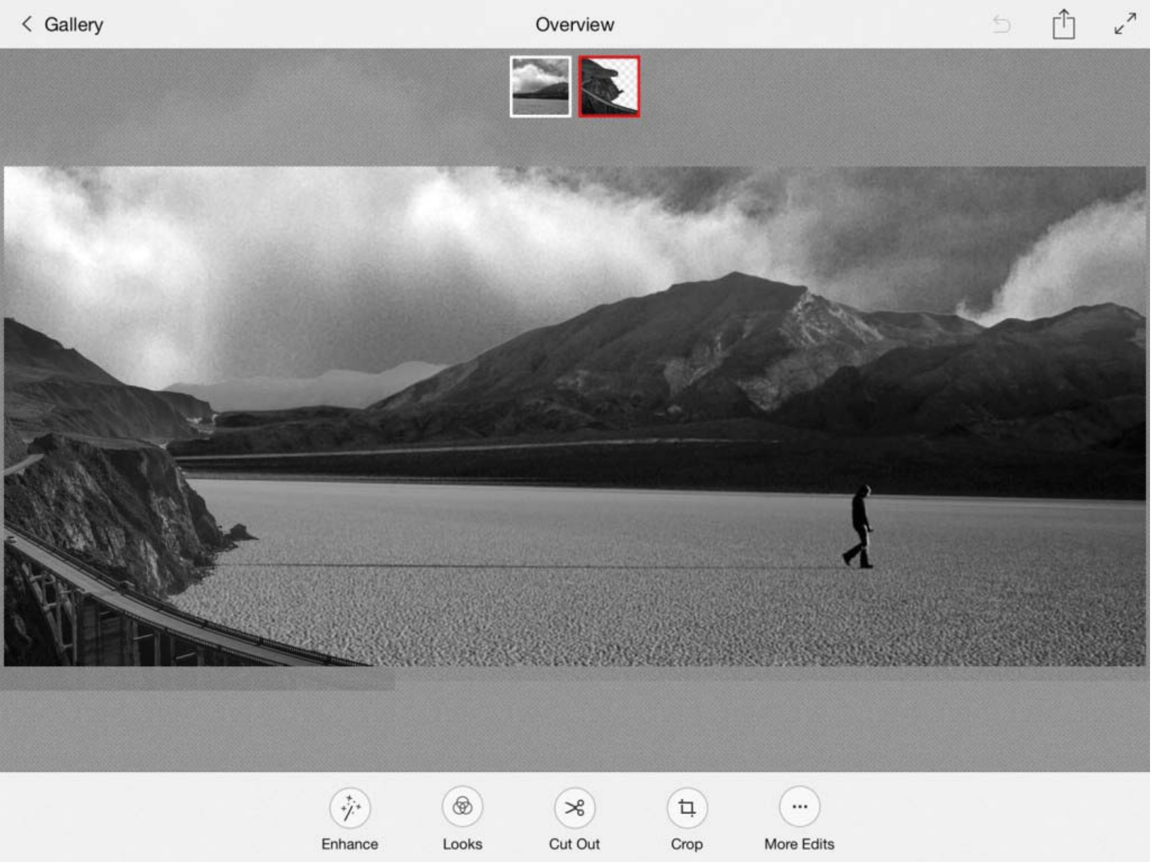
In preparation for the Museum's upcoming exhibition *Make Software: Change the World*, our media team has been documenting the development of Photoshop Mix from the beginning stages of the project to its release in June 2014. *Make Software* will not only examine how software is developed, but also present the personal stories of the makers and users of software. We will be focusing on seven software applications and exploring the impact these applications have had on society. Selected for its ability to alter imagery and, with that, our perception of the world around us, Photoshop will be one of these seven applications.

As part of the larger exhibition, the Museum will also create a software lab to document and make accessible the technical and creative processes of software development. The making of Photoshop Mix will be featured as a documentary film that will be played in the lab. Thanks to the Adobe team, led by the efforts of Photoshop Senior Quality Engineering Manager Jackie Lincoln-Owyang and Bryan O'Neil Hughes, we were able to document the development of a new product up close to share with our visitors.

The story of Photoshop Mix is interesting because it unfolds just how you'd like a good movie to unfold—with an intriguing storyline and great characters. Colleague and cameraman Eric Dennis and I first interviewed the Adobe crew at the 2013 Photoshop World conference in Las Vegas, Nevada. Hughes described Adobe's technology prototype of leveraging processing power in the cloud, which then had the working name "Octopus," as a small "skunk works" project, referring to a term used by Lockheed during World War II to describe a small, flexible research project that was developed outside of the ordinary corporate structure of the business. At that time, the entire team consisted of Chien and a small group of engineers in China. Their goal was to implement Chien's long-held ideas that the cloud and computing could be integrated to create a seamless whole.

By the next time we checked in with the team, this time at Adobe headquarters in San

BY JON PLUTTE
DIRECTOR OF MEDIA



Top: A screenshot of Photoshop Mix 1.1. Version 1.1 includes undo/redo commands, image swapping, Dropbox support, and the ability to open larger files, even panoramic images as shown.

Bottom: Jeff Chien, Adobe senior principal scientist, with David Wadhwani, Adobe senior VP and general manager of digital media, at a Photoshop Mix meeting in April 2014.

Jose, interesting developments had ensued. Octopus had been applied to a new product, Orion, but more importantly, Adobe had begun to shift its business model. Photoshop had traditionally been a closely held product. Only Adobe's internal software crew could touch the underlying code. But now Adobe was considering letting outside developers see their closely guarded infrastructure, beginning with Apple who would be the first to adapt Photoshop to their mobile operating systems. Chien and his team in China, with the full support of Adobe, were also starting to reimagine how Photoshop is built. Octopus and Orion were opening everyone's eyes to the new possibilities of the cloud and tablet computing, along with the future of Photoshop itself.

On our latest visit in June 2014, the Chinese development team had relocated to San Jose and had just three days to lock down the code on the release version of Photoshop Mix (that is, they had to finish writing the program). The next week, they were debugging; then the week after that would be a software submission to Apple to clear the program for release on the Apple store. The usual period of time for this kind of clearance is six weeks, but Adobe had planned a New York release party in only two weeks, counting on Apple to understand the gravity of the release.

The good news for Adobe? The product got completed, the debugging went well, Apple approved the product for release on time, and the release was a great success.

It's not often that a museum gets to document history as it unfolds, but here, it's something we're getting good at. The development of Photoshop Mix is an exciting example of how a large corporation can adapt to the times and move forward. This is an ongoing project. To find out the end of the story, you'll have to see the movie when *Make Software* opens. ○

[1] Statista, "Global shipments of tablets, laptops and desktop PC's—additional information," accessed October 13, 2014, http://www.statista.com/statistics/272595/global-shipments-forecast-for-tablets-laptops-and-desktop-pcs/.

LECTURES

REVOLUTIONARIES

PIXAR'S ED CAMULL ON CREATIVITY AND MANAGEMENT

Pixar co-founder and author of *Creativity, Inc.* Edwin Catmull.

BY JOHN C. HOLLAR
PRESIDENT & CEO

As a young man, Ed Catmull dreamed of being an animator and an artist. When he learned that he lacked the natural talent for hand-drawn animation, he turned to his other passions—physics and then computer science.

He nurtured that dream as a PhD student at the University of Utah, where many computer graphics pioneers got their start. He eventually forged a partnership with George Lucas, an alliance that led to his founding of Pixar Animation Studios with Alvy Ray Smith, Steve Jobs, and John Lasseter in 1986. Nine years later, Pixar released *Toy Story*—the first feature-length film created entirely on computers. It changed animation forever.

Today Catmull is president and CEO of both Pixar Animation and Walt Disney Animation. In his 2014 best-selling book, *Creativity, Inc.*, Catmull explores the essence of creativity and his lessons on management at Pixar and Disney. He talked about *Creativity, Inc.* at the Museum on May 8, 2014, as part of our landmark speaker series, *Revolutionaries*.

Hollar: You say that at the University of Utah, you were the guy who was always sleeping on the floor at the computer lab just to get some more hours on the mainframe. What was the magic for you of computing at that time?

Catmull: It was clear that with computer science we were close to the frontier, whereas in physics it was a long haul to get to the frontier. With computer science, I always had the sense that it was like being at an Easter egg hunt, and I was at the front of the line, and they just cut the ribbon. I was intending to go into computer languages. But as soon as I took that first class in computer science, I said, "We can make pictures with this."

Hollar: After graduate school you go east to the New York Institute of Technology [NYIT]. You begin assembling a team to do computer graphics. And you begin to work out your early ideas about management.

Catmull: I had a theory about how to manage a group based upon the fact that I didn't actually want to manage. I wanted to be in charge, but I didn't want to manage.

I came up with a theory about how to have a flat organization and the kind of people to hire. The first person was Alvy Ray Smith. At first I'm a little nervous, because here's a guy who's really smart. And I wondered: Should I be threatened by this? But I did the right thing, and I learned something from it.

Looking back, my feeling at the time was—about two-thirds of my theories were working and about a third of the ideas were a complete crock. I still think that's the way it works. A lot of people have these 80-20 rules, 90-10 rules. I think that's too optimistic. It means we think we're right more than we are.

Hollar: In 1979 you go to work for George Lucas. Eventually, you and your team develop the Pixar Image Computer. You built a company around that hardware. What happened, and what did you learn?

Catmull: We had the hardware, but starting up as a company we didn't know what to do. We had to learn about manufacturing. We brought in marketing people and built up a sales force, and made a lot of mistakes along the way—a couple of them fatal. But we stayed together through the failures, and we benefited in the end from having stayed together.

There were two parts to what I learned. One, I knew that we were doing original things. There's something exciting about the fact that you're coming up with new discoveries.

Two was a question. In watching other graphics companies like Sun, Silicon Graphics, and others, I began to ask: What are they doing that makes them work, and what do they do that makes them go off the rails? These were smart people. They had great engineers. They had good customers and good marketing. And then a significant number of them would do something, which, at the time, would look foolish. I'm thinking, "OK, these are really smart people. They're really creative. What's going on?"

Hollar: Meanwhile you moved Pixar from hardware to storytelling. How did you become your own studio?

Catmull: Desperation. I remember at the time I was reading books about how you manage, and one of the pieces of advice was focus, focus, focus. That has to be the most worthless piece of advice. The fact is, most companies are focused. The question isn't whether or not you should focus. It's what you're supposed to focus on.

We were trying to be a hardware company, and we failed. Then we started doing software. Wasn't big enough. Wasn't making the payroll. We started doing commercials. Then we tried making short animated films. The short films were good. Because they were good, Disney tried to steal John [Lasseter] away.

But he and I believed that there was something new that was happening with 3D animation. Our belief was it was going to be big. It was a struggle to figure it out. But in the process of that, we had the good fortune to learn that our first four people were pretty remarkable.

Hollar: You write that everyone working on any creative endeavor for a long period of time gets lost. You've made "getting lost" explicit as part of your innovation process.

Catmull: You want to get at the truth. You want people to say what they think. It turns out that being candid is a hard thing. Sometimes I'm not going to be candid because I don't want to embarrass myself. Or I don't want to embarrass somebody else. Or I want to impress somebody. Or there are powerful people in the room who signal that they don't want to hear the truth. You've got human dynamics—some of which people aren't even aware of.

More and more of my job is to look at the dynamics. If you don't, every now and then—especially if you've got a difficult problem and a large group—the thing will go off the rails.

Hollar: What does it look like when something goes off the rails at Pixar?

Catmull: If I were to look at this over our history, usually our group operates very well—and it shows in the films. Once in a while it doesn't work at all.

The key is to realize that when we start, it doesn't work right. You want to generate an original idea. That means that all of our babies are ugly, or they start that way. You actually have to protect them. So there's a period of protection. It can't be forever, or they get lost. And it can't be too short a time where you don't allow things to develop. But you do have to protect the early baby.

It was actually *Toy Story 2* where the question was called. It wasn't good, and we did a restart nine months out. It was truly a brutal thing to go through. But in doing so, we produced an excellent film. I think we defined ourselves by doing that.

Hollar: You worked very closely with Steve Jobs for 26 years, perhaps the longest professional partnership he had with anyone. You write in your book, "While many anecdotes of Steve Jobs as a young executive are probably accurate, the overall portrait is way off the mark. The reality is Steve changed profoundly in the years I knew him." Can you talk about the change you saw?

Catmull: Like others, I saw him in the early days. Steve was very smart. And he did some

Pixar co-founder and author Ed Catmull joins Museum CEO John Hollar for a conversation about how to build a sustained creative culture, nurturing both the technical and artistic "poles of creativity."

things where he was swinging for the fences, and he hit some things, which looked like home runs at the time.
He realized later that was bad for him. His way of behaving, interacting with people, was over the top in the early days. I found after a while he figured that out, and he changed.

Our directors do the same thing. You're in advocate mode. You're testing. You're having other people come back questioning you. You'll listen. And if you're wrong, you'll abandon it. That is what he did. I think that was largely missed by people. It was like the classic hero's journey, where they're cast out of the kingdom because of bad behavior. They're wandering around, and they discover something. They return a different person. That was my experience with Steve.

Hollar: Was he proud of what you achieved together at Pixar?

Catmull: Oh, very proud. He expressed it many times. He would say, "The one thing that I know is that 75 years from now most our stuff will be in landfills, but these stories will be around forever." ○

Major funding for CHM Presents *Revolutionaries*: "Creativity, Inc." was made possible by Intel Corporation.

REVOLUTIONARIES GOES ON THE ROAD

BY CAROL STIGLIC
VICE PRESIDENT OF PROGRAMMING & BUSINESS DEVELOPMENT

In 2014, the Museum took its acclaimed *Revolutionaries* speaker series on the road to capture the stories and unearth the history from computing pioneers around the globe. Heading out on the road on a limited basis also affords us many other opportunities, including the ability to expand and extend the awareness and influence of the series and the Museum. It also gives us the opportunity to deepen our ties with key partners like Intel and KQED, who have both played important roles in the success of our series. Additionally, we can make some new strategic partnerships with a select few host organizations. Finally, going on the road will expand the potential for new Museum members and donor prospects. It's all very invigorating, for sure.

Our first road trip in October took us to NPR's beautiful new headquarters in Washington, DC. John Hollar moderated an engaging conversation with entrepreneur and philanthropist Steve Case. We couldn't have asked for a better inaugural guest, who was every bit as inspiring and engaging as we'd hoped he would be. And the acoustics in NPR's Studio One, not surprisingly, were amazing.

Looking ahead, we plan to stage *Revolutionaries on the Road* at KQED's studio in Europe, New York City, and KQED's studio in San Francisco. This gives us the opportunity to extend our geographic reach to audiences who might never travel to Mountain View to attend one of our programs. Stay tuned!

BY KATE MCGREGOR
EDUCATION PROGRAMS

Middle school students from Black Girls Code and Level Playing Field Institute gather together for a group photo before starting the logic maze.

EDUCATION TEAM EMPOWERS YOUTH WITH NEW DESIGN_CODE_BUILD PROGRAM

EDUCATION

It is imperative that students not only become familiar with using today's new technologies, but also develop the confidence and knowledge needed to *design* and *create* with those technologies. Being able to understand the way in which computer programs are structured and how they process information will help students interpret their own relationships with software, hardware, social media, and the Internet. As a result, they will develop skills to express themselves and create change in meaningful ways. Programming is more than a technical skill, it is a creative outlet that teaches a plethora of concepts, while helping to develop critical thinking skills, inspiring students to develop an intrinsic desire to experiment, explore, and learn. Learning to code prepares students for success in all aspects of their lives.

This year, the Museum's Education Department is

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striving to inspire future generations to become excited about exploring technology, coding, and computer logic. Middle school students are at a critical point in their educational journey and, with encouragement and knowledge, they will become technological innovators who address important global problems that will shape tomorrow's world. Our new program, *Broadcom Presents Design_Code_Build*, launched in partnership with Broadcom Foundation, is an exciting educational event series that connects with hundreds of middle school students from around the Bay Area each year and helps them to think critically while solving problems, designing programs, building computers, and having fun!

During each full-day event, students explore computer programming, actively learning in a hands-on environment and interacting with industry professionals and role models. "Rock star" professionals from the tech community share their stories and discuss how computer programming and STEM (science, technology, engineering, and mathematics) studies are part of their daily lives. Students build their own computers using a Raspberry Pi, design instruction sets to guide their partners through a life-size maze, work with Museum docents to investigate historic methods of computer programming, and learn about tech industry pioneers. After gaining knowledge and experience over the course of the day about instruction sequences, loops, conditionals, and the need for problem solving and innovation, students work in teams to prepare and present a culminating project. Each team incorporates aspects of computer programming in their work, while also highlighting important skills such as critical thinking, brainstorming, and collaboration. These skills are useful and truly necessary for all youth as they move forward into the future.

The industries that exist today have evolved and changed dramatically from those that were crucial only decades ago. Technology has become a part of everyday life and is a critical aspect of most industries in today's society. Computer programmers, medical doctors, and aerospace engineers are all examples of incredible STEM professionals, as are architects, high school teachers, communications professionals, construction managers, and food scientists. Science, technology, engineering, and mathematics will become increasingly necessary in the years to come. Tech companies today are in need of thousands of skilled computer engineers to design and build both hardware and software. Jobs are available and waiting to be filled. Although the tech industry is booming, many groups are underrepresented within the workforce. Each *Design_Code_Build* event will connect with girls and students from under-resourced communities in order to help these young people see their own potential and the opportunities that lie ahead for them. The Museum is partnering with wonderful community organizations such as Engineers 4 Tomorrow (E4T), whose volunteers help to facilitate these events, and connecting with organizations that support middle school youth such as Aim High, Level Playing Field Institute, Black Girls Code, Girls Innovate!, NASA SEMAA, Coder Dojo, TechGYRLS, and others.

While the need for more skilled professionals to fill the existing and future jobs in the tech industry and related fields is real, learning to code and understanding the fundamentals of computer programming will do much more than provide incredible employment opportunities for our students as they prepare to join the workforce. As they learn to code, students learn to be persistent, to deconstruct problems into smaller specific parts, and to address each issue in a logical, organized way while accounting for a myriad of variables. They will learn to be comfortable trying, failing, and persevering, all while gaining important insights into the engineering design process.

Learning to code is about much more than programming languages and engineering job; it opens up opportunities to learn many important life skills and concepts. The *Design_Code_Build* program guides students through a process of exploration, helping them gain confidence and become inspired to take on new challenges and work together to change the world! ○

Middle school students from Black Girls Code work together at the Raspberry Pi station.

E4T (Engineers For Tomorrow) volunteers with Level Playing Field Institute middle school student in the Raspberry Pi Station.

DESIGN_CODE_BUILD SPOTLIGHTS

BY KATE MCGREGOR
EDUCATION PROGRAMS

ENGINEERS 4 TOMORROW (E4T)

Engineers 4 Tomorrow (E4T) is a nonprofit organization that believes now is the time for the engineers of Silicon Valley to lead through social entrepreneurship to close the minority gap in science, technology, engineering, and mathematics fields.

E4T is a collection of Silicon Valley's technical professionals who encourage today's youth to embrace STEM education and pursue careers in STEM fields. The organization strives to "Introduce, Inspire, and Excite," as it develops and delivers creative, technical, and intuitive curriculums to middle school students of the Bay Area.

E4T is partnering with the Museum to bring their collective enthusiasm, expertise, and diversity to help inspire and empower middle school students.

ROCK STAR: NANCY DOUYON

Nancy Douyon is a user experience research program manager at Google. She grew up in a low-income area of Boston, Massachusetts, the daughter of undocumented Haitian immigrants. Her childhood was challenging. She struggled in school and spent time in foster care, while her parents adapted to a new country with different cultural norms and little personal security in terms of health care, housing, and food.

At the age of 12, Nancy was in middle school and became involved with an after-school program focused on computer skills and coding. Her excitement about technology grew, and she began to see herself and her potential differently. She continued to face barriers due to race, gender, and societal standards, but she learned to believe in herself and persevered. She earned a scholarship from Intel and, after graduating from high school and college, went on to complete a master's degree in human computing interaction.

Nancy has since worked for such companies as Intel, Accenture, IBM, and is now at Google. She is also working towards her PhD in human factors engineering. Nancy is a wonderful and engaging role model. She loves connecting with youth through her story and mentoring students to believe in their own potential as they become excited about technology and computer science.

BY SARA LOTT
SENIOR ARCHIVES MANAGER

Senior Archives Manager Sara Lott pulls collection documents for a researcher.

COLLECTION

FROM THE ARCHIVE

MUSEUM COLLECTION PROVIDES ESSENTIAL SCHOLARSHIP TO RESEARCHERS

For four decades the Museum has been the world's leading institution collecting the history of computing and chronicling its ongoing impact on society. The Museum's commitment to not only preserve computing history, but also to present and make that history accessible, is reflected in its archive, which contains hundreds of collections of significant research value. The Museum's archival material is used by scholars, authors, hobbyists, and other interested parties from around the world on a daily basis. The archive responds to over 400 requests each year to use material in publications, original research, and school projects. Since the launch of *Revolution: The First 2000 Years of Computing* in 2011, the archive has seen the number of researchers visiting the archive more than double, and scholars are using the archive to answer more than just technological questions. A PhD student studying the psychology of human-computer interaction and computing's effects on office and school management culture used the MIT Computing Projects Collection and various companies' marketing brochures to shed light on how early artificial intelligence projects shaped human-computer interaction design. A professor of management and technology, working in the area of innovation management, used the James Porter Papers to study disk drive companies and how disk drive manufacturers survived different technological transitions over a 20-year period. Another PhD student examining the history of capitalism, technological innovation, and global politics in the Cold War era, accessed the Don Liddie Papers on Signetics to examine the connection between the emergence of Silicon Valley as a uniquely entrepreneurial region and the reorganization of the American political economy during the 1960s and 1970s. A graduate student from Cambridge University studying economic and social history used the archive to research the history of Silicon Valley and its relation to theories of regional agglomeration.

Collecting is only one part of preserving records. The Museum archive also organizes, describes, and publicizes archival holdings so historians can locate and access archival material and write those stories, further contributing to our current understanding of the Information Age. The archive holds so many more stories that have yet to be written; stories that provide insight into how technologies were developed, produced, marketed, and sold, and how those technologies and the individuals involved have come to impact our society. The history of computing technology is a rapidly growing and important area of research relevant to scholars of business history, legal history, social history, and education. While other institutions may have technology- or business-related collections as part of a broader collecting scope, the Museum is the only institution founded explicitly to document the Information Age. The Museum's deep and broad collections offer scholars a unique platform to conduct in-depth original research in the history of computing technology and its allied disciplines. The archive has so many wonderful collections that have never been accessed. What stories will the Museum archive help tell this year? ○

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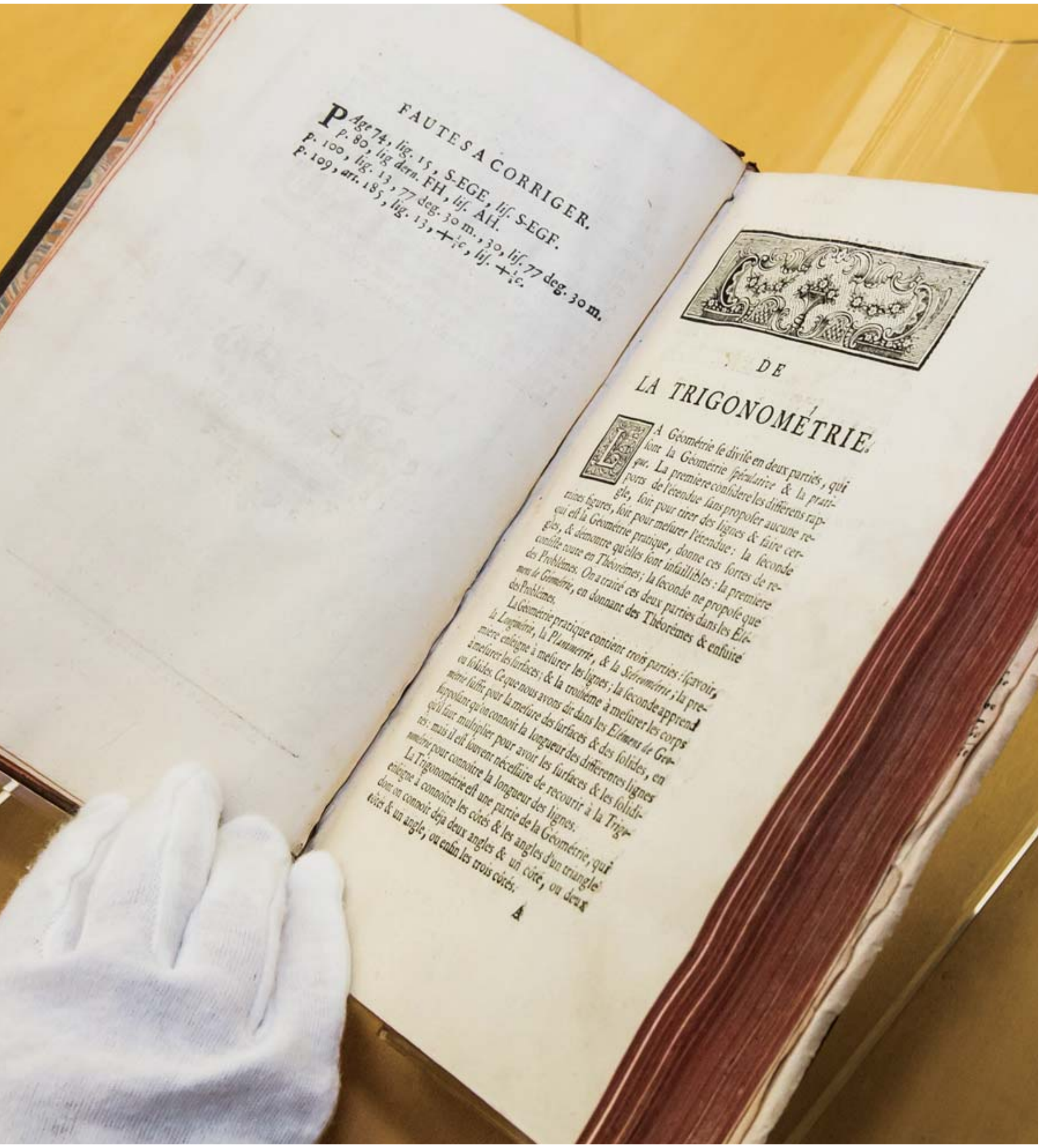
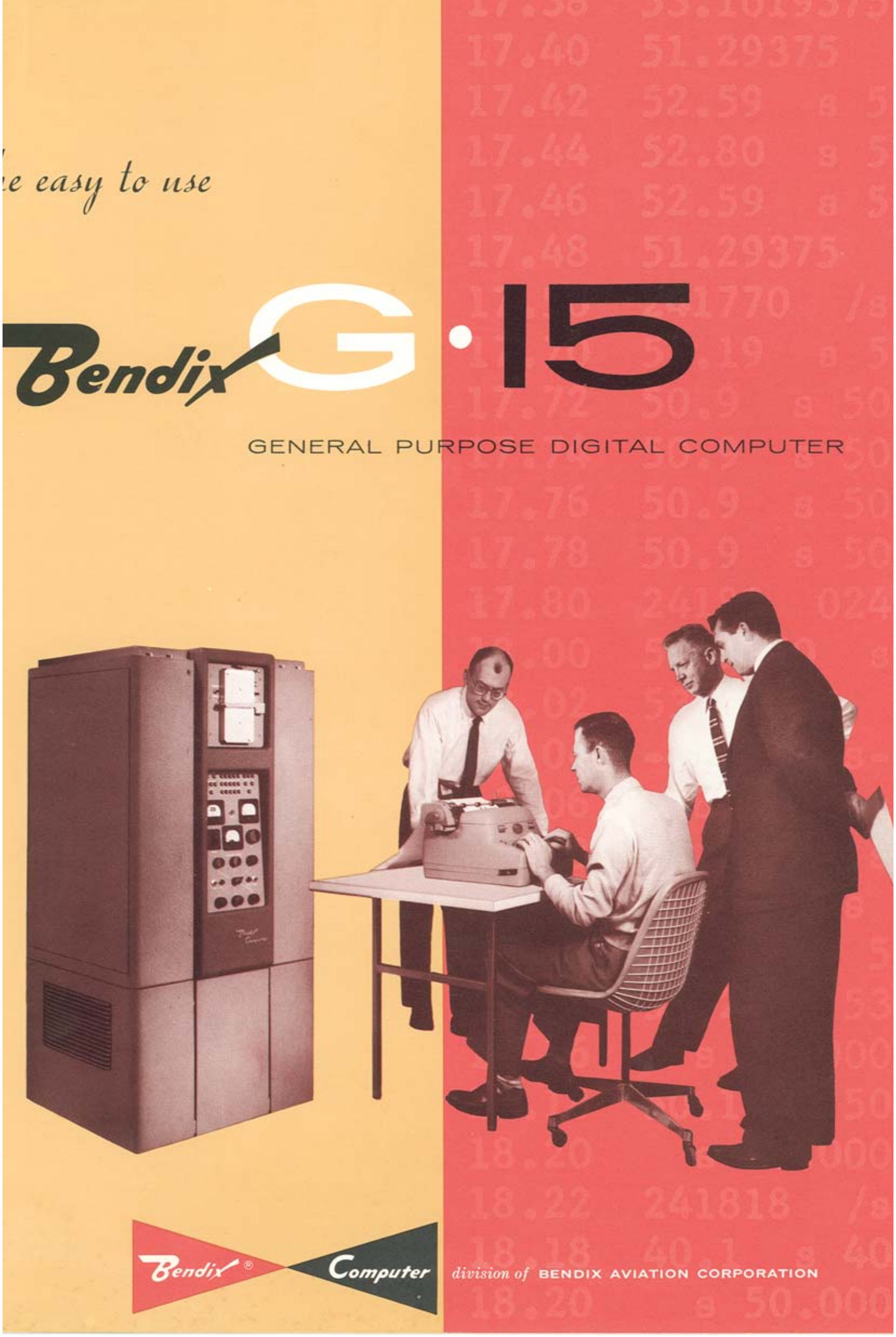


Left: ***Trigonometric rectiligne et sphérique: avec la construction des tables Des Simus, des Tangentes, des Sécantes Et des Logarithmes*, by Dominique François Rivard, 1750. Gwen Bell Early Book Collection of Algorithms, Tables, and History of Calculations.**
Right: Film canisters (top) and slide collection (bottom) from the Museum's Media Archive.



Bendix G-15 advertisement

HEAVY METAL

A RARE AND IMPORTANT COLLECTION COMES TO THE MUSEUM

It was the era of Big Iron—an era when multimillion dollar computer systems came packaged in a dozen or more refrigerator-sized cabinets wired together with cables the size of pythons. In the late 1950s, computers were celebrating nearly a decade of commercial availability. IBM was in the forefront of scientific and business computing even then, though it had competitors such as Remington-Rand (with its UNIVAC system), RCA, and Burroughs.

Most computers made in the 1950s—IBM's included—fell into these two broad categories: Customers were either using them as "number crunchers" or for business and accounting purposes. On the one hand, scientific users required high speed and often dealt with very large or very small numbers. Business users, on the other hand, required only moderate speed and dealt with the relatively small decimal numbers seen in business.

These powerful—and gigantic—machines are long gone … or are they? As Margaret Mead famously noted, "Never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it's the only thing that ever has." Thanks to one such thoughtful, committed citizen—Paul Pierce of Portland, Oregon—several of these legendary computer systems from the dawn of

BY DAG SPICER
SENIOR CURATOR

commercial computing survive. Pierce, a former Intel engineer who worked on supercomputers for a living, accumulated these machines over several decades. It was a tough slog—collecting mainframe computers is neither easy nor inexpensive. Because one Big Iron system can require thousands of square feet of storage space, even when closely packed, Pierce moved occasionally to larger or more convenient storage spaces before eventually acquiring his own warehouse. Pierce's commitment to rescuing the systems is based on a deep respect, and even love, for the skillful engineering, impressive size, and unique computing technologies of a bygone era.

Early in 2014, the Museum and Pierce began discussions about finding a good home for some of his largest systems. Pierce was satisfied with his collecting, and while he had entertained the notion of starting his own computer museum in the future, he no longer wished to pursue that option. We were thrilled that an opportunity to add these classic computers to the Museum's Permanent Collection had arrived. A site visit was arranged and a detailed inventory was created. The Museum decided to accept the following complete systems: the IBM 650, IBM 709, IBM 7094, and Bendix G-15.

What are these computers and how were they used?

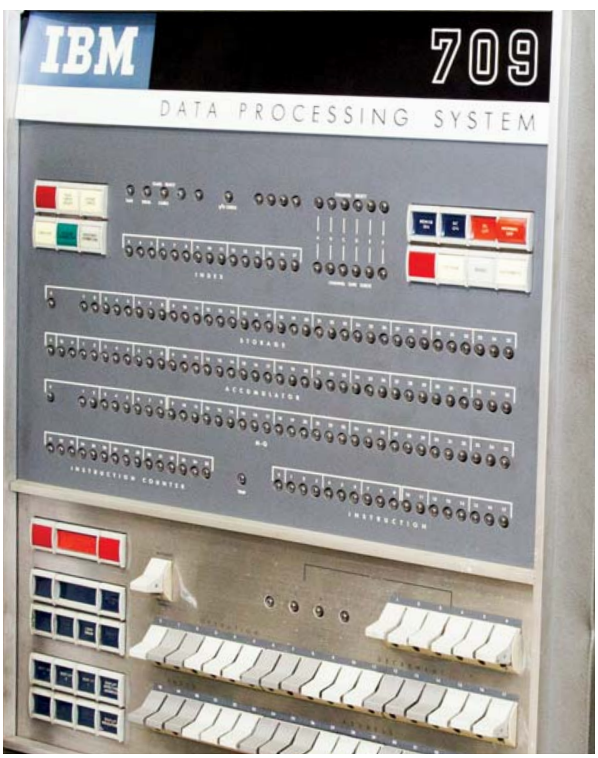
Let's start with the IBM 650. This medium-sized computer system was IBM's first mass-produced electronic computer, with over 2,000 machines manufactured between 1953 and 1962. In a world with only a few thousand computers, that was a huge deal. The IBM 650 was equally at home with scientific applications as it was with business ones—a rare case of a computer appealing to both major computing markets. It was also during this time that IBM was showing its customers a new way of computing, one without plugboards—a turn-of-the-century technology that was adopted to electromechanical business equipment and some early computers. Instead of wiring up a rat's nest of colored wires to tell a machine what to do, instructions could be stored in the computer itself and changed rapidly through a stored program. As an IBM announcement at the time stated, the 650 would be "a vital factor in familiarizing business and industry with stored program principles." All computers today are stored-program computers.

The IBM 650 also had a big influence on early generations of programmers, many of whom first learned to program on one. The most famous is undoubtedly Stanford University professor of computer science Donald Knuth, who learned how to program a 650 in college. In his memoirs, Knuth remarks: "There was something special about the IBM 650, something that has provided the inspiration for much of my life's work. Somehow this machine is powerful in spite of its severe limitations. Somehow it is friendly in spite of its primitive man-machine interface."[1]

The next mainframe system from Pierce is the IBM 709, a large-scale scientific and business-oriented computing system, comprising 10 closet-sized cabinets, 6 feet tall, and built using vacuum tubes. Announced in August of 1958, the 709 was an improved version of an earlier large-scale computer, the IBM 704 (1954), which sported magnetic core memory, a then-new technology that became central to all computers built over the next 20 years.

Just over a year after the IBM 709, IBM announced a transistorized version of it, called the IBM 7090, a system designed for scientific and engineering applications. The IBM 7090 was six times faster than its year-old brother and rented for less than half the price. This small one-year difference shows the speed of technological change in this era. The transition from vacuum tubes to transistors offered immediate benefits: smaller size, lower cost, and less power. IBM made use of transistors beginning

IBM 709 Data Processing System



Top: Close-up of some of the IBM 709's thousands of vacuum tubes.
Middle: Paul Pierce, Museum Chairman Len Shustek, and Museum Trustee Gardner Hendrie
Bottom: IBM 709 operator console from the Paul Pierce Collection.

with an internal company policy to "go solid-state in '58." ("Solid-state" meant using transistors).

Twenty-two 6-foot-tall cabinets make up Pierce's IBM 7094 system, an enhanced and speedier IBM 7090, which was in production from January 1962 until July 1969—a remarkably long run. The IBM 7094 was IBM's flagship scientific computing system for much of the 1960s and played a crucial role in the US space program (Mercury and Gemini), oil exploration, weather forecasting, and all-purpose scientific computing, especially in government, the military, and universities. A 7094 with 32K 36-bit words of memory then cost about $3.5 million (about $27 million today).

The final machine donated to the Museum from Pierce's collection is the Bendix G-15, a personal computer—in the sense that it was made for just one user at a time and cost a fraction of what mainframe systems cost. Designed by 2013 Museum Fellow Harry Huskey, the G-15 was released in 1956 and was one of a small number of single-user computer systems like the Librascope LGP-30 and RPC 4000. It sold for about $60,000—a very low price for its capabilities—and was used in engineering and scientific offices, as well as in universities for teaching computer science.

In early summer of last year, three massive trucks finally delivered Pierce's very special cargo of historic computer systems to the Museum's offsite environmentally controlled storage facility. After unloading, items were carefully vacuumed and cleaned, packaged for storage, and placed on pallets. Receiving over 40 gigantic cabinets—not including 14 pallets of cabling—is not a casual procedure, but the Museum's Collections team processed it quickly and efficiently. It was a magical day for the Museum—all of these systems were on our historical wish list as highly significant computers that tell important stories about the early days of computing. A few months later, Pierce himself visited the Museum's storage facility to see the progress, reminding us all of how being able to see these long-extinct computer systems in real life and knowing that they are now preserved for history is what the Museum is all about. ○

[1] Donald Knuth, "The IBM 650: An Appreciation from the Field," *IEEE Annals of the History of Computing*, Volume 8, Issue 1 (January–March 1986): 50–55.

THE IBM 1401 DEMO LAB RECEIVES TONY SALE AWARD

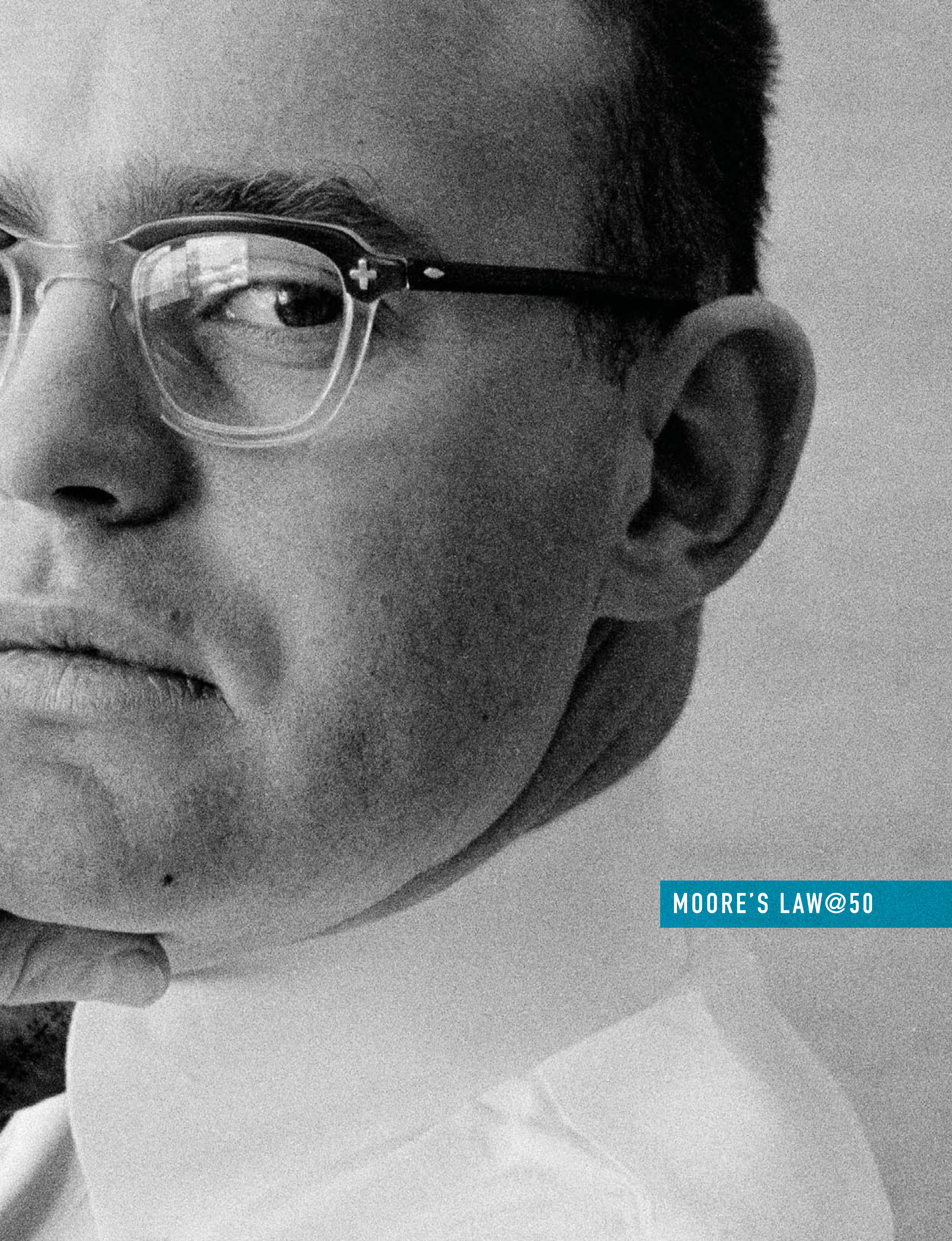
BY DAG SPICER
SENIOR CURATOR

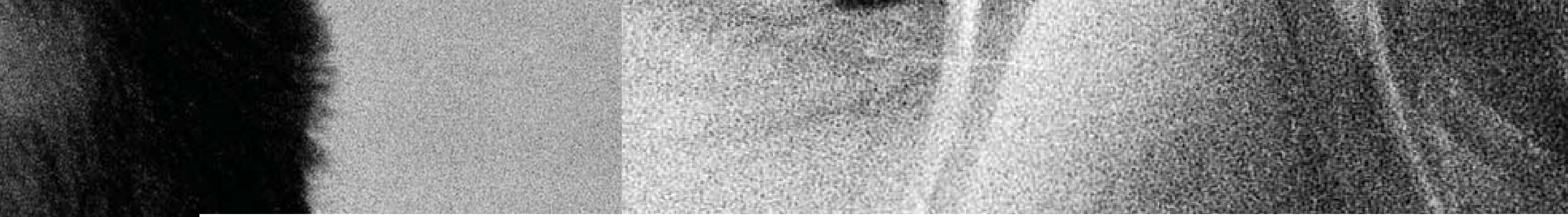
On November 6, 2014, the Computer Conservation Society, in association with the British Computer Society, the Science Museum of London, and the Manchester Museum of Science and Industry, awarded the Museum the prestigious Tony Sale Award for Computer Conservation for its IBM 1401 computer restoration. The project began in 2004 under the guidance of Museum volunteer Robert Garner, who led a passionate team of retired IBM field engineers and programmers in the restoration of not one—but two—complete IBM 1401 data processing systems, including magnetic tape drives, paper tape readers and punches, keypunches, and printers.

The IBM 1401 was the most popular computer of the early to mid-1960s, selling many times IBM's initial estimates. The world was computerizing fast and by 1965 at least half of all computer installations in the world included a 1401. This is why the 1401 was chosen for restoration—it was the classic medium-scale business computer of the 1960s: low-cost, easy to program, and extremely reliable.

We invite you to come experience what our amazing restoration team has accomplished in the Museum's *IBM 1401 Demo Lab*. We are incredibly proud of them and the long-term effort they have invested in the project. The Tony Sale Award is an international acknowledgement of the quality of their efforts. Thank you, team!

Robert Garner accepts the Tony Sale Award from Margaret Sale, widow of Tony Sale.

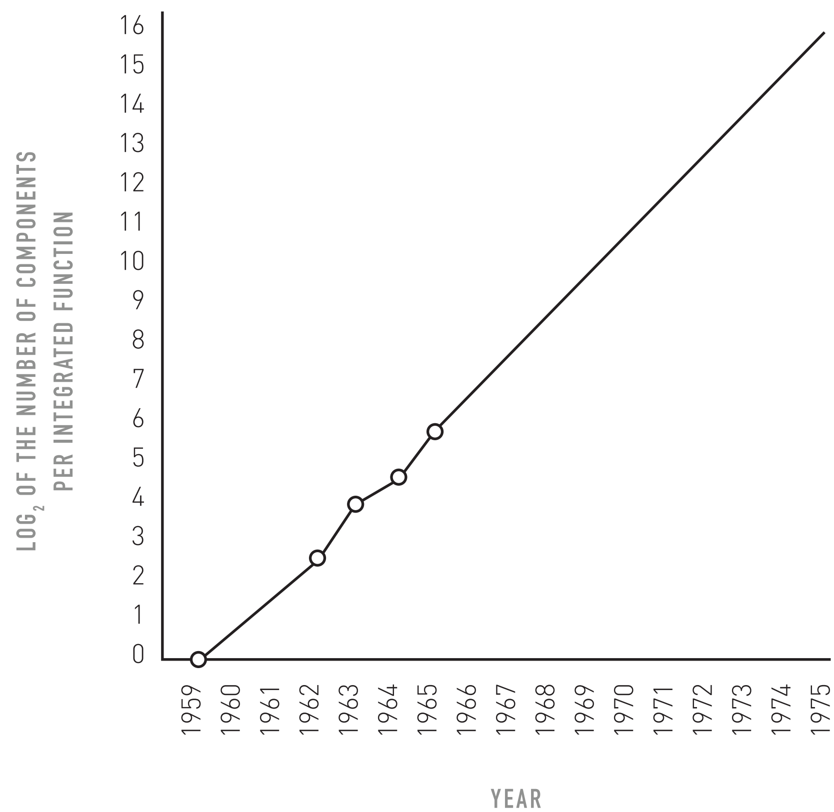





Moore's Law, the historic 1965 forecast made by Fairchild Semiconductor Director of R&D Gordon Moore, predicted that the number of transistors that could be placed onto a single integrated circuit (IC) would double about every two years for at least the next decade. This, in turn, would revolutionize the way technology could be used. Derivations of this "doubling effect," rooted in Moore's original prediction, continue to hold true today and are still used to forecast costs and production volumes. In honor of its 50th anniversary, four renowned experts come together to take a critical look at Moore's Law: what it is, its relevance today, and its future fate.

Walter Isaacson, author and chief executive officer of the Aspen Institute, discusses Moore's Law in his latest book, *The Innovators: How a Group of Inventors, Hackers, Geniuses, and Geeks Created the Digital Revolution*, and the importance of the primary sources he accessed at the Museum. David C. Brock, senior research fellow at the Chemical Heritage Foundation and co-author of *Moore's Law: The Life of Gordon Moore, Silicon Valley's Quiet Revolutionary*, delves into the history behind Moore's Law. Steven Levy, editor-in-chief of *Backchannel* on Medium and author of the definitive Google biography, *In the Plex*, writes about the presence of Moore's Law today, specifically looking at Google and its co-founder Larry Page. Finally, Steve Jurvetson, partner of the venture capital firm Draper Fisher Jurvetson, looks to the future and contemplates a reengineering of Moore's Law.

MOORE'S LAW GRAPH, 1965



BY WALTER ISAACSON

HOW THE MUSEUM ARCHIVE BRINGS HISTORY AND MOORE'S LAW TO LIFE

The joy of a treasure like the Computer History Museum is that it makes vivid how history can inform the future. And one very powerful example of history informing the future is the topic of this special issue: Moore's Law.

After the invention of the microchip by Jack Kilby at Texas Instruments and by Robert Noyce, Gordon Moore, and Jean Hoerni at Fairchild Semiconductor, the device became faster, cheaper, and more powerful each year. Thousands of microchips were produced for guidance systems in rockets and missiles, and they soon were cheap enough to be used in pocket calculators and other consumer devices.

This was especially important because two industries were growing up simultaneously, and they were intertwined: the computer and the microchip. "The synergy between a new component and a new application generated an explosive growth for both," Noyce later wrote.[1] The same synergy had happened a half century earlier when the oil industry grew in tandem with the auto industry. There was a key lesson for innovation: Understand which industries are symbiotic so that you can capitalize on how they will spur each other on.

If someone could provide a pithy and accurate rule for predicting the trend lines, it would help entrepreneurs and venture capitalists to apply this lesson. Fortunately, Gordon Moore happened, almost inadvertently, to do so. Just as the microchip sales were starting to skyrocket, he was asked to forecast the future market. His paper, titled "Cramming More Components onto Integrated Circuits," was published in the April 1965 issue of *Electronics* magazine.

Moore began with a glimpse of the digital future. "Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment," he wrote. Then he produced an even more prescient prediction that was destined to make him famous. "The complexity for minimum component costs has increased at a rate of roughly a factor of two per year," he noted. "There is no reason to believe it will not remain nearly constant for at least 10 years."[2]

Roughly translated, he was saying that the number of transistors that could be crammed, cost effectively, onto a microchip had been doubling every year, and he expected it to do so for at least the next 10 years. One of his friends, a professor at Caltech, publicly dubbed this "Moore's Law." In 1975, when the 10 years had passed, Moore was proven right. He then modified his law by cutting the predicted rate of increase by half, prophesying that the future numbers of transistors crammed onto a chip would show "a doubling every two years, rather than every year." A colleague, David House, offered a further modification, now sometimes used, which said chip "performance" would double every 18 months because of the increased power as well as the increased numbers of transistors that would be put onto a microchip. Moore's formulation and its variations proved to be useful to this day, and it helped chart the course for one of the greatest bursts of innovation and wealth creation in human history.

Moore's Law became more than just a prediction. It was also a goal for the industry, which made it partly self-fulfilling. The first such example occurred in 1964, as Moore was formulating his law. Noyce decided that Fairchild would sell its simplest microchips for less than they cost to make. Moore called the strategy "Bob's unheralded contribution to the semiconductor industry." Noyce knew that the low price would cause device makers to incorporate microchips into their new products. He also knew that the low price would stimulate demand, high-volume production, and economies of scale, which would turn Moore's Law into a reality.[3]

When I was writing my latest book, *The Innovators*, this tale was brought to life for me by the Museum. The notebooks of Noyce and Moore, from their days at Fairchild and Intel, are preserved and displayed for all to see. You can look at the entries by Noyce, Moore, and Hoerni and feel the thrill of the creative process, marveling at how innovation really happened step by step, day by day. In addition, there is a wealth of oral histories that add color and narrative to the daily jottings. And on display are the results: the wondrous machines and components that drove the digital revolution.

The Museum is especially valuable for those trying to envision where technology is leading. As Gordon Moore taught us, a great feel for history helps us discern such trend lines. ○

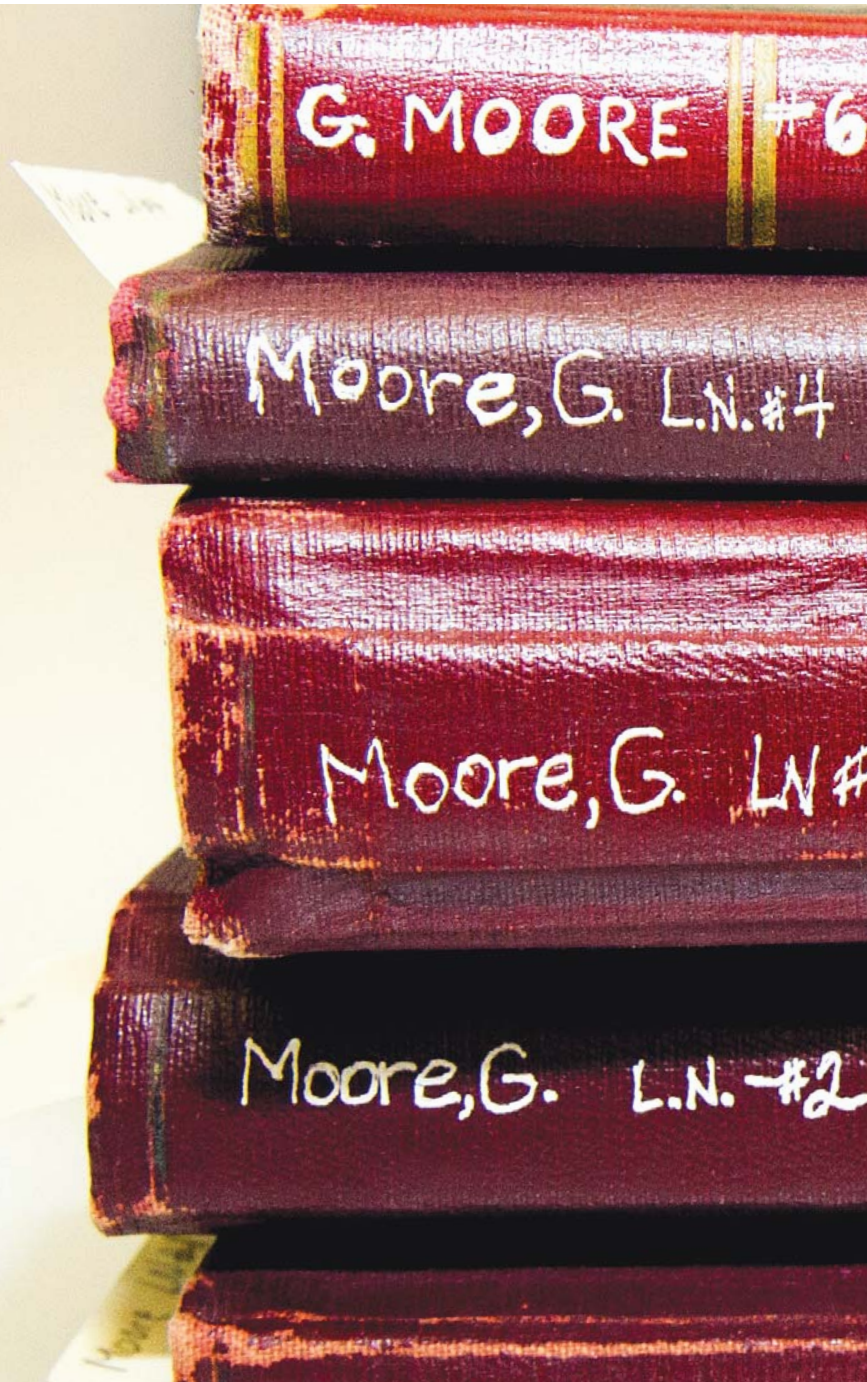
[1] Robert Noyce, "Microelectronics," *Scientific American*, September 1977.

[2] Gordon E. Moore, "Cramming More Components onto Integrated Circuits," *Electronics*, April 1965.

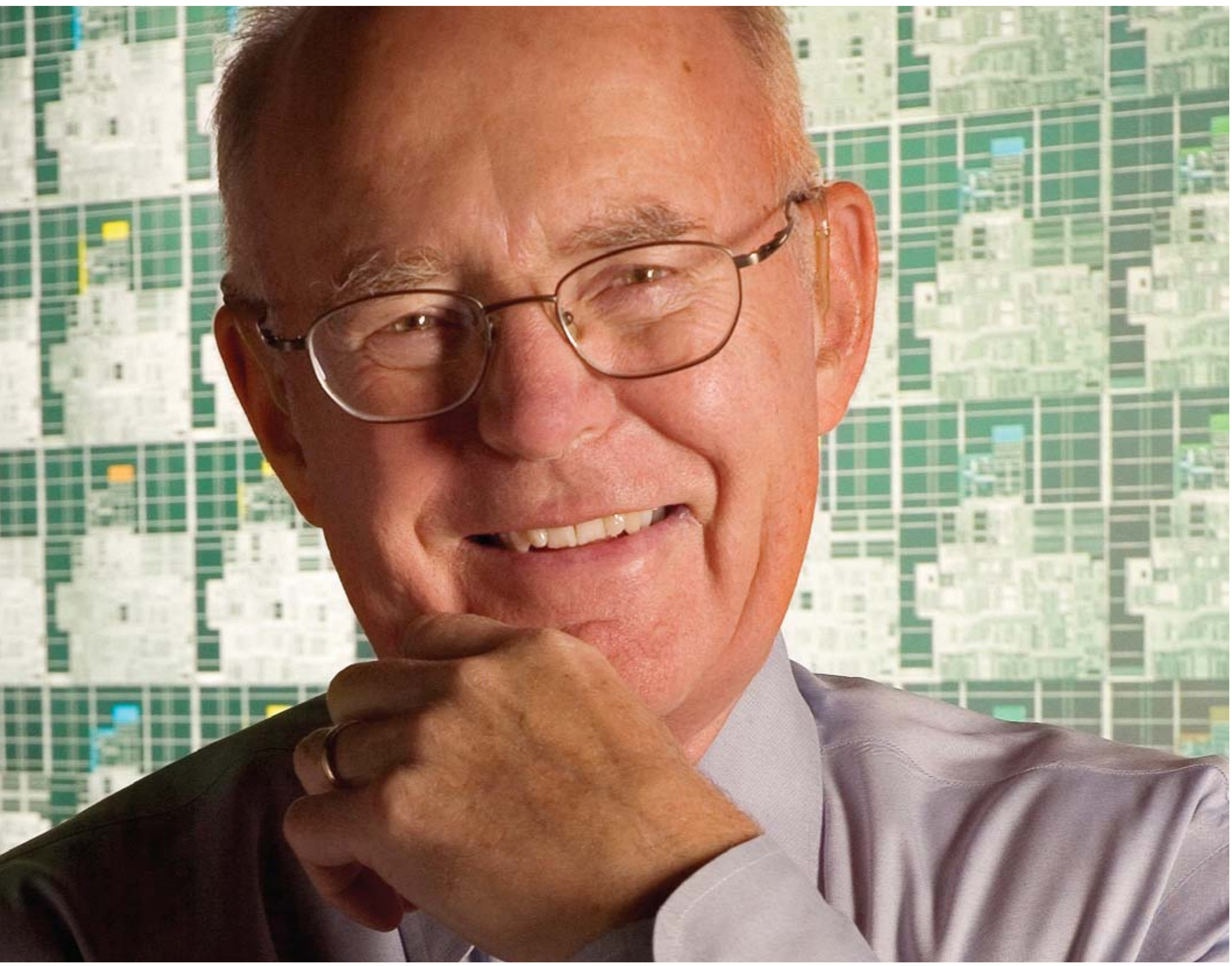
[3] Leslie Berlin, *The Man Behind the Microchip: Robert Noyce and the Invention of Silicon Valley* (New York: Oxford University Press, 2005), 3177.

A portion of this article is excerpted from Isaacson's latest book *The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution.*

Gordon Moore's patent notebooks from the Museum's collection of Fairchild Semiconductor notebooks and technical papers.



Gordon E. Moore, co-founder, Intel Corporation.



BY DAVID C. BROCK

HOW MOORE'S LAW CAME TO BE

Let's begin with a conclusion and then tease out its meaning: Moore's Law is the product of human imagination. "Moore's Law" first came into circulation as a phrase in the mid-1970s after a decade of publications and lectures by Gordon E. Moore on his understanding of the basic dynamics of and possibilities for manufacturing silicon microchips. During this decade, Moore, a Caltech PhD in physical chemistry, went from co-founding and directing R&D at Fairchild Semiconductor to co-founding and directing R&D at Intel Corporation, where he would eventually serve as CEO.

In his publications and lectures, Moore developed an argument and made a prediction. His argument was that the silicon microchip could make electronics profoundly better and, most importantly, cheaper. With this, he saw that electronics would pervade all facets of society with "revolutionary" consequences. His prediction was that this revolution would happen in a particular fashion: constant, dramatic change in the nature of microchips and the reduced cost of improved electronics that they represented.

Fairchild had achieved a breakthrough in the manufacturing technology for making transistors (electronic on-off switches, the basic building blocks of digital circuitry) that set the stage for its pioneering of the silicon microchip as we know it. Simply put, microchips are made by chemically printing tiny transistors onto a piece of silicon crystal, along with the interconnections and other components needed to form an entire electronic circuit. Conventional circuits of the day were, in contrast, made by wiring together individual components.

Moore made several key contributions to this chemical printing technology at Fairchild and at Intel. The silicon microchip was created initially for military electronics where price was of little importance. More critical were considerations like miniaturization, power consumption, and reliability. Moore was perhaps the first to realize that Fairchild's chemical printing approach to making the microchip meant that they would not only be smaller, more reliable, and use less power than conventional electronic circuits, but also that microchips would be cheaper to produce. In the early 1960s, the entire global semiconductor industry adopted Fairchild's approach to making silicon microchips, and a market emerged for them in military fields, particularly aerospace computing.

By 1963, Moore saw that the possibility he had seen for the microchip had, in fact, come true. Fairchild's simple digital microchips were cheaper to make than the set of individual components required to build the equivalent conventional circuit. The microchip had already become the cheapest form of digital electronics. As a scientist, Moore could see no fundamental barrier yet looming for the ongoing improvement of the chemical printing technology that underlay integrated circuit production. With the required investment of effort and money, the technology could be engineered to chemically print ever-finer features with great fidelity. With improved chemical printing, microchip makers would find their best competitive advantage by making microchips more complex; that is, containing larger numbers of transistors. And these more complex digital microchips would represent profoundly cheaper electronics.

In April 1965, Gordon Moore's vision of this potential future reached its largest potential audience to date: the tens of thousands of readers of *Electronics*, a major weekly industry magazine. He wrote an article, "Cramming More Components onto Integrated Circuits," presenting his view of the future of electronics and the microchip with a new twist: a numerical prediction. The view was, as always, about economics as much as technical possibility. He described how the chemical printing of microchips was, in effect, open-ended. If the investment were made, the technology would advance. Moore's point was that such an ongoing investment would reward microchip makers handsomely. By shrinking transistors and putting more of them onto microchips, everything got better: More complex chips would enjoy cost and performance advantages. By making good electronics more inexpensive, its use would spread. He described a world that he subsequently helped make real: "Integrated circuits will lead to such wonders as home computers—or at least terminals connected to a central computer—automatic controls for automobiles, and personal portable communications equipment."[1]

To underscore his message, Moore made a numerical prediction. From Fairchild's chemical printing breakthrough of 1959 into 1965, he observed that the number of transistors on chips had doubled every year, going from a single transistor to a microchip containing around 50 transistors. To achieve the cheapest digital electronics, microchip makers had doubled the transistor count on their chips every year. With nothing on the horizon to trip up the technology development or the economics, Moore predicted that this dynamic would continue for the coming decade to 1975. Microchip makers would continue to invest strongly in chemical printing technology, doubling transistor counts each year to get the best economic advantage, minimizing the cost of digital electronics. The microchip of 1975 would contain not 50, but rather *65,000* transistors.

There is little evidence that Moore's 1965 article made much of a splash. However, some influential members of the electronics community, like Caltech electrical engineering professor Carver Mead, picked up Moore's message and predictions, and helped to spread awareness of them. Most importantly, Moore was certain of his view and acted on it. At his second company, Intel, he led by example. The company pursued, with extraordinary success, cutting-edge chemical printing and highly complex microchips, first for memory chips and then for microprocessors. In 1975, Moore—now Intel's CEO—gave a talk that was quickly published. He returned to his 1965 prediction and found that it had been fulfilled. Transistor counts for microchips had indeed doubled every year. Microchips did contain 65,000 transistors each. From a niche military product, microchips had come to completely dominate in computing. Again, he could see no roadblocks to the continued development of chemical printing or to the economics of the microchip industry. However, Moore believed that the effort would become harder and more expensive. He predicted that in the coming decade his "annual doubling law" would shift, doubling every year and a half, with the cheapest electronics of 1985 found in the form of microchips with 16 million transistors on them.

For the half-century from 1965 to 2015, this regular doubling of microchip complexity to minimize the cost of electronics and to maximize economic reward has been continually realized by the microchip industry and its suppliers of materials, equipment, software, and services. In a very direct sense, Moore's Law has been the achievement of a wide community, a social production inspired by an imagined future and an experienced past. The development of chemical printing and the design of complex microchips have required many billions of dollars and the coordinated effort of hundreds of thousands of people. As the ongoing effort became more extensive, social innovations were required: consortia like Sematech and the US DARPA VLSI program, as well as technology roadmaps. Indeed, Moore himself was instrumental in the creation of the first National Technology Roadmap for Semiconductors with the Semiconductor Industry Association.

As the transistor count on microchips has climbed past the billion mark, the cost to manufacture a transistor has dropped below the nanodollar, and the transistor-on-a-microchip has become the object most manufactured by humanity. Estimates of the number of transistors produced *in a single year* now match, or exceed, estimates of the total number of all the grains of sand on all the world's beaches. With computing devices made of microchips, the price of computing has fallen over a million-fold, while the cost of electronics has fallen a billion-fold. The microchip business has grown into a profitable, multibillion dollar industry.

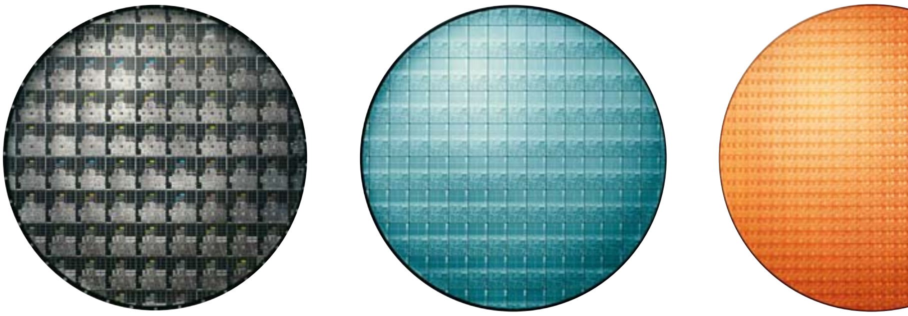
Moore's Law has been the deliberate human creation of an unusually regular pace of unusually rapid change in the cost and capability of electronics, most notably computing. It may be unprecedented in the history of technology. And this regularity of revolutionary change has become so commonplace, that many take it for granted. For decades it has been possible for system-makers and consumers to simply plan on the fact that computing and microchips will become better for less at a steady rate. But this is changing.

In the 2000s, Gordon Moore himself wrote about the end of Moore's Law. "No exponential change continues forever," he wrote, "not even the transistor counts on silicon microchips."[2] On the technical side, he saw that the atom itself presented a fundamental barrier to chemical printing: It would be impossible to print something smaller. In 2015, some features of the transistors on microchips are already just tens of atoms thick. But it was the economic side of Moore's Law, in its way the most social part of this community production, that he believed most likely to disrupt the dynamic. The expense of the chemical printing technology, now conducted in factories that cost several billion dollars apiece, would change the economics and create uncertainty about the future of the microchip and, with it, computing. And it is precisely this uncertainty that the electronics and computing communities are starting to discuss ever more widely. Some look with excitement to possibilities beyond the traditional, like novel computing architectures, quantum computing, and superconducting computers. Others look to exciting materials like carbon nanotubes and graphene. Still others see a longer run for the silicon microchip, with layers of transistors atop one another, or pulses of laser light interconnecting them. Moore himself sees the glass half-full in the eventual shift in the microchip dynamic: "But even if the doubling-times stretch in the future, the rate of progress in the semiconductor industry will far surpass that of nearly all other industries. It is truly a revolutionary technology!"[3] ○

[1] Gordon E. Moore, "Cramming More Components onto Integrated Circuits," *Electronics*, April 1965.

[2] Gordon E. Moore, "No Exponential Is Forever: But 'Forever' Can Be Delayed,"(paper presentation, ISSCC, February 9, 2003, Session 1, Plenary 1).

[3] Ibid.



Wafers containing integrated circuits. Left to Right: Wafer of Itanium® processors, Wafer of Intel® Xeon™ processors, Wafer of Pentium® 4 processors.

BY STEVEN LEVY

HOW UNDERSTANDING MOORE'S LAW MADE GOOGLE POSSIBLE

Gordon Moore's famous calculation of the gains in power and economy that would drive chip production continues to have profound implications for every enterprise, no matter what the sector. But most of us have difficulty grasping the full impact of what Moore has laid out. Our handicap is that we are laboring under the illusion that the impossible is impossible.

But those who truly understand Moore's Law know its corollary: The impossible is the inevitable. Right after Moore's prescient prognostication, anyone with a slide rule—or a Texas Instruments calculator—could have easily run some numbers and determined that within a generation there would be computational gains of a billion-fold or more. The much more difficult task would be to believe this, let alone figuring out what it meant for rates of innovation, for businesses, and even for the human race. The nonlinear gains that Moore predicted are so mind-bending that it is no wonder that very few were able to bend their minds around it.

But those who did would own the future.

Case in point is Larry Page. From his birth in 1973, Larry Page was incubated in the growth light of Moore's Law. His father and mother were computer scientists. He grew up on Michigan college campuses, never far from a computer center. He took for granted the dizzying gains in computation that would come. So he did not think twice about proposing schemes that exploited the effects of Moore's Law, especially the big idea he had as a Stanford graduate student of dramatically improving search by taking advantage of the links of the World Wide Web.

When his thesis professor noted that such a task meant capturing the whole web on Stanford's local servers, Page was unfazed. With a firm grip on how much more powerful and cheap tomorrow's technology would be, he realized such a feat would eventually be relatively trivial; so would making the complicated mathematical analysis of those links, which would have to be done in well under a second. These would be written by Page's partner, Sergey Brin, who shared Page's comfort with the nonlinear effects of Moore's Law. Both knew for the first time in history, the massive computation required to analyze all those links was within the grasp of grad students. Thus, by recognizing the "new possible," Page and Brin were about to do what once was impossible—instantly comb through all of human knowledge to answer even the most obscure question.

In interviews, including those I conducted with him while writing *In the Plex*, my biography of Google, Page has outlined what might be known as his own variation on Moore's Law:

Huge acceleration in computer power and memory
+ rapid drop in cost of same
= no excuse for not pursuing wildly ambitious goals

Companies that develop products for the world in its present state are doomed for failure, he says. Successful products are created to take advantage of tools and infrastructures of the future. When Google whiteboards new products, it assumes they will be powered by technologies that don't exist yet, or do currently exist but are prohibitively expensive. It is a safe bet that in a very short period of time, new technologies will exist and the cost of memory, com-

Close-up of the Google Server Rack

putation, and transit will fall dramatically. In fact, Moore's Law (and similar phenomena in storage and fiber optics) means that you could bet the house on it. "The easiest thing is to do some incremental improvements," says Page. "But that's guaranteed to be obsolete over time, especially when it comes to technology."

A clear example of this came in 2004 when Google announced Gmail, its web-based email product. It was not the first entry in the category. But the competitors offered very limited storage. The most popular product at the time, Microsoft's Hotmail, gave users 2 megabytes of free storage. Users constantly had to pare down their inboxes. Gmail gave users a gigabyte of storage—five hundred times the industry standard. (It soon doubled the amount to 2 gigs.) At the time, it was so unusual that when Gmail was announced on April 1 of that year, many people regarded it as a prank—how can you give away a gigabyte of data? Indeed, in 2004, the outlay of such RAM storage to millions of users drained Google's resources. Yes, it was costly. But only temporarily. As Page says, "That's worked out pretty well for us."

When Page takes meetings with Google's employees, he relentlessly badgers them for not proposing more ambitious ideas. Much worse than failure is failing to think big.

Earlier, Steve Jobs of Apple had a similar conundrum when releasing the Macintosh. The problem was that in 1984, technology was not ready for the computer his team had designed. To provide a satisfactory user experience, the Macintosh required at least a megabyte of internal memory, a hard disk drive, and a processor several times speedier than the Motorola 68000 chip that drove the original. Jobs knew that Moore's Law would provide help soon and wanted to initially sell the Macintosh at a money-losing $2,000 to grab the market share. But his bosses at Apple did not understand that setting a low price would only mean losses temporarily—the company would soon be paying less for much more powerful chips. Indeed, in a few years the Macintosh had all the power and storage it needed—but had lost the market momentum to Microsoft.

Ray Kurzweil, the great inventor and artificial intelligence pioneer now at Google, has a theory about those who are best suited to create groundbreaking products. The common wisdom, he says, is that one cannot predict the future. Kurzweil insisted that, because of Moore's Law and other yardsticks of improvement, you can predict the future. Maybe not enough to tell if a specific idea will succeed, but certainly well enough to understand what resources might be available in a few years. "The world will be a very different place by the time you finish a project," he told me in an interview a couple of years back.

The problem, explains Kurzweill, is that so few people have internalized that reality. Our brains haven't yet evolved in sync with the reality that Moore identified. "Hardwired in our brains are linear expectations because that worked very well a thousand years ago, tracking an animal in the wild," he says. "Some people, though, can readily accept this exponential perspective when you show them the evidence." The other element, he adds, is the courage required to act on that evidence. Accepting Moore's Law means understanding what was once impossible is now within our grasp—and leads to ideas that may seem on first blush outlandish. So courage is required to resist that ridicule that often comes from proposing such schemes.

For the past few years, critics both in and out of Silicon Valley have been griping about what I call the "Jetson Gap." The critique is embodied in venture capitalist Peter Thiel's charge, "We were promised flying cars and instead what we got was 140 characters." But flying cars are rather tame compared to the fantastic inventions we now use every day: a search engine that answers our most challenging questions answered in less than a second; a network of a billion people sharing personal news and pointers to news and gossip; and a palmtop computer that, among other things, can beam live video to the world and have a conversation with you.

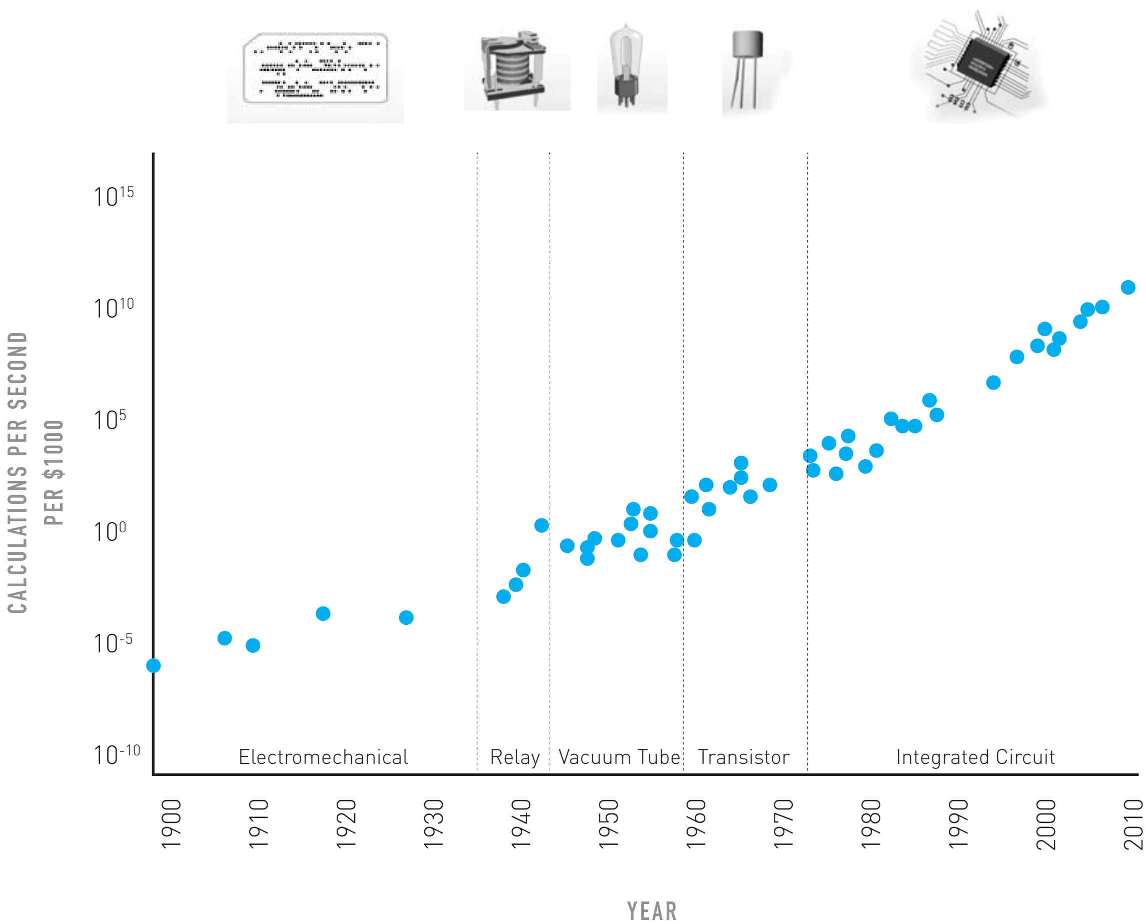
Those who understood Moore's Law had the fortitude to make such advances. And more people are catching on. A generation raised on Google thinking is now working on new inventions, new systems, and new business plans. Businesses in virtually every sector are being challenged—and in some cases shut down—by young entrepreneurs applying Moore's Law. (Call it the "Uberization" of everything.) It's quite probable that on someone's drawing board right now is a project that will change our lives and earn billions—but is a funding challenge because the pitch sounds, well, crazy.

But as Page told me in 2012: "If you're not doing some things that are crazy, you're doing the wrong thing."

Moore's Law guarantees it.

All quotes, unless cited otherwise, were gathered during Levy's research of *In the Plex* or subsequent reporting.

Google CEO and co-founder Larry page and co-founder Sergey Brin.



Source: Ray Kurzweil, *The Singularity is Near* (New York: Penguin Books, 2005), 70.
Note: Each dot is a computing machine.

"110 YEARS OF MOORE'S LAW"

BY STEVE JURVETSON

TRANSCENDING MOORE'S LAW TO FORGE THE FUTURE

Moore's Law is both a prediction and an abstraction. The popular perception of Moore's Law is that computer chips are compounding in their complexity at a near constant per unit cost. This is one of the many abstractions of Moore's Law, and it relates to the compounding of transistor density in two dimensions. Other abstractions relate to speed (the signals have less distance to travel) or computational power (speed x density).

Unless you work for a chip company and focus on fab-yield optimization, you do not care about the transistor counts that Gordon Moore originally wrote about. Integrated circuit customers do not buy transistors. Consumers of technology purchase computational speed and data storage density. When recast in these terms that matter to customers, Moore's Law is no longer a transistor-centric metric, and this abstraction allows for longer-term analysis.

And more profoundly, what Moore observed in the belly of the early IC industry was a derivative metric, a refracted signal from a longer-term trend, a trend that begs various philosophical questions and predicts mind-bending futures.

Humanity's Compounding Capacity to Compute

Ray Kurzweil's abstraction of Moore's Law shows computational power on a logarithmic scale (opposite page) and finds a double exponential curve that holds over 110 years! A straight line would represent a geometrically compounding curve of progress.

Through five paradigm shifts—such as electromechanical calculators and vacuum tube computers—the computational power that $1,000 buys has doubled every two years. For the past 30 years, it has been doubling every year.

Each dot is the frontier of computational price performance of the day. One machine was used in the 1890 Census; one cracked the Nazi Enigma cipher in World War II; one predicted Eisenhower's win in the 1956 presidential election. Many of them can be seen in the Museum.

Each dot represents a human drama. Prior to Moore's seminal paper in 1965, which predicted the future of integrated electronics and later became known as Moore's Law, none of these machines even knew they were on a predictive curve. Each dot represents an attempt to build the best computer with the tools of the day. Of course, we use these computers to make better design software and manufacturing control algorithms. And so the progress continues.

Notice that the pace of innovation is exogenous to the economy. The Great Depression and the World Wars and various recessions do not introduce a meaningful change in the long-term trajectory of Moore's Law. Certainly, the adoption rates, revenues, profits, and economic fates of the computer companies behind the various dots on the graph may go through wild oscillations, but the long-term trend emerges nevertheless.

Any one technology, such as the CMOS (complementary metal oxide semiconductor) transistor, follows an elongated S-shaped curve of slow progress during initial development, upward progress during a rapid adoption phase, and then slower growth from market saturation over time. But a more generalized capability, such as computation, storage, or bandwidth, tends to follow a pure exponential curve—bridging across a variety of technologies and their cascade of S-curves.

In the modern era of accelerating change in the tech industry, it is hard to find even five-year trends with any predictive value, let alone trends that span the centuries. I would go further and assert that this is the most important graph ever conceived.

Why This Is the Most Important Graph in Human History

A large and growing set of industries depends on continued exponential cost declines in computational power and storage density. Moore's Law drives electronics, communications, and computers and has become a primary driver in drug discovery, biotech and bioinformatics, medical imaging, and diagnostics. As Moore's Law crosses critical thresholds, a formerly lab science of trial-and-error experimentation becomes a simulation science, and the pace of progress accelerates dramatically, creating opportunities for new entrants in new industries. Boeing used to rely on the wind tunnels to test novel aircraft design performance. Ever since CFD (computational fluid dynamics) modeling became powerful enough, design moves to the rapid pace of iterative simulations, and the nearby wind tunnels of NASA Ames lie fallow. Engineers can iterate at a rapid rate while simply sitting at their desks.

Every industry on our planet is going to become an information business. Consider agriculture. If you ask a farmer in 20 years' time about how they compete, it will depend on how they use information, from satellite imagery driving robotic field optimization to the genetic code in their seeds. It will have nothing to do with workmanship or labor. That will eventually percolate through every industry as IT innervates the economy.

Nonlinear shifts in the marketplace are also essential for entrepreneurship and meaningful change. Technology's exponential pace of progress has been the primary juggernaut of perpetual market disruption, spawning wave after wave of opportunities for new companies. Without disruption, entrepreneurs would not exist.

Moore's Law is not just exogenous to the economy; it is why we have economic growth and an accelerating pace of progress. At our investment firm, Draper Fisher Jurvetson, we see this in the growing diversity and global impact of the entrepreneurial ideas that we see each year. The industries impacted by the current wave of tech entrepreneurs are more diverse and an order of magnitude larger than those of the 1990s—from automobiles and aerospace to energy and chemicals.

At the cutting edge of computational capture is biology; we are actively reengineering the information systems of biology and creating synthetic microbes whose DNA is manufactured from bare computer code and an organic chemistry printer. But what to build? So far, we largely copy large tracts of code from nature. But the question spans across all the complex systems that we might wish to build, from cities to designer microbes to computer intelligence.

Reengineering Engineering

As these systems transcend human comprehension, we will shift from traditional engineering to evolutionary algorithms and iterative learning algorithms like deep learning and machine learning. While these techniques are powerful, the locus of learning shifts from the artifacts themselves to the process that created them. It is more analogous to parenting than traditional engineering.

Unfortunately, the complex artifacts created by an iterative algorithm are inscrutable, like the human brain—a black box defined by its interfaces. There is no mathematical shortcut for the decomposition of a neural network or genetic program, no way to "reverse evolve" with the ease that we can reverse engineer the artifacts of purposeful design. The beauty of compounding iterative algorithms (evolution, fractals, organic growth, art) derives from their irreducibility. And it empowers us to design complex systems that exceed human understanding, which we increasingly need to do at the cutting edge of software engineering and microbial engineering. For example, these processes present a plausible path to artificial intelligence.

Consider machine learning and the latest developments in deep learning that have achieved super-human performance: computer vision, speech recognition, and diverse diagnostics across medicine, finance, and networking. Deep learning algorithms consists of neural networks—layers of synthetic neurons with inputs, outputs, and many hidden layers. These hidden layers contain hierarchies of abstract representations of the data inputs, analogous to how the human brain builds internal abstract representations of the real world over many iterative exposures.

The most exciting aspect of neural networks and deep learning is that it encompasses a "process innovation," completely changing the paradigm of software engineering. Computers no longer have to be provided instructions to accomplish tasks. They can make inductive inferences based on training data with limited human interaction. These advances were possible due to massive amounts of training data, cheap compute power, and powerful yet simple algorithms inspired by the brain.

While the model of artificial neural networks may be biologically inspired, there is still much progress to be made to achieve parity with the complexities of the human brain. The 2012 Google Brain Project on deep learning that discovered cats in YouTube videos without explicit labeling used 16,000 compute cores with one billion connections (synapses).[1] Humans have 100 trillion synapses, and while a 100,000x difference may seem daunting, it is surpassed by 17 doublings of Moore's Law. And many interesting products may ensue along the way, with intelligent systems that fall short of the somewhat arbitrary human benchmark.

Danny Hillis summarizes succinctly in the conclusion from his programming primer *The Pattern on the Stone*: "We will not engineer an artificial intelligence; rather we will set up the right conditions under which an intelligence can emerge. The greatest achievement of our technology may well be creation of tools that allow us to go *beyond* engineering—that allow us to create more than we can understand."

Why Does Progress Perpetually Accelerate?

All new technologies are combinations of technologies that already exist. Innovation does not occur in a vacuum; it is a combination of ideas from before. In any academic field, the advances today are built on a large edifice of history. This is why major innovations tend to be "ripe" and tend to be discovered at nearly the same time by multiple people. The compounding of ideas is the foundation of progress, something that was not so evident to the casual observer before the age of science. Science tuned the process parameters for innovation and became the best method for a culture to learn.

From this conceptual base comes the origin of economic growth and acceleration of technological change, as the combinatorial explosion of possible idea pairings grows exponentially as new ideas come into the mix (on the order of 2^n of possible groupings, per Reed's Law). It explains the innovative power of urbanization and networked globalization. And it explains why interdisciplinary ideas are so powerfully disruptive; it is like the differential immunity of epidemiology, whereby islands of cognitive isolation (for example, academic disciplines) are vulnerable to disruptive memes hopping across them, much like South America was to smallpox from Cortés and the Conquistadors. If disruption is what you seek, cognitive island-hopping is a good place to start, mining the interstices between academic disciplines.

It is the combinatorial explosion of possible innovation pairings that creates economic growth, and it's about to go into overdrive. In recent years, we have begun to see the global innovation effects of a new factor: the Internet. People can exchange ideas like never before. Long ago, people were not communicating across continents; ideas were partitioned, and so the success of nations and regions pivoted on their own innovations. Richard Dawkins states that in biology it is genes that really matter, and we as people are just vessels for the conveyance of genes.[2] It's the same with ideas or "memes." We are the vessels that hold and communicate ideas, and now that pool of ideas percolates on a global basis more rapidly than ever before.

In the next six years, three billion minds will come online for the first time to join this global conversation (via inexpensive smartphones in the developing world). This rapid influx of three billion people to the global economy is unprecedented in human history and so, too, will the pace of idea pairings and progress.

We live in interesting times, at the cusp of the frontiers of the unknown and breathtaking advances. But, it should always feel that way, engendering a perpetual sense of future shock. ○

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[1] http://research.google.com/pubs/pub38115.html.

[2] http://en.wikipedia.org/wiki/The_Selfish_Gene

ONE OF A KIND

REMARKABLE PEOPLE

EVELYN BEREZIN

COURTESY OF EVELYN BEREZIN

BY DAG SPICER

SENIOR CURATOR

Women in the history of computing are a rare breed. Although recently historians have sought to illuminate and reclaim the often hidden roles women have played in the development of the modern computer, in some sense the lack of women in traditional narratives of computing *is* the story. Why is this so? The reasons are even more complex today, but at least women now have a chance of becoming engineers, scientists, or programmers. For much of the story of computing, women were virtually invisible to their male counterparts and were usually given menial tasks that were often repetitive and boring—with no hope of advancement into more senior roles.

How exciting then to discover a woman who not only participated in the computer revolution as a technical contributor, but who also founded and led a highly successful computer company of her own.

That woman is Evelyn Berezin. You have probably never heard of her, but her story is fascinating and a rare example of a woman succeeding in a heavily male-dominated industry.

Berezin was born in the Bronx in 1925, about a mile away from the famous Bronx Zoo. Her parents were poor Russian immigrants who fled to the US in search of a better life. Her upbringing was that of a poor but hardworking Jewish immigrant family who barely made ends meet and who shared their 440-square-foot apartment among six people. Berezin excelled in school, studying liberal arts at the all-girls Hunter College before deciding that she wanted to study physics, which Hunter did not teach at the time.

America's participation in World War II began with the attack on Pearl Harbor on December 7, 1941. Even before then, war clouds were clearly on the horizon, and it was widely assumed that American men would soon be leaving to serve in the armed forces. Because there would eventually be fewer men at universities, both public and private universities throughout the city chose fewer but specific fields of study to support so they could cut the number of classes as their students left for military service. Anyone who went to one of these schools in the city could take classes anywhere in the city, and Berezin went to all of them for free. "It was a blessing for me because I could use the availability of those schools to study mathematics and physics." Berezin was 15 when she started university; she worked as a technical assistant at the International Printing Ink Company at the same time.

After graduating from NYU in 1945, she began graduate work at New York University (NYU) in physics under an Atomic Energy Commission fellowship, studying mesons in a handmade cloud chamber on the roof of an NYU building. She remembers handling radioactive compounds quite casually, since radiation's effects were generally not well understood and safety precautions were almost nonexistent. She started her graduate school classes on the day of the Hiroshima explosion, August 6, 1945, in a class on nuclear physics.

It was in 1951 that she began to look for a job. Due to government cutbacks in the recruitment of physicists, which had seemed so essential to national security only a few years earlier, Berezin's graduate advisor suggested she consider other opportunities. Berezin recalls: "I went to a headhunter who was despondent about the lack of jobs he could find for people. And I said, 'Have you heard of any jobs in computers?' I have no idea of where I knew about computers. And he said to me, 'I never heard of computers, but this morning I got a phone call from somebody in Brooklyn who's looking for people for a computer company.'"

Berezin went over to the new company—Electronic Computer Corporation (also known as Elecom)—and, after a test of her abilities, was hired as their logic designer. This alone was remarkable as such work was considered a man's job even at this early stage in which only a handful of people had ever worked on computers at all.

After designing several computer systems at Elecom, including one for the US Army's Aberdeen Proving Ground and another for *Fortune* magazine's subscription system, the company was acquired in 1957 by the Underwood Typewriter Company. Sadly, the firm went bankrupt shortly thereafter. Berezin was quickly hired by Teleregister, a well-established systems company that provided equipment for the New York Stock Exchange (NYSE) "main board" and also provided equipment and information around the country to subscribers of its service. Teleregister's technology was relay-based; huge arrays of custom-designed switching circuits provided the nervous system of their products. Wanting to update their technology, they asked Berezin to train their 10 existing relay logic designers in the new technologies of digital logic and computing. Teleregister was brought into the electronic era and quickly designed several important computing systems, including the largest online, real-time, country-wide system in existence at that time (1962), a passenger reservation system for United Airlines.

Commuting several hours each day to and from Teleregister headquarters in Stamford, Connecticut, Berezin decided to try a new job and got an interview courtesy of her current Teleregister boss. The job was to update the NYSE's main board with computer technology. Berezin was certainly qualified but, sadly, the NYSE board of directors vetoed the decision to hire her, allegedly concerned that the salty language of the trading floor might be offensive to her. "At the time, I was probably one of two people in the world who knew how to design a machine for them. I was really just stunned," Berezin recalls. "And my contact was so sorry to say this, and he said to me, 'The board said that you're a woman, you'd have to be on the stock market floor from time to time. And the language of the floor is not for a woman's ears.' I had worked in laboratories all my life. I had seen practically naked men working inside these enormous hot machines and had heard every epithet known to man or woman. What in the world was he talking about? But there was no way I could get back to them."

Berezin speaks of a similar example of chauvinism in the experience of a friend, Marian, working at General Electric: "She was in the ladies' room with the other woman who worked there, and the other woman told her, I got a raise of $3 a week. And Marian was really frightened because she thought she had done something wrong. And so she went to the head of the department, and she told him that she had heard that this other woman had received $3 and she only got a $2-a-week raise. She [Marian] didn't understand—had she done something wrong? She would like to know because she wanted to do the right thing. 'Oh, no,' the supervisor said, 'it's because she's a blonde.'"

After the stock exchange disappointment, Berezin started work at Digitronics, a start-up founded by former Elecom employees. Digitronics designed and built special-purpose systems that included computers. One system was used for racetrack betting, not unlike the work of Teleregister in some of its basic concepts. At this time, Berezin had been running logic design departments for over a decade and came to realize that she would never ascend to higher levels in any company not run by herself.

Encouraged by friends, she started her own company, Redactron Corporation, to make word processors. IBM had not yet entered the market beyond its cumbersome Magnetic Tape Selectric Typewriter (MT/ST), which did not use digital electronic techniques, and Berezin saw an opportunity to be first. Redactron did very well with Berezin as founder and CEO, eventually growing to just under 500 employees and selling their machines across the US, Europe, and Australia. Redactron was also the first company to build a custom MOS central processing unit (CPU) using integrated circuits, reducing the Redactron design to just 13 chips in September of 1971. After weathering the tough economic recession of the early 1970s, including shouldering the burden of customers who insisted on leasing their machines, Redactron was bought by computing giant Burroughs Corporation.

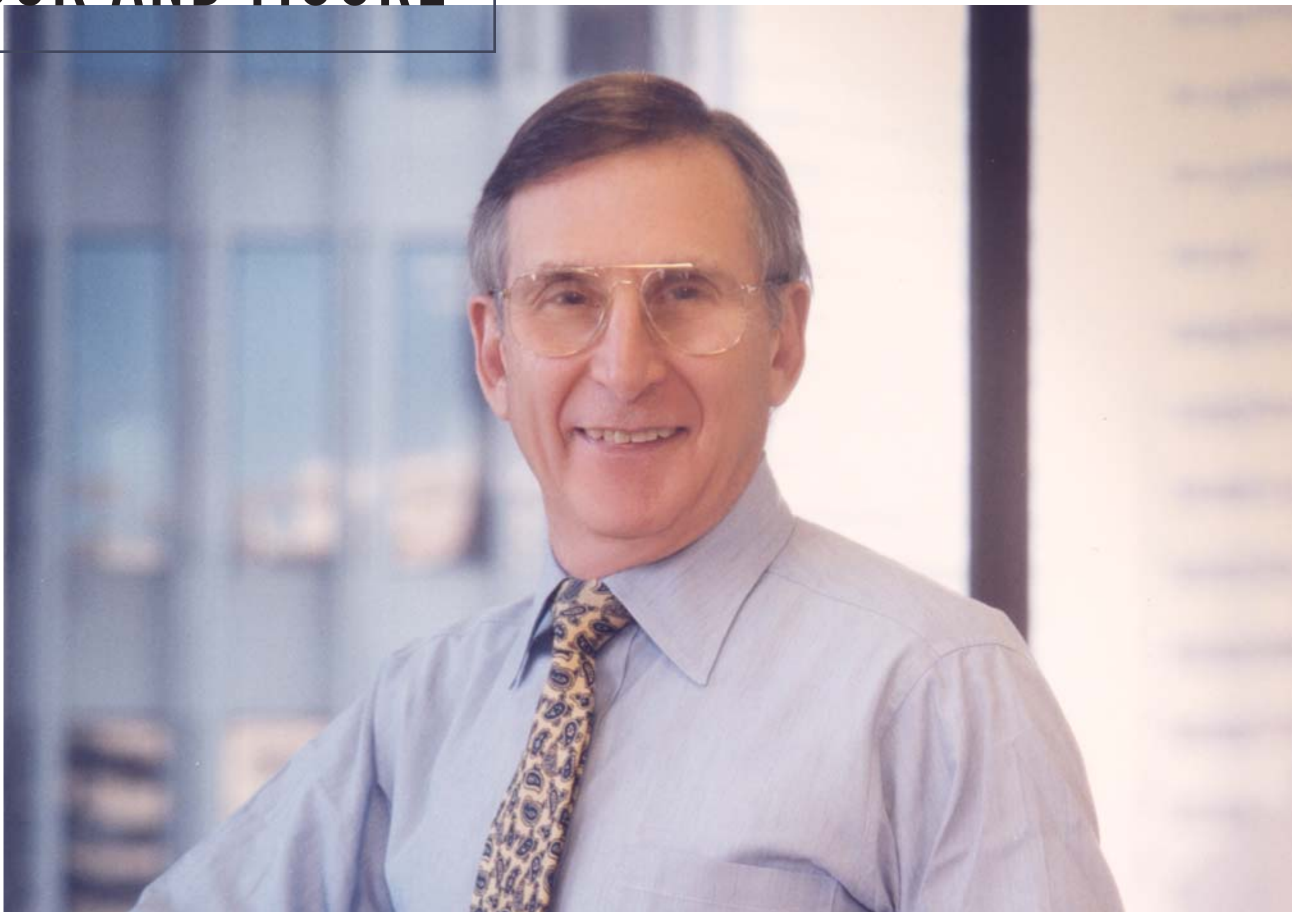
Berezin worked at Burroughs for a short time and then left after disagreements about the direction of the company and its plans for Redactron. Since that time, Berezin has served on large company boards, as well as the boards of a number of start-up companies, and has been involved with a program that helps women get the training they need to start their own companies. Now 89 years old, Berezin remains actively involved in life.

As we look for examples of women in computing to draw inspiration from, Berezin reminds us that perseverance in the face of prejudice is a powerful force that can overcome life's trials. Her attitude, I believe, can be nicely summarized by writer Margaret Sanger: "Woman must not accept; she must challenge. She must not be awed by that which has been built up around her; she must reverence that woman in her which struggles for expression." ○

All quotes, unless cited otherwise, are from Evelyn Berezin's oral history, conducted by Gardner Hendrie for the Computer History Museum on March 10, 2014.

Remarkable person and Musuem 2015 Fellow Award Honoree Evelyn Berezin in 1974 when she was CEO of Redactron.

ROCK AND MOORE



INTERVIEW BY JOHN C. HOLLAR PRESIDENT & CEO

& DOUGLAS FAIRBAIRN STAFF DIRECTOR, SEMICONDUCTOR SIG

ORAL HISTORIES

TOGETHER

In the Valley of Legends, Silicon Valley, there are few who stand taller than Arthur Rock and Gordon Moore. Rock and Moore's friendship goes back to 1957. Moore was one of the "traitorous eight" who had left Shockley Semiconductor looking to start their own operation. Rock was the one who arranged the financing for this group to found Fairchild Semiconductor in 1957.

Arthur Rock can truly be called one of the fathers of modern venture capital—the engine that has fueled the technological explosion centered on Silicon Valley.

Gordon Moore was an early employee of Shockley Semiconductor and a founder of Fairchild Semiconductor. A decade later, Moore joined Robert Noyce to found Intel. He was also the mind behind Moore's Law, which has been the driving force in the advance of electronics for over five decades.

Rock and Moore recently sat down with the Museum's John Hollar and Douglas Fairbairn to discuss the early days of venture capital and the founding of Intel.

Hollar: Gordon, if I could start with you, I want to ask you, specifically, about the circumstances that gave rise to the idea that you and Bob Noyce would leave Fairchild and form your own company.

Moore: It was a complicated combination of factors that made it happen. Fairchild was going through a top management change looking on the outside for a new CEO. Bob was the logical internal candidate and they were clearly passing him over. So he was interested in another opportunity.

When I heard he was going to leave, I said, OK, I'll come along, too. And I told him earlier that I saw the first opportunity I'd seen in years that I would consider big enough to start a new company with semiconductor memory. With that idea and with the push we had from Fairchild management, we decided to start all over again.

Hollar: Was it an intimidating idea to think that the two of you would leave Fairchild?

Moore: Not especially. We belonged to the culture of the Valley that failure is something that, if it happens to occur, you can start all over again. There's no stigma attached to being a failure. And we had had enough success at Fairchild. We were reasonably confident we knew what we were doing.

Hollar: What was it about the semiconductor memory opportunity that you felt was worth all this?

Moore: It was the one use of integrated circuits where it looked like you could make something complex that we used in large volume. The trouble the industry was running into was anything that got complex tended to become unique. And there wasn't enough of them to spread all the design effort across. But memory was a universal function in all digital systems. And it looked like one could actually make a standard product and develop a fair business on it.

Hollar [to Rock]: What was the nature of your conversation with them [Noyce and Moore] during those years before this?

Rock: It was a friendship. We went hiking together and climbing and skiing. It wasn't about the company. But they knew that I was there and, I guess, thought highly enough of me to continue the friendship.

Hollar: And then were you aware that Gordon and Bob were having these thoughts?

Rock: Not until Bob called me.

Hollar: Do you remember that conversation?

Rock: I do, indeed. It wasn't much of a conversation. Bob called me and said they wanted to do it and I said I'm in. And that was that.

Moore: It had to have been the easiest financing of a start-up, I think, that has occurred in Silicon Valley.

Hollar: So talk about how that happened, Arthur. From that moment when you talked to Bob, what were the next steps?

Rock: I asked them how much money do you need? $2.5 million. How much are you willing to invest? $250,000. And then we talked about what percent of the company should go to the investors and figured that out. It was done within 10 or 15 minutes.

Hollar: Were you surprised, Gordon, at how short an amount of time it took to raise the money for Intel?

Moore: Not especially. I knew Arthur was someone who could make a decision in a hurry. And he did.

Hollar: How quickly did things move after this initial conversation?

Rock: This was days before electronic communication. So it took me about a day and a half to call the people I thought would be interested and get yeses.

Hollar: Were you attracted to Arthur, specifically, Gordon, as the person to do this?

Moore: Well, we knew him. We knew what he had done in the past. So it was certainly the one place we would think of going. And it worked out fine.

Hollar: Were you talking to Gordon and Bob about the specific opportunity that they saw?

Rock: No.

Hollar: Did that come later?

Rock: In the 15-minute conversation, they told me what they wanted to do. And I said, gee, that sounds great.

Hollar: There was a famous one-page proposal, wasn't there?—that was drafted to explain what the nature—

Rock: It was three pages, double-spaced. Some of the investors wanted to have something in their files. So I wrote this three-page double-spaced memo. It didn't say anything.

Moore: I didn't realize you had written it. I thought Bob did.

Rock: No, I did. I think Bob would have been more specific.

Moore: Probably. It was rather nebulous what we were gonna do.

Hollar: So what were the first steps then, Gordon, that you and Bob took to start the business?

Moore: Hiring. At that time, we had to get to a critical mass to do the things that were necessary to get a product out. So we were incorporated on July 18. And our goal was to be to about 100 employees by the end of the year. And we started right away.

I told Andy Grove I was going to leave. He said, I want to come along. That was recruiting there. And we tried to select young, high- potential people from various places in the industry hoping they could grow with their jobs.

Fairbairn: Did you have a specific product in mind?

Moore: Well, semiconductor memory. And we went after that with three different technological approaches. I refer to it now as our "Goldilocks Strategy."

One was too easy. It was a variation on the theme of the technology that was being used to make simple circuits. And well, we got product out. In fact, our first product was—the people who had been making the logic circuits could copy it pretty rapidly. So we didn't have an advantage. One was too hard in that we didn't have the technology well enough developed. We would probably have gone broke if that had been our only approach.

But one of them, by fortune and accident, was just difficult enough. When we were focusing on it, we could get by the two or three rather serious problems that had to be solved. But we ended up, then, with a monopoly of about seven years before anybody else got over on the silicon gate MOS transistor structure that we were using.

So it really worked out beautifully. Luck plays a significant role in these things. It was just a very lucky choice.

Fairbairn: What was that Goldilocks product—the middle one?

Moore: It was a technology—the silicon gate MOS. Individual transistors had been made. But nobody had tried to make a production technology out of it before. We drove in that direction. ○

COLLECTION

RECENT ARTIFACT DONATIONS

RABBITS, READERS, AND REDACTRONS

BY ALEX LUX
RESEARCH ASSISTANT

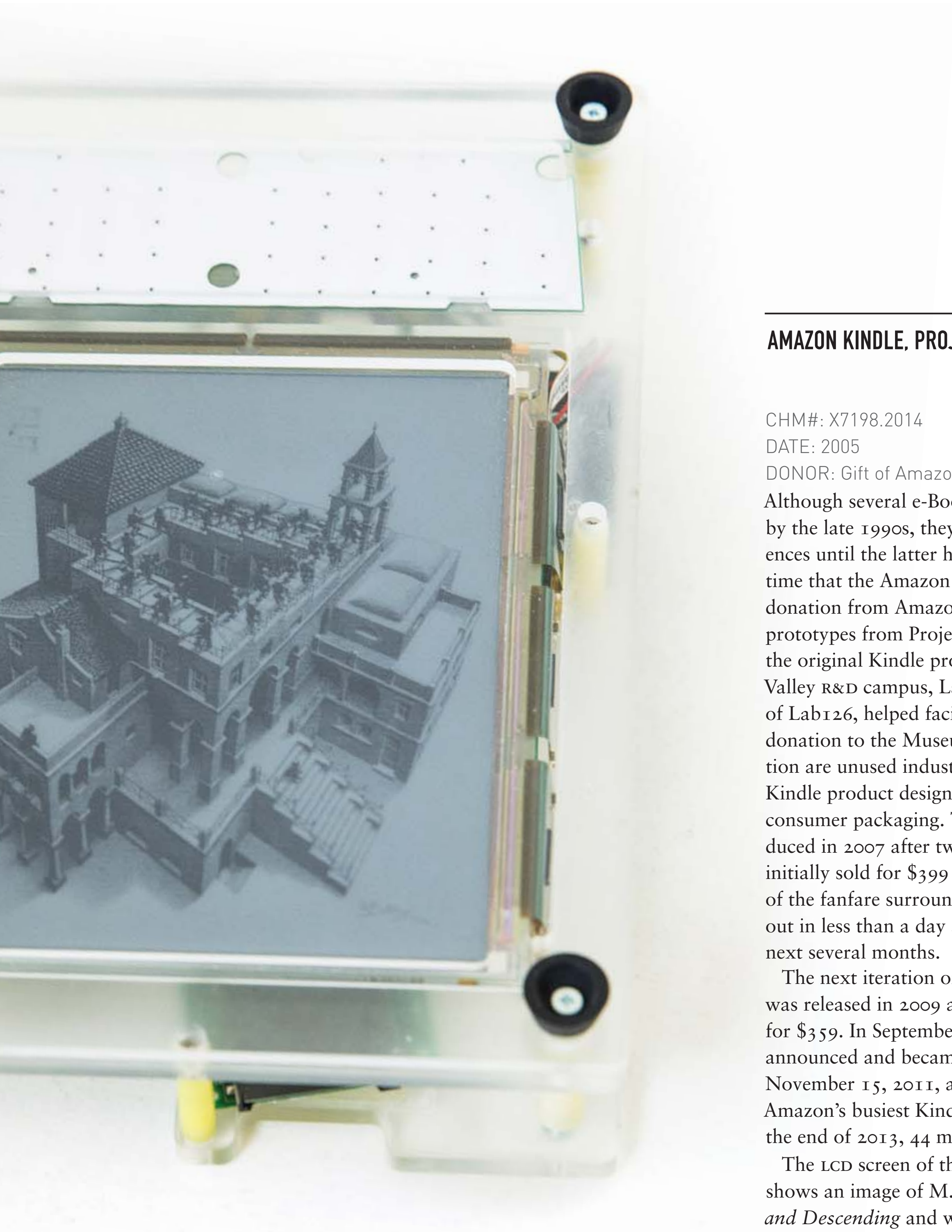
HONEYWELL RABBIT SCULPTURE

CHM#: 102741002
DATE: ca. 1965
DONOR: Gift of Richard "Dick" Pantano

The Honeywell sculptures—referred to internally by the company's advertising firm BBDO as "Morrie's menagerie" after its director, Morris Dettman—were featured in one of Honeywell's most successful and innovative ad campaigns. The sculptures are unique in that they were constructed almost entirely of computer components. The Rabbit sculpture is composed of resistors. Before personal computers became fixture in homes, the sculptures and the advertisements they starred in exposed the public to the enigmatic, inner world of the computer. As Honeywell was striving to compete against IBM's powerful and monolithic sales force, some of the ads where the Rabbit was showcased ran with the tag line "How Honeywell keeps a jump ahead." The campaign in its entirety spanned 15 years, from 1964 to 1978.

The 100-plus creations were modeled after animals, biplanes, and racing cars—even a chess set was among the many highlights of the campaign. Repeatedly featured in *BusinessWeek* magazine during its initial three-year run from 1964 to 1967, the Honeywell animals were consistently among the highest scoring advertisements according to in-house *BusinessWeek* rating metrics.

The Rabbit's donor, Dick Pantano, was a concept creator and art director for the advertisements. Sculptor Ralph Moxcey fabricated the Rabbit, which now joins a growing assortment of these unique sculptures in the Museum's Permanent Collection. ○



AMAZON KINDLE, PROJECT FIONA PROTOTYPE UNITS

CHM#: X7198.2014
DATE: 2005
DONOR: Gift of Amazon

Although several e-Book readers were available by the late 1990s, they did not attract mass audiences until the latter half of the 2000s—around the time that the Amazon Kindle was introduced. This donation from Amazon includes some of the earliest prototypes from Project Fiona, the name used for the original Kindle project at Amazon's Silicon Valley R&D campus, Lab126. Gregg Zehr, president of Lab126, helped facilitate the transfer of this donation to the Museum. Included in this donation are unused industrial design concepts, the final Kindle product design and cover, and designs for consumer packaging. The Kindle was first introduced in 2007 after two years of development and initially sold for $399 amid intense hype. With all of the fanfare surrounding its release, Kindles sold out in less than a day and were out of stock for the next several months.

The next iteration of the device, the Kindle 2, was released in 2009 and was originally available for $359. In September 2011, the Kindle Fire was announced and became available to consumers on November 15, 2011, a date noted for being one of Amazon's busiest Kindle-ordering days on record. By the end of 2013, 44 million Kindles had been sold.

The LCD screen of the prototype, pictured here, shows an image of M.C. Escher's drawing *Ascending and Descending* and was last refreshed in 2005.

REDACTRON WORD PROCESSOR

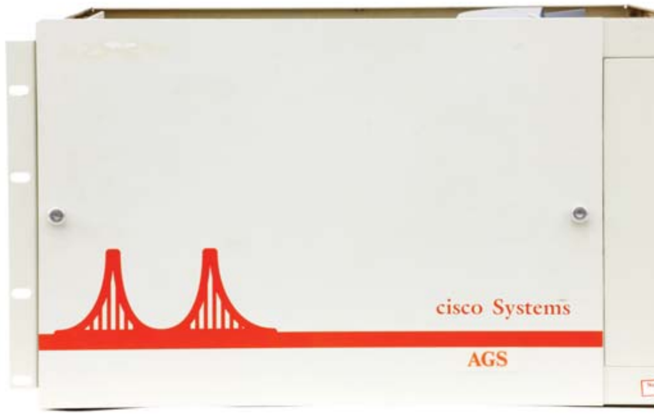
CHM#: X7189.2014
DATE: ca. 1971
DONOR: Gift of Gwyn Headley

The Redactron word processor served as an automatic typewriter system capable of editing documents and saving written work to either magnetic cards or magnetic tape cassettes, depending on the model. These magnetic storage devices reduced workloads and allowed typists to make revisions, additions, or deletions without having to retype unchanged text.

The Redactron system in this donation was purchased in 1979 by the London-based Headley Plachta Rolfe. Its magnetic memory stored press contacts, and according to the artifact donor, it could easily generate and print over 300 letters per day, including adding personal touches like, “Fancy a drink, George?” With these features, the Redactron served as an efficient, automated composition tool.

Founded by Evelyn Berezin, the Redactron Corporation started manufacturing its signature systems in September of 1971, but the company was later sold to Burroughs. After Redactron, Berezin became involved in venture capital and served on several high-profile boards. She is a 2011 inductee into the Women in Technology International Hall of Fame and a 2015 Museum Fellow.

This AGS router was Cisco Systems' first product. It was able to map one network protocol into another. The software was originally developed by Bill Yeager at Stanford, then licensed and enhanced by Cisco founders Len Bosack and Sandy Lerner.



DONOR PROFILE

MUSEUM AND CISCO COLLABORATE TO BUILD CORPORATE ARCHIVE

The Computer History Museum is undertaking a new and groundbreaking collaboration with San Jose-based Cisco Systems, Inc. to preserve its three-decade history. The newly established Cisco Archive will document, preserve, and reveal Cisco's significant role in shaping the Internet and becoming the worldwide leader in networking.

Cisco, named after San Fran*cisco*, was founded in 1984 by computer technologists Len Bosack and Sandy Lerner. They envisioned disparate networks that talked to each other and shared information reliably. To experiment with connecting detached computer networks, Bosack and Lerner ran network cables between two different buildings on the Stanford University campus, connecting them first with bridges and then routers. But for the networks to be truly interconnected, a technology had to be invented that could deal with the varied local area protocols. With that idea, the multiprotocol router was born.

BY PAULA JABLONER
DIRECTOR, CISCO ARCHIVE

"We are very pleased that Museum involvement will provide gravitas to the Cisco Archive endeavor by tapping into their extensive archival and curatorial expertise," says Museum Trustee and Cisco Senior Vice President Don Proctor. "Correspondingly, by generously supporting the Museum we are making a commitment to preserving the broader and unparalleled history of Silicon Valley."

The Cisco Archive has already collected original router software documentation, first generation routers, and a variety of ephemera. The Archive is actively working with Cisco's Marketing and Branding team, in search of more Cisco history and aiding a concurrent oral history project.

This collaboration is exceptional. We are unaware of any other collaboration between a business and nonprofit to found a corporate archive. Yet it makes sense. The Museum is singularly committed to preserving the stories and artifacts of the Information Age. Who better than Cisco to represent that era with its 30-year history of communication innovation in the Information Age?

With the rise of technology and its impact on the world economy in the 21st century, business is more than ever at the intersection of everyone's lives. Modern society can no longer be understood without documenting how communication, the Internet explosion, and business practices are changing the world. We hope other tech giants follow Cisco's lead by investing in saving their own stories. We applaud Cisco's forward thinking and generosity in supporting the Museum in making Silicon Valley history a reality. ○

Generous contributions from individuals like you support our work in collections, exhibit development, and educational programming. We strive to foster greater understanding of the computing revolution's worldwide impact on the human experience. Please help us tell the fascinating stories of the Information Age by making a gift today. For more information, go to computerhistory.org/contribute/.

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The Computer History Museum is the world's leading institution exploring the history of computing and its ongoing impact on society. The Museum is dedicated to the preservation and celebration of computer history and is home to the largest international collection of computing artifacts in the world, encompassing computer hardware, software, documentation, ephemera, photographs, oral histories, and moving images.

The Museum brings computer history to life through large-scale exhibits, an acclaimed speaker series, a dynamic website, docent-led tours, and an award-winning education program.

Wednesday–Sunday
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Gordon Moore, 1960.

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