The Disappeared: Beyond Winning and Losing

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When "others" (such as women and people of color) make innovative contributions in scientific and technical fields, they often "disappear" from later history and their contributions are ascribed elsewhere. This is seldom deliberate—rather, it's a result of the accumulation of advantage by those who are expected to innovate. This article chronicles an example of such a disappearance and introduces the Conway Effect to elucidate the disappearance process.

As part of this special issue's focus on the challenges surrounding both "winning" and "losing" in IT projects, our coverage would not be complete without considering the struggles of women and underrepresented minorities in computing-related fields. People throughout STEM (science, technology, engineering, and math) fields have been debating this issue for decades. As a transgender person who transitioned from male to female 50 years ago, I have learned much about society's treatment of "others," and can thus provide an interesting perspective on the issue at hand.

This article is my own personal account. It might be dismissed by some as more axe-grinding by someone with an axe to grind, but that is not my intent. This article is motivated by the idea that important hidden causes of the struggles of "others" in STEM fields can be uncovered. In this case, I investigate why "others" who make major contributions tend to disappear from later history.

DISAPPEARANCES OF "OTHERS"

Millions have seen Theodore Melfi's 2016 film *Hidden Figures*, which was based on Margot Lee Shetterly's book *Hidden Figures: The American Dream and the Untold Story of*

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the Black Women Mathematicians Who Helped Win the Space Race. It tells a true story that had disappeared from history books about the critical role played by women in the 1960s "space race" between the US and the Soviet Union.

Similarly, Megan Smith, former Chief Technology Officer of the United States under President Barack Obama, discussed in a 2015 interview how women who played key roles in the US computing industry had disappeared from historical accounts (www.youtube.com/watch?v=fHyRdAyqV5c&t=0m1s.) As a classic example, she described how the women involved in developing Apple's Macintosh computer were not recognized for their contributions.

This phenomenon is neither new nor limited to the space program or computing. As historian Margaret Rossiter notes in her three-volume *Women Scientists in America* series, women have been disappearing from the history of science for a very long time.[1] Rossiter called this "the Matilda Effect"—namely, the systemic repression of contributions of women scientists and the attribution of women's contributions to male colleagues.[2]

That such disappearances happen is beyond dispute. Of course, some women are remembered. Marie Curie is recognized as an important female scientist. After much rehabilitation, Ada Lovelace was recognized as the first female—and perhaps the first, period—computer programmer. Grace Hopper is revered in the computing world. But compared to the legion of men remembered for their contributions, the ranks of women seem small.

What causes these disappearances?

The big question is why these disappearances happen. It would be convenient to focus on stories that revolve around bad versus good, with bad people "disappearing" the stories of good people. Such accounts make for popular storytelling, perhaps with bad men disappearing good women. However, this is far too narrow a view of the phenomenon.

Sociologist Robert K. Merton had an interesting idea that influenced Rossiter. He coined the term "the Matthew Effect" to describe how eminent scientists get more credit than lesser-known scientists, even if the work of the eminent scientist is similar to that of the lesser-known one.[3] For example, prizes are often awarded to the most senior researcher in a project, even if a graduate student or post-doctoral student did the primary work.

This is an example of "accumulated advantage," in which advantages flow to the prominent, not the less prominent. In societies where men are more prominent than women, it is accepted that advantages flow to men as the "natural order of things." Over time, the less prominent might become discouraged and stop striving to contribute and innovate, thereby unwittingly reinforcing and continuing the perceived "natural order." Many good people are prominent—they aren't deliberately being bad. They often just don't notice what's going on.

This suggests that the issue is culture rather than explicit policies. It's doubtful that any major organization—such as a university or tech company—would tolerate an explicit policy to reward prominent men over less-prominent women. Yet the problem remains, in large part because it is deeply buried within our culture, and culture can be difficult to change.

To illustrate these effects, I discuss my personal experiences in the very large scale integration (VLSI) revolution in silicon microchip design and manufacturing. It is a story of engagement, disappearance, and eventual reappearance.

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THE VLSI REVOLUTION

I was involved in the VLSI revolution that spawned the microchips that triggered the expansion and impact of California's Silicon Valley. The revolution built upon the 1960s integrated circuits of transistors and wiring that were "printed" onto chips of silicon. As advances in lithography enabled smaller features to be printed, the number of transistors that could be printed on chips increased. In 1971, the Intel 4004—the first microprocessor; a complete computer on a chip—was created with 2,300 field-effect transistors (FETs). Each FET was analogous to an almost perfect little toggle switch.

Gordon Moore of Intel observed that the number of transistors on commercial chips doubled about every two years. Carver Mead, a professor at Caltech, dubbed this insight "Moore's law." At Caltech, Mead and Bruce Hoeneisen determined that there were no physical limits to printing a million submicron FETs per chip. Robert H. Dennard and his colleagues at IBM Research determined that as FETs were scaled down, their power density remained constant, as both voltage and current scaled down with length. This discovery is known as "Dennard scaling."[4]

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Dennard scaling made supercomputers on single chips conceivable by 1990, without excessive heat generation. However, there were no means to design such complex chips. It was as if the printing press had been invented, but no written language existed in which to write printable stories.

In 1976, Bert Sutherland of Xerox Palo Alto Research Center (PARC) and Ivan Sutherland of Caltech launched an effort to attack this problem. A collaborative project began—I led the team at PARC using my expertise in computer architecture, and Mead led the team at Caltech using his expertise in semiconductor device physics.

It was the perfect place and the perfect time, given PARC's recent innovations in personal computing and networking, including interactive-display mouse-controlled personal computers (Altos), local-area networks (Ethernet), and the xerographic laser printer. PARC was also connected to ARPANET, the precursor to the Internet. Few outside advanced computer research circles knew that such technologies existed. We entered a vast new frontier for exploration, armed with these secret weapons.

Our collaboration in 1976 and 1977 yielded results. We created new methods for designing digital systems in silicon (methods that could be quickly learned by digital system designers with limited backgrounds in semiconductor circuit design and device physics), enabling wider explorations of the architectural potentials of silicon technology.

These methods enabled designers to visualize and craft digital systems using graphical design software tools running on Altos. Key to this was a novel set of scalable VLSI layout design rules expressed as dimensionless geometric inequality equations. These enabled chip layout patterns to be numerically encoded, scaled, and reused as Moore's law advanced. The re-scalable rules also enabled sharing of chip subsystem modules (what we now call "open source").

Our explorations intertwined technological and social innovation (in other words, they were techno-social). For example, one could envision a "scripted iterative process" coalescing into a social ritual as Moore's law progressed. Design tools running on current computers would be used to design chip sets for more powerful future computers, and these chip sets were then printed using the next-denser fabrication process. Some of the more powerful chip sets would be used to enhance computer-design computers running updated chip-design tools. The whole process repeated, iteration after iteration—with each iteration timed by Moore's law. As more engineers and design-tool builders engaged with the process, working on more powerful computers, the process could generate ever more powerful and innovative digital systems.

However, even a powerful "canned script" can't take off through unfocused, scattered actions. The number of necessary engineers and programmers could not be recruited and trained at scale through existing methods. A solution was to create a rapidly evolving textbook that would show working design examples applying the new VLSI methods and would include all the basic concepts of digital design, computer architecture, electronic design automation (EDA), and chip fabrication. It would consistently express materials using the new streamlined VLSI design methods. The methods would be presented as already proven and sound. I suggested this idea and Mead agreed. The result was an evolving, computer-based book that was quickly printed on PARC's laser printers and circulated. This became the seminal 1980 textbook *Introduction to VLSI Systems*, which has been called "the book that changed everything."[5]

In 1912, Charles Steinmetz used his seminal text to propagate his revolutionary AC electricity methods at Union College.[6] A sabbatical from PARC in the fall of 1978 enabled me to use the Steinmetz story as a script while developing a VLSI design course at MIT using the draft book. Students learned the streamlined methods of chip design and then created their own design projects. Their chip designs were fabricated at HP Research's Integrated Circuit Processing Lab (ICPL; led by Pat Castro), and packaged chips were returned to the students shortly after the course ended. One student (Guy Steele) designed a complete Lisp microprocessor.

The MIT course stunned Silicon Valley.[7] Then mysterious, large-scale chip design was the province of a few engineers working for chip manufacturers with access to semiconductor "printing plants." Now, apparently anyone could do it, and many major research universities wanted to offer such courses. It held the promise of "freedom of the silicon press!"

We faced the challenge of how to quickly fabricate project chips for many courses. This led to the visualization of an embryonic e-commerce system: students remotely submitted digital design files via ARPANET to a server at PARC. The server's software then packed the designs into files for multi-project chips (MPCs) and multi-project wafers (MPWs). These were then fabricated as one small lot among many boatloads of mass-production chips.

This method promised widely shared, economical access by many individual chip designers to expensive chip-manufacturing facilities. Users could electronically transmit design specs to a remote "silicon foundry" (as it later became called), where their designs would be manufactured and shipped back to them. HP Research's Pat Castro played a key role in this, as did PARC's readiness to participate.

With all the pieces in place, an announcement was made on ARPANET to electrical engineering and computer science departments at major research universities about what became known as "MPC79." On the surface, while appearing to be official and institutionally based, it was done in the spirit of a classic "MIT hack"—a covert but visible technical stunt that stuns the public, who can't figure out how it was done or who did it. (I'd been an undergrad at MIT in the 1950s.)

The bait was the promise of chip fabrication for all student projects. Faculty members at 12 research universities signed on to offer Mead-Conway VLSI design courses. This was bootleg, unofficial, and off the books, underscoring the principle that "it's easier to beg forgiveness than to get permission."

MPC79 escalated into a huge ARPANET "happening." Faculty and 129 participating students and researchers acted together, creating scores of innovative designs.[8] The resulting chips were returned from Castro's "foundry" one month after the design cutoff—an astonishingly short turnaround time. One prototype design, the Geometry Engine by Stanford University's Jim Clark, led to the creation of Silicon Graphics, Inc. (SGI).

A huge success by any measure, MPC79 provided a demonstration and validation of the VLSI design methods, the "book that changed everything," the design courses and tools, and the e-commerce chip-prototyping infrastructure. MPC79 also bootstrapped a budding VLSI techno-social ecosystem for design into existence. By 1983, Mead-Conway VLSI design courses were being offered at 113 universities around the world. Moore's law held for decades, and modern chips now contain complex systems composed of billions of transistors.

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EARLY ACCOLADES, THEN DISAPPEARANCE

By the early 1980s, it was clear that VLSI was important. In 1981, the prominent industry trade magazine *Electronics* honored me and Mead with its Annual Achievement Award for our "effort to create a common design culture for the very large-scale integrated era." Our pictures appeared on the cover of the magazine, with an article about us and our work inside.[9] We both received the Pender Award from the Moore School of the University of Pennsylvania in

1984, as well as the Wetherill Medal from the Franklin Institute in 1985. Mead was elected to the National Academy of Engineering (NAE) in 1984, and I was elected in 1989.

My disappearance began in the late 1980s after George Gilder—an influential speechwriter for Ronald Reagan and author of the anti-feminist books *Sexual Suicide* (1973) and *Men and Marriage* (1986)—published *Microcosm: The Quantum Revolution in Economics and Technology* in 1989.[10] In it, he described Mead as being behind the rise of Silicon Valley and an exemplar of elite science-based capitalism. High-tech business and conservative political organizations liked the book, and it became a national best seller. Gilder later became a founding Fellow of the Discovery Institute and promoted "intelligent design." His book mentioned my activities, but I was portrayed as Mead's assistant.

After the book gained popularity, Mead received increasing attention. He was elected to the National Academy of Sciences (NAS) and the American Academy of Arts and Sciences (AAAS); he received the Electronic Systems Design Alliance's Phil Kaufman Award, the IEEE John von Neumann Award, the ACM Allen Newell Award, the $500,000 Lemelson-MIT Prize, the Computer History Museum Fellow Award, and the NAE Founders Award; he was inducted into the Inventors Hall of Fame; and he received the highest honor of all—the National Medal of Technology.

Whether Mead deserved these awards is not the point. The point is that I no longer received any such awards. Some of Mead's awards cited innovations that were solely mine. MPC79 wasn't even noticed, despite its role in innovating, prototyping, and demonstrating at large scale an Internet-based, evolving "techno-social dynamical system" that was foundational and paradigm-shifting. As a woman, I disappeared from history and so did my innovations.

[AS A WOMAN, I DISAPPEARED FROM HISTORY AND SO DID MY INNOVATIONS.]

In 2009, my disappearance was complete after the Computer History Museum's gala celebration of the 50th anniversary of the integrated circuit. Sixteen men were described by the media as "the Valley's founding fathers." They were inducted into the National Inventors Hall of Fame for their contributions to microelectronics. Top billing went to Gordon Moore and Carver Mead.[11] I was not invited to the event, and didn't even know it was happening. Pat Castro was not mentioned, either. As with the Macintosh story, key women (Castro and Conway) disappeared, along with their contributions. Again, no one set out to do this. It just happened.

INVESTIGATION, REAPPEARANCE, AND REFLECTION

My reaction to this very personal disappearance was one of accumulating shock, stress, and even despair. One day, while reflecting on Rossiter's work, I had an epiphany: I should research how and why I disappeared.

I began by telling the story as I remembered it, compiling an online "VLSI archive" with help from veterans of the VLSI revolution (http://ai.eecs.umich.edu/people/conway/VLSI/VLSIarchive.html). By 2010, the archive contained scans of many original documents, technical reports, course notes, design reports, and chip photos. A treasure trove of artifacts, it provided a foundation for my research. I built a timeline, sorting out flows of events.

As my research progressed, previously foggy events became clear. I began writing. For the first time in decades, I began sharing my perspective. I wrote about the IBM-ACS project,[12] the MIT 1978 VLSI design course,[13] and the overall VLSI revolution in a special issue of *IEEE Solid State Circuits Magazine*.[14] I clawed my way to reappearance.

I also came to see how my transgender journey impacted my role in the VLSI revolution.[15] I was fired from my research position at IBM while transitioning in 1968 and had to start my career again with a covert identity. I rose from contract programmer to computer architect at Memorex and was then hired by PARC in 1973, all while living like a foreign spy in my own country. I was always looking over my shoulder, terrified that I'd be outed and lose my career again. Never wanting to call attention to myself, I used the practical "tradecraft" I learned during my transition to take covert actions to make interesting things happen. In some ways, I disappeared myself.

Now, my reminiscences are helping me reappear.[16] I became a member of the Hall of Fellows of the Computer History Museum and received an honorary doctorate from the Illinois Institute of Technology in 2014. I received the prestigious IEEE/Royal Society of Edinburgh James Clerk Maxwell Medal in 2015. In 2016, I was named an AAAS Fellow and received an honorary doctorate from the University of Victoria.

THE CONWAY EFFECT

Perhaps the greatest payoff of my recent research has been the coalescing of what I call the "Conway Effect."[17] It borrows from the Matthew and Matilda Effects but adds a new element—people tend to be blind to innovations made by "others," or those they don't expect to make innovations. People usually don't notice when something that has never been done before is happening right in front of their eyes. Even if people sensed that it was an innovation, they'd think a "known innovator" was responsible, not a person who isn't expected to make innovations.

Examples of blindness to innovations

Consider that most students in the MIT 1978 course thought they were learning how chips were designed in Silicon Valley—the known institutional innovator. Most didn't realize they were learning radical new methods that were not yet used in the Valley. Silicon Valley's cognoscenti were in turn astonished at "what MIT did," but, then again, MIT was a known innovator. Many universities rushed to follow the leader and offered "MIT VLSI design courses."

The participants in MPC79 took for granted the innovative infrastructure they were using, not realizing it was a deliberately and covertly generated, paradigm-shifting hackathon that would launch fabless design, silicon foundries, and e-commerce. Flying under the radar and exploiting ARPANET and PARC's computing power, we had deployed a radical new techno-social functionality that appeared to users as existing institutional infrastructure.

MPC79's success validated the Mead-Conway VLSI design methods. DARPA began a major VLSI program in 1981 and funded Mead-Conway-style research explorations in VLSI system architecture and EDA. It also funded the technology transfer of the MPC79 system to the USC Information Science Institute (ISI) to provide ongoing chip prototyping to the emerging DARPA-funded VLSI research community. ISI's MOSIS service, which became a national research infrastructure for advanced chip prototyping, is historically known as a development of the established innovator DARPA.

In tradecraft terminology, by covertly sailing under the "false flags" of MIT and DARPA, we spurred and spread the VLSI revolution. DARPA's historical reputation as an innovator was so great that government-sponsored MOSIS-like services sprung up in other countries. MIT's mystique triggered the rush to offer VLSI design courses at other research universities. The VLSI revolution appeared to proceed from known innovative institutions, and few knew that it had been covertly orchestrated via an escalating series of techno-social "happenings."

The social process of credit assignment

Social awareness of important innovations spurs the process of credit assignment. Credit for innovation is subliminally assigned, gained, granted, bartered, and seized as modulated by visibility, status, prestige, class, power, location, credentials, prejudice, popularity, influence, wealth, and accident. Wide public visibility via awards, medals, high honors, media coverage, biographies, and so on often masks the story of how innovations are made and sustains the social-crediting rituals—rituals that then reinforce (often inaccurate) beliefs about how and by whom innovations are made.

One might argue that Gilder's storytelling projected Mead as a vital force behind the rise of Silicon Valley, and the story then spread in the consciousness of high-tech industry leaders and national political leaders.

[PEOPLE TEND TO BE BLIND TO INNOVATIONS MADE BY "OTHERS," OR THOSE THEY DON'T EXPECT TO MAKE INNOVATIONS.]

Mead never explained in detail how the VLSI revolution had actually unfolded. He didn't have to—Gilder had framed the story.

I remained hidden and silent for decades, but in 2012 I emerged to explain my view of how the VLSI revolution had been orchestrated. By then, gender stigmatization had diminished somewhat, and I hoped my account would rise above the noise. Portions of the real story are now understood, at least by some.

A corollary

It is possible to trigger a large paradigm shift in the open, as long as people have no clue what you're doing and thus don't question or resist you. Expertise creates silos. Most people are not programmed to notice that a profound change is underway, much less visualize the degree to which they are recruits in bootstrapping and exponentiating that change. They just go with the flow. MPC79 was subsequently (sometimes subliminally) reverse-engineered. It was mimicked and evolved into a diverse techno-social e-commerce infrastructure. Four decades later, the public has enough experience using this "futuristic infrastructure" to evolve shared concepts and language to talk about, and possibly follow, the story behind the innovation.

> **TO BE ABLE TO "WIN AT INNOVATION," WOMEN MUST BE EXPECTED TO BE ABLE TO WIN. THE CULTURE MUST CHANGE.**

Time and change

Discussions of "broadening participation"—the preferred phrase of some organizations for issues like diversity and underrepresentation—usually close with lamenting the shortfalls and insisting on vigorous redress. Yet the problem persists. Change, even though it seems to be going in the right direction, takes a long time. Perhaps Theodore Parker was speaking about this when he said of slavery in 1853, "The arc of the moral universe is long, but it bends toward justice." Those who suffer injustice find cold comfort in the "long" part, but some might eventually be recognized as having been on the winning side.

Change can accelerate as it bends toward justice, but this requires addressing root causes. One root cause is expectation. If computing innovations are not expected from women, the stories of women's innovations, even major ones, disappear. This has a manifold effect on innovation by women. Credit for the innovation goes to men associated with the innovation who do not have to aggrandize credit. Credit goes to men as they are remembered and as women disappear. This discourages women who do or would innovate, and adds to the misconception that women do not innovate. Women can be discouraged from acquiring the necessary skills to be innovators. If women are not prepared, the "pipeline" is blamed and the problem is perpetuated.

WINNING AND LOSING

So, who wins and who loses? Obviously, women who make innovations only to disappear afterward lose. The larger society suffers from the loss of knowledge about how these innovations were made, and sometimes even loss of knowledge about what the innovations were. Women are often discouraged from entering or staying in the computing field, seeing the game as rigged against them.

Further loss is seen in society's failure to acknowledge contributions that might have been made but were not, either because the contributors didn't actually do the work or quit before it was finished. This is worse than the loss incurred when the contribution is made but improperly attributed. There are no means to account for contributions that never occurred.

Perhaps the biggest loss is to the social order that suffers when behaviors are both unjust and inefficient, as this story of disappearance reveals. To be able to "win at innovation," women must be *expected* to be able to win. This expectation must live inside women themselves. And to live inside them, it must first be in society. The culture must change.

Despite setbacks, some progress is being made. The "Me Too" movement is calling attention to long-buried (and therefore long-accepted), deeply harmful behaviors. Efforts to bring more "others" into computing and other STEM fields might be sustained, despite the difficulties.

On the gender front, constructive anxiety about gender roles and expectations is painful but helpful. It enables what sociologist Susan Leigh Star noted when previously marginalized people are brought in and expected to contribute.[18]

As one of the previously marginalized, my struggle was difficult at times, especially during the decades of my disappearance. Fortunately, that struggle yielded insights into how people can be wronged even when no one is deliberately doing wrong. Such insights can empower the marginalized and trigger positive social change. ◼

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