Thanks for the Memories

By Sally Adee

PHOTO: David Yellen

Ask Robert Dennard about the invention of DRAM, and he will probably do three things.

First, he will show you the patent notebooks IBM encouraged its inventors to keep, which hold all his ideas about dynamic random-access memory, meticulously dated and witnessed by other people, “to make sure we had proof of our inventions.” He stores these pristine notebooks in an armoire under a wall crowded with his awards.

Second, he will spend half an hour showing you how he had the revolutionary idea of substituting a single transistor and a single capacitor for the memory technology then being usedmagnetic rings, like miniature Cheerios, each of which stored one bit based on the polarity of its magnetic field. He will draw the circuit diagram for the one-transistor DRAM, including every amplifier, data line, and inverter.

Finally, he will comment on a certain online article that suggests that Intel engineers, rather than Dennard and IBM, should be credited with the invention of DRAM. Intel released a three-transistor DRAM in 1970, three years after Dennard entered the one-transistor DRAM into his patent notebook. The misattribution annoys Dennard to no end: “They asked someone from Intel who worked on the chip, ‘Did you invent DRAM?’ And he said, ‘We don’t care about inventions. We care about products.’ ” Dennard pauses. “A lot of people think Intel invented DRAM, because they were the first to come out with something labeled dynamic RAM,” he says. Just about everywhere else, Dennard is credited as the father of DRAM, and for that achievement he is being awarded this year's IEEE Medal of Honor.

The wrestling over who gets credit is no hopelessly irrelevant teapot tempest. Random-access memory inhabits pretty much everything that has electrons coursing through it: your laptop, car, game console, digital camera, and cellphone. The amount of RAM in these devices might even be taken as a kind of shorthand for their approximate level of performance. That's because ever-increasing memory capacity is one of the key factors driving the evolution of most electronics.

Semiconductor memory is now a large extended familyincluding EEPROM (electrically erasable programmable read-only memory) and NAND flasheach category with different drawbacks and benefits. But dynamic random-access memory is an important ancestor. "Random access" means what it says: A microprocessor can withdraw any stored "word" (8 bits of data) from this memory in any order.

In Dennard's one-transistor DRAM, each bit of data is stored separately inside its own capacitor. A single transistor controls both reading and writing. A charged capacitor means "1," and an uncharged capacitor means "0." The word dynamic in the name derives from the fact that the act of reading the bit discharges it and it must be rewritten back into memory. A capacitor's charge eventually wanes, so the memory must be reinfused with fresh charge several times per second to prevent it from losing information. That fact led one researcher to joke that Dennard had won prestigious awards not for his invention but rather for having the temerity to refer to such a thing as "memory."

Amazingly, in an industry defined by its constant advances and compulsory forward movement, the one-transistor DRAM has endured for 40 years.

In 1958, when Dennard walked into IBM's still-unfinished Thomas J. Watson Research Center for his first day at work, he didn't know exactly how a transistor worked. In those days, not too many engineers actually did. Dennard, fresh out of Pittsburgh's Carnegie Institute of Technology (now Carnegie Mellon University), had just earned a Ph.D. in electrical engineering after completing undergraduate and master's work in EE at Southern Methodist University, in Dallas.

But what he recalls most fondly is his first educational experience, one from a bygone era. "At the National Inventor's Hall of Fame, a bunch of us guysall very successfulwere having a conversation, and we found out that all of us went to one-room schoolhouses," he says. "That was the common denominator."

Growing up in a 5000-person farm community near the Louisiana border of Texas, that's all there was. No Baby Einstein classes for Dennard, no Mozart symphonies on a phonograph. The Depression was just ending; his community hadn't been electrified. "We survived just fine," he says, adding that the secret to his success was that he had a lot of spare time as a child. "I learned everything very slowly and concentrated deeply," he recalls.

In those days, he wasn't interested in science or engineering at all. "I had a crystal radio," he declares, "but I never got that thing to work." What he loved was science fiction; he devoured old anthologies that included authors like Edgar Rice Burroughs and H.G. Wells. “One story really influenced me,” he recalls. “It was about probability.” The short story, “Inflexible Logic,” by Russell Maloney, was published in 1940. To test the theory that patterns would emerge out of randomness, a man assembled six monkeys and set them to typing, to see if they would come up with anything rational or intelligible. After quite a short time, the monkeys began to write some very familiar prose. The man shared the results with his friend, a professor.

“And the monkey was coming up with great stuff, and [the professor] was walking around scratching his head and thinking, It couldn’t have happened so soon.” Dennard pauses and laughs uproariously. “So he shoots the monkey!”

Science fiction was as close as he got to an interest in science until he took physics classes at SMU, which he attended on a dual academic/band scholarship as a French horn player. He liked his physics classes, particularly the emerging field of semiconductor physicsso much so that he decided to pursue a doctorate in electrical engineering, which was then an interesting discipline that in some ways hadn’t quite found itself. “I had some advanced physics courses, solid-state materials, and so forth,” he says, “but I still didn’t understand exactly how a transistor operated.” Armed with his Ph.D., he followed some friends to IBM, which was on a research-scientist hiring binge. He figured he’d stay for a few years. Fifty-one years later, he’s still there.

He started as a staff engineer in the applied research group, studying what were then brand-new metal-oxide-semiconductor field-effect transistor (MOSFET) designs and circuit applications. Then one day in the fall of 1966, he attended an internal IBM Research review conference. One project was an attempt to commercialize magnetic core memory, the standard at the time. The magnetic rings were strung together on a mesh of wire, forming a grid perhaps 30 centimeters on a side. “The truth is, it probably wouldn’t have worked,” Dennard says. “But it looked good. It was still big, but they had put lots of bits in there.”

Dennard went home that night wondering if he could replace the magnetic ring with a small capacitor to store charge. So for the next couple of months he worked on the problem every day and every night. “The first thing I did was put a transistor in series with a capacitor. Then you could write the charge into the capacitor and turn it off.” But how to read it? After months of hair pulling, Dennard was seized with his great eureka moment: a single field-effect transistor and data line could both read and write the charge stored in the capacitor. So in 1967 he detailed his invention in his standard-issue IBM patent notebook, and so was born the one-transistor dynamic random-access memory.

DRAM, like almost all great inventions, has many fathers. Three years before Dennard drew his circuit diagram in his notebook, fellow IBMers Arnold Farber and Eugene Schlig had created a memory cell with two transistors and two resistors. A year later, in 1965, IBM researchers refined that idea into a 16-bit monolithic memory array. Also that year, J.D. Schmidt developed a semiconductor random-access memory, but he used six MOSFETs per memory cell, inflating both the footprint and power consumption. Dennard’s patent for a one-transistor DRAM was awarded in 1968, but IBM didn’t turn it into a product. Instead it shipped computers that used six-transistor SRAM, a technology the company considered less risky.

Then, in 1970, Intel released the first commercially available DRAM memory chip, the three-transistor 1103, which could store 1024 bits [see "25 Microchips That Shook the World," in this issue But that's not what people mean when they speak of DRAM today, Dennard insists. "That's why they don't call it 'one-transistor DRAM,' " he says. "It's just DRAM."

Dennard also conceived the scaling theory of MOSFETs, which predicted that the speed of any chip would increase in direct proportion to the decrease in size of its transistors. This theory is commonlyand erroneouslyfolded into Moore's Law, which actually predicted only the continuing size decreases, not the associated performance increases.

"Bob Dennard was the person who correlated scaling with performance, and it's as important as DRAM," insists Juri Matisoo, who worked on magnetic memory at IBM in the 1960s before Dennard wiped out the competition with semiconductor memory. Matisoo went on to become vice president of technology at the Semiconductor Industry Association. "Moore was projecting the timescale; the IBM people described how to actually do it."

The sprawling T.J. Watson research complex in Yorktown Heights, N.Y., is 61 kilometers north of New York City, but it borrows the city's grid layout, with 40 numbered alleys on each of its three levels. You can't get lost. The Watson campus architecture, finished in 1961, rejected the caste system of corporate ambition: No offices have windows. Instead, architect Eero Saarinen crafted an enormous communal corridor with a three-story wall of windows overlooking rolling hills and leafy greenery in the summer, bare branches under ice and snow in winter. That bucolic view is available to Nobel Prize winners and postdocs in equal measure.

Dennard's window view is a bit of a cheat. He doesn't actually have a window. But his door does open directly onto the magnificent corridor; his is one of only three offices with that luxury.

For all the spartan egalitarianism, Saarinen designed the offices in a bright spectrum of cheery colors. Dennard's office is as brash and upbeat as a Piet Mondrian print. Big color blocks of built-in filing cabinets cover an entire wall. Dennard spent the majority of his career in a blue office buried in the center of the building; the first-among-equals office he has now is a happy lime green.

The IEEE Edison Medal hanging on the wall behind his desk squeezes in next to a row of IBM awards, which in turn rub elbows with a Lemelson-MIT Lifetime Achievement Award. On the armoire beneath, haphazard stacks of plaques suggest that at some point Dennard gave up the 40-year jigsaw puzzle of fitting all the honors onto a single wall.

Soon Dennard will need to reorganize again to make room for his 2009 additions: the Charles Stark Draper Prizean annual US $500 000 award conferred by the National Academy of Engineeringand the IEEE Medal of Honor. "They're not making it any easier," he says, laughing, as he examines his favorite, the heavy bronze National Medal of Technology awarded to him in 1988 by President Ronald Reagan.

"We just didn't imagine how far it would go," he says, of the one-transistor cell, "how much it would totally change computing."

The wall opposite the awards is almost completely filled by a chalkboard that hasn't been erased in months, or maybe years. Its runes are of different sizes, with some squeezed into the spaces between previous scribblings. There is a small patch of equations with signs for high-k metal dielectrics. In another corner, barely visible under some fresher chalkings, is an equation for measuring capacitance. Dennard preserves them all as artifacts of the part he likes most about his role at IBM, which is mentoring incoming employees.

"It's not official mentoring; it's more like being a professor at a university," he explains. "I work with the new people. I work with them on projects, helping define them, monitor progress, and develop the people. Some of them like it. Others want to stay well away," he laughs.

Ghavam Shahidi, who is also an IBM Fellow, says he benefited from Dennard's perspective when he started at the company as a postdoc 20 years ago. "I knew of him for years before I came to IBM," he says. "I only knew of his accomplishments, and that was very intimidating at first. I thought, Here's the man who invented DRAM. This guy is famous." But Shahidi says Dennard was so approachable, down-to-earth, and humble that the impression did not last. "He was not the way I imagined him at all."

Shahidi, who is credited with the development of silicon-on-insulator semiconductor technology at IBM, says many of his epiphanies were born out of long talks with Dennard. "He's great to sit down with and just throw out ideas. He has a broad perspective that he applies to narrow problems."

Dennard applies his perspective liberally, including to the recurring "the end is near" refrain that plagues the semiconductor industry. "The first paper warning of the end of scaling was published by RCA before I even got into this business," he grouses. "You can always find a reason things can't be done."

"That's the thing about the future," he exclaims. "It's totally unexpected. It's been the same for 50 yearswe could never see anything more than three years down the road."

Robert Dennard


PHOTO: David Yellen

Most Recent Awards: Charles Stark Draper Prize, IEEE Medal of Honor

Date of Birth: 5 September 1932

Birthplace: Carthage, Texas

Family: wife, Jane Bridges, software consultant and teacher; two adult daughters from a previous marriage, each with two children

Pets: Two Scottish terriers, Bonnie and Ferguson

Favorite Leisure Activity: Scottish country dancing, two nights a week, and choral singing

Mantra: “Attitude is everything.”

Current Title: IBM Fellow

Favorite Movie: “I don’t watch movies. They’re too loud. The last one I loved was La Ronde, which I saw in graduate school 55 years ago.”