Oral History of Gordon Hughes

Interviewed by:
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Dennison: This oral history records Doctor Gordon Hughes's contributions in the field of magnetic recording technology at Xerox and at Seagate, and as a successful researcher and educator at the Center for Magnetic Recording Research, a joint university industry research center at the University of California at San Diego. He is credited with advancing the technology development of hard disk drives and their early product development at the start of Seagate Technology in the early 1980s, where he made major contributions to Seagate's success. He is also the author of a personal adventure novel relating events in his career, especially those at Seagate Technology, entitled "Hard Drive! As the Disk Turns." My name is Ron Dennison, and I will be conducting the interview. So Gordon, tell us about your family background, where you were born, grew up and received your early education.

Hughes: I was born in West Los Angeles, to an attorney father and a mother that managed the personnel department of a department store, and I went to public schools in West Los Angeles, Hamilton High School, and for college I applied to and was admitted to Caltech, and so I lived in Pasadena through my undergraduate years and I took my graduate years also at Caltech. I got a Bachelor of Science in Physics at Caltech, and also a PhD in EE.

Dennison: Okay. Let's move back a little. We're going to talk more about your higher education, but what were some of the things that interested you while you were growing up in L.A.?

Hughes: Well, I early became interested in electronics. I was a ham radio nut and had a general class license, W6QBI. I learned a lot about electronics. Throughout high school I built electronic kits, transmitters, and that's my major hobbies.

Dennison: Okay. Let's move forward then and talk about Pasadena and Caltech. Did you apply to other schools besides Caltech?

Hughes: I had a backup plan, of course, to UCLA, which I didn't need to use, and that was it.

Dennison: Tell us a little about your Caltech experience. I understand that Linus Pauling and Richard Feynman were there then.

Hughes: Yes. That was a part of my undergraduate experience that current Caltech students wish they had. I had gotten terrified of the difficulty of the courses at Caltech due to a Time Magazine article at that time. This is about 1955, and I actually studied the Freshman calculus math courses, going through its textbook <laughs> all summer vacation before I went to Caltech. And as a result <laughs> I was the highest scorer on math tests at Caltech when I first went there.

Professor Linus Pauling gave the chemistry lectures to the freshmen at those years. We were about a hundred or so of us sitting in rows in the chemistry theater, all wearing slide rule holsters on our belts and most of us wearing glasses. We were, of course, in awe of Linus Pauling. He'd gotten his first Nobel Prize by that time. The second one, the Peace Prize on ending atomic testing in the earth's atmosphere was to come later. He would peer over his bifocals at us and smile tolerantly at "his boys" and he would occasionally do an unusual thing, pulling out a six-inch slide rule and reading off atomic lattice constants of various minerals; and he would read them off to six significant figures, which amazed us, because we knew that an analog slide rule was only good to three figures. We would afterwards try to figure out what he was doing and none of us realized until years and years later that he possessed an interesting character of a really good teacher, which is showmanship. <laughs> Those lattice constants were only known to three figures. You could look them up in the physics textbook. He added the other digits to amaze us and keep us interested in what he was saying.

Dennison: And Feynman.

Hughes: Richard Feynman was also present at that time. My best Feynman story was that he once gave a Wednesday evening demonstration lecture. These were open to the Pasadena public, and I was sitting near a couple of typical Pasadena white-haired grandmothers. He gave us a lecture on quantum mechanics and it was fascinating. All of his lectures were fascinating because he was very good at being prepared to be entertaining. In this case, on the way out after the lecture I heard one of these Pasadena ladies saying to the other, "I never realized that quantum mechanics was so simple until Professor Feynman explained it to us." I knew that they had not the slightest grasp of quantum mechanics, but he had convinced them, and I thought that was absolutely marvelous.

Dennison: <laughs>

Hughes: Feynman would come to the student houses and sometimes play his bongo drums for us; and tell us stories of his career in the atomic bomb project of World War II in Los Alamos. He would talk about picking locks on safes, and how he would send letters back and forth to his wife in Albuquerque, coded letters which drove the security people of Los Alamos crazy. He did it because he thought <laughs> it was funny and we all loved him for it.

Dennison: Can you talk a little bit about your PhD work at Caltech, what work you did and what project and who funded it?

Hughes: When I started there was a research effort going on depositing permalloy thin-films on glass substrates and setting the magnetic properties of these films. So I started trying to do that and I was rapidly convinced that I should stop and not further break the equipment.

Dennison: <laughs>

Hughes: I made a discovery, which has been important throughout my life, a discovery of going directly after what I really wanted out of graduate school, which was I wanted out with a PhD. And I rapidly decided that I should do something in pure mathematics, which I did in threshold logic switching theory, which has application to computer logic. I also applied it to pattern recognition for weather prediction. The only funding that's necessary for a mathematical thesis is for computer time, and at that time they had the first large-scale transistorized computer, the IBM 7094, and they also had FORTRAN. FORTRAN was then new, and so I got financial support for computing time to study the performance of these threshold logic networks.

Dennison: Okay. What was graduate work and life like? Any interesting stories from that era?

Hughes: Well, my office mate, Bob Harter, was an interesting character. He introduced me to the High Sierra Mountains, first by hiking them and then by scaling their peaks. I believe I scaled seven of the 14,000-foot peaks. Rappelling down them and hiking the John Muir Trail, was perhaps the most interesting hobby then. I also bought a Austin-Healey sports car, and I had a motorcycle that I, for some reason, I liked to drive back to my house in West Los Angeles with my laundry so that my mother could do the laundry over the weekend. I would go to Los Angeles via the riverbeds, down the Pasadena Arroyo Seco River to the <laughs> main L.A. River. I forget why I did that, but it was fun.

Dennison: <laughs> Which Austin-Healey?

Hughes: A 1954 Austin-Healey sports car.

Dennison: Oh, okay. My brother had a 100-6, so I'm kind of familiar with all the various models.

Hughes: I no longer recall the exact model.

Dennison: <laughs> Okay.

Hughes: But the best model was one year later, I remember that.

Dennison: <laughs> Okay. You did some very interesting work after Caltech, like working on the Minuteman missile system. Can you talk about that and its hard disks and so forth?

Hughes: I had a job during my graduate school years with a disk drive company in Burbank. Librascope was its name. They made very large format drives, with 20-inch diameter disks, for the Navy, and they were put in submarines. They were gigantically bigger than, say, two refrigerators back-to-back, and they stored about five megabits - that was all they stored.

Dennison: These were the head per track drives..

Hughes: And when I got my PhD degree they couldn't match a salary offer that I'd gotten from Autonetics, which was the division of North American Rockwell, that invented and built the Minuteman missile inertial guidance gyros and electronics, which used the very first integrated circuits and the very first integrated circuit computer. Integrated circuits came of life in that program, because the government <laughs> was willing to spend any amount of money for missile defense in the Cold War. IC production went from a few percent yield to finally high enough yield for commercial IC products like calculators. I first worked on a pattern recognition contract that I had gotten from the Air Force and I did theoretical work. In fact, the best theory work I've ever done, in my own opinion, on statistical pattern recognition.

Published it in the IEEE Journal on Information Theory. But then I wound up working on the Minuteman missile itself, on radiation hardening of its electronics. This idea was the Cold War notion that the Russians, if a war started, might prevent the Minuteman missiles from launching by Russian missile "pin-down" attacks; exploding atomic weapons above the Minuteman silos. It was important to try to make the electronics resistant to such radiation. I found a electronics box near the tail of the missile that had been overlooked. Most of the work had been concentrated on the integrated circuits inside the computer, which was in the nose cone, and was about the size of a shoebox. It had something like 32 kilobytes of memory on a disk drive that oddly enough used perpendicular recording, which was unheard of at the time, but which allowed a very ruggedized disk drive, to survive the launching vibration environment. I discovered that down in a circuit box near the tail of the rocket was a DC transistorized amplifier that controlled the steering vanes of the missile, the carbon steering vanes. And I did an analysis on what radiation would do to the transistors. They needed a current-limiting circuit to prevent overcurrent that might destroy the transistors. I did that kind of work until the company lost a big contract with the Air Force, that resulted in a mass layoff. I just left and went back to a disk drive company, joining the disk drive people that I had been working with in Burbank. They were now in El Segundo working for a company called Scientific Data Systems that was making minicomputers with big diameter disk drives similar to the Librascope drives, and they were also designing a new 14-inch disk drive.

Dennison: So that was Scientific Data Systems?

Hughes: That was Scientific Data Systems.

Dennison: Okay. So then you were out of the defense business. Was Scientific Data Systems related to Xerox or how did that Xerox connection happen?

Hughes: I should first say that one of the happiest moments in my work with Autonetics was turning in all of my document receipts, the top-secret document chits. You, as a worker, don't know what will happen to you if you leave the company and you fail to turn in all of them. <laughs> Having been relieved of all the top-secret documents was a major pleasure. Just before I went to this small company, SDS, they'd been bought by Xerox, which was attempting at that time to try to grow out of its traditional copying business, the analog copying business that it had invented; and go into computerized document processing, the environment that we all use today. So it had bought this minicomputer company, Scientific Data Systems. But like many other large enterprises, Xerox really was a one trick pony. It couldn't decide to manufacture products beyond its original copiers. The original Xerox employees, the old-timers, called SDS "Xerox's billion-dollar mistake." The founders of SDS were able to use the Xerox money to cash out their stock options and then they all left. <laughs> Leaving the company with no founders. <laughs> It was quite interesting.

Dennison: Can you tell us about the technology of these disk drives?

Hughes: They had been making large diameter head-per-track drives, similar to those Librascope made, but they wanted to also make industry-standard drives, state of the art technology which I'll call "imitate IBM" or "plug-compatible IBM." The group I joined was designing similar drives to the IBM 2314 disk pack of that time. I designed the recording channels, the electronics, and the disks and recording heads. But they were standard technology that had been originated by IBM, so essentially the job was designing recording channels.

Dennison: Okay. When did the cobalt phosphorus thin-film media come in?

Hughes: SDS had one interesting technology, a manufacturing process that it had inherited with the people that worked for Librascope in Burbank. They brought over the manufacturing of plated thin-film disks from Librascope to SDS. These disks were a cobalt alloy, a cobalt phosphorus alloy that was electroless plated onto aluminum substrates that had been first given a hard layer by means of nickel plating and polishing; then the cobalt phosphorus layer was plated on top - that was the six-microinch thick recording layer, and this was unique. There were only one or two companies that made disk drives that used thin-film cobalt media and Scientific Data Systems was one of the more successful ones.

Dennison: Yeah. I should point out that at that time I was at Burroughs and they were using also cobalt phosphorus.

Hughes: Burroughs was one of the other ones, that’s right.

Dennison: Yeah.

Hughes: Burroughs used a different variety of electroplating, but it was a thin-film cobalt-based recording disc. The benefit then and now was that you could double the recording density without having to change too many other parameters such as the flying height of the heads. That was important to the products that SDS was making, very large refrigerator-sized disk drives with 20-inch diameter disks. They stored twice as many bits per disk that you could do with an iron oxide disc, "brown paint" disc. (IBM's original disk drive RAMAC used such oxide discs.) Thin film disks would turn out to be critical in my getting the job at Seagate much later.

Dennison: Can you talk about some of the interesting people you met at Xerox?

Hughes: Well, the most interesting one was a researcher at Xerox PARC, which this Los Angeles lab I was in reported to after SDS failed. As I said, the principals left and the manufacturing failed and so the lab I was part of became a research lab connected with the Palo Alto Research Center of Xerox. At PARC, Tu Chen was a rather well-known and respected scientist doing magnetic work but not magnetic recording per se. But he became very much interested in the cobalt disk work that we did at SDS and he developed a sputtering process to make a thin-film disk using vacuum sputtering instead of electroplating. Tu was unable to convince Xerox to use it in manufacturing, and at that time, this SDS division was running out of production opportunities anyway. Tu did a very interesting thing: he left Xerox, and found venture capital financing for a company he started, a company called--

Dennison: Komag.

Hughes: Komag made thin-film disks with the sputtering process he had invented. He became remarkably successful. I say remarkably because it's rather unusual to find a scientific researcher with business sense. But Tu formed a very successful company, which for many, many years was very profit-making selling thin-film disks to the disk drive industry.

Dennison: So, much has been written about Xerox's failure to make good on technology that they invested in, including all the sorts of things that were developed at PARC. Can you tell us your views on their failure?

Hughes: Well, Xerox once sent a manager to Komag to find out why Tu left, and Tu, being Chinese, told him exactly what he thought of Xerox inability to manufacture *any* new technology, including disk manufacturing, in words that were <laughs> barely printable.

Dennison: <laughs>

Hughes: Xerox had a talent for financing research, and it did a remarkable job in financing the Palo Alto research lab, PARC. It didn't put technology into production, but Steve Jobs was around at Apple Computer at that time, and he <laughs> easily saw the power of the Alto desktop computers that PARC was constructing for its own internal use. Steve duplicated it and made the Apple Macintosh desktop computer. <laughs> So the Xerox technology became very useful and Apple, of course, now is the biggest computer in that industry. But Xerox made nothing off it; it only knew how to manufacture the one thing. It knew how to manufacture copying machines. It wasn't willing to support Tu Chen in making thin-film disks, and that was it. Xerox was a good supporter of research, but not manufacturing.

Dennison: Okay. So after Xerox, you state in your book that you had a choice between working for Seagate or for IBM. Can you say something about that choice? What led you to ultimately pick Seagate and how you feel about that today?

Hughes: There was a interim after they had closed my Xerox lab in a budget crunch, and I consulted for Apple briefly on a floppy disk drive that they were manufacturing. I was getting a little frustrated because when you work for yourself you don't get medical benefits, you don't get retirement, you don't get much of any benefits. I got an opportunity through a friend of mine, Bob Potter, to go interview at IBM Research in Almaden Valley. I went up there and I showed them some research on magnetic theory that I'd done at Xerox, and they gave me a job offer. Simultaneously a head hunter that I'd never heard sent me to Scotts Valley near Santa Cruz to talk to the CTO of Seagate. Seagate was hardly a year or two into manufacturing its first disk drive, a 5 megabyte, 5 1/4-inch disk drive, using conventional oxide disks and conventional ferrite recording heads. Doug Mahon, the CTO, offered me a job as a Director of Technology to form my own recording group at Seagate, to do head, disk, and recording channel design. I asked my friend Bob Potter which one I should take because, frankly, I thought the IBM job sounded much more conservative and safe. Seagate sounded a little dangerous, but Bob said it'd be much, much more interesting to go to work for Seagate, and so I did. Fortunately I didn't realize just exactly what that meant.

<laughter>

Hughes: Exciting in a Silicon Valley company way. <laughs> But that's where I went. Married my wife, moved up north, and started work at Seagate. I brought up many of the people who had worked with me at Xerox into this group to do recording technology at Seagate, and off we went. This was 1982, I think.

Dennison: Okay. On the subject of people, you had the privilege of working with some of the most colorful personalities in the hard drive business in the early days at Seagate. Can you talk about them and some of the interesting stories?

Hughes: Well, the most interesting story, of course, is Al Shugart himself, and I rapidly learned several things. I had to learn what the environment was in a Silicon Valley company, and the odd environment for a researcher-type person like myself is that a Silicon Valley job is total teamwork, and I had to get used to that. Took me a while. It meant that anyone could go talk to Al, or the other Seagate founders In fact, many Seagators would ask questions or discuss management problems after work at Malone's Bar down the street from the small factory that was all of Seagate at that time. Al would talk to anybody when he was at Malone's. He was just a completely honest, open guy, and he's famous for it. His idea was that technology was only significant when it allowed shipping more drives out the loading dock. He knew that technology was important but the details, once invented, would be soon known to everybody. Al was an exponent of open source technology. That was a point he made with me from time to time. His trick was to want to make disk drives by the millions. They had been built by IBM rather like Boeing airliners, one at a time, and IBM sold them for hundreds of thousands of dollars and made lots of money. Well, Seagate was going to sell them for a hundred bucks <laughs> and make lots of money by making millions of them - that was Al.

So what would be a good Al story? Well, I remember once I told Al that I had a opportunity to attend a recording conference, the Arrowhead Conference, but that I would have to do a little horse trading when I got there. Everyone going to this conference, from all the disk drive companies including IBM, would know that we were working on thin-film disk recording at Seagate; that we were going to double the data density on our disk drives by means of it. And the people at the conference would ask me about recording details. I told Al that I would have to give up a few details but they would discover them anyway by experimenting a while, and I would get good secrets in return. He absolutely approved of that. <laughs> He told me at Malone's Bar, "Go for it, Gordon."

Another famous personality was Tom Mitchell. He was originally the vice president of production and had been at the original meeting to form Seagate that had Tom as VP of production, Doug Mahon as the CTO, and Al Shugart as not just the president and CEO, but critically also the person with past respect in the disk drive industry that would be able to get venture capital money to help support Seagate. That would be Al's initial role as president - and of course there was also Finis Conner, who had the original idea for selling a 5 1/4-inch hard drive that fit in the same hole in a personal computer, designed for the 5 1/4-inch floppy disk drive, and store maybe 5 or 10 or 20 times as much data. This new marketplace was Finis's idea, and, of course, in Silicon Valley history legends, these ideas are always drawn on the back of a cocktail napkin at a Silicon Valley bar. That was the original Seagate startup story and that's how Tom got to be production manager. Tom's background made him absolutely unforgiving of mistakes by others. Because if you can't make and sell disk drives because of some failure, the cost can be many millions of dollars. Tom was famous for jumping on anybody that failed to do his or her job properly. He had a Vietnam War hand grenade on his desk and people would wonder whether if it was a live grenade or not. Tom also had a tale of his jumping on the desk of a marketing guy, one of Finis's people, who wasn't satisfying Tom's demands; Tom kicking every object off the man's desk except the picture of his wife and then asking the guy if he was going to listen to him seriously now. <laughs> That was typical Tom Mitchell.

Dennison: You mentioned Doug Mahon. Any interesting stories about Doug?

Hughes: Doug was a good example of the heart of a Silicon Valley company. The four men that I told you got together and discussed not only making a hard disk drive to replace a floppy, but they also discussed what would be the best kind of a Silicon Valley company. As Doug later explained it to me, they decided to toss out every idea they had hated, in every disk drive company they had ever worked for. <laughs> That's what they did, and essentially they made a totally open-communications company. There were no secrets. Doug held a weekly meeting with his management staff, including myself, and we knew what the company was doing; we knew whether IBM was going to buy our disk drives or not buy our disk drives; and we knew how well the new startup thin-film disk division Grenex was doing. We knew everything, because the four believed in an open company and Doug was an excellent part of that.

Dennison: You brought up Grenex just now. Can you talk a little bit about Grenex and the Seagate relationship and...

Hughes: When Seagate started, Silicon Valley venture capital people had no experience with disk drives for personal computers. They only knew about very expensive IBM disk drives for large, very expensive multi-million-dollar computers. That made it impossible for Shugart to get venture capital money. Seagate were able to start manufacturing anyway, because one of their smart decisions was to use IBM standard components. They used standard recording heads and standard recording disks. Of course, they made the diameter 5 1/4 inches instead of 14, but that was a minor issue. The disks had to be slightly redesigned, and the disk drive heads had to be slightly redesigned. But it was no problem and it was very easy to get into volume production. As soon as they did that, two critical things happened. First, they established a marketplace, Al's marketplace of "let's make disk drives by the millions." Al also had another critical belief, and that was open-source technology. The Seagate recording channels were slightly different from the floppy drive it replaced, and Al made them public. He gave the electronic diagrams to companies like Texas Instruments so they could design personal computers with electronics to record on their own hard disk drives. All open source. No secrets.

Dennison: So this was the genesis of the standard-- what became the drive industry hard drive ANSI standard specs

Hughes: Correct. So at this point, Seagate is making money. Two things happen. One is that immediately Seagate gets competition, because other disk drive companies can buy the same open source components. But Al knows that if he's quick enough, he can take the money that he's making, and use it to stay ahead of them. He can get his manufacturing costs low by staying as the major volume manufacturer. That became the primary contribution of Tom Mitchell, and it makes it difficult for competitors to make money unless they also get to large volume. Secondly, Shugart also knew that he had to use the money he was making to go into advanced technology of heads or disks, that his competitors would not be able to easily copy. There were several possibilities and Al and Doug settled on the idea of replacing the oxide brown paint 5 1/4-inch disk with a thin-film cobalt alloy disk. By this time Seagate was very profitable and was able to get venture capital money to expand the company. Venture capital money people were happy with the profits they were now making on Seagate and they were more than happy to sponsor a thin-film disk division of Seagate. They decided that it would be started as a separate company that its president, Earl Blevis, called Grenex.

Grenex established a research facility, a small quantity disk manufacturing facility in Sunnyvale, and they started working on sputtering technology to make cobalt-chrome alloy thin-film disks. But there was a mistake made in the business plan for this company. They were promising Seagate would make more profits on disk drives of greater storage capacity, than the competitors could make with their brown oxide disks. The mistake was not only promising a thin-film cobalt disk but also promising perpendicular recording on them - which is done today because the drive industry has been able to develop recording heads to properly get high recording densities on perpendicular recording disks. But at that time in the 1980s there was no such recording heads available, and they didn't become available for several decades after that time. In my initial interview with Doug, I said this would be a serious problem but there was an easy solution, because of my recording experience at Xerox with the SDS cobalt disc, using conventional recording heads in what's called longitudinal recording. That allowed SDS to easily double the density of an oxide disk with ordinary heads. Although it was in violation of Grenex's contract with the venture capital people, it would be a viable backup plan and would certainly not fail. That's what finally happened. But in any case, when you start a facility to make volume production of something like recording disks, it takes years to get the process clean enough, and stable enough, and low cost enough. It is months and years of work, and it doesn't matter whether you're developing perpendicular disks or longitudinal disks. So off we went with the venture capital money, developing a perpendicular disk process. After several years, I'll call it three or four years, the venture capital people got tired of waiting to make profits on Grenex. Shugart, who knew this backup disk story, bought Grenex out, and on we went to double density storage using conventional longitudinal recording and conventional heads. Seagate was one of the first disk drive companies to have volume production of thin-film disks, large volume production.

Dennison: Yeah. There's a very interesting story in your book about the details of how that happened. So what were some of the important contributions that you made to Seagate's success, you personally, or your team?

Hughes: Well, the most important-- most important feature that I brought to Seagate was simply an understanding that they could double their recording density without much difficulty by using cobalt thin-film disks. That making disks by sputtering technology would have a far superior future than the electroplating methods that we had used at Xerox, and that Grenex's sputtering process was reasonable.

But I told them it wasn't going to be easy to bring it into volume production but that I knew how to design recording channels that would double the density using conventional thin-film longitudinal media. We just had to change the perpendicular cobalt-chrome alloy a little bit

Dennison: Now, you were also scaling flying height, right?

Hughes: We needed to scale the head design like flying height a little but that is part of disk drive technology anyway. It's part of its evolution. The flying heights get lower, the critical dimensions of the heads get smaller, but that's part of technology. It's nothing unusual but it would've had to happen with perpendicular disks or longitudinal disks. It just was an amount of energy that had to be expended. It took a number of years and some clever inventions <laughs> -- not only in the magnetic sputtering cobalt layer but also in the electroplating of the nickel underneath. It finally worked, using the venture capital money and then the Seagate money. Grenex became a division of Seagate, Seagate Magnetics, and Tom Mitchell ramped it into large volume production. We took a 20-megabyte Seagate disk drive and just about instantly turned it into a 40-megabyte disk drive. Selling for about the same price.

Dennison: You mentioned the nickel plating underneath. Do you want to talk about the asperity story and the chemistry chain?

Hughes: Well, I have been alluding to the difficulties in putting disk production in a successful volume, and one of the problems is simply getting an atomically smooth disk surface layer with no asperities. It seems like you're just putting a mirror-like metal surface onto an aluminum disk, but the mirror has to be perfect. <laughs> Has to be perfect to a millionth of an inch, and so you need to have clean rooms and excellent clean room technology with people wearing bunny suits and masks. It sounds like the dreary details of production, but they're critical, they're absolutely critical. They're important as the recording technology. You can't just put cobalt metal films on aluminum substrates. They're too soft. They will gall and wear and crash the heads. At Xerox, and other places like Burroughs, it was known that you needed to put a hard metal layer on top of the aluminum and then polish it very, very smooth. That's electroplated nickel. So that was fairly known, but the details of getting into clean volume production were not known and in fact it took a non-production, <laughs> a non-technical step. I don't want to take credit for this, but I did go to Tom Mitchell as head of Seagate manufacturing. I told him that Grenex had hired a bunch of research people who were trying to make disks with a research mentality that wasn't going to work in production. I told him to hire a hard-headed production guy, and Tom found one that was manufacturing recording heads in San Diego. His name was Tom Maher, and he had exactly the right mindset, so we brought him into Grenex and we told him what the problems were. He started in the Grenex factory and he immediately noticed that Grenex clean room discipline was terrible. People weren't even wearing their masks and nobody was enforcing cleanliness. He fired the production supervisor right on the spot to get everybody's attention. They were all terrified! Very interesting that this production guy was very much like Tom Mitchell himself. People were terrified of Tom Maher. Over the months that followed, the disks became flyable and recordable and everyone wound up loving Tom Maher. It was quite remarkable. When I went over here for status meetings I would see him in the clean room wearing his gigantic white bunny suit, bunny mask and everything. H e was a very big guy. <laughs> His hobby was wrestling.

Dennison: <laughs>

Hughes: And weightlifting. He was in there personally, as the president of Grenex, he was in there cleaning up the process, <laughs> making the process steps clean. It worked and their disks became flyable and we went into volume production.

Dennison: Okay. Any other Seagate stories that you want to relate before we move on?

Hughes: Well, I did a few more things but they were not basically technical management. By that time, a number of disk drive companies, including IBM and Seagate, had formed the Center for Magnetic Recording Research, at UC San Diego, where it is to this day, and we would go down occasionally to interview students. They're being educated at this institute in the very technologies that you need to do disk drive development; in mechanics, in electronics, in signal processing, in magnetic physics. Once I learned at CMRR that a new high density recording channel had been developed by IBM called partial response recording, and I saw my role was to bring it into Seagate, demonstrate how it would work, find out where to get the parts and how to use it, and to educate the engineers in Seagate - and so we followed IBM and went into <laughs> partial response recording.

Dennison: Okay. Can you talk about your decision process for leaving Seagate and to join academia?

Hughes: Well, as I mentioned earlier in this interview, I hadn't realized how exciting Seagate was going to be.

Dennison: <laughs>

Hughes: I went through three major business cycles at Seagate. They start with a gigantic boom where everybody's happy and then there follows a gigantic bust. At one point, IBM decided it was going to stop buying disk drives from Seagate. It was going to make its own disk drives. So it canceled all purchases, and it was our the major customer of Seagate, 80 percent of the business. That caused a gigantic layoff, including more than half of my people, my engineers and researchers.

After my third business cycle recovery, I was at one of the twice-a-year meetings at CMRR and its director, Shelly Schultz, approached me to take a job there as an Associate Director and leave Silicon Valley. I didn't take him up on that for a while, but I gradually learned that Jim Lemke had recommended me for the job. Jim is a very smart guy in data storage technology. I had had more than enough business cycles with Silicon Valley and I was happy to go back to a job that looked like my old Xerox research job, with no product production, no business cycles, and no more management. So I accepted the CMRR Associate Director offer.

Dennison: Who were some of the people that you worked with at UCSD and CMRR and who were there when you joined, and to what extent that they contribute to you joining UCSD?

Hughes: Well, as I say, I think that Jim influenced Shelly Schultz the then-director to invite me in. When I went to Seagate, I became de facto in charge of all recording technologies. That included the mechanical technologies, such as fly height. I ran the computer programs that designed Seagate's recording heads for fly height, for example - something that's normally done by a mechanics technologist. That's Professor Frank Talke at CMRR. And of course, I did the Seagate signal processing. That was the field of Professor Jack Wolf at CMRR, who I was close friends with. And my basic recording physics background was that of Professor Neal Bertram, so I worked with Neal. I actually taught parts of their several courses that they gave to undergrads, on recording physics for Neal and on signal processing for Jack. I helped them run an experimental lab from time to time. Those were the main people that I worked with there.

Dennison: You mentioned the experimental lab. What kind of projects did that take on?

Hughes: These were recording projects to give (principally) undergrads experience on actual magnetic recording, in reading and writing, adjusting recording currents, recording frequencies, looking at spectrum analyzers, that sort of thing. It was done on tape because it's more convenient and easy to do. Signal processing is, as a course is concerned, is mathematics-- it's done on blackboards.

Dennison: Okay. What were the dynamics of working with the folks at CMRR? I mean, how did that work on a day-to-day basis for you?

Hughes: It's a remarkably friendly place. It's the opposite of what I would've expected in academia. I think that since everybody there is involved with recording on tapes or disks, in general, all the people I was working with had an understand of not only the technology of magnetic recording but also the companies involved. So basically, we were all of a like mind, and so in a talk with Neal Bertram on recording physics, it was much easier to be comfortable than in an abstract talk on pure magnetic physics unrelated to recording They were all very easy to get along with and I was easily welcomed. They treated me very nicely.

Dennison: What were some of the first projects that you worked on at CMRR or your grad students?

Hughes: I before I went down, Shelly gave me background on where the money <laughs> comes from; unlike all the companies I had worked for, you need to get grants in academia. You have to support yourself. The state of California, for example, only pays professor's salaries when they teach students at UC campuses. It turned out that he could get me a several-year grant from the Sloan Foundation, for work related to disk recording but not for just pure technology. The grant was for aspects of user experience with products, specifically for predictive reliability. It's a feature that already existed inside disk drives, a technology that allowed drives to have a signal they could send out to the computer using the disk drive that it was about to crash, say. That sort of value is a Sloan thing. It isn't recording density or fly height or mechanics. It's usefulness to the computer user.

Predictive reliability was in the open standards for disk drives. Drives all use open ANSI standards so you can put any manufacturer's disk drive in your computer. And in those standards is a feature called S.M.A.R.T, that allowed a signal to be sent to the computer that a drive was about to fail. Unfortunately, the technology methods that the drive people selected to try to predict possible failures wasn't very good. You can imagine what methods would be used. Drives do make errors when recovering data, but they correct them using error-correcting codes in their recording channels. A drive is aware of how many times it corrects, and if it starts to have to correct too many errors it might very well predict that it's about to fail due to a head crash or similar thing. That's what they were doing, counting errors, and it just was not a very successful technology. If you talk to people about S.M.A.R.T., they'll say that it was put in at the request of one of the computer makers, the Compaq computer company, but wasn't very successful. And so we worked on better prediction methods. We used nonparametric statistical theory. The work involved mathematics theory, simulation, and a number of students who worked with me, grad students and undergrads. We tested these improved methods for failure prediction by using about 4,000 Quantum disk drives that had failed and come back to Quantum for failure analysis - out of the millions of disk drives manufactured. They gave us the data from about 4,000 failures that they had analyzed for errors. It's not commonly known, but there's a failure analysis group in any disk drive company, that analyzes returns from customers - and one surprising fact is that many "failed" disk drives work when they're tested by their manufacturer. <laughs> They aren't failed at all. Nobody quite knows how this happens. So I had this failure data from Quantum and we used it to verify these methods, which we published in the IEEE Journal on Reliability. That was one of our major projects at CMRR.

Dennison: Any others you'd like to mention?

Hughes: Was-- I mentioned that I put thin-film disks into use with conventional recording channels, because that didn't require additional research. But for the future, you want to consider unusual recording methods. Perpendicular recording finally did become possible, when recording heads could be designed to record properly. I decided I would work at CMRR on something that had no near future promise of production, but maybe future promise. That was bit patterned media where instead of a featureless uniform cobalt film over a disk, it would have separate spots of cobalt, each spot being one bit. And so I did theoretical work for a number of years at CMRR on recording channels suitable for bit patterned media and topics of that sort.

Dennison: Do you have any feeling for when bit patterned media may actually happen in production?

Hughes: In my own opinion, the answer is it's already here and it will surprise you. It will be the industry that we think of as flash memory chips and solid state drives. Those are bit patterned, but at a very low density compared to magnetic disks. They are twice as expensive as magnetic disks per byte, but are improving greatly in both density and price, because there's a lot of money in the market that flash memory and solid-state disks sell in. Bit patterned disks may never happen in magnetic recording. They may not be able to compete against flash memory drives.

Dennison: Okay. Any other projects at CMRR that you want to talk about? Maybe some that you consulted on that were in other parts of the group?

Dennison: Secure erase.

Hughes: Oh. Oh. That's a little hard to explain, but it was another Sloan project. In all the drive industry goals that I've talked about, the idea is to store bits reliably on a disk, to get more and more of them onto each disk, and to make sure that they stay written there and will allow you to read back stored data successfully. Well, what happens when you want to dispose of a disk drive, and your financial data's on it, your medical data, all your personal data is on it, but you want to erase the disc? So I ran projects for several years on secure erase of disk drives, and it's more subtle than people realize. There's an industry feeling out there that people believe all you have to do, if you worry about erasing your recorded data, all you have to do is overwrite it with some random data. Just overwrite it completely to erase it, and if you worry that it won't be successful, just do it several times. If you worry about that, do it 30 times. Well, that turns out to be fallacious and so we worked on establishing a proper method to secure erase disk drives. CMRR was able to get a standard put into these open standards for disk drives, the so-called ATA and SCSI standards for today's disk drives. Today, 99 percent of production drives have, per the standards, a command to securely erase the drive. We worked on what the disk drive should actually do to make sure that the data is actually gone.

Dennison: And this involves track edge effects and so forth?

Hughes: It involves addressing issues of track edge effects, and more. If you look into the fact that recording heads can be slightly misaligned, and may not record exactly over prior data track already on a track. In maybe the 1960s or '70s disk track densities were low enough that not entirely erasing prior data was an issue. But it has little consequence in today's track densities, which are very high. We studied all those effects, but additionally there are system level effects that result in some disk areas that are just not normally erasable; and system level problems are just as important as track by track problems. The name of one of them that's of interest is the so-called Host Protected Area on ATA drives, that's often reserved by operating systems to store user backups or diagnostic programs. A HPA is an area that won't be normally affected by a secure erase, and we wrote software programs that people could download off the Internet to securely erase their disk drive. It makes sure that if there is a host protected area set, it eliminates it by means of software commands and then erases that too.

Dennison: But it doesn't hit the super tracks or the factory tracks, right? Where the map is stored and things like that?

Hughes: No. If you did that the disk drive wouldn't work anymore.

Dennison: Right. Okay.

Hughes: Tracks like that are not accessible to users. What we're talking about is erasing all the so-called native data accessible tracks, including the host protected areas.

Dennison: Right. User accessible.

Hughes: Yeah, ever user accessible. Hypothetically ever user accessible.

Dennison: <laughs> Can you talk about some of the relationships that you had with various companies during your career at CMRR? For example, Seagate, IBM.

Hughes: Well, one of my duties as Associate Director was to help get sponsors to support CMRR. So I would visit sponsors, including Seagate and IBM. Seagate by then had its main recording division in Longmont, Colorado, so I visited them and gave talks describing the work that CMRR was doing, its various research projects, including secure erase, and which CMRR students that would be available for employment soon.

Dennison: So CMRR made many key contributions to hard drive technology. What are the key contributing factors to its success and its longevity? I mean, it's still there as a center.

Hughes: Well, because it was a sensible idea when it started, and it still is. I'll say that CMRR was a Jim Lemke idea. Jim had used the Semiconductor Industry Association as a model. Companies that started making chips, like Fairchild and Texas Instruments, then Intel, had had grown a major business area making integrated circuit chips, memory chips, etc. They collectively founded a series of research institutes to work on far-out technologies that these commercial companies wouldn't find profitable; and additionally to educate students in the technologies involved in making these chips, to provide a future source of employees for the industry. Jim wanted to duplicate the entire SIA idea for disk drives. We went to a number of universities, including Stanford, UCLA, and San Diego, to find a university that would welcome this institute, designed to educate students in technologies for tape, disc, any sort of information storage, including flash; and in the engineering and physics disciplines that are involved: mechanics, electronics, hydrodynamics, magnetic physics, coding, information theory. It would educate university students in areas that would get them jobs in the data storage industry. That was important in the 1987s when this all started with disk and tape drives, and it's still true today. Virtually all of the CMRR students go into the storage industry, especially the disk drive industry. Research institutes now exist not only at UC San Diego but also at the University of Alabama. There's even one in Singapore, all doing the same things - educating students in the proper technologies for more and better storage products for the future.

Dennison: Okay. What do you think were some of the key contributions that you made in the hard drive field over the many years in the industry?

Hughes: Well, I would say that it's primarily the work on thin-film disks. That's what got me an IEEE Fellow Award, the thin film disk work in several different companies that I've discussed. I have to say that what I'm proudest of is designing recording channels for commercial disk drives that millions of people voluntarily buy. I think that's neat.

Dennison: Okay. And what was the most satisfying of these?

Hughes: Well, that's the most satisfying one. Plus, my original research paper on statistical pattern recognition theory, and my work helping making better disk drive products happen faster and sooner.

Dennison: Okay. You've trained many graduate students over the years for master's and PhD programs. How many graduate students approximately have come out of your group and how many went into the data storage industry? And where did the others go if they didn't go into these?

Hughes: Yeah. I don't have records, but I'll say that it's about a dozen. They're mostly grad students but I hired undergrads too, because the S.M.A.R.T. work needed hands-on drive testing. That's not graduate level work.

Dennison: Right.

Hughes: So I had hired undergrads to do drive testing. And a number of grad students. I'll say more than a half dozen to do the work that we've discussed in this interview, and they're the funnest part of any university. The students were the funnest part of being at UCSD.

Dennison: Is there a key philosophy or ground rules or strategy that you follow in terms of training and educating your students?

Hughes: Well, basically you want to tell them that anything's possible. Amazing new technologies are possible. You can wind up working for a job where you help millions of people in their lives with stuff that turns out to be valuable to them. But I have to say that are the students are <laughs> pretty smart. They seem to know all that anyway. <laughs> W hat I told them was that, "You need to have the right education and you need to get the degree and get out and get a job." They seem to know that too.

Dennison: Did you talk to students about the Seagate way or-- and would you talk to us about the Seagate way?

Hughes: Well, as I said, when I went to Seagate I was a researcher and I had to understand teamwork, and then you need to educate new employees that you hire, on teamwork. So I made a small one-page series of mottos. <laughs>

Dennison: These are in your book, by the way.

Hughes: They're in the book. I guess the funnest one to explain is: "Sneak around behind somebody. Do him a favor. Improve his job. Deny all credit for it."

Dennison: So did you talk to the students about this stuff or...

Hughes: No, I did not. Did not tell them the Seagate way.

Dennison: Okay. What did you look for in a student that you picked for your projects or programs or accepted as a student?

Hughes: Well, they're all reasonably bright or you wouldn't be talking to them, and so you basically, you're looking for somebody that either has the-- it's the mathematical ability, sometimes it's the programming ability, and sometimes it's the electromechanical test capability to just do the work. <laughs> I guess it's rather similar to hiring somebody, but after you've done this for so many years you sort of forget what you're doing. It's automatic.

Dennison: Okay.

Hughes: Attitude and aptitude is what it is.

Dennison: Are there any particular former students that you would like to comment about where they work now or what they're doing?

Hughes: Well, the single smartest one was Joe Murray. He was a physics student. Absolutely brilliant. All the things I just described, he did all of them. Quite remarkable. Great attitude. Really brilliant guy. Unfortunately, there was a tendency a few years ago, that the financial community was snapping up physics students to do what they call quants, quantitative <laughs> predictions of what the stock market or a stock is doing. And so Joe wound up working for a financial company. I wasn't surprised at all a year later when he wound up working in a data storage company. We still get requests for several papers that we published, in the S.M.A.R.T. program on disk drive predictive reliability.

Dennison: And he was involved in that?

Hughes: He was the best student I had in that, yeah.

Dennison: All right. Do you have any other favorite stories about the industry or the people that you haven't mentioned that you'd like to?

Hughes: Well, not that come to mind.

Dennison: Okay. Are there any other people that you haven't mentioned that had a big influence on you?

Hughes: I mentioned Jim Lemke. I believe he got me my Seagate job. I believe he recommended me as Associate Director of CMRR, and I know he got me interested in small airplane flying, which became one of the major excitement and adventures of my lifetime, 45 years of owning and flying small airplanes. <laughs>

Dennison: Yeah. We should point out that you have over 5,000 hours and that you--

Hughes: Five thousand, three hundred hours of flying ______.

Dennison: And Seagate let you fly on business, right?

Hughes: That was one -- <laughs> another Al Shugart story. I wanted to talk to Al after I got the job offer from Doug Mahon, and both were in Las Vegas. At that time there was a yearly personal computer convention called COMDEX, which was hugely successful and Seagate was there because it included disk drives. So I flew my airplane to Las Vegas to see Al, to make sure that a research guy like me would be welcome in a commercial disk drive manufacturer. It's sort of funny laughing at this now. I was pretty naïve guy. Would I be welcome? I guess I thought that was a reasonable question to ask, and I found Al down at the craps table. He was down by $70,000, and that didn't seem to bother him at all. I asked him if I would be welcome, and I asked him <laughs> if I could fly my small airplane on Seagate's business. I was able to do that at Xerox but it was very difficult to avoid the legal department catching me. But Al said I could do that -- occasionally I had to remind the Seagate financial people of that promise. On my job question, he just asked me "when can you start?' Al left me talking to Doug and he went back to the crap table; and was soon up by about $70,000. It was <laughs> rather amazing to watch. Not just the money involved, but the fact that it didn't bother him any more or less being up than it had been being down.

Dennison: That's a good story. So and all this time you were flying your plane-- how much time did you fly on business then compared to how much on, for, pleasure?

Hughes: Well, during the Seagate years I would say that maybe a third of my flying was on business.

Dennison: Can you talk about some of the places that you flew and, by the way, we should point out that you flew a Mooney, a turbocharged Mooney that was capable of flying in jet flight levels.

Hughes: I once was on the radio reporting to air traffic control that I was at flight level 230, which is 23,000 foot altitude, and a gravelly voice came on the radio from a jet pilot, asking what kind of a Mooney <laughs> could be up at 23,000 feet. <laughs> And I said, "Well, it's a turbo Mooney." <laughs> "I can go up to 25 or 26,000 feet." You have to have an oxygen system to do that. I don't know why, but I was pretty pleased with myself. So I flew this Mooney and earlier a Cessna 182, over pretty much most of the North American continent. Canada, Montreal, the Bahamas, and Mexico as far south as Oaxaca. Tip of Florida. Flew around the Alcan Highway once. Pretty much most of North America.

Dennison: All right. What are you most proud of, about, in your career?

Hughes: I have to say when all's said and done it's the pleasure of helping to make disk drives commercially successful for computer and television storage, to a point where millions of people buy them voluntarily and pay money for them. That's very satisfying.

Dennison: Okay. What are you doing now?

Hughes: Mostly traveling. My wife and I are going to Iceland in July.

Dennison: Could I ask why you picked Iceland?

Hughes: Well, I've been almost everywhere else.

<laughter>

Hughes: Already been to Antarctica. What's left? Iceland.

<laughter>

Hughes: And been to Alaska. Went around Alaska several times.

Dennison: Did you fly the Mooney?

Hughes: Flew the Mooney to Alaska with another Mooney. We got as far north as Barrow, north of the Arctic Circle. Where we had-- this is August-- where we had northern lights.

Dennison: Oh, wow.

Hughes: It was very light, almost light until midnight.

Dennison: So I know you've just recently sold your Mooney. What are your other passions or hobbies or interests?

Hughes: Well, I've taken an interest in personal financial investing. It's a fun hobby and it has the advantage you can make money with it. Right now the enjoyment is making sure that you're getting out of long bonds because interest rates are about to rise due to inflation; It's sort of a fun game of staying ahead of the other guy.

Dennison: Are you using your mathematical skills for that?

Hughes: Doesn't take very advanced math.

Dennison: <laughs>

Hughes: But it takes system analysis. I mentioned the Minuteman missile program. By looking at the entire missile I was able to find a problem near the tail of the missile where they weren't looking, and the same is true of financial analysis. If you listen and watch and get some experience doing all this, you can follow market trends so that you don't get badly burned before you turn to a different form of investing. Stocks instead of bonds or dividend stocks instead of performance stocks.

Dennison: Okay. If you could do your life over, what would you change?

Hughes: I would've married my wife, Shirley a couple years earlier. That would be it.

Dennison: Want to comment why? <laughs>

Hughes: Well, I married her because I had to leave Los Angeles, when my job in Xerox ended after my lab was closed. I was going to work for Seagate and rather than lose her, I married her. I should've married her years earlier.

Dennison: Okay. We've talked a little bit about flash versus rotating storage here. Basically the rotating storage is being replaced in many applications by solid-state at an increasing pace. Do you have any prediction about where hard drives will be in the future? Is there still a place for hard drives, and will they continue to survive, and if so, for how long?

Hughes: Well, flash first took over the marketplace for, let's call them, small diameter disk drives, like the 1-inch disk drives. That happened some years ago. It was very easy to make solid state flash more capable and also less expensive than very small diameter disk drives. It probably will soon take over the 2 1/2-inch disk drive market. It will take over the modest capacity, modest cost PC market. Flash is about twice as expensive per gigabyte than disk, but that's not important if you only need a few tens of gigabytes, and flash drives will take most of that market. Flash also has a place in large server farms, as staging devices.

But large storage capacity systems, including the Internet itself, and large database storage, is still on disks and probably will remain that way for the foreseeable future. The content of the world's Internet is in fact stored on rotating magnetic disks, not on flash storage. And as long as disk retains its ability to provide twice as many "bytes for the buck" - as I put it - as flash, it will stay that way. Television digital recorders can remain using their low-cost disk drives since their serial write/read speed is actually faster than flash. TV program streaming is serial access and doesn't need the high speed random access that flash offers. For very expensive computing systems, flash will be used with disk drives as staging and backup devices. Disk drives have to stay low cost and very large terabytes capacity.

Dennison: Okay.

Dennison: What vision do you have for the future of computing and storage?

Hughes: Well, there are several stone age technology elements to computing that have never changed. It's true that the punch cards that I used at Caltech in my graduate work have been replaced by keyboards, but keyboards are a terrible way to put information into a computer. Keyboards have to go. I sort of think that visible displays ought to go too. We should have some kind of a telepathic kind of hat with wires in it that you put on your head and compute, But oh, we have to get rid of passwords and usernames. They're the evil of our day.

Dennison: Amen.

Hughes: The first thing that has to happen is get rid of passwords !!

Dennison: So what are the key challenges you see ahead for the computing industry and technology in general?

Hughes: Well, that's an interesting and very broad question. I'll put it this way. Computers are driven, and have always been driven, in a direction towards user-friendliness. But user security is the opposite of friendliness and the situation will probably turn fatal. I'm speaking of things like foreign hacking of the U.S. electrical system, for example. Privacy on the Internet is now almost nonexistent and that can't stand. There has to be some way to put reasonable privacy back; which has to be automatic and easy for ordinary people. If a company like the Equifax credit assessor can't protect its user data, how is an ordinary person going to be protected from having his computer used as part of a robot network when he's not using it? I would say that the problem is not the megabytes or the megaflops or any of the electronics or operating systems. The problem is basically the user interface, especially its security. When we get user security we won't have to have passwords, will we?

Dennison: Exactly. What advice would you give to a young person starting out in their career?

Hughes: Go into disk drives, <laughs> or go into data storage, including flash, solid-state and magnetic rotating. Even go into disk drive research. It's a great occupation.

Dennison: Okay. Any other comments or thoughts or anything else you want to...

Hughes: No. I think that's all I got.

Dennison: Okay. I'm going to circle back then a little bit and ask you about Alluvial Fansome.

Hughes: <laughs> Well, I was an undergrad at Caltech, living in one of the student houses called Fleming, and I had picked up a Popular Mechanics magazine. I came across an ad that was popular then. This is the middle 1950s. The ad was for the Rosicrucians, which is a museum of sorts here in San Jose area, and it said I could send away for a booklet called "The Mastery of Life," something about the Knights Templar. Well, I thought that would be sort of fun. Sort of stupid too, I realized, so I didn't want to use my real name. So I sent away the little coupon for a copy of this book on "The Mastery of Life," but I had to invent a name. I'd been taking geology class at Caltech and so I thought of the name alluvial fan, which is a geological name for a dirt pile, and so I used the name Alluvial Fansome. Since I graduated from Caltech, we alumni get invited back once a year in May to have an alumni day. We hear talks about what the researchers are doing, and get to see the students. I discovered a long time ago, way after I left Caltech, that Alluvial had his own mail slot at Fleming House, and he was still getting mail. I asked the Fleming House guys. I discovered that Alluvial had a driver's license, he had a car license, he'd been in the Army and had a distinguished discharge, and he had a wife. Even a web site you can Google.

<laughter>

Hughes: I never quite knew what Alluvial's wife name was, maybe Alluvia. Every year since when I went back I'd look for Alluvial's mailbox..

Dennison: Okay. Any other fun stories you--

Hughes: <laughs> None that are printable.

Dennison: None that are printable. Okay. I think we're done.

Hughes: Okay.

Dennison: Thank you very much, Gordon.

END OF THE INTERVIEW

