Oral History of Walden (Wally) C. Rhines

Interviewed by:
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Fairbairn: Alright we're here at the Computer History Museum, it's August 10th, 2012. My name is Doug Fairbairn, and we're here to interview Wally Rhines, who is the CEO and Chairman of Mentor Graphics, Corporation. Wally has a rich background in both semiconductors and electronic design automation and we want to try to cover both elements of that career in this oral history. So welcome, Wally, glad to have you with us.

Rhines: Glad to be here, Doug.

Fairbairn: So Wally, we want to start at the beginning, we want to talk about where you grew up, what it was like growing up, a little bit about your family life and especially how that might have influenced your career in technology. So just start off, where were you born? How did it all start?

Rhines: I was born in Pittsburgh, Pennsylvania in 1946. My father was a professor at what was then Carnegie Tech and he was an engineer by training, a chemical engineer and later a metallurgical engineer and his father was an architect and so had a long history of engineering architecture and things like that, and when I was 10 or 11 years old, we moved to Gainesville, Florida where my father started the Material Science and Engineering Department at the University of Florida, which today is the largest in the US and so my recollections of childhood are heavily weighted toward Florida; going to junior high school and high school there, and most of my exposure to technology was associated with all the things you do at that age, science fairs and projects tied into the University of Florida so there was a lot of engineering influence all along.

<crew talk>

Fairbairn: So it came time, you had an interest in science; you figured that was going to be a career path in one way or another, is that right?

Rhines: So I wasn't that confident of directions when I was in high school. I liked science, math, but I also liked languages, literature, a variety of things so it wasn't so clear. But I had a father who was very engineering oriented; He would ask me what I wanted to do. If I said, well I might like to be a lawyer, he would say, well, engineering is an excellent preparation for law school. Or if I said, well, I think maybe being a doctor might be interesting. He would say, well an engineering undergraduate degree is a terrific way to get started in medicine and so pretty soon I figured out what the message was.

Fairbairn: You did have an influence.

Rhines: He did have an influence and we traveled the country looking at universities and he influenced that too. He decided that the University of Michigan had the best undergraduate practical engineering education in the country and so, although I didn't really have a good feel about what I would like, and at that time I could get into virtually any university, I went along with it and so I went to the University of Michigan and...

Fairbairn: So had he gone there as well?

Rhines: As it turns out, he had gone there, although that didn't seem to influence him so much as the actual program, but we went to each of the schools, met with the professors; of course he knew a lot of the people and for a while he was pushing Illinois and ultimately the only one he vetoed was MIT because he felt all his friends at MIT didn't spend enough time with undergraduates and he was looking for an undergraduate experience, so that's why he thought Michigan was the best <inaudible>.

<overlapping conversation>

Fairbairn: What about the west coast? What about Stanford?

Rhines: So he viewed Stanford as too theoretical; he thought U.C. Berkeley was terrific and in fact when it came time for graduate school, I only applied at Berkeley and Stanford and I got into both with fellowships. He felt that my decision to go to Stanford was a mistake— I could have gone to Berkeley; he felt Berkeley was the premier place and going to Stanford I was going to end up a scientist and maybe not employable.

Fairbairn: So stepping back; you went to the University of Michigan, the engineering school there and what was your major?

Rhines: My original major was chemical engineering but I graduated with a specialization in metallurgical engineering.

Fairbairn: So not electronics, not computers or anything like that.

Rhines: Not at Michigan, but when I went to Stanford as a graduate student, I became interested in solid state electronics, because that's what was happening in the Bay Area and an interesting person from the industry, Craig Barrett was a young professor there and his research and career had all been metallurgical engineering, high temperature creep, jet engine alloys, all that kind of thing; he was a metallurgist and Craig was the youngest professor so he spent time with the grad students and we went out and drank beer and so, as it came time to choose an area of research, Craig was interested in getting into electronics and the only electronics exposure he had had was one student who did mechanical properties of silicon. So I was the first that actually did anything in electronics and I had Gerald Pearson on my committee as well with Craig; Gerald was one of the original transistor group at Bell Labs and Dave Stevenson served as Principal Advisor. And so I did my thesis like so many others in electronics history, on gallium arsenide and it was enough of an exposure for Craig that he moved in the electronics direction and enough exposure for me that I did too.

Fairbairn: So what years were you at Stanford?

Rhines: I started at Stanford in the fall of ’68 and I completed my PhD in October of ’72.

Fairbairn: And so you went directly from Michigan to Stanford?

Rhines: I did but it was a very troubled period in the United States; the Vietnam War was at it’s peak and in February of my senior year in college, President Johnson decided that there would no longer be deferments for graduate students, so I had to find a path. I’d already been accepted in graduate school and I ended up getting into a program that was really designed for students coming from junior colleges to get into ROTC in their junior years, but graduate students could apply as well and they favored engineers over lawyers and other majors and so I ended up going in the military the summer of my senior year, going to Fort Benning, going through basic training, and then going into the two year ROTC program at Stanford and ultimately being commissioned at Stanford as a grad student and then having an obligation after that.

Fairbairn: So you graduated in ’72, you got your PhD in gallium arsenide; what aspect of that...

Rhines: So I dealt with light emitting diodes; my thesis was on precipitation that occurred during zinc diffusion in gallium arsenide but I shared an office with Herb Maruska and he was doing gallium nitride; we were all in three-fives and so one afternoon, we were sitting around in the office speculating about what had not been done in gallium nitride and we got a periodic table out and we started going down all the doping elements and Herb knew results for most of them and we looked up others for what had emitted what kind of light and we came to magnesium and we couldn't find anything on it and Herb said, “I don’t think anyone has ever doped gallium nitride with magnesium”, so Herb went in the lab and did it and made a light emitting diode and low and behold, there was blue, actually blue-violet, light and that was in fact the first magnesium doped gallium nitride light emitting diode and today all the blue LEDs, all the future of lighting, is all based on magnesium doped gallium nitride, so we got a patent. We have a patent that issued in 1974. It was actually a p/semi-insulator “diode”— we couldn't make N-Type gallium arsenide so it was a P-Type with semi-insulating GaN on the substrate for the emission and later people figured out how to make PN junctions that were much more efficient but anyway, that's where blue light came from in LEDs.

Fairbairn: And you were just looking for new things to do, <laughs> you didn't have any particular application or even— I mean had you predicted the blue light would come out? I mean was that your...?

Rhines: We had not.

Fairbairn: <Laughs>.

Rhines: Herb had a lot of experience in gallium nitride. He'd worked for Jacques Pankove at RCA and they had produced blue light with up-converters or down-converters but they'd never found anything that had intrinsic emission down in that range in the spectrum.

Fairbairn: Interesting; so you got a PhD and time to get a job; how did that happen?

Rhines: So I began interviewing as I was coming toward the end and went to lots of companies and the world was just recovering from a recession and in the Bay Area, the recession had hit very hard; In 1970 Fairchild had had really substantial layoffs and so at Stanford, the students really didn't think too highly of Fairchild then because so many friends had been affected and most people didn't want to leave the Bay Area. Having grown up in Florida, I was looking for the next frontier, and I thought gee, it used to be the East Coast, now it's the Bay Area, some time in the future it will be Texas, so Dallas sounded fine to me and so I went to work at Texas Instruments in a group that was developing CCD image sensors.

Fairbairn: So what attracted you to TI, other than it was in Texas or sounded like a new thing, was there an individual or a job that was particularly interesting?

Rhines: It was. There was a group there headed by Barry Bebb who had an insatiable appetite for work; so when I showed up for the interview, they were very interested in my thesis and the interview went until 9:00 at night; we had dinner and then we came back and interviewed some more. I didn't get out until midnight and my thought at the time was, "Wow this is my set of people; they love their work so much, they work long, long hours and they're doing all these great things and they did have a lot of things going on, especially in imaging and display". They had an LCD display group, they had an imager group and right about the time I came out was when Fairchild announced the buried channel CCD and a tri service bureau research effort was set up under Larry Sumney who now heads SRC and has for many years. Larry administered the program and TI, Fairchild, and RCA were the three contract recipients and we all had CCD programs, so that was my first project and we did large area imagers and our unique thing was we thinned the silicon; so we built the CCD and then we thinned it back to about 25 microns and then you could shine light on the back. The reason the military was interested, was because they made image intensifier tubes at that time called Starlight Scopes and they wanted to put a CCD in one of these starlight scopes, shine the image on the back of the CCD and then clock it out, and if you tried to shine it on the front of the CCD, you had electrodes, polysilicon and metal, shielding the CCD, so this backside illumination was a big attraction.

Fairbairn: So was Gil Amelio still at Fairchild at that time?

Rhines: Gil was at Fairchild. With Boyle and Smith he had been in the group at Bell Labs that did the buried channel CCD, so he was recruited by Fairchild. Jim Early played a role at Fairchild in getting him there and he had become effectively a Department Manager that had that group and Fairchild clearly was the early leader in that technology.

Fairbairn: So you went into work with the CCD group, tell me about the next steps or what evolved in that group; any major breakthroughs or...?

Rhines: The most interesting thing was unrelated to the CCDs themselves. We had a lot of challenges because these were enormous devices; we did a 400 by 250 CCD, a million elements in an era where the technology was...

Fairbairn: This is 400 mils by 250 mils.

Rhines: Actually it was; four-tenths of an inch, yeah just about, just about 400 mils and the programs were successful. We were working on a consumer product, we were trying to do a consumer video camera and recorder and so we developed a special hard disk drive, that is, a different group did. I wasn't in that group but my group did the imagers, but in the course of doing it, since we were getting the government to fund it, we were selling contracts and we pretty well saturated them on what they wanted to fund and so things sort of stalled out and Dean Collins who headed the group was always sniffing out new sources of money and everywhere he went, they said, "Look, we're interested in display, heads up displays for pilots and so on, but we're not going to fund anything more in imagers". So Dean, being a guy oriented toward how to get more money, came back and Larry Hornbeck, who was one of the group, said "Well, as long as we're thinning these devices, we could just thin them into little elements and then you could make a display out of that and we could just put electrodes beneath the elements and then maybe the flaps could be manipulated to modulate the display and so he built the first 3X3 version of what's now called the DLP or digital light processor and got the patents on it. That was all part of the CCD imaging group and TI continued to develop the technology for 20 more years without a nickel of revenue but finally got it to a point where in the mid 1990s, they could introduce a display device and eventually it become a substantial business, approaching a billion dollars.

Fairbairn: So tell me a little bit about that, I mean I thought that the DLP required some micromachining of mirrors or whatever.

Rhines: It was a MEMS product.

Fairbairn: But in these early stages it was that? I don't understand how you got...?

Rhines: The connection?

Fairbairn: Yeah.

Rhines: So the CCD imagers, remember, worked on the principle that they were thinned to 25 microns, or in that range. Light impinges on the back of the CCD and generates an electron hole pair which is then collected in the wells of the CCD, the charged coupled device, and clocked out. Well in order to make a uniform etch, we had P on P+ silicon and we had what were orientation dependent etches, the things you saw later from T.J. Rogers, when he did VMOS and used an orientation dependent etch. Well these were actually diffusion concentration dependent etchants, so we would etch right down to the P layer on P_+ and then stop and so we had very good control so what Larry did was instead expose a pattern with a photomask and etch it so that it would leave little flaps of silicon. On the layer underneath he patterned metal so that you could modulate the voltage and the flaps would move out of the focal plane. We used Schlieren optics so when it moved out the focal plane then it became lighter, a white dot, and that's how the original DLPs worked.

Fairbairn: So what was the period you were in this group? How long were you working in CCDs?

Rhines: I was there from 1972 through about mid '76 and I had been promoted; I was managing the CCD imager development for this consumer product and along came a disaster for TI. The disaster was that, while TI was one of the big three, TI, Motorola, and Fairchild, TI had made the most credible transition to MOS from bipolar, and actually had a decent MOS business which had started with shift registers under Don Brooks and other products and moved into memories. Intel had surprised the world with the 1103 1K DRAM.TI was trying to make an equivalent and not doing very well at it, but TI made it back into the market with the 4K, and got to market early. . TI finally was in the memory business, doing well, and then Mostek came along. Now Mostek was run by L.J. Sevin; L.J. had been at TI most of his career and he had quit when the company moved the MOS business to Houston and he took Bob Proebsting and other key designers with him. He hired Paul Schroeder from Bell Labs and they had done a 4K that initially wasn't that promising; the 4096 was an MNOS structure, and not very exciting, but then Schroeder came along and did the multiplexed 16-pin 4K and then we got into the liar's contest of what's the right way to go with DRAMs? Do you go 16-pin multiplexed, or do you do direct address, which was 18 or 22-pin. Well for a manager, it was, "Well gee, if you multiplex it, it's going to take twice as long, you've got to handle address and data, so it's going to be really slow" Since performance was important, this 18/22-pin strategy made a lot of sense and for a while. TI was sort of mesmerized into the belief that, sooner or later, we would win because we'll have better performance, but Schroeder's design was much too good and so it was fully competitive performance wise, it was a brilliant design, so all of a sudden the people in the DRAM group lost credibility and the CEO of the company, Fred Bucy said, "I'm fed up with this, go get one of those smart kids out of the Central Research Labs and we're going to design one just like Mostek. At that time, it was not illegal to copy parts; in fact, that's the way all the second sourcing was done, you just copied your competitor's part.

Fairbairn: Took photographs of the mask and copied the mask, right?

Rhines: Absolutely; early design automation. <Laughs> And so I showed up in Houston, of course I was persona non grata because the people who had been working on TI's 4K architecture, the 18/22 pin were now in the dog house, and I didn't know that much about memory design, it's just I was somebody new. My first day there, I talked to Dick Gossen, and he said, "You had better fill out your resume fast, because what those people up in Corporate don't understand is that a DRAM is truly an analog product, and what they've seen before are copies of digital products where they're easy to copy and they usually work. A DRAM has a sense amplifier you're never going to copy; it's never going to work, so get ready, you are going to be in big trouble six months from now. Well I was really scared to death, so we started sectioning the Mostek devices and started analyzing everything about them because now I realized this copying was not going to be that easy. The actual copying of the layout was relatively straight forward; we just got some parts and went over to Japan to Toppan. Toppan took a step and repeat camera and did a layout that was half the size of this room and digitized it, and we had photo masks, but the problem was the manufacturing process? In the course of sectioning all these devices, I discovered a unique thing.When the Mostek people left TI and formed Mostek, they took the process with them. So the Mostek process was identical to the TI MOS process, so when we ran the components, they worked perfectly; had 50 percent yield in the first lot, 70 percent on the second lot. No one at TI had ever seen yields like that with a memory and so it was a major success, so all these wonderful things I thought I had accomplished with CCDs and all these other technologies were forgotten and all of a sudden I'm now the favored boy because of the success of the 4K DRAM, which really didn't require innovation at all; it required a clever discovery that you could use the same process and produce the same results.

Fairbairn: Now your experience in CCD should have helped in the thing; I mean there was some common technology there between these dynamic RAMs and CCDs, right?

Rhines: Oh absolutely. So the CCDs were in fact, a standard MOS process, n-channel MOS, and my background had been process when I worked in grad school and then when I first got to TI, I was doing the process development for the CCDs but early on, I got involved in design. Actually, <laughs> the reason I got into design was because I looked in the annual report and TI listed every Vice President of the company in the annual report, and I kept asking people, who is this, who is this, and over a period of time I noticed, there wasn't a single person in that annual report who had ever run a wafer fab. I found this to be very strange; here's a company that's the largest semiconductor company in the world at the time, and nobody who is a Vice President has ever dealt with manufacturing silicon wafers and I kept asking people why and I finally figured out, in those days, sooner or later, every wafer fab has a crap out. There's a yield problem and all of a sudden the yields go to near zero and somebody gets fired or pushed aside and they bring in new management and so on. So the mean time between "crap out" was such that no one had ever made it to a Vice Presidential level.

Fairbairn: Never got out of it huh?

Rhines: And I decided, wait a minute, if you're in the Air Force and the pilots are the heroes, then the designers are the heroes here, and so I switched to design, but I still had a lot of process background.

Fairbairn: So I want to step back; you mentioned the work in CCDs was oriented towards consumer products, at least for imaging. TI was an early factor in the consumer business; tell me a little bit about TI's interest in that and how it drove the company and so forth?

Rhines: Yes. I joined the company in 1972 and about 3 months before I joined, TI announced that they would produce a calculator. Up to that point they made calculator chips. There were companies like Bomar and others who used the TI chips, but TI had not been in end products and Pat Haggerty, who was one of the early visionaries at TI, second only to Jonsson in that respect, felt that when TI did the transistor radio, they made the mistake that they recruited Regency to sell the radio but TI did all the work of developing the transistors and designing the radio and then Regency marketed it. Regency made all the money and TI sold transistors for ever declining prices, so Haggerty decided that we needed to get involved in the end equipment and one by one he was moving into end equipment businesses. He got TI in the minicomputer business, we already had the defense business, and consumer products were the big opportunity ahead so as I was arriving at TI, the Consumer Products Division was ramping up, building the Datamath calculator which was a phenomenal success— it was a four function add, subtract, multiply, divide calculator and it sold for under $300 dollars, so quite a bargain and it was really hot and the Consumer Products division or what was called CALD then, the Calculator Division soared and became a real highlight of the company. When I got the opportunity to work on a CCD that would go into a consumer product, that was really exciting and so I actually changed groups in order to take the job as manager and TI was at that time enthralled by consumer products and was developing many, many calculator chips and other types of consumer products.

Fairbairn: Okay so getting back to the DRAMs, when did you get the 4K chip operational?

Rhines: We actually got usable devices with good yield in the fourth quarter of 1976.We were ramping up production but in the course of this, when I had been drafted to do this DRAM program, Morris Chang was running the semiconductor group and I was drafted from the working on a consumer product in the research labs but a consumer product that was really directed by the consumer products group. I was sort of stolen to go do this DRAM project.

Fairbairn: So the consumer products were sort of in parallel to the semiconductor group?

Rhines: They were, and Stewart Carroll who had previously run Semiconductor Europe was heading the Consumer Products Group and so he and Morris Chang had a bit of a rivalry there; Morris ran Semiconductor and Stewart ran Consumer Products, so as soon as the DRAM was a success, Stewart came back and said, “We want Wally back”, because at that time they were moving Consumer Products from Dallas to Lubbock, Texas and nobody wanted to move to Lubbock, so this was from my perspective, the land of opportunity. <Laughs> No one else wanted to go and so I did a step function promotion from supervising a group of 5 engineers to supervising a group of 125 engineers and designing all of the chips for consumer products, about 25 unique P-channel MOS chips each year, going into the various calculators that TI introduced and the only penalty was that I had to move to Lubbock, Texas, which for a person in his 20s was a pretty big sacrifice.

Fairbairn: Were you married by this time or...?

Rhines: No, no; I was single and the thing that's interesting...

Fairbairn: So you could make your own decisions? <Laughs>

Rhines: I could. Yeah having a wife, even one as adventuresome as mine, it might have been difficult but interestingly, the people who moved with me were notable. We all reported to Ron Ritchie who was the division head; he recently passed away; There was also Peter Bonfield who is now Sir Peter Bonfield who was head of Professional Calculators and he went on to become CEO of British Telecom; he’s now on the Taiwan Semiconductor Board, the Ericsson Board, the Sony Board; he’s Chairman of NXP and so on. Rob Wilmot was in charge of what became the home computer and he became CEO of ICL, which was the largest computer company in Europe. Tommy George was the manufacturing manager and he became President of Motorola Semiconductor. Kirk Pond was manager of Specialty Products; he became CEO of Fairchild Semiconductor. Jim Clardy was head of Consumer Calculators and he became CEO of Harris Semiconductor and later founder of Crystal Semiconductor that became Cirrus Logic, so it was quite a group of people at the time.

Fairbairn: So what was this group set up to do?

Rhines: Because the consumer products were growing so fast at TI, they needed space, they needed the ability to expand and Fred Bucy, the CEO, was from Tahoka, Texas, near Lubbock and he felt that that wasn't a bad location and we had to spread out to more than Dallas; the Dallas labor market for manufacturing labor was totally limited so there was a need for expansion; the choice of Lubbock for consumer products in retrospect is a little strange because consumer people are not as much like Lubbock people as they might have done better in Houston or Austin or something like that but anyway...

Fairbairn: But it was chosen because it was a good manufacturing area potentially for the <inaudible> market?

Rhines: We already had a wafer fab there too, so we had a building and so we could expand that, and that became the Consumer Products Group and it was an intense environment. The consumer Electronics Show was twice a year but the January CES was the big show.

Fairbairn: This was 1976, '77?

Rhines: Right; '77 — I actually moved in '77.

Fairbairn: What were the major products you were going after?

Rhines: It was almost all calculators, so 4 function calculators and scientifics, but when we had started out the SR-50 had been introduced to compete with the HP-25 and then HP-35, but TI was way behind; HP dominated the programmable market and the scientific market. So the SR-51, "Slide Rule 51", sort of closed the gap a little. But it was really the SR-52 that brought TI even with Hewlett Packard and that was against the HP-65 and TI now had 50 percent of the market, HP had 50 percent and then Rob Wilmot, Peter Bonfield, Gary Slagel, and a great group put together the TI-59 and absolutely blew HP away; mostly because it was really inexpensive <laughs> by comparison. HP was perceived to be the very high end; it was sort of like a Mac versus PC kind of environment and TI moved to 90 percent market share and that product...

Fairbairn: Were you making good money on it?

Rhines: Enormously profitable; sold for $400 dollars from the day it was introduced for the next 10 years and the other was the scientific one, the SR30, the single chip scientific calculator which was also done at that time and those two products were enormously profitable and covered all of the massive losses of the rest of the business, so people like Jim Clardy were stuck with the job of competing in 4 function consumer calculators against the Sharps and Casios and all of the Japanese manufacturers and it was tough. TI could not make money in consumer calculators and we continued to try and we designed better and better chips but ultimately one of the things that saved the Consumer Calculator Division was a guy named Paul Breedlove who was searching for some way to get out of this rat race in 4 function calculators where we just couldn't compete. He went to a Central Research Laboratory Colloquium and they showed that they had done compressed speech where they could get understandable speech at about 1,000 bits per second. Paul came back and he conceived a product initially referred to as the Spelling Bee and then later it became Speak & Spell and somewhere along the line there it was actually moved over to Kirk Pond's group where Gene Frantz was and Gene worked on the product definition and I had all the Consumer Products engineering design so my job was to head up a group that would design the chips for it. Of course we only knew how to design P-channel MOS, we had two inch wafers, and this was really low cost technology to be competitive in consumer products. The semiconductor people were used to N-channel MOS and all these advanced technologies. We were viewed as using really archaic kinds of technology, but because that's all we knew, that's what we did and for some other reasons, because the wafers were really cheap, both because it was a 5 level process and so it wasn't very expensive to manufacture, but also <laughs> because internal transfer pricing was a big issue. Morris Chang ran Semiconductor Group, Stewart Carroll ran the Consumer Products Group, and the pricing of wafers to the Consumer Products Group which had it's own designers that were working for me was very controversial; we were always fighting for lower prices and so on, and Morris finally got fed up with the whole battle and just said, "Look, $25 dollars a two inch wafer, whatever you want, no more negotiation, design whatever you want, it's $25 dollars a wafer". Stewart said "Fine, we'll do it" and so there was no choice, Speak & Spell had to use P-channel MOS.

Fairbairn: So Speak & Spell was a product that was I mean very innovative at the time; you weren't copying anybody, I mean who...

Rhines: Absolutely. And the engineers loved it. This was Paul Breedlove's idea that we've got to get out of 4 function calculators and a product that speaks would be really different. He was a very imaginative guy and so it was pretty revolutionary; enough so that we were able to get corporate funding to support the product.

Fairbairn: But it was aimed at a totally different audience, right? I mean this is a...

Rhines: Well it actually was aimed at the consumer market for educational products and we did actually have some experience there; we had a product called the Little Professor and it was a calculator with red LEDs that would simply teach children to add, subtract, multiply, and divide and you would enter the answer and it would come back and flash if it was incorrect and so on and that product was successful for a long time and would never go away. We kept forecasting no revenue next year, and yet we would get revenue. So we knew this educational market had a lot of stability to it and it was really attractive and it wasn't so price sensitive. People will spend money for their children if they think it helps their education. So there was a lot of sense that this was a good market, but this was an expensive development and the people in the Semiconductor Group really didn't like us very well. We were a competing design group in a way and Dean Toombs, who was really the Chief Technical Officer effectively of Semiconductor Group, said "You will never build ROMs as big as you need to build them" because we had to build 128 Kbit ROMs, two of them per Speak & Spell. And the Semiconductor Group was struggling with the 16K ROM. Remember, theirs was n-channel MOS, ours was p-channel MOS. Theirs was 450 nanosecond access time. Ours could take milliseconds because you could clock it out serially for speech. So there were a lot of differences. It wasn't as tough a job. But designing a pipelined multiplier in p-channel MOS was an achievement, and Larry Brantingham figured out how to do that almost out of the naivety of, "I have no choice." National Semiconductor had announced a speech-ship set with n-channel MOS, but the speech quality was marginal because the data rate wasn't there and here we were with p-channel MOS; it was really amazing that it worked. Our design group was split between Lubbock and Houston, with the layout people in Houston, and the engineers were fascinated with this. The die sizes kept growing during the program and we got to the point where we knew we would not have to sell the product for more than $40. And there were people in Consumer Products who said, "Kill the program. We can prove to you that you will never have a consumer product over $40." "The reason is because, to spend over $40, requires a spouse's assent in a decision, so it can't be a compulsive purchase," and et cetera, et cetera. All these good reasons were given for why Speak 'N Spell is going to die.

Fairbairn: <laughs>

Rhines: And we introduced it at $60 with very thin margins.

Fairbairn: Mm-hm.

Rhines: And within a month we raised the price.

Fairbairn: <laughs>

Rhines: To$65. And one of the key breakthroughs early on was when Jane Pauley interviewed Charlie Clough on "The Today Show."

Fairbairn: <laughs>

Rhines: And they demonstrated it and Gene Frantz was there and they had maybe a dozen Speak & Spells lined up <laughs> because they weren't very reliable and they thought, "Oh, please, please, make it work on the show." <laughs> And it came off beautifully. And that got a lot of buzz around the world and it took off and we didn't catch up with production for, oh, over six months after that.

Fairbairn: That was ’78?

Rhines: Yeah, it was. It was ’78. Introduced in ’78, yeah.

Fairbairn: So was this chip, was this your first foray into any kind of digital signal processing?

Rhines: It was. It’s where I was introduced to digital signal processing. Actually, we had a summer student from MIT, Jim Cherry, who, you know that name?

Fairbairn: Yeah, I do.

Rhines: —from EDA?

Fairbairn: Yeah.

Rhines: He did the Pearl, the static timing analyzer later in his career.

Fairbairn: Uh-huh.

Rhines: But Jim was there for the summer, or actually on his sixth month, 6A MIT co-op program, and so he and Larry Brantingham were the principal logic designers for Speak ‘N Spell. So, effectively, we were doing digital signal processing without really knowing we were doing it.

Fairbairn: I was going to say. Did you call it that or know you were doing that? <laughs>

Rhines: We didn’t. We didn’t. We called it linear predictive coding for the algorithm we used. We called it pipelined multiplication. But it wasn’t DSP. No one thought of it as DSP. There was no DSP as far as we were concerned.

Fairbairn: Mm-hm.

Rhines: DSP came in my next step as I moved around the company.

Fairbairn: Okay. So Speak & Spell was a big success. Were there any other products that came out of that Lubbock group or was that sort o

Rhines: Yes.

Fairbairn: —all-consuming and just took—

Rhines: Well, the interesting part is that more and more, except for the scientific calculators, we started OEM-ing Japanese calculators, mostly from Toshiba, because we couldn't compete in four function calculator cost. So it was getting to the point where the high-end scientifics and Speak 'N Spell were the only products where we could make money. In everything else, we were losing money. And so that OEM business continued because TI had a very good brand name, but we were much more of a pass-through kind of marketing organization.

Fairbairn: Mm-hm.

Rhines: And somewhere in that phase, as they did more and more educational products, TI developed better and better understanding for the education market. And after I had left the group they continued to focus on education, and ultimately figured out how to lock themselves into the curriculum for education in the U.S. with calculators.

Fairbairn: Hmm.

Rhines: They developed courses, they provided incentives for teachers. They developed a set of calculators that would match the courseware and got school boards to approve the courses and then later went worldwide. And the funny part is, the consumer product business, which looked like a dog after it had declined for a long period, started taking off because they had this franchise with the education market to the point where by the year 2000 it was approaching or exceeding 70 percent gross margin for a business over $500 million a year.

Fairbairn: Hmm.

Rhines: And became so big that TI stopped breaking out the numbers, for which I have to conclude, having been there a long time,(this is long after I left), that the numbers became embarrassing because calculators were so profitable that they stopped reporting them separately.

Fairbairn: Mm-hm.

Rhines: And to this day, the TI calculator business for the education market is enormously successful.

Fairbairn: Hmm.

Rhines: So the roots of success were the same. Little Professor, Speak & Spell and then educational calculators.

Fairbairn: Hmm. Okay. So what was your next step, or what was the next step in this group, '78 to when did you leave there?

Rhines: By this time I'm about 32 years old, and Lubbock is not the greatest place in the world to live for a single person.

Fairbairn: <laughs>

Rhines: I spent a lot of time with Sir Peter Bonfield and others, but I was not opposed to other opportunities. And about this time, another blow-up occurred in the Semiconductor Group. TI had a 16-bit microprocessor because they had missed the boat on 8-bit microprocessors. So they had done a second source of the 8080, or 8080A actually, and tried to sell it, but they were learning that you couldn't just produce a part. You had to have application engineering support. So TI had not been very successful. Jack Carsten at that time was head of MOS, and he had under him, in addition to the second source 8080, there was a 5500 family of 8-bit processors. It didn't do very well either. Well, it did well in some places, but didn't become famous. But the lifesaver was going to be the 9900. And there was a corporate strategy. This was a microprocessor that was compatible with our mini computers and terminals and our military business. One microprocessor architecture for the whole company at the 16-bit leading edge. And so the 9900 had been developed starting I guess sometime in the '70s. And it was struggling. Because it had a 16-bit logical address space. So the only people who really needed 16-bit microprocessors that would use the 9900 did it for performance or resolution, 16 bits versus 8. But in terms of performance, that was a pretty narrow niche. And so they, in trying to make a success of the strategy, (which at that time reported to Jim Van Tassel), got a young engineer, Kevin McDonough, to design a version with an 8-bit data bus. They called it the TMS 9980. And you could use 8-bit peripherals, since the most visible problem up to that point had been no peripherals for the 16-bit microprocessors. Now we've got peripherals. Well, Jack Carsten had gone to Intel and he was watching what we were doing and he thought we actually knew what we were doing. And so Intel said, "Oh, my gosh. TI has got an 8-bit wide data port on their 16-bit microprocessor. Let's put one on ours." And there the Intel 8088 was born. And so Intel had the 8086, which they introduced in April of 1978, and TI had the 9900 which was not doing very well in the market and the 9980 not doing much better. And by then the TI microprocessor group was losing credibility and so there was a blowup and the manager was moved to another position. And the logical person to come run it was the one who was running the successful design group in Lubbock. And of course, I <laughs> wasn't anxious to stay in Lubbock. So I moved to Houston and took over the microprocessor group, which was a big responsibility for my age, but a job that no one else wanted. Because everyone knew the 9900 was not going to make it. And one of the first things I had to do was conduct exit interviews, because everyone was quitting because of another 16-bit microprocessor, a single chip micro-controller, that they couldn't manufacture. . So everybody was quitting. It was a real disaster when I arrived, but it was better than living in Lubbock.

Fairbairn: <laughs>

Rhines: But the first big issue I had to face was this group from Boca Raton that represented IBM was choosing a microprocessor for the PC. And they were down to really three candidates. Because Intel had announced early with the 8086 in April and Motorola had announced the 68k. Motorola, however, wasn't going to have a fully qualified part until much later in the year, possibly the end of the year or even into 1979. The Z8000 had the same problem. They had announced, but they weren't ready for production either. So it really came down to, if you wanted a 16-bit microprocessor, there were really only two in the market. There was the 8086 and there was the 9900. Now, it's my understanding that Akers [IBM CEEO] had only one constraint on the Boca group and that is, "Don't damage the IBM name, so use IBM qualified parts." And you couldn't pass an IBM qual without production parts. Otherwise, the 68k was clearly their choice. It was a big Indian like the IBM machines. The 8086/8088 was a little Indian. The 68K had everything they wanted. It was a 24-bit logical address space with easy expansion to 32. The 8086 was only 20-bit, 9900 was only 16-bit. The 68k was a hands-down choice. But it wasn't ready for production and couldn't pass a qual. And so the choice really came down to the 8086, or actually 8088, because they needed peripherals, versus the 9980 or 9900. So given that choice, four bits of logical address space certainly was enough to drive the decision. Intel won that decision and history became what it is today.

Fairbairn: Mm-hm.

Rhines: But if TI had put another 8 bits of logical address space on the 9900, the world could've been different. What's really amazing is the 8088 decision. The 8088 had the same problem the 9980 had. To get 16 bits of data, you took 8 bits and then you took another 8 bits in a subsequent cycle, so it was half as fast as a genuine 16-bit microprocessor. And so one wonders what's the advantage of a 16-bit microprocessor that runs at the same or slower speed than an 8-bit microprocessor. At that time, you could address 16 bits of data with an 8-bit microprocessor. So the 9900 and 8088 would have been failures except that the 8088 won a very critical design and that design—

Fairbairn: Right.

Rhines: —changed history.

Fairbairn: Changed everything. Okay. Okay. So you're right in the microprocessor business. Things aren't looking too good. IBM makes the decision to go with the 8088. Doesn't sound like that was a big surprise.

Rhines: No.

Fairbairn: You made some effort but that was not something you thought you had a real chance of winning.

Rhines: Right. So we already understood the 9900 was not going to be a big success. And so here I am in charge of the microprocessor business. We really don't have much in the way of products. At the time I took it over we had total revenue per year of $4 million. It had crept up in my first year or two to maybe close to eight million. But it was clear that we didn't have a winner.

Fairbairn: You must've had a pretty big group.

Rhines: It was. We had lots of people.

Fairbairn: Designing microprocessors.

Rhines: It was in the range of 200 engineers in this group. And so it was a noticeable expense to the company.

Fairbairn: Hmm.

Rhines: On the other hand, the failures that had occurred were visible enough that most people in the company had little hope for it. They still had their TTL business, which was a massive cash cow at the time that could cover a lot of sins. But MOS really was pretty much in the dog house. At some point along there, Don Brooks came to Houston and took over all of MOS. Eventually I reported to him as well. But I had the microprocessors and I had little hope for the future. So meanwhile, the corporate management is arranging corporate presentations for me to give about once a month or more frequently on what I'm going to do to counteract the Motorola 68k, which they thought was going to be the big winner.

Fairbairn: Mm-hm.

Rhines: And the TI Corporate management wanted us to do one that was twice as fast or half the price or something.

Fairbairn: Mm-hm.

Rhines: Something to fight back as they always had previously in the component businesses. What wasn't really widely understood among the management was that this is really a systems business and you don't just build one twice as fast and take over the market.

Fairbairn: All right. Building the chip itself was not the—

Rhines: It was not just the chip.

Fairbairn: —the solution. Right.

Rhines: And our view among my group and the people I worked with is the battle for the 16-bit host microprocessors is over. That war occurred years before. We need to look ahead.

Fairbairn: Mm-hm.

Rhines: And we had several people with ideas for how to move on. John Hughes was in charge of the strategy, and the general view was, "Look,if single chip host microprocessors with 16-bits is the big thing today, then maybe special-purpose microprocessors will be the thing in the future." So he put together a team under Kevin McDonough, and their job was to look at special-purpose microprocessors and say, "Where might there be an application that would require special purpose microprocessors?" And they had a whole bunch of different alternatives. Linked list processors, graphics processors and so on. And so Kevin headed that group and they identified four areas, and defined four categories of products. One of them was communications based on digital signal processing, and that one was designated the number 320. The 340 was graphics. The 360 was mass storage, and the 380 came along later and that was local area networking. And we put to work a guy named Ed Caudel to define what would a digital signal processor be for communications applications? And Ed took the better part of a year defining it, looking at the various algorithms, and Kevin McDonough persuaded systems people, with John Hughes help, to write code to implement various things, and so refining the instruction set. But Ed used mostly discrete cosine transforms as a metric of how well you could process DSP algorithms. And he finally came down to the conclusion that what we should do is a chip that could do a single cycle multiply/accumulate, which meant you would need a hardware multiplier on board, and then if you could do everything in a single cycle multiply accumulate, then you could execute these algorithms really efficiently. So that's what we did. We headed off down the path. We got funding from Semiconductor

Group Strategy Manager Bill Holton at that time, who controlled funding for special projects. And Harvey Cragon, TI's computer architecture guru, worked for him and thought it sounded good. So we didn't get that much resistance doing it. But we headed down the road to develop it, and were doing really well in the development—

Fairbairn: So plowing pretty new ground here. Were there other things you were looking at as being competitive or you were really thinking of establishing a new market here?

Rhines: So we knew it had to be a new market. Because we had lost out in what was going to be the big market for microprocessors. And we were the Microprocessor Division. So we had to do something new. We looked at applications. And we had 10 applications we targeted. Top of the list was MODEMs and then speech synthesis, speech recognition, and related applications. Ten years later I did an analysis of the top ten we identified; only one of them made it into the actual top ten of revenue for the TMS 320.

Fairbairn: Hmm.

Rhines: So the actual applications of the DSP turned out to be very different from what we anticipated, which is a lesson I've learned in product development. Do an innovative product, get it in the hands of innovative people, and these people will innovate for you and drive you in a direction that leads to success. But anyway, a side issue. Ed's definition was implemented. Kevin McDonough worked with the people in the defense systems group and just wrote code with the proposed instruction set and refined it to get it so you could implement a 300 baud modem You could do other things as well, and we started the design. The design was under Tony Leigh who was in Bedford England, and we had a stroke of luck that Surendar Magar was hired by the group in Bedford, and Surendar was a big system DSP guy. He had been at Honeywell, and he had designed multi-board digital signal processors. And he's the one who really drove the architecture which was what we really needed to do. Ed's was conceptual single cycle multiply accumulate. Surendar drove the implementation. Eventually we brought everybody over to Houston to work on it, and we're feeling really good that we have something great here. And then "boom". John Hughes walks in my office one day and says, "Intel just introduced our digital signal processor." And we went, "Oh, no the 2920" architected by Ted Hoff. Oh, my gosh". The guy who's credited with the 8080, 4004, oh no, they'd done it. And it was a day of massive depression. We'd been working on this now for a couple years, and we were getting pretty close, and all of a sudden Intel introduces it. And over a period of the next week, we got more and more information on the 2920. And John keeps coming in my office and updating me. He said, "You know, we just had our people try to implement a CODEC." He said, "The 2920 only has five bits of a-to-d and five bits of d-to-a on the chip. It's just not enough to do a 300 baud modem." Well, this is encouraging. One by one, every application we had benchmarked couldn't be done, because Intel's 2920 put the A-to-D and D- to-A on the chip. It was a true single chip DSP, including the analog-to-digital and digital-to-analog conversion.

Fairbairn: Mm-hm.

Rhines: We weren't planning to integrate the A to D and D to A so we weren't hampered by the resolution of the A-to-D. So we got more and more excited that what Intel had introduced, while very interesting technically and announced with a splash at ISOCC in February, really wasn't that good at doing practical things. So we became re-energized We needed to be at the February '82 ISSCC for announcement, and we had to have a die photo in time for the abstract submission deadline, and so on.

Fairbairn: <laughs>

Rhines: So it was a tight race. And we got there and Tony Leigh, Surendar Magar and Ed Caudel were the authors on the original paper. We named it the TMS 320. Of course, at the same time, we were doing the 340, and 360 because these are all special-purpose processors. So it wasn't a slam dunk that the 320 was going to be the big winner, because nobody really knew whether graphics would be a bigger market.

Fairbairn: Okay.

Rhines: <laughs> Maybe graphics is a bigger market. Anyway, we announced the 320 and got a good reception. February '82. Ah, terrific. This is a really neat chip. Ben Rosen did a big write-up saying that, "Finally TI has emerged in the microprocessor business," and so on. But the corporate management was not particularly happy. The security analysts said, "This is a special-purpose thing. It's not that important." And so the heat from the corporate front office didn't die down just because of the 320. In fact, they were not that interested in it. And another problem existed in that nobody knew what digital signal processing was. Jerry Rogers, who was head of the design group, had a thrust to drive all sorts of collateral educational materials. Data sheets, books, training, all that kind of thing. Well, all sorts of barriers existed in a company like TI, because a TTL data sheet was no more than two pages. And so the people who did the data sheets couldn't understand why we needed more than two pages for the 320, and here we wanted to publish whole books explaining <laughs>" What is DSP?" And here we had this list of all these speech processing potential customers and nobody was doing speech processing. But we found a company, Lear Sigler, that was doing analog repeaters for buried cables in the ocean.

Fairbairn: Yeah.

Rhines: And they needed to convert a signal to digital and amplify it. And so they were our first big customer. But the business was pretty lackluster. Dave French was the first business manager and he remained business manager through the infancy of the product until he finally left and went to Fairchild to work for Don Brooks. And then John Scarisbrick took over as DSP Manager.   Scarisbrick was very perceptive about support and how it worked. And so we struggled, but I had always had a relevant metric. I had told John, "You're never really profitable in a business until you get your first order from someone you've never heard of." And that means you're no longer holding their hands and working with them to design in your product.

Fairbairn: Right.

Rhines: And in 1985, John called me and said, "An important thing happened today." He said, "Number one, we showed a true profit, fully loaded." " And we received an order for 27,000 TMS 320 units from the GE Tank Division in Santa Barbara, and nobody has ever met with them, talked to them, or done anything to help them.

<laughter>

Rhines: So my gosh. We finally made it. And the other factor was that we could never get our people in TI Japan interested, because everyone in Japan, the big volume consumer application people, all had custom chips. And it was well-known by our Japanese employees that, "Japanese customers only use custom. We don't want a general purpose programmable product." And so they didn't market it and we didn't sell many DSP's in Japan. But John Scarisbrick had a program generating data sheets for DSP applications, and someone in Seattle had written an application note on how to design a FAX modem using the TI 320C10 DSP. The application note was published and nothing much happened. And then a group in Australia read the application note and built a FAX modem and sold the design to Murata in Japan. So Murata calls up the TI Japan office and says, "Do you have a three two zero C one zero part?"

Fairbairn: <laughs>

Rhines: Well, of course, the Product Marketing Engineer who was answering the phone call said, "Gee, I don't know. I never heard of that. Let me see." He opens the book and he says, "Three two zero c one zero. Yeah, that's $35." Well, we hadn't sold one north of $5 in the whole history of the 320. <laughs> Nobody paid list price

for a DSP, but he said, "Thirty-five dollars," and the Murata people said, "Great. I'll take 100,000 units."

<laughter>

Rhines: And yeah, all of a sudden, the world opened up. So the Japanese, all of a sudden, now, became really interested and their design group was very capable. They did the 320C25, which was the first really high-volume integer DSP that we did. And at the same time, in the U.S., we had figured out that we needed to address off-chip memory and do a bunch of other enhancements. And so we did the 320C20 and then we ultimately did the floating-point DSP, the 320C30 as well, which ended up being used in graphics applications. The business started to really take off, and then it just grew and grew.

Fairbairn: Now, wasn't Rockwell in the business of FAX modems?

Rhines: I'm sorry, who?

Fairbairn: Rockwell.

Rhines: Oh, yeah. So we were competing against custom parts, and ultimately we were competing with Rockwell. You had to be down near a dollar to get into a MODEM. We tried hard to be designed into Hayes modems and I met with Dennis Hayes a number of times without success. But we did get into U.S. Robotics modems eventually.

Fairbairn: Mm-hm.

Rhines: And some others. So as it turned out, the only application that we correctly anticipated, modem's, did in fact become important. But amazingly, one of the largest volume applications, among the top few, was closed loop servo control. For people producing hard disk drives. Nobody ever imagined this would be an application, and yet it became enormous volume, as did graphics (because of the floating-point processor in the 320C30).

Fairbairn: Mm-hm.

Rhines: And so there were lots of surprises. We evolved the product line accordingly. And I continued to move up the line. By this time I'm running a big portion of the semiconductor group. But DSP was becoming a bigger and bigger portion of revenue. And then, ultimately, I had the whole semiconductor business. We began looking at really specialized DSPs. We did DSPs for wireless, we did DSPs for hard disk drives. And we created DSPs for other things. And in 1987, we made a corporate agreement with Ericsson to be their primary chip supplier and to help them build a fab to manufacture parts themselves, and one of our key targets became getting DSPs designed into a cell phone.

Fairbairn: Mm-hm.

Rhines: We worked on that one very hard, and in fact, made our way in. And at the same time in Europe, Gill Delfassy was the application engineer who had the job of getting designed into the Nokia cell phone, which he achieved in about 1988or '89. And by the time the cell phone market took off, the 320 had become the de facto choice for baseband, and volume really soared in the late 1990s. I used to call Rich Templeton, who by then had become head of the Semiconductor Group, and kid him that, “Gee. When are you going to do something new?”

Fairbairn: <laughs>

Rhines: “Rich, we won all those designs while I was still there.” And he would grumble a little. But Tom Engibous, who had taken my place, moved up when I left in 1993, had now become CEO of the company, and he told me that the DSP-based business, including wireless, now constituted more than 40 percent of the total business.

Fairbairn: Hmm.

Rhines: So what was a desperation move, because we had no microprocessor, became a core technology for the company. And the others didn’t do that badly. The 340 graphics chip was actually the processor of choice for a standard called 8514A that IBM introduced. But unfortunately, VGA came shortly thereafter and blew it away, and so it had a fairly short life. The mass storage controller was a second source from Standard Microsystems and it didn’t live long. But the token ring local area network processor revenue became substantial as IBM tried to create a competitor for Ethernet, but ultimately failed in that respect. Of the 320, 340, 360, 380, the 320 became massively dominant in terms of the TI interest and spawned what was really the recovery of the whole company and then ultimately became the embedded core that let TI make the move to system on a chip in the 1990s.

Fairbairn: Hmm. So what were the following products? When did the 5100 come along, and what was the…

Rhines: 5100. You’re thinking Motorola, I think.

Fairbairn: Oh, okay.

Rhines: So our competition— well, okay. Back to the history. I have this entertaining presentation I give that is sort of tongue-in-cheek, “How to have a great product development.” And it has things like, “Define your target market accurately.” And I show the target markets for the DSP.

Fairbairn: <laughs>

Rhines: And then I show the real markets for DSP. And I have, “Be first to market.” And then I show the five DSPs that were already in the market when we introduced the 320. Once again, single cycle multiple accumulate with hardware multiplier was the differentiator of the actual hardware design.

Fairbairn: Mm-hm.

Rhines: And the ones that preceded it didn’t have that.

Fairbairn: Okay.

Rhines: But the one 320 predecessor that I think was most seriously accepted was NEC’s DSP.NEC had two processors, a graphics and a communications processor. One was the 7220 and one was the 7720, I think. I may have the numbers wrong. And we considered them the primary competition. The DSP from AT&T was a threat, but not as much.

Fairbairn: Now, were these other people copying you or did you come along and one-up them?

Rhines: No. They were in the market before we were, but we were all obviously developing in parallel without knowledge of each other. It’s just that we weren’t the first ones there.

Fairbairn: Mm-hm.

Rhines: In fact, the 2920 was in the market a year before us and we got a lot of heat after the 2920 failed to get traction. People within TI said, “Why are we wasting money doing what Intel has already shown the world won’t succeed?” But, of course, we were engineers who were—

Fairbairn: Right.

Rhines: <laughs> We were committed.

Fairbairn: We’re different.

Rhines: We were convinced that we were going to make this happen independent of what anyone else thinks. And meanwhile, we’re getting all this pressure. “Look at the 68k. Look at the 8088. Look at the 80286 and so on. You’re just getting killed. You’re nothing in the market.” I would give talks to security analysts and talk about DSP, and I remember Mike Krasko at Merrill Lynch would see me at the meetings and say, “What are you going to talk about today, Wally? DSP? Ha, ha, ha, ha.” <laughs> He openly said, “TI, you missed the ballgame. You’re just not a factor.” So I took a lot of personal heat over that. But ultimately, I was vindicated. But the thing that actually was most important to DSP becoming core to the whole business, and its role in the industry in wireless, was that once it was designed into that Ericsson cell phone, Ericsson came back to us and said, “We want to integrate this whole baseband function into a single chip.” Well, there were two ASICs, there was a static RAM, there was the TMS 320 DSP and maybe some miscellaneous other stuff. We had already had an experience with Tellabs where they were doing an echo canceller and they wanted to put a DSP together with an ASIC. And we had just taken the layout data in GDS2, and just printed it, bond pads and everything, on a piece of silicon right next to the ASIC. And Tellabs took it to market, and it worked and it was a success. So when Ericsson came along and said, “We want this on a single chip,” we said, “Look. Let’s just take the ASIC netlists, combine them with the 320 and the static RAM, and we’ll make a single chip”. Well, as you, Doug Fairbairn, would realize, this is a lot tougher than it looks, because you don’t just put the netlists together, it requires simulation of all the interfaces and lots of problems emerge. But we struggled through that and we made it work. And then we did the same thing for Nokia, but in the course of doing it, we realized there was a fundamental problem, and that was that the ASIC business at TI, which was a dog business, losing money, which also reported to me, was separate from the microprocessor business and had a different layout grid from the microprocessor business. The layout grid for the DSPs was different from the layout grid for the ASIC group. It was very tough to combine a physical layout between the two groups. So with encouragement from Bala and some others, I did what was considered a very controversial thing. Everyone told me, “You don’t ever want to mix your microprocessor business with your ASIC business, because ASIC is cents per gate and microprocessor is value-added. You have 65 percent gross margin in DSPs and you have, on a good day, 20 percent gross margins in ASIC. If you ever put them together, they’re both going to go to 20 percent. It’s going to be a dog.” But we didn’t have any other way that we could solve the problems that all these cell phone manufacturers had of putting ASIC together with DSPs, and by then, the same thing was true of disk drive people. Everybody wanted to do what ultimately became the “system on a chip”. So we bit the bullet.. We went to a common grid for ASIC and DSP. And it turned out to be a terrific decision, but at the time, pretty controversial. It was about that time that I put Rich Templeton in charge of what was the combined ASIC and microprocessor business. Actually, Bala was in charge first and then later, not long after, Rich took it. But it put the ASIC business together with the microprocessor business It was very controversial, but in fact, it brought those two groups’ design assets together. They now had the same grid and they now had the same cell library. They could quickly crank out system chips for customers. And then we went after the markets for single chip DSP-based applications, and that turned out to be an enormous winner, particularly in wireless, but also in the other markets. It really was the design-enabler that allowed us to quickly design things that others were trying to do from the ground up. And we had the leading DSP anyway, but now we could use that DSP and leverage it into system products and so it became a big success.

Fairbairn: Right. So send me through the rest of your TI career there and are there—

Rhines: Okay.

Fairbairn: —any other major highlights you want to point out along the way?

Rhines: So by this time, I'm now in charge of the semiconductor business, and the microprocessor part is a respectable business now. We had memory, under Akira Ishikawa, and Tom Engibous became the head of the whole microprocessor and ASIC piece. Then we had digital logic and linear products under Del Whitaker. Memory, of course, was a troubled business but, anyway, we had those three and it was early 1990s and the semiconductor market was not that healthy. The semiconductor business was losing a lot of money in DRAMs and the corporation decided, "We're not going to build any more Fab's for DRAMs so Ishikawa went off and did his third party Fab thing that led to what was the TI/Acer Fab and the Tech Singapore Fab. All these Fabs were built with third party money because the corporation didn't want to invest in the DRAM Fab's and, in fact, some in the corporation didn't want to invest in semiconductor at all anymore. The CEO's changed and Jerry Junkins became CEO.- I had reported directly to Jerry in a portion of my career and I was now in charge of the semiconductor business. Pat Weber had Semiconductor Group plus Consumer Products Group plus Materials and Controls Group and I worked for him. Jerry Junkins, on a trip we were taking, told me, "I didn't get this CEO job until I was 55 so I've got to tell you, I'm going to be here for another ten years. I know you're 47 years old, you probably have other ambitions, and I won't stand in your way, but you're going to be a “lifer” if you wait for me." And, "Oh, by the way, there's no guarantee that you get the job, either." He even had another favorite that I won't bring up because I don't want to dredge up too much of the who might have been and so forth. Anyway, I was in a situation where it was stay at TI and do the same job, or something else at TI, for the rest of your life or go do something new somewhere else. I had a non-compete agreement. I could not work in the semiconductor industry in competition with TI and it was a non-compete agreement that had teeth in it. It had already been prosecuted against Don Brooks and Hal Moyers successfully, or at least with settlement, and so I looked around. I wanted to leave on good terms. I had to look outside the semiconductor industry and design was always the thing that wedded me to the industry. To me, product definition and design were where the creativity was. I had run big manufacturing facilities and I knew how but it was a lot of work and I just viewed the product development side as the creative side. So I talked to some EDA companies very confidentially. The problem was, I was in such a visible position, I couldn't go out and interview for jobs. Mentor Graphics, however, was actually in desperate straits because they had introduced an integrated product with a framework called...

Fairbairn: System 8?

Rhines: Version 8.0 (eight dot oh), which subsequently became nicknamed version late dot slow, and they were struggling.. They had had massive turnover. The cash was draining. They had approached me many times regarding whether I'd be interested and I hadn't been but, at some point, I started talking to my wife asking, "What do we do? I can't work for a semiconductor competitor". We had young children and she was worried about schools in the Bay area and Oregon sounded nice. I knew that Mentor was in trouble because TI was a customer and we had suffered through a lot. But Mentor had integrity. When they got in trouble with Version 8.0, they just drowned us with application engineers and we got through the problems. I had a lot of admiration for Mentor in that respect. I thought about the fact that companies have screw ups with products but you can always come back. What you can't easily do is take a company that has no integrity and give it integrity. That's something you have to build from the bottom up. And so I really respected that about Mentor. I knew it would be tough but, gee, I'd had a lot tougher jobs than that Taking over the Microprocessor Division at TI in 1978 was certainly not a picnic, and so I wasn't intimidated by that at all. So, in November of 1993, in late October, I accepted the position and became CEO at Mentor Graphics.

Fairbairn: Who was CEO before?

Rhines: Tom Bruggere. He was one of the three founders, Tom Bruggere, Dave Moffenbeier, and Gerry Langeler, and he was the only one still there because there had been a lot of in-fighting with all the problems of 8.0 They had made the decision that they were going to hire a new CEO and Tom would move on. The attraction of Mentor versus other things was that most places wanted to hire a COO because the founder and CEO didn't want to work so hard anymore and they needed someone to run the company. Mentor was actually hiring a CEO and, while the company was clearly troubled, it did have that advantage.

Fairbairn: So it was quite a move from- where were you in Texas? Were you in Dallas at this time?

Rhines: So I was in Dallas at that time. I had been in Dallas four times. I worked for TI in Dallas four times, Houston twice, Lubbock once and Austin once. I lived in sequence in Dallas, Houston, Dallas, Lubbock, Houston, Dallas, Austin, and Dallas. And so I had been around Texas for 21 years and Oregon was very new.

Fairbairn: But your wife- by this time you had a wife, of course.

Rhines: That's right. <laughter> I was no longer so easy to move. In my early career, it was always, ”Who can we send? Hey, Wally's not married; he costs almost nothing to move; send him”. Now I was married and had children. It was not so easy anymore but my wife's a real adventurer and it could have been Afghanistan, she would have said, "That sounds interesting." So I came to Mentor.

Fairbairn: So you said it was troubled. What were the core strengths of Mentor outside of the problems they had with the 8.0 system?

Rhines: So, for modern electronic design automation, Mentor was one of the three key companies that emerged early on- Daisy, Mentor and Valid. Before that, for the generation before what we call EDA today, it was really automated layout and that was Computervision, Calma and Applicon. But it was always three dominant companies, actually, which is sort of interesting. And, of course, at TI, all our own tools were developed internally until the mid-1980's. I In fact, design automation was considered a differentiator for TI. The whole TTL success had been because TI developed a fast design environment where they could crank out one TTL part a week and build a base set of parts quickly. So TI was not using commercial products historically. But for modern EDA, Daisy and Valid both introduced proprietary hardware to go with their design software. Mentor's unique approach was that it was the first one to go with a standard third party workstation, the Apollo, and, as it turned out, as the industry evolved, Mentor could put all its resources on the software whereas Daisy and Valid had to keep upgrading and updating the hardware. That was a diversion compared to Mentor's strategy and so Mentor prevailed and became the leader in EDA as the ASIC market emerged. But the initial market that existed in the 1984/'85 period was very heavily systems oriented. It was military, aerospace, automotive, and companies like that and Mentor fought against Daisy and Valid for all those and won a disproportionately good share. But it was mostly doing printed circuit board layout and some simulation but more layout tools than other aspects of design. And it really was with the emergence of ASIC as a methodology with both gate arrays and semi-custom design that, in fact, modern EDA grew and Mentor grew with it.

Fairbairn: So at the time you came, what were the actual products that you thought were the winners? What was your strategy coming in? How were you going to rescue this company from its mistakes?

Rhines: So this is a little laughable in retrospect but I just assumed that any company like Mentor would have some jewels buried in the rough that could be polished up and the company could recover from this disaster of Version 8.0. I didn't realize that the whole company had been drafted and mobilized to try to get 8.0 to work and so there wasn't much on the shelf. Regarding my impression of Mentor, the most favorable part was that I'd always been a great lover of emulation because when I did all those calculator chips in consumer products, we built TTL emulators for every . We then hired college students to come in and bang on the keyboard and find the bugs in the designs. That was our design verification approach and the emulators were very reliable and they found bugs and TI had quite a good reputation for having bug-free calculators. In the 1980s, I had been introduced to Mentor and they had the most advanced emulation technology. There was a startup called Quickturn that also had it, and another one later, PiE. When I joined the microprocessor group at TI, commercial emulators were becoming commonly used. We used the PiE emulators to do a virtual prototype. In fact, when we did the Token Ring Local Area Network, every Friday, we would take a tape from our emulator across town to Compaq and they would use the emulation of the Token Ring LAN chip to design their add-in card for the PC so that, on the day we announced the chip, they announced the board. That was unheard of at the time. Virtual prototyping had actually led to an accelerated product introduction. So I was excited that this is the way the world is going to go and my recollection of Mentor was that they had really great technology as well. I thought, "that's an area that they probably haven't exploited". Quickturn had really not done very well. They had acquired PiE but were struggling and that could be an opportunity. It was only after I got to Mentor that I discovered they had sold their emulation technology to Quickturn. <laughs> They didn't have emulation any more. So there were a lot of big surprises that I had to deal with but, early on, the first thing that- the first jewel I came across was through acquisition, acquiring a company that had a design for test methodology and so we focused on design for test...

Fairbairn: What company was that?

Rhines: CheckLogic. And Wu-Tung and John Waicukauski- several very key technologists were part of that company. John Waicukauski, who later actually went to Synopsys,did their current generation of TetraMAX. But, anyway, we introduced FastScan and that was a big success and we recruited other people and ultimately Janusz Rajski, who had been a professor at McGill University, came in, and brought in other people and came up with the idea for compressed test and that led to the introduction of TestKompress and ultimately a big success for Mentor in a relatively small market. But at least we got the largest market share by quite a large margin. That was a big success and, three months after I came to Mentor, we began development of a physical verification product. Now, interestingly, when I was at TI, we were, I think, the first company to do automated physical design verification. We used it on a chip design that we did in about 1980 and we did schematic verification and reconciled the layout to schematic. It was quite successful and so we did it routinely at TI and ultimately Mentor, who had been OEMing the Dracula product that ECAD had developed, adopted it. Cadence bought ECAD so all of a sudden Mentor didn't have a physical verification product so they decided to OEM the TI physical verification product, which they called Checkmate. And so I actually signed that contract, as I did, by the way, the second ARM contract ever signed as well, while I was still at TI I'm told that Al Stein signed the first one. Mentor had had a lot of experience with physical verification with a small market share compared to Dracula. But there were some very key people who really understood what was needed in a product but were not really given freedom to do much. By the time I got there, things were desperate and people began initiating new projects. We were searching for areas that we could excel in and one group had their own version of a physical verification product that it wanted to make into a real product. And so they started in 1994, first quarter of '94, after I got there, and actually, in the latter part of 1996, they introduced it and it was called Calibre. It was named Calibre because we planned to have an extraction product as well and everyone thought that would be neat, to have Calibre and then ExCalibre. Unfortunately, the extraction wasn't that successful so you don't hear much about ExCalibre nowadays but Calibre was successful.

Fairbairn: Calibre was successful.

Rhines: Yes. So Calibre became sort of a de facto standard that really propelled Mentor. Calibre became, oh, 25 to 30 percent of Mentor's total revenue and that really got us out of the doghouse and got us on a path of growth to recover from Version 8.0.

Fairbairn: So this is '94/'95. We're now 15 years...

Rhines: Yeah. So here I am at Mentor and I'm beginning to realize that this EDA business is not so easy as it looks from the other side. When you're in the semiconductor business, you own inventories. Those inventories depreciate in value all the time. You're always fighting cycle time. It looks so easy to those people who are in the software business. They have zero costs of good sold. If they get a winning product, then they can just collect all the money and do the support. The problem with EDA is that there are really only, on a good day, 100,000 designers in the world that need your tools. More likely 50,000. So it's a very limited market for what we classically call EDA. During that period when Mentor was off chasing Version 8.0 and trying to keep the company alive, Cadence and Synopsys were going gangbusters with new products, very focused point tools that could expand into more successful design platforms and they had really done a job on Mentor. Mentor went from being number one to being number three; there were still three big companies in the industry but Mentor had really lost momentum. So the 1990s were a period of recovery and what we decided to do was find specific areas where we could be number one, where there was either a turn of technology coming and a door opening for something new or where nobody else was doing anything and we could develop a market, like ESL for example, Electronic System Level design. And so the first of those was Design for Test and physical verification was another. Physical verification became the basis for a whole variety of other related businesses like resolution enhancement but, at the same time, we had to be in simulation to be a major player in EDA. Mentor's simulation product, Quicksim had been very popular in the industry and, when the world went to language-based design, moving from gate level and schematic capture to RTL level, Verilog and VHDL, Mentor had really lost it. So, in order to catch up, in 1994, the first year I was there, we acquired Model Technology, who had a direct compile simulator. It only did VHDL because, of course, Verilog was a proprietary standard of Cadence but we hired the company with the understanding that they would do a co-simulator that would do both Verilog and VHDL. They actually compiled down to an intermediate pseudo code structure that then did the code generation for various processors and systems. And so that got us back in the simulation business. And, although VHDL was far more competitive than Verilog because there were so many other people competing, over time, it allowed us to grow a major business. Today, Mentor, Cadence, Synopsys all compete with direct compile simulators but the market is quite fragmented and Mentor is number one every few years, Synopsys is most often number one, Cadence is normally third despite its early lead in Verilog. The basic RTL simulation market today is really the big three competing with one another with roughly equal market shares.

Fairbairn: So tell me a little bit about, you know, what were the other major areas? You mentioned system level design.

Rhines: We decided very early that embedded software would be important so, in 1996, we acquired Microtech, which was one of three leading embedded software companies. They were tied to the Motorola 68K family of microprocessors. That proved to be a troubled acquisition but it introduced us to the challenge of embedded software development and that challenge turned out to be much greater than I anticipated. I assumed that, if you could do hardware and software co-design together, then all these problems that occurred at system integration, when you brought the hardware and the software together, could go away. You could have a smooth integration. And if you just provided people the tools to do co-design at an early stage, then most of the problems would be solved. Microtech was our solution. What we didn't realize was that the embedded software people were not sitting around waiting for the opportunity to work with hardware people. And the hardware people had no comprehension of the software world. And so, as we developed co-design products, we were able to sell them quite successfully to the hardware designers who wanted to use the embedded software as a test bench but we weren't able to sell them to the embedded software people. Our Microtech organization was experiencing organ rejection because of the difference in cultures of embedded software and hardware and so we struggled but we stuck with it. We did more acquisitions. Accelerated Technology, which had the Nucleus real-time operating system, came later and a whole variety of other acquisitions and developments helped build the business. But it was really a 15-year journey to get to the point where we actually had products that embedded software developers wanted to use to develop their embedded software. One of the interesting things that came together at the same time was emulation. As chips got so big that people couldn't use simulation for full chip verification, emulation took off and the software developers liked developing software on the emulator and so all of this started coming together and that became the verification platform for functional verification that is quite successful today.

Fairbairn: So where do you find Mentor today? What are the key products? What are the key technologies? How do you see things evolving over the next few years?

Rhines: So, once again, Mentor took a unique strategy, we internally called it, “Do what others don't do”, and we kept looking for markets for new capabilities like ESL, like embedded software. And we looked for technology turns like compressed test or like the hierarchy for physical verification, things like that would open doors. The thing that made Mentor different, that I became aware of early on, is Mentor's history really was with systems companies… military, aerospace, etc. Mentor worked its way from systems down to transistors whereas Cadence and Synopsys worked their way from transistors up toward systems. So Mentor has, to this very day, a customer base that's about 50 percent systems companies and 50 percent semiconductor. Even though our total revenue is about 70 percent IC design, some of that is IC design done by systems companies, but it's also printed circuit board design and signal integrity for system design and other kinds of system design skills. In fact, about the time I arrived there, Mentor started getting business in automotive cabling and wire harnesses from a product developed by the consulting business. Today, the wire harness business has grown to be nearly ten percent of revenue and is one of the most promising growth businesses in the company. So, as we moved along, I've kept looking for where does the chip become a system, where can you leverage system technology. One of the opportunities that appeared was embedded software, another simply the ability to do system level design, ESL, products that could take C source code and synthesize it into data path and other RTL-based design implementations. We invested heavily in ESL when none of the other big companies were interested, for more than a decade, 15 years. We invested in PCB when everyone else thought that was a dead business and we expanded it into thermal analysis and other kinds of system design. We invested in embedded software when no one else was interested and they still aren't interested. <laughter> And we invested in focused areas where we had platforms that could create a customer franchise. The physical verification platform with Calibre led to more than 30 different products that were based upon it and could grow revenue from a number one position where we had a franchise. Now the strategy of the big companies in EDA has traditionally been one of having everything the designer needs so that he will buy the whole flow from a single vendor, even though no one has ever done that. That was the strategy of the Falcon Version 8.0 that Mentor pursued. It was “Buy it all from me---single interface, single database, single everything”. It’s easy to convince customers that they don't want to deal with multiple vendors because, if things don't work, they'll point at each other for the blame. And that's been the message that really resonated with customers. Mentor, at least in my period there, went the other way.

We said, "Let's build platforms that are best in class, standard in the industry and let's be sure that they are open and well integrated with the other major flows" and we can build on a best in class. And, for things where someone already dominates a business, like Logic Synthesis, for example, let Synopsys have it. If they're already dominant, why confuse the market with yet another alternative. The industry doesn't need three companies working on the same thing just trying to imitate each other. It's an industry where the number one provider in each market segment has a 66 percent market share. How much benefit do you provide if you say, "Me, too" and try to keep up with the leader? You just can't spend enough R&D to do that. So that's what we did and we created centers of excellence that are design platforms that occupy big portions of the flow but we don't really sell a turnkey flow, although we can. We actually have everything in the flow but, in general, we try to interest the customer in a unique capability in some part of the flow.

Fairbairn: So what can you say about the future evolution, especially the relationship between EDA and semiconductors? Where is that headed and where is the EDA industry headed?

Rhines: The EDA industry is an enigma in some sense because, once all 50,000 people have tools, then there is not that much growth from new designers coming in the market. All of the growth comes from new applications and from growth in R&D spending by semiconductor companies. Well, R&D spending by semiconductor companies does grow essentially every year and has only decreased three years in history, and one of those was not very significant. So EDA can grow at the same rate as the semiconductor industry. But if the EDA industry really wants to grow, it has to solve new problems. There are many, many new problems. From my perspective, the most challenging are system level problems, bringing hardware design together with other aspects of the system. Examples include bringing the electrical design of the chip together with the embedded software, with the thermal analysis, with the board level system analysis and with the whole system design and architectural trade-offs with the high level design. All of these are incremental businesses and I believe the EDA industry has a growth ahead of it far greater than anything in the past as it solves the problems of true system design. Today, automobiles are designed, to a large extent, through physical prototyping. Sure, there is some simulation and there are subcomponents that are simulated and designed and, of course, chips. But, in general, the verification approach is to build a car and drive it 10 million miles, and see what the problems are, and fix them. Ultimately, all that verification has to be done virtually. Cars have become really mobile electronic networks and the only way you can debug a system like that is virtually, as we do in the semiconductor industry. We think nothing in EDA of designing a chip with a billion transistors and having it work correctly in the first pass silicon chips. In the automobile industry, no one has even taken the first major step in that direction and so I believe that's all ahead of us. All of that system level design and verification is an enormous opportunity. All of the embedded software development that is now a critical part of chip design is a market yet to be tapped by the EDA industry and a whole variety of new capabilities; thermal analysis for stacked die or thermal analysis for systems are rapidly growing businesses that are just emerging. One of our fastest growing businesses today is thermal analysis.

Fairbairn: It is a major problem in the business these days, isn't it?

Rhines: Heat is a big problem and power is a big problem. And so while the traditional toolset for EDA produces about the same revenue every year, more than 100 percent of the growth in revenue in the last decade has come from totally new capabilities---- resolution enhancement, embedded software, reusable IP, ESL, system level design tools, formal verification, etc. All of these are things that nobody needed 10 or 15 years ago. Today, they are a significant portion of the EDA design tool budgets and so there's growth to be had for anyone who's willing to look ahead and say, "What's the problem that's going to pop up that we need to solve in the future?" But as long as EDA companies spend their time just reproducing each others' products, and our industry does spend a lot of time trying to take market share from each other, then it's very hard to grow the industry's total revenue. It's true that we need to advance those products, keep them current, keep them competitive, but that's not where the revenue growth will occur. The revenue growth will occur from new products, new challenges and new capabilities.

Fairbairn: Well, to some extent, those businesses are shrinking, aren't they?

Rhines: Modestly. Core EDA is actually a shrinking business. Now, in Mentor's case, our core EDA, and in fact, our total revenue has grown about twice the rate of the industry but it's because we had large market share in businesses that didn't exist a decade ago like resolution enhancement, like compressed test, like ESL and formal verification. And so the growth of our traditional kinds of businesses, the basic simulation, verification, place in route, so on, really haven't grown substantially during the decade. They may have grown better for us than others but the total market has been relatively flat or declining, actually declining a little each year.

Fairbairn: All right. So I'm going to wrap things up here. I think we've got a pretty good coverage here unless there's some particular points you wanted to make outside. One of the questions I wanted to ask was that you have a pretty broad base of experience from semiconductors to software, embedded software, systems and so forth. Where do you, you know, for somebody, a technologist like yourself, entering college or entering the workforce these days, where do you think the exciting opportunities are? If you were that student today, what direction would you be most fascinated by?

Rhines: In electronic design automation?

Fairbairn: Well, no, just in, I mean, looking in a broader sense. Not just looking at your business today but looking at your broad base of experience, you have knowledge of semiconductors, you have experience in electronic design from chips on to systems, in those related areas, where do you think the exciting developments over the next 10, 20, 30 years are?

Rhines: So starting at a very high level, it's true that, in engineering in particular, different disciplines of engineering become exciting for periods of time and, at any given period, there's one that is growing very fast and there are some that are not growing fast at all. And one of the lucky choices I made, getting into materials, is that, regardless of what's hot in the current period, whether it's electronics or chemical engineering or mechanical engineering or civil, they all need new materials. And so materials tends to be the stable one that will attach itself to whatever is growing. In my case, electronics was growing as I came out of grad school so electronic materials were key and it formed a basis to get me into totally unrelated things, like design, for example, but the electronics industry was a very exciting place to be during the '70s, '80s, '90s, and it still is today. Now, as I look forward and say, "Well, what's changing?" You've solved a lot of problems but there seems to be a degree of stability now. I have to look first on the electronics side and, as I had mentioned, system design, I believe, is a whole new frontier and design in general is something for a new graduate that is the epitome of engineering. It's really what engineers create. The name “engineer” comes from ingenious or inventors and design is one of the most exciting disciplines. I think that, as chips become true systems and as we have to put disparate technologies together, mechanical with electrical with optical with control and so on, that system design challenges and the accompanying embedded software, will be an area of growth for as far as we can see into the future. If I look more broadly and say what, beyond electronics or electrical engineering, looks exciting? The things that are happening on the materials front today in nanotechnology, in the evolution of totally new materials that are driving new industries and the evolution of where the information technology of the future goes provide a wide variety of opportunities to take new basic technology capabilities and design products. And those could be biologically driven, things where you're doing engineering at the genetic level to create new kinds of drugs or new kinds of medical treatments. It can be design that brings together nanotechnologies and other capabilities to create new solutions to problems like chemical pollutant detection or the ability to sense chemicals in security systems at the airports to stop various kinds of unwanted...

Fairbairn: Threats.

Rhines: ...threats to our security. It can be the ability to analyze the effects of various environmental chemicals. When we talk about material products, there are limits to consumption. I'm sure I could own 20 or 30 cars but I really don't need them. There's a point at which you have a home, cars, and other material goods and there are some limits. But information is one commodity for which there is no limit. I can consume more information as more becomes available. Yes, my bandwidth is limited but information technology is unique among the things we've produced. People will consume more and more. There is no limit to the number of videos on YouTube that people will want to watch. There's no limit to the amount of information on the internet. And there's no limit to the innovation that's created when people share information and interact with one another. And so I think graduates today are in a very, very exciting period of bringing insights together from disparate sources. Information technology together with advances that have occurred in the basic fundamental sciences, make it possible to design new products, new capabilities, that make life better for everyone, increase the wealth of the world and make life really exciting and satisfying. And certainly I've been a real beneficiary of that excitement.

Fairbairn: Great. That's a great optimistic point to leave our discussion on. I thank you very much for taking the time to share your thoughts and experience with us.

Rhines: Thank you, Doug.

Fairbairn: Thank you, Wally.

END OF INTERVIEW

