David_Shanno Interview by Irv Lustig, Washington Crossing, PA, December 14, 2017

Early Life

IRV LUSTIG: I'm here today with my former colleague, Dave Shanno. My name's Irv Lustig, from Princeton Consultants. And Dave has had an illustrious career in the area of math programming. And we're looking forward to our conversation today to learn about Dave's early life, and his career in the field. So Dave, tell us where and when you were born.

DAVID SHANNO: I was born in Hazleton, Pennsylvania, in 1938.

IRV LUSTIG: And Hazleton is located where?

DAVID SHANNO: It's in the heart of the anthracite coal regions.

IRV LUSTIG: Coal region. And you said, it's about 100 miles from here. We're now in eastern Pennsylvania, right by the river. Tell me about your family.

DAVID SHANNO: My father was the principal of the high school. My mother was trained as a math teacher. And she was not teaching when I was in school. But she went back to teaching when I left school.

IRV LUSTIG: What grades did she teach?

DAVID SHANNO: High school.

IRV LUSTIG: All right, high school. Did she have a subject that was her specialty?

DAVID SHANNO: Everything.

IRV LUSTIG: Everything.

DAVID SHANNO: She was better than I was.

IRV LUSTIG: OK. Was she teaching at the same high school that your father was the principal of?

DAVID SHANNO: Yes.

IRV LUSTIG: OK. And so you went to school then in the Hazleton school system?

DAVID SHANNO: Yes.

IRV LUSTIG: And did you end up taking courses from mom?

DAVID SHANNO: No, she was not teaching--

IRV LUSTIG: Oh, but she was after you graduated.

DAVID SHANNO: Yeah.

IRV LUSTIG: And then, if you got in trouble with the principal, was it a home problem, or a school problem?

DAVID SHANNO: Well, fortunately, I never did. Occasionally, there were home problems. When I dented the fender of the car. Never school problems. My father said he never knew I was there.

IRV LUSTIG: Oh, OK. That worked out well. What subjects were you interested in, and good at, back then?

DAVID SHANNO: Well, I was very good at math. I was the district math champion. And I loved everything, except languages. The French course, I had to fight through. And Latin too. My mother drilled me at home on those things. But chemistry, physics, I loved English, I loved history, that was the entire curriculum.

IRV LUSTIG: Were there things that you felt that you did back then that-- you had the interest in math that would have connected you to the types of work that you ended up doing in your career?

DAVID SHANNO: Yes. I started out to be an engineer. And this was in the 50s, when there were lots of jobs in engineering. And my father had gotten a degree in engineering, but came out during the depression, and the only thing he could get was a teaching job. And so, he thrived in it. So he just stayed there, became the principal, and eventually assistant superintendent.

IRV LUSTIG: But, if your father had that background in engineering, did you think that had some influence on your interest in math, and physics, and chemistry?

DAVID SHANNO: Yes, both of my parents were talented in mathematics. And my brother was a historian. And things skip a generation.

IRV LUSTIG: What's the difference in ages between you and your brother?

DAVID SHANNO: Three years. I'm three years older.

IRV LUSTIG: So, you took the math side, he took the history side--

DAVID SHANNO: Right.

IRV LUSTIG: And your parents said, that's all well and fine. Even though they were maybe more mathematically bent.

DAVID SHANNO: Right.

College at Yale

IRV LUSTIG: So, after high school, where did you go to college?

DAVID SHANNO: Yale.

IRV LUSTIG: And what made you choose to go to Yale?

DAVID SHANNO: I was not planning to go to Yale. Every kid in my high school that was really talented in math and science went to Lehigh. And I was given a free ride to Lehigh. My father, as the principal of the school, had a much wider range of schools. And he insisted that I apply to Yale. And so, I said, I'm going to Lehigh. But in those days, applying to a school was filling out one sheet of paper. And sending in transcripts with it.

And it was very interesting, because Yale, at this point in the '50s, was going from being a rich boy's school to trying to get bright kids from public high schools all over the country. And they invited me up for an interview, and a classmate of mine. But I think it was only because they wanted to meet my father. He was the principal.

And they treated us unbelievably. Dinner at Mory's. Stayed in the athletic dorm, where visiting athletic teams were. And I walked away snowed. And I said, I'm going to Yale. And, fortunately, they admitted me. So I went there, and I've been delighted ever since.

IRV LUSTIG: Now, were those really the two choices, just Lehigh and Yale at the time? Or were there other—today, students send 30 applications out, it's kind of crazy. But, back then it was only just a few.

DAVID SHANNO: I had been admitted to Lehigh when I was a junior. And I saw no reason to apply to anybody else. And I won scholarships to five schools, in math contests.

IRV LUSTIG: OK. Your father picked Yale out of a number of prestigious schools. Do you have a sense as to why he chose Yale over any--

DAVID SHANNO: Yes, because there was-- someone had died in Luzerne County, Pennsylvania, who had left four scholarships to Yale. And my father-- a high school principal in those days-- could not afford Yale.

IRV LUSTIG: Right.

DAVID SHANNO: And he had no idea how much money was available for his good students. And he knew Yale, he knew Harvard, he knew Princeton. But there was a scholarship there for Yale. And he had me apply, and I got the scholarship.

IRV LUSTIG: So, I guess, because of the scholarship, that enabled you to go to Yale. Were it not for the scholarship, you probably would have ended up at Lehigh.

DAVID SHANNO: Yeah. They had offered me a free ride.

IRV LUSTIG: OK. So, when you got to Yale, what became your study of interest?

DAVID SHANNO: Well, Yale is known as a school for the liberal arts. And I started off in engineering. They had an engineering school. It was the Sheffield School of Engineering. But, my freshman year, all freshmen are sort of in the same curriculum. I had calculus. And I had very little other science, because I was exempted from chemistry. And I took English, philosophy, economics, and then one engineering course. Which shows how far back I go.

The first semester was engineering drawing. And then the second semester was statics. Which is sort of physics.

IRV LUSTIG: Right.

DAVID SHANNO: And I loved every course I took. And sophomore year, I got into a lab. And I discovered I hated the lab, and the lab hated me. After the first three weeks, they didn't let me turn on-- I was an electrical engineer-- they didn't let me turn on my experiment. I had blown too many fuses.

IRV LUSTIG: OK.

DAVID SHANNO: So the teacher just came over and looked at it and laughed, and went away. Fortunately, it was only one sixth of the grade. I got an 83.

IRV LUSTIG: OK. And so, after that lab course, it was clear you weren't going to be an engineer. So then, what happened after that?

DAVID SHANNO: I loved philosophy, my freshman year. So, Yale had a double major in math and philosophy. And that's what I wound up doing.

IRV LUSTIG: And did you end up doing things that connected the two areas?

DAVID SHANNO: Yes. Logic, symbolic logic, is in philosophy departments, but it's all math.

IRV LUSTIG: Right.

DAVID SHANNO: And so, everything there. And a lot of the philosophy that you got was the underpinnings of math and science.

IRV LUSTIG: I see.

DAVID SHANNO: The philosophy of science. But we got other things too. Like logical positivism. We had a lot of Kant. Because what you knew and how you knew it-- mathematically, that's one thing. It's very different from saying your tire is flat.

IRV LUSTIG: Right.

DAVID SHANNO: So, I enjoyed both of them.

IRV LUSTIG: Now, I forgot to ask you, when you actually went off to Yale, when you were younger, did you have some aspirations of what you would want to do when you grew up, as a teenager, as a young man?

DAVID SHANNO: I wanted to go to space. I wanted to be the first person to land on the moon. I was a serious science fiction fan.

IRV LUSTIG: And this is in the '50s. So this predates Kennedy making his speech about, we're going to go to the moon. The astronaut program was in its infancy. I know, when I grew up in the '60s, that was a big thing. There was all of this talk about-- you used to do these career things. Astronaut was one of the things in there, and the games you would play, and what have you. But we're talking here about 10, 15 years earlier.

DAVID SHANNO: I was just in love with science fiction, like many teenagers that are interested in science.

IRV LUSTIG: And that was kind of the inspiration for saying you wanted to go to space.

DAVID SHANNO: Arthur C. Clarke was my hero. And I wanted to be the first to land on the moon. But, needless to say, I had none of the attributes to be--

IRV LUSTIG: An astronaut.

DAVID SHANNO: An astronaut.

First Job at Union Carbide

IRV LUSTIG: So you finish up at Yale. You've got a double major in math and philosophy. And what came next?

DAVID SHANNO: I sat down in January of my senior year. I had five applications in front of me to go on to graduate school in math. Five for a law school. And five for business school. And I didn't have the energy to fill out any of them. So I decided I had no idea what I wanted to do.

And Yale had a very good placement office then. And I went over and signed up for interviews, and they said, you can do math? There's a new thing out there called a computer. And there was none at Yale at that point.

IRV LUSTIG: This was what year?

DAVID SHANNO: 1959.

IRV LUSTIG: OK.

DAVID SHANNO: And there was not a digital computer at Yale. There was one analog one in the electrical engineering department.

IRV LUSTIG: Which they wouldn't let you near.

DAVID SHANNO: No, they wouldn't let me near it. And any switch, no. And so I took interviews. And Union Carbide offered me a job in New York City. And a lot of my friends were going to New York City. They were all bankers. And they sent me to IBM school, because programming was not taught in colleges at that point.

And I loved computing. And there was very little to know then. There were assembly languages. And there was something called Fortran out there, and I learned it on my own.

IRV LUSTIG: OK.

DAVID SHANNO: And I was the scientific programmer for the whole thing. And this comes into operations research, by the way. Because, in those days, you couldn't buy an IBM machine. You could only rent them.

IRV LUSTIG: Leasing was their primary model.

DAVID SHANNO: Yes, it was. And a court decision came down in that year, that IBM had to offer a lease or a sale. And a PhD in math, that was working in my office, was assigned with someone named Jim Townsend, to determine whether Union Carbide should lease, or buy, every piece of IBM equipment that they needed. They were planning to get a 7090. One of the first commercial ones.

And they used a lot of economics, and a lot of modeling, in a model that I was the only one that could debug. Because I was the only one that knew the machine language. In those days, if a computer program didn't work, you took a core dump. And then you sat there and figured out what was going on. And I was the only one that could figure it out.

IRV LUSTIG: So, this was one of the applications you worked on at Union Carbide was trying to figure out whether they should make the, basically, buy or lease decision for the next IBM problem.

DAVID SHANNO: And Jim Townsend got very rich on this. He left the company and took the model with him. And he founded the companies, Rent or Buy. And he got totally rich, but he blew all the money investing in Broadway shows.

IRV LUSTIG: OK.

DAVID SHANNO: So, I realized that I had not heard of OR at that point. But I realized that mathematical modeling, through this project, could do a lot for companies. And there were ways of getting optimum decisions out of this.

And I went to Pittsburgh for a meeting. And a close friend of mine from Yale was in the math department at Carnegie Mellon. And I saw him out there, and he said, have you ever thought of going to graduate school?

I said yes, but I want to do it in computing. But there were no computer science departments in the country at that point. Alan Perlis was at Carnegie Mellon. And he said, we have computing in the math department. And the most distinguished academic computer there. He was the first winner of the big prize from the ACM.

IRV LUSTIG: Oh, the Turing.

DAVID SHANNO: Yeah, the Turing Award.

IRV LUSTIG: You were invited to Carnegie Mellon and you met Alan Perlis.

DAVID SHANNO: Yes.

IRV LUSTIG: And you were saying, Alan Perlis was the first winner of the Turing Award from the ACM. So, tell me more about Alan, and that interaction you had.

DAVID SHANNO: Well, I took the only course that he offered in the math department. Which was, in those days, numerical analysis.

IRV LUSTIG: But let's step back, before we get to the coursework, you were at Union Carbide for how long?

DAVID SHANNO: A year.

IRV LUSTIG: Just for a year. So, towards the end of that year, someone came to you, you said you had a friend who said, oh, you should go for graduate school in math.

DAVID SHANNO: Right.

IRV LUSTIG: Went over to Carnegie Mellon. You met Alan Perlis. What made you decide to say, OK, I'm going to go for a PhD in math?

DAVID SHANNO: Well, I wanted to do one in computing. I loved the concept of solving problems on a computer. And most computing in those days was just data processing.

IRV LUSTIG: Right.

DAVID SHANNO: Or numerical analysis. And, the data processing part, I had dismissed at Union Carbide, because it wasn't interesting to me. And I was working with a PhD in math there, on this rent or buy program.

IRV LUSTIG: Was that the only problem you worked on at Union Carbide?

DAVID SHANNO: No, there were a lot of different ones. I was there six months, and I was made supervisor of all computing. And that was nothing to do with my abilities. It was just the fact that they promoted people every six months. Because, otherwise, you could move up one floor in the building and get a 10% better offer, because there were no computer scientists around then. There were no people trained in computers.

IRV LUSTIG: But, with that mission of-- you said you were doing scientific computing-- do you recall any of the other types of problems that you were looking at back then?

DAVID SHANNO: Yeah. It was a chemical company. And I was generating tables for them. They were not very sophisticated. The sophisticated models I got into were my next job.

Graduate Work at Carnegie Mellon

IRV LUSTIG: OK. So, you get introduced into Carnegie, you say, OK, I'm going to try and figure out what I can do with computing, and make it more scientific. And you said there was this one course in numerical analysis.

DAVID SHANNO: And it was of solving matrix equations. And solving different differential equations.

IRV LUSTIG: OK.

DAVID SHANNO: And it was a classical mathematics department, other than Alan Perlis.

IRV LUSTIG: OK.

DAVID SHANNO: And I was determined to do my thesis on differential equations. Somehow I wanted to do it with Lyapunov stability of systems of equations. And use computers to generate systems that were stable.

IRV LUSTIG: OK.

DAVID SHANNO: I wanted to get married. I didn't want to get married on a student stipend. So, Gulf Oil offered me a job at their research center.

IRV LUSTIG: After how much time at CMU?

DAVID SHANNO: Three years.

IRV LUSTIG: So you were sort of in the middle of your program?

DAVID SHANNO: I was through all the course work, and I'd gone through the qualifying exams.

IRV LUSTIG: And then the stuff that you mentioned with the differential equations, and the Lyapunov stability, you knew was going to be the subject of your thesis?

DAVID SHANNO: Yes, but Gulf said that I could work on my thesis there.

IRV LUSTIG: OK.

DAVID SHANNO: And, the first problem they gave me, was integrating differential equations numerically, which I could do in my sleep at that point. And the next one they gave me was a very interesting problem. Which is nonlinear optimization. And what they were trying to do is estimate-- when petroleum comes in, you can't measure every aspect of that. So they would use it to refine, they'd send it to the refinement and measure the quality of the products that came out.

And then they would look for certain constants in that particular well. That was a nonlinear regression analysis. And so, they asked me if I could do non-linear regression. And I'd never heard of it, but no one else there had either. And there was a guy at Esso who wrote the two Esso programs, which he called Esso-A and Esso-B. A was linear regression. Esso-B was nonlinear regression. And it didn't work.

IRV LUSTIG: OK.

DAVID SHANNO: And the mathematician I worked with at Union Carbide had built a-- they were a chemical firm as well, and they wanted to get the same information. And he built one using the nonlinear regression, the Quasi-Newton method. It was one where you just use first derivatives to establish a matrix. And it didn't work. These things didn't work. And then they switched to steepest descent, when it didn't work. Which was provably convergent. But it would take hours.

So the question was, why? What was going on? And there was a guy named Don Marquardt at DuPont, who worked with Ken Levenberg. And introduced the idea of Levenberg-- adding a diagonal element to a matrix. And they converged. And I looked at it, and I was able to find the derivative with respect to the whole problem of this thing that you added down a diagonal. And they were so thrilled with this at Gulf, that they said I could use it for my PhD thesis. And I introduced linear constraints to it. And I did everything.

IRV LUSTIG: All right, so, you were working at Gulf, and trying to finish up your thesis at the same time. And so your thesis topic, then ended up being--

DAVID SHANNO: In optimization.

IRV LUSTIG: In optimization.

IRV LUSTIG: And what was the title of your thesis?

DAVID SHANNO: I don't remember any more. It's nonlinear regression.

IRV LUSTIG: OK.

DAVID SHANNO: It was nominally a method--

IRV LUSTIG: And your advisor was Alan Perlis?

DAVID SHANNO: No. He was not my advisor. I had no advisor. I worked by myself. And Gerry Thompson was there in GSIA and he knew optimization. Especially linear and integer programming. And he agreed to be my advisor. And he didn't know what I was doing. I'd go in and talk to him about it, and he'd say, that looks very good. That's interesting.

And no one there taught optimization, other than linear programming.

IRV LUSTIG: Right. So, in doing this work, were you then starting to interact with members of the-- while you were pursuing your PhD-- with members of the nonlinear programming community?

DAVID SHANNO: Yes. I met Don Goldfarb. And I met Garth McCormick. And Tony Fiacco. And all of them became lifelong friends. Especially Garth.

IRV LUSTIG: OK.

DAVID SHANNO: And the one thing I'll give Gerry Thompson, was he gave me the first paper of Fiacco and McCormick and said, you've got to read this. This is totally different. And I read it, and I loved it, and I got to meet Garth and Tony.

IRV LUSTIG: At the time, you were getting into nonlinear programming, without knowing that there was nonlinear programming happening out there.

DAVID SHANNO: Yes.

IRV LUSTIG: Because you didn't have somebody, as an advisor, to say, hey, wait there's this other literature or things going on.

DAVID SHANNO: Well, I got to meetings and-- it was in a meeting in Toronto where I first met Mike Powell. And he was lecturing on the DFP the Davidon-Fletcher-Powell method for quasi-Newton methods. And then I met Don Goldfarb, who had done DFP for linear constraints for his thesis at Princeton. He was in chemical engineering. Mike was working for a physics lab.

IRV LUSTIG: OK.

DAVID SHANNO: And so they were into hard science. And this was not taught anywhere I'd been. I just learned it myself.

IRV LUSTIG: And your PhD was in math, then.

DAVID SHANNO: Yes.

IRV LUSTIG: And even though your official advisor was Gerry Thompson over in GSIA.

DAVID SHANNO: Yes.

IRV LUSTIG: OK. So you finished your PhD in what year?

DAVID SHANNO: 1966. The degree was awarded in 1967, because I missed the deadline by one day in September.

IRV LUSTIG: Oh, I see. OK. Now you mentioned earlier that one of the reasons you decided to, in parallel, take a job and also pursue the PhD, was because you wanted to get married. I presume--

DAVID SHANNO: She's out there.

IRV LUSTIG: I presume you had met Kathie by that point in time.

DAVID SHANNO: Yes I had.

IRV LUSTIG: OK. So that was also starting.

From Gulf Oil to Academia

So you finish up your PhD then, you have a job at Gulf. Did you remain at Gulf after you received your PhD?

DAVID SHANNO: Uh, a little while. Until she got her bachelor's degree at Carnegie-Mellon.

IRV LUSTIG: OK.

DAVID SHANNO: And Gulf was just a dead, dead company. And I used my ability with differential equations and modeled with an engineer there a ethylene cracking problem. And they had the things that they could get out of this problem, and the prices that they got. And we looked at the model, and integrated it through the entire cracking process, and optimized it, and showed them that they were losing a million dollars for every train load that they got.

And I went into my boss, and I said, we saved this company. We made this company a million dollars. And I think I deserve a raise. And he said, David, you have to understand that in the oil business, a million dollars is nothing. So, that discouraged me from staying in the oil business.

IRV LUSTIG: So then, what happened after that?

DAVID SHANNO: I didn't know that I was going to be an academic researcher. I wasn't that confident that I could do it. And I took a job with a small electronics firm in Princeton, Electronics Associates. And they made computers, and they wanted me to be their mathematical software guy. But the company was going under.

IRV LUSTIG: OK.

DAVID SHANNO: So, my boss was involved with Princeton, and he sent me up to Princeton to work on the Mars landing.

IRV LUSTIG: You mean Princeton University?

DAVID SHANNO: Yes, Princeton University. The company was in Princeton.

IRV LUSTIG: OK.

DAVID SHANNO: This guy, Bob Vichnevetsky was my boss there. He wound up on the Rutgers faculty with me. Years later. And so, I discovered that I loved academic research, I thought it was fascinating. And I had been offered a job when I took the EAI, Electronic Associates job.

I'd been offered a job by the University of Chicago, in their business school. And I called them up, and I said, is that job still open? And they said, absolutely. And I went there, and I just learned what operations research was. Alex Orden was there. And Bob-- I don't remember their name.

IRV LUSTIG: Don't worry about it.

DAVID SHANNO: But Alex was the guy that introduced math programming to that.

IRV LUSTIG: Was he also in the business school as well?

DAVID SHANNO: Yes.

IRV LUSTIG: OK.

DAVID SHANNO: He was in the business school as well. And they were building an OR group. Because they thought it was the thing of the future.

IRV LUSTIG: So what year was this?

DAVID SHANNO: 1967.

IRV LUSTIG: OK. So you really had a short time at that position at Princeton, in that small company. So you started in Chicago in Fall of '67?

DAVID SHANNO: Yes.

IRV LUSTIG: And so, you were in the business school, and what types of things did you end up teaching then?

DAVID SHANNO: I taught Mathematics, and the students rebelled. They said, why don't you go to Bell Labs? So I learned to tame it down for the business school.

IRV LUSTIG: Right.

The BFGS Algorithm

DAVID SHANNO: And meanwhile, I had seen Mike Powell and Don Goldfarb lecture on the DFP algorithm. And I wondered if you could use the lambda parameter on the diagonal to that, to make it better.

IRV LUSTIG: OK.

DAVID SHANNO: And so, I had no success with that. But Bill Davidon had written the report that started this whole thing. And I was at Chicago, and he had been at Chicago, and I got his report on it. And he had built a parameter into his that everyone had ignored. And I looked at it and I thought, this could be used to condition the matrix. And my BFGS paper came out on conditioning quasi-Newton methods.

IRV LUSTIG: OK.

DAVID SHANNO: And I found the maximum conditioning. And just using this parameter, putting it in to the formula. And lo and behold, I got to BFGS.

IRV LUSTIG: So, now, the BFGS stands for--

DAVID SHANNO: Broyden, Fletcher, Goldfarb, and Shanno.

IRV LUSTIG: And how come all four names are attached? It wasn't one paper with the four of you.

DAVID SHANNO: No. Every one of us did it completely independently, and completely differently. It was very interesting. Because when Mike Powell first met me, he said, you're the one that did it non-linearly. Fletcher did it linearly.

IRV LUSTIG: OK.

DAVID SHANNO: So, that was what led to the BFGS. You're trying to get something that behaved better. The DFP-- it was better than things had been up to that point. But it was just not stable on very hard problems.

IRV LUSTIG: Now, how, back then, we're still-- I mean, we're not in the really early days of computing, but we're still in the earlier days. Was the quality of these algorithms evaluated by implementing them numerically?

DAVID SHANNO: Yes.

IRV LUSTIG: And so, when things were said, this is better, it was because some computational experiment was done.

DAVID SHANNO: Yes.

IRV LUSTIG: And this is the late '60s.

DAVID SHANNO: Yes. And there was a very small test set at that point.

IRV LUSTIG: And these were all pure non-linear minimize linear, non-linear functions, no constraints at the time.

DAVID SHANNO: Yes.

IRV LUSTIG: Who made the realization that BFGS was, hey, these guys are all doing the same thing?

DAVID SHANNO: I don't know. I had never met Charles Broyden. And I had met Roger Fletcher and Don Goldfarb and we talked about it.

IRV LUSTIG: OK.

DAVID SHANNO: But, all of the algorithms came out before we had talked about this, BFGS. And the formula was always, always the same.

IRV LUSTIG: OK. So you all came to the same formula, just from four different directions.

DAVID SHANNO: Yes.

IRV LUSTIG: OK.

DAVID SHANNO: And it was sort of like Boston traffic. It all winds up in the same place. And so, it was fairly named. We each worked on it, we each got it right, and all without knowing each other. All taking it from a different direction.

IRV LUSTIG: And you each got an independent publication about it.

DAVID SHANNO: Yes.

IRV LUSTIG: So you're at Chicago. That was probably your first main result that you had as an academic. How long did you stay at Chicago?

DAVID SHANNO: Three years. Because our son was born. And there was gang warfare in that area of Chicago, at that point.

IRV LUSTIG: OK. And this is around 1970 or so?

DAVID SHANNO: Yes.

IRV LUSTIG: OK.

DAVID SHANNO: So it was just an unsafe neighborhood. And I didn't want to stay there and raise a child where you couldn't put him out to play.

IRV LUSTIG: Right.

DAVID SHANNO: Any kid that went out with a bike, came home without it.

IRV LUSTIG: Well, I would imagine then, the university must have been struggling with the same kind of issues from many faculty members, probably.

DAVID SHANNO: Yes. I had a student there, Paul Kettler, who the year after I left, was shot.

IRV LUSTIG: Oh, wow.

DAVID SHANNO: And it was touch and go for a long time. He was shot in the stomach, and it took him a year to recover.

IRV LUSTIG: And so you left Chicago and you went to where?

DAVID SHANNO: University of Toronto.

IRV LUSTIG: OK. And was there any results, and how long were you at Toronto?

DAVID SHANNO: Five years.

IRV LUSTIG: And was there anything that you felt, from a research perspective, that was significant in that period of time, when you were there?

DAVID SHANNO: No. They asked me to be president of the University of Toronto.

IRV LUSTIG: And you were young.

DAVID SHANNO: I was in my early 30s.

IRV LUSTIG: OK.

DAVID SHANNO: I got very politically involved there. And my wife said, you don't want to do this. You don't want to be an executive. I'm not changing my citizenship to be president of the University of Toronto. I had adoptive Canadian citizenship. So I came back to the United States, and immediately got back into research. Which is what I've done all the rest of my life.

IRV LUSTIG: And so you left from Toronto to where?

DAVID SHANNO: A nine month stop at the University of Mississippi. And then six years at the University of Arizona, which had a very good applied math program.

IRV LUSTIG: OK. And then at Arizona. So when did you start at Arizona?

DAVID SHANNO: I started there in 1976.

From Unconstrained to Constrained Optimization

IRV LUSTIG: OK. Five years. And so now you're back into research. You started in '76 in Arizona. And was there interesting research that you did in that period of time?

DAVID SHANNO: Yeah. Up till that point, the BFGS is just for unconstrained optimization. And I got interested in constrained optimization. And I looked at Fiacco and McCormick's stuff. Which, as we all knew, had a lot of problems at that point. And I looked at sequential quadratic programming, and I did something with both. And it was not very exciting. I was thinking of getting into the statistics, do numerical statistics.

IRV LUSTIG: OK.

DAVID SHANNO: Because the statisticians didn't know how to do numerics very well at that point. And Karmarkar came on.

IRV LUSTIG: Well, that was 1984. So, you said you started in Arizona in '76, and you were there for six years, right?

DAVID SHANNO: Right.

IRV LUSTIG: So you went from where in '82?

DAVID SHANNO: I went to the University of California at Davis.

IRV LUSTIG: And what made you decide to move?

DAVID SHANNO: I didn't like the heat. I got tired of the heat. Now I welcome it. Back then, I didn't have arthritis.

IRV LUSTIG: Right.

DAVID SHANNO: So, I got there, and I worked with a guy named David Rocke. And we were doing stuff on outliers. Outlier points on nonlinear regression.

IRV LUSTIG: OK.

DAVID SHANNO: And we devised a method that was numerically able to identify these points, and show exactly how significant they were. And so this is why I wanted to get into statistics, computational statistics. Because there was a lot lying there that the statisticians didn't know how to do.

IRV LUSTIG: Right.

DAVID SHANNO: And then Karmarkar.

IRV LUSTIG: So, prior to the Karmarkar stuff, and you were doing the works. You did BFGS, then you said how people evaluated it, as you implemented it. And there was work that you did later in constrained nonlinear optimization. You were always considered a nonlinear programmer.

DAVID SHANNO: Right.

IRV LUSTIG: Were you also-- were you still doing your own implementations, or having students do them for you?

DAVID SHANNO: At that point I was doing most of my own. But I had worked with Roy at the University of Arizona.

IRV LUSTIG: This is Roy--

DAVID SHANNO: Roy Marsten. And we did one paper together, where he actually did the programming.

IRV LUSTIG: And we all know, and you and I having worked with Roy, know that Roy loves to program.

DAVID SHANNO: Yes. He was very good at it.

IRV LUSTIG: Yes.

DAVID SHANNO: So, that was the first time I hadn't done everything myself. And it was all Fortran IV.

IRV LUSTIG: Right. So now, you were at Davis from what period?

DAVID SHANNO: I was there from '82 to '86.

IRV LUSTIG: Right. And then you came to Rutgers at that point.

DAVID SHANNO: Yes.

Interior Point Methods for Linear Programming

IRV LUSTIG: And you said, hey, well Karmarkar came along, which was around 1984 or so.

DAVID SHANNO: Right.

IRV LUSTIG: And we know it was having an impact in the linear programming community. But you were the nonlinear programmer. So what attracted you to what was going on there at that point in time?

DAVID SHANNO: Just the simplicity of it. The idea that you could use basically a nonlinear technique to solve linear programs.

IRV LUSTIG: So before you and I started collaborating, which was around 1988, or so--

DAVID SHANNO: Yeah.

IRV LUSTIG: And you were out in Davis, what was some of the early work that you did in interior point methods?

DAVID SHANNO: It was the dual method that Roy and I had done together.

IRV LUSTIG: OK. So you were collaborating with Roy. He was still out at Arizona. You were at Davis, and you were saying, hey Roy, implement this.

DAVID SHANNO: Yes.

IRV LUSTIG: OK.

DAVID SHANNO: And he was thrilled to do it. They took his picture at the University of Arizona with a big problem he solved laid out on the football field.

IRV LUSTIG: OK.

DAVID SHANNO: So, we were both very excited about this. And when you and I started working together with Roy, no one knew exactly how to go about this thing. Initially the dual variables were just ignored.

IRV LUSTIG: That's right. I mean, the original Karmarkar method was primal.

DAVID SHANNO: It was totally primal. And a lot of this stuff was totally dual, and totally primal. And you were the first one that came up, that had a solvable primal dual method.

IRV LUSTIG: Right. Because, well, prior to that there was a primal dual that required feasibility.

DAVID SHANNO: Yes. That was Kojima.

IRV LUSTIG: So you were at Rutgers. The Karmarkar stuff was all happening. You started working with Roy. We met in 1987. And the primal dual methods, there was the work done by Kojima. That started it. And then I started working on, wait a minute, we've got to deal with this requirement of feasibility.

DAVID SHANNO: Yeah.

IRV LUSTIG: So, I know the story. I lived the story. But I think we're telling a story for our viewers in the future. Can you say, tell the story of how things were developing from your point of view, of me sitting as the new academic in Princeton. You were the veteran nonlinear programmer. And how you were getting into linear programming.

DAVID SHANNO: Well I call this period, the period when I was going straight. And I was a nonlinear programmer. And I just looked at the Lagrangean of this problem, and took the derivatives-- no one dealt with derivatives in linear programming, because they didn't mean anything.

IRV LUSTIG: Right.

DAVID SHANNO: And so, I took the derivatives of that, and it turned out to be exactly what you had derived using duality.

IRV LUSTIG: Right.

DAVID SHANNO: And it didn't mean a thing for linear programming, because you'd already gotten it.

IRV LUSTIG: Right.

DAVID SHANNO: But it mattered a lot in nonlinear programming.

IRV LUSTIG: And you ended up, later in your career-- we had a collaboration for about my six years at Princeton on applying the primal dual methods, and all the activity that was going there. And I know you've written a long article that's out there, that people can read, that tells the story of our adventures back then. Can we summarize maybe, for our audience, a little bit of the journey that we took together, from the beginning and the work that we did, that led to our capstone paper that we put out around '93?

DAVID SHANNO: There was real competition with the simplex method. And John Forrest, we both owe a lot to his willingness to run competitively with us. Bixby and Forrest were the two developing faster and faster methods of the simplex method.

IRV LUSTIG: Right.

DAVID SHANNO: And Forrest, we went up to IBM regularly to compete with him.

IRV LUSTIG: Right. And he was writing which code? It was OSL.

DAVID SHANNO: OSL.

IRV LUSTIG: That was the OSL And he was actually working on that with John Tomlin.

DAVID SHANNO: Yes. So they were writing that, and it became a competition to see who could solve the toughest problems the fastest. And that's what we were doing. We were improving the conditioning of the matrix. Roy was finding ways using sparsity to save operations.

IRV LUSTIG: Right.

DAVID SHANNO: And you and I were looking at problems that arrive in all computation, where you just have no accuracy.

IRV LUSTIG: Well, yeah, and I had Mike Saunders once said to me, the most amazing thing that we did at the time is, we had no proof of convergence.

DAVID SHANNO: Right.

IRV LUSTIG: In fact, I'm not even sure if there ever was one produced yet. So we were flying blind without convergence, and yet it was working.

DAVID SHANNO: It was. And we kept improving it. It was an endless cycle. And we were invited everywhere. It was a lot of fun.

IRV LUSTIG: And there wasn't-- I think some of what helped us, was the competition that was happening with simplex. We had computing that was allowing us to turn things around quite quickly. So, I know I can tell the story, but this is your story, Dave. Can you tell a story a little bit about some of the times, and how we were collaborating together and producing results each day?

DAVID SHANNO: Yeah. You would set up a whole set of runs, overnight. And we'd come into the office at Princeton. Sometimes when you went to CPLEX, it was in your house at Princeton.

IRV LUSTIG: Right.

DAVID SHANNO: And we'd sit down and look at these results, and figure we can improve this. And we were moving the starting values of the dual variables. We were the first to think of using different estimates for the dual variables than the primal variables. And Yinyu Ye, I remember, said to us, that's a great idea. And everything we were looking at, we found a lot.

IRV LUSTIG: Right.

DAVID SHANNO: And I can't remember all of them. That one was a biggie.

IRV LUSTIG: Yeah. And even today, the influence of the starting point is still an issue in barrier methods.

DAVID SHANNO: Yes. We tried every starting point imaginable. And we made them, sometimes, problem dependent. We had ways of doing that. Someone has once said, mathematicians are either philosophers or plumbers. And in those days, we were plumbers.

IRV LUSTIG: Oh, yes. Yes.

DAVID SHANNO: You have to know the philosophy to be a good plumber. You have to know what problem you're solving, what the theory is.

IRV LUSTIG: Now, at the time, you were at Rutgers. Which is where you ended up for the rest of your career. We ended up working together, because you had a sabbatical at Princeton that year. Which is when all things were happening there. I know I left Princeton in '93.

Interior Point Methods for Nonlinear Programming

So tell us about the post interior point linear programming work. I guess after your straight period.

DAVID SHANNO: Yeah. Well, the most important thing I saw there, was in that 1985 meeting in Boston, where we first met. Margaret Wright gave a talk on how the gang of four plus John Tomlin had equated this with Garth McCormick and Tony Fiacco's interior point method. And I wondered about that, because people had given up on that completely, as a method of solving nonlinear programs.

IRV LUSTIG: And why was that?

DAVID SHANNO: The problem was hideously conditioned. Feasibility was a problem. There were a whole set of problems with that. And lo and behold, if we just took the Lagrangean of that, and differentiated it, then we got something else that was really good. And it was the next sabbatical I took at Princeton, where I worked with Bob Vanderbei. You were gone.

IRV LUSTIG: Right.

DAVID SHANNO: And he and I developed this code to solve nonconvex nonlinear problems with this thing. And we both learned a lot from linear programming. Like how to set the dual variables, how you conditioned the problem, so you could solve the equation well. And that led to an enormous amount of work.

And yeah, the nonlinear programming problem is much harder than the linear programming problem. And as far as I know, there are not settled codes to do this stuff. When Bob and I thought we had something really good, Andreas Wächter and his thesis advisor at Carnegie-Mellon, Beigler. Larry Beigler--

IRV LUSTIG: OK.

DAVID SHANNO: --had shown that there was an instability in this thing. That it would go crazy. And we were bringing back the Fiacco and McCormick stuff, and putting all sorts of things into the problem. And Fiacco and McCormick came back. Big, big time. And Garth was very happy about it, before he died. It was great stuff. It's still going on, I'm still working on it with Bob Vanderbei, and Hande Benson, who was our joint student at Princeton.

IRV LUSTIG: Right. And now she's at Drexel.

DAVID SHANNO: She's at Drexel.

Career Retrospective

IRV LUSTIG: Right. So, we've gone through your academic career of the first significant thing, I mean you have an algorithm with a letter. Right? BFGS. You're the S. In that area. Then we have the work that you did with me and Roy on interior point methods and primal dual methods for linear programming. And then you have the work that you've done with Bob and Hande in nonconvex interior point methods. Maybe I've summarized for you those are kind of the main contributions to the field. Out of all of that, what do you find is the main one? Because they're all good. But if you had to pick one, and you're allowed to not pick the stuff we did.

DAVID SHANNO: I would say the nonlinear stuff I've done. We've made huge contributions to linear programming.

IRV LUSTIG: Right.

DAVID SHANNO: And I've been trying to kill the BFGS for 30 years. And it's back. It is huge. The machine learning people are--

IRV LUSTIG: Yes, that's right.

DAVID SHANNO: --using it all the time. And Hande and I have a paper under review, final review, at *Math Programming*. Where we use these symmetric rank one with a modification that takes third order information into things, that beats it on large problems.

IRV LUSTIG: No, but it's interesting that you mention it. Because now, we're doing this interview at the end of 2017, machine learning is the hot thing this year. And I have read about how they're all starting to look back at the BFGS work that was done in the early '70s, realizing that it's important in their field. So, maybe that's actually the lasting impression, is that it's something that's still relevant today in a very hot field. As is the interior point method work that we've done.

DAVID SHANNO: Everything. The barrier method for interior point, for linear programming. Any big problem, if you talk to anybody that's in software, any big problem you have to solve initially with a barrier method.

IRV LUSTIG: Actually, it's funny. I've seen it both, there's all the tests that have been done, and I tell people we're at a stage now where it's around 40% to 45% of the time barrier wins. And 40% to 45% of the time, dual wins. And primal is the afterthought at 10 to 15. It depends upon the test set and the computer you're on. Barrier can be done in parallel. That changes things. And then there's a question of, well, do you have to include the basis crossover, all these arguments. Having been too close to the debate, everybody thinks, oh, you want barrier to win. And I'm like, however I can solve my problem the fastest is what's important.

Perspectives on the Field of Operations Research

So let's talk about the field of OR and how you've seen it progress over your career. So you mentioned that when you started-- when you were doing your PhD, you were just barely getting introduced to it, at that time. You were doing nonlinear programming in a university that nobody knew what that was.

DAVID SHANNO: Right.

IRV LUSTIG: Now we have healthy journals, conferences, etc. How have you viewed this evolution of the field over the course of time that you've seen it grow, from back when you started in the '60s, to where we are today, almost 50 years later?

DAVID SHANNO: Well, we saw it, when we were doing the linear programming stuff. The airline- assigning planes to routes, and assigning crews to planes. We made huge advances there. And the airlines were very happy with this, and the railroads did the same thing. The Canadian railroad schedules all of their wheat cars. They use linear programming to get-- they have three weeks of wheat mowing on the Western provinces. And there's a huge amount there, and they've got to get it to the coast.

IRV LUSTIG: Right.

DAVID SHANNO: It's made huge progress. But the one that's coming, that is the biggest problem. Machine learning is just a small part of this. It is the self-driving traffic, the thing. Can you imagine a schedule, set up nationally, that keeps track of every car, every road, gives you warnings when there's an accident ahead?

IRV LUSTIG: Yeah. And I think that maybe what you're leading to is today's world, people talk about the self-driving vehicles as being relatively autonomous. But if they now start coordinating their work--

DAVID SHANNO: They have to.

IRV LUSTIG: Right.

DAVID SHANNO: They have to coordinate them, to make an improvement. And that is the biggest potential thing I have seen of O.R.

IRV LUSTIG: That's really an interesting insight Dave. I mean, I hadn't thought of it that way.

DAVID SHANNO: Well, I don't think anyone in Washington understands economics. But economics planning is a very much an OR field. You can use data to get far better, there's much more data around. And you can forecast better. And then you can plan better. And you can schedule openings of stores, you can evaluate markets.

It's like forecasting the weather. Forecasting the weather, when I was a kid, you looked what was west of you a day ago. And then you say, you're going to have that weather today. As they've built mathematical models of it, and used sophisticated mathematics, they've used some of our optimization. I was at NCAR years ago, and they were using my stuff. And it's so much better now.

IRV LUSTIG: Right.

DAVID SHANNO: It's not perfect. Nothing is perfect. But, you can use all of these tools. Statistical analysis, optimization, everything under the sun, to machine learning. Machine learning actually has more components to it than that. The things that taught machines to diagnose breast cancer made it likely that you could infer from that, by the health of those women, what were likely to lead to breast cancer things. And I think it's a wide open field.

IRV LUSTIG: And, in your career, you've seen this growth.

DAVID SHANNO: Yes.

IRV LUSTIG: Right? When you were first doing work in the '60s, right?

DAVID SHANNO: Two variable problems. Four. Four was a big problem.

IRV LUSTIG: Right. So, you've had this career, the things that you've done or have been used. We started with small problems, moving to larger problems. And you've went from doing computing, to letting the rest of some of your colleagues, like myself, do. And then Hande and Bob Vanderbei do the computing.

DAVID SHANNO: Right.

Current Activities

IRV LUSTIG: Did you ever feel, in the latter parts of your career, that you wanted to do any more coding at all?

DAVID SHANNO: I'd love to now that I'm retired. Just little problems. But I don't even know the current languages.

IRV LUSTIG: Right.

DAVID SHANNO: I'm a Fortran guy. Fortran IV.

IRV LUSTIG: Right. And finding a Fortran compiler isn't so easy these days.

DAVID SHANNO: No, it isn't. And I'd have to go back and learn things. And I'm going to be 80 in April, and I'm not sure that I'm capable of concentrating that long. I'm too busy just keeping alive.

IRV LUSTIG: Right.

DAVID SHANNO: It's fun to do this. I enjoy working with Bob and Hande.

IRV LUSTIG: So, how often do you still go to Princeton these days?

DAVID SHANNO: Three or four times a semester.

IRV LUSTIG: OK.

DAVID SHANNO: Generally. We haven't done as much this year, because I've been operated on. And Bob's been operated on. And Hande's adopted a child.

IRV LUSTIG: Life goes on.

DAVID SHANNO: She's learned that being a mommy isn't all that easy. But we're circling back. This thing that Mike Powell proved, that a quasi-Newton method cannot get a convergence proof for it. And we've got one for the SR1. With taking in three dimensions on it. And for many, many years, the problem occurred in nonlinear programming, what do you do with negative curvature? When you ski over the edge, and it drops off like that.

Nick Gould and Phillipe Toint did something on it. They analyzed it. They had beautiful theoretical results, but their programs didn't match up. They couldn't beat things out there. Hande and I took it apart and made it work. So now the old problems are coming back up when you're dealing with huge data sets. And there are new ideas out there.

Concluding Remarks

IRV LUSTIG: Well, and I think the other thing, trying to tie the beginning to the end, when you first started working at Union Carbide, you started saying, oh I can do some math on a computer.

DAVID SHANNO: Right.

IRV LUSTIG: And started to solve it and then you discovered mathematical modeling. And then your career has been developing algorithms for certain problems. And it wasn't always about the proof of convergence, and you've had a lot of those, but it was also making it say, hey, let's make sure we can implement it.

DAVID SHANNO: Yes.

IRV LUSTIG: And that's always been the theme that's been true from back in the BFGS days, to the work we did in interior point methods for linear programming, to the work that you've done with Bob Vanderbei and Hande Benson in the nonlinear world. You're still out there implementing, and evaluating the quality of these algorithms. And I think, to your credit, and maybe you're not giving yourself enough credit here, so I'll do it. Is to say, that insight, which occurred in the mid '60s, when there wasn't a lot of computers around back then. Even earlier than that.

That is something now that's inspired people like me to do that kind of work, as well as a lot of our colleagues and friends. And now, doing the computation has become a major part of our field. So, I want to credit you, Dave. And give you the thanks for inspiring people like me, and our other colleagues, for making that connection. And saying that solving the problem is what matters.

DAVID SHANNO: Yes. I hate pure math. I don't care how many angels can dance on the head of a pin. Pure mathematicians have made incredible breakthroughs. But it takes people like us to use them. Science that is not usable is, to me, not science.

IRV LUSTIG: Well, and I think there was another thing that reminded me of this, is that I go back to that comment that said, when we were flying blind and this thing worked, and we never proved convergence. Anything in work that was done prior to that was always, your work was, OK, I've got the proof of convergence, and I'm going to implement it. And then we flipped that on its head and said, well let's implement it, and if we can get a proof of convergence, that's good.

DAVID SHANNO: Right.

IRV LUSTIG: And I think that's kind of inspired a lot of work in the field, to say we don't always require that proof. And I think that was a philosophical change that happened, and I think you've had a big influence on that.

DAVID SHANNO: Every proof of convergence I have looked at, that is for a non-trivial problem, throws a bunch of parameters in there that you can't estimate, if you're trying to implement it.

IRV LUSTIG: Right.

DAVID SHANNO: And so, why bother? If you can make it work, if you know the theory-- you have to know the theory. You can't ignore theoretical things. So, if you know it, try it. And see what you can make work.

IRV LUSTIG: Right. And that's been a good story of your career.

DAVID SHANNO: Yep.

IRV LUSTIG: All right, Dave. I want to thank you for your time today. It's been good to hear the full story of Dave Shanno, and relive a little bit of our collaboration. So, thanks Dave. It's been a pleasure.

DAVID SHANNO: It's been a pleasure for me. Thank you for setting this up.

IRV LUSTIG: My pleasure.