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Brian Carlisle

An interview conducted by
Peter Asaro
with
Selma Šabanović

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Q: Okay, so why don't we just start by having you introduce yourself and tell us where you were born and where you grew up.

Brian Carlisle: Hi. I'm Brian Carlisle. I was born in San Francisco. I grew up in both San Francisco and Marin County and then later lived down in the Peninsula.

Q: And where did you do your undergraduate studies?

Brian Carlisle: I went to both undergraduate and graduate work at Stanford University. So I studied mechanical engineering there at Stanford. And a professor was a gentleman named Bernie Roth, who was very well known in the robotics community and who was also the advisor and professor for a number of other colleagues that I subsequently worked with, including Bruce Shimano, whom I believe you've also interviewed.

Q: How did you first become interested in robotics?

Brian Carlisle: I was always kind of interested in mechanical things. My grandfather was a pattern maker who made patterns for big diesel engines. So what he did was make big wooden patterns for these giant engines that would pull freight trains around. And I visited him several times in Ohio. And he took me one time to his factory where he worked. And I was sort of fascinated by the whole process of making things, and creating something that was big and strong and powerful and mechanical. So that got me interested in mechanical things at a very early age. And then later, as I was a teenager, I got interested in model railroading. And I got a big model railroading thing going for a while when I was 16, 17, 18, and did that. And then finally when I went to college, I decided I wanted to go into engineering.

Q: And when did you decide you really wanted to focus on robotics?

Brian Carlisle: Robotics probably about my senior year, I would guess. I started generally in mechanical engineering. I met some folks through Bernie Roth, my advisor. My senior year a gentleman named Vic Scheinman, who was also at Stanford, and Bruce Shimano. And Vic was working on some robots there at Stanford, which we'll talk about here in a little bit. And so I got together with Victor and with Bruce kind of my senior year, master's year. And then when I graduated with my master's degree, I went to work with Vic and Bruce in a very, very small company.

Q: Did you do a Ph.D. also?

Brian Carlisle: No. Just I did a master's. Actually, I did most of my undergraduate work in mechanical engineering and design, and mechanical engineering. And then most of my master's work in electrical engineering. And I was particularly interested in servo mechanisms. And at that time, microprocessors were just coming out. I graduated in 1975 with my master's. And microprocessors were coming out in the early, mid-'70s. And so servo control was transitioning from essentially an analog process to a digital process. And so I took a number of courses in microprocessor-based control and sort of servo engineering and servo mechanisms. And all that was, you know, kind of led right into the robotics thing.

Q: What kind of microprocessors were they using for that?

Brian Carlisle: The very early ones that first came out for microprocessor motion control were things like the, what was it? It was the 8088, it was not the 8088. It was 6802 I think. Or 6502 was the number. It was a little small eight-bit slow 10 megahertz processor. But the first Intel architectures were coming out kind of in the mid-'70s. And also DEC, who is no longer with us, Digital Equipment Corporation, came out with a minicomputer, which they sort of turned into a microcomputer, and that was called the LSI-11. And they had taken something that had been a 32-bit architecture and kind of squeezed it down into something that would fit in kind of a breadbox. And that was kind of the first more general purpose, high level microcomputer/minicomputer kind of architecture. And so we used that early on in the mid-'70s to actually do the computations to control the robots. And we used things like the very small 6502 microprocessors to control the individual motors.

Q: How were you programming them?

Brian Carlisle: The microprocessors or the robots?

Q: Both.

Brian Carlisle: Well, robots have several layers of control in them. There's a layer of control which is motion control, which is basically controlling the motors. And then since you have some number of motors in a robot, ranging typically from three motors to six or seven motors, you need to coordinate all of those motors together to make the robot move. And you do that typically by having a mathematical model of the robot called a kinematic model. And you can tell the robot at a higher level computer what kind of motions you want to make, and typically straight-line motions in Cartesian space. And then the computer figures out all of the individual commands for the individual motors. So you have at the sort of supervisory control level a language which is a robot programming language, similar to many computer languages, with its standard control structures, do loops and if loops and while loops and case structures and so forth. But then in addition to that, you have a whole library of motion control commands. Open the gripper or move in a straight line, or in some cases talk to a vision system and get information from some kind of a sensor and then make some decisions about that. So my partner that I've worked with whom you interviewed, Bruce Shimano, really was kind of the software guy, and he was the guy that was expert in the kinematics and the language and the mathematics to move the robots. And I was more the hardware guy, the mechanical guy and electrical guy in terms of the mechanisms themselves.

Q: So what were some of the big challenges for the electrical and mechanical design of the first systems you worked on?

Brian Carlisle: Well early on, certainly in the early '70s, the earliest robots were hydraulic-powered machines. They were very big and they were very powerful, but they really didn't have much of a control system in them. The earliest controllers were rotating drums in which analog information was stored. It was like a player piano. The drum would rotate around and it would send out some analog information to some servos and the robot would sort of lurch around and open and close a gripper. And so that was not a real sophisticated controller, but nonetheless, some early applications in the 1960s, were done that way. The computer control of robots was really introduced in the mid-1970s, and Stanford was one of the principal locations where that was done. MIT was also working in that area at the time and Carnegie Mellon a little bit. One of the big challenges was first of all, how do you make all this complicated mathematic execute quickly enough in the computers that were available at the time? Secondly, how do you replace these hydraulic servos with electric servos or electric motors that were strong enough to move some of these big mechanisms around? So there was both a software design and then kind of a mechanical design challenge in making the early electric robots.

Q: Where there any memorable breakthroughs in that?

Brian Carlisle: Well, I think probably the biggest software breakthrough was a thesis done by Don Piper in 1968. He was another one of Bernie Roth's students. And Don's thesis was essentially how you solve a six-axis kinematic – the inverse solution for a six-axis kinematic transformation. That is, how you invert the rather large and complicated matrix that results when you're trying to figure out how to move six degrees of freedom in a robot arm to get the tip to move in straight lines. So Don Piper sort of figured that out, and that was kind of the basis for computer control of robotics. That was an important breakthrough, and that came from Stanford also, in Bernie's group.

Q: The first system you worked on was the Vicarm?

Brian Carlisle: Yeah. We have a bit of a history slide here. We have sort of in the 1969 timeframe something called the Stanford Arm, which was a Cartesian sort of a polar coordinate robot that rotated and extended and had a wrist and so forth. And that was developed by Vic Scheinman at Stanford and a couple of other students there. Bruce Shimano was involved in doing some of the controls for that. The control system for that robot was a PDP-10 computer. It was the size of a Volkswagen, and a very big, fairly expensive computer at the time. It was used just really primarily in research at Stanford for a couple of years. Then in 1975, when I graduated from Stanford, I joined Victor and Bruce joined Victor, and three of us had this small company called Vicarm or Vic's Arm. And we sold one of these robots to the General Motors research lab. I remember delivering that on my birthday in a snowstorm, my birthday happens to be in February, to Troy, Michigan. And dragging this robot to the loading dock there at General Motors through the snow. That was entertaining. And then going in and installing it with a couple of fellows who are also known in the robotics community, a gentleman named Lothar Russol and another fellow named Mitch Ward.

And so we delivered that robot to them with a – at that time, we had packaged the language that Bruce had developed at Stanford into something that would run on one of these LSI-11 computers. And so we delivered the robot and a controller. Actually I take that back. I think that was early enough that we didn't have the language in the portable computer yet. We just delivered the robot, and the repackaging came a bit later. So that was a direct sort of transfer of technology from the university to a big interested commercial prospect. General Motors had been using robots for some time, but they were these large, hydraulic, very simple robots. And GM was interested in the idea of a robot that was more human scale and that could do small part assembly and material handling. So GM did some research then for a little while on that early Vicarm robot. And then Vicarm kind of carried on doing a bit more work and starting to develop the packaging of the controls into the LSI-11 computer environment.

And then in early, maybe late 1976 or so, GM came out with an RFQ for something that they called the PUMA robot, which was a GM acronym for programmable universal machine for assembly. And that whole concept was in part based on this Vicarm robot that we had delivered. And so there were a number of companies that bid on that, including some very large companies like ABB and Cincinnati Milacron, and Bendix and Honeywell and so forth. And then there was Unimation, and then there was Vicarm. Unimation was sort of the existing commercially-viable robot company at that time. In 1977, they were doing maybe $25 million a year selling these large hydraulic robots, primarily to the automotive industry. Vicarm was a tiny company and had no resources to successfully bid on a proposal from General Motors. We couldn't have credibly done that. So we sold Vicarm to Unimation and then bid on the PUMA contract. And we won that contract because we really had, relative even to these very large companies, we had technology that worked and we could demonstrate that. So we went on then over the next year and a half to develop kind of a commercial product, which was called the PUMA. And this was the very first prototype that was delivered to the Smithsonian, by General Motors actually, in 2003.

But we delivered that first prototype about a year later, sometime in I would guess early 1978, somewhere in there. And GM really liked it, and then we did a more packaged version of it with castings and kind of the more industrial version rather than just a prototype. And that grew very quickly into quite a good business for Unimation. It grew into about a $40 million business in the next three or four years and more than doubled the size of Unimation. And there were some thousands of these PUMA robots that were built and sold all over the world. And there are still a few of them hanging around university research labs that people still tinker with. And the PUMA came, so we developed that in various sizes. There was kind of a small version that we did, which you can see – I don't know if you can see it in the camera, but over here in the background. And that small version was done in the early 1980s, and there were some bigger versions, and so forth. So that was kind of a technology transfer story, really, from university to a very small company, then to sort of a medium-size company and out into industry.

Q: What were some of the big innovations that were realized in the PUMA? How was it different than the preceding arms?

Brian Carlisle: The preceding arms were essentially all hydraulic. Unimation had made these very large, heavy hydraulic arms with these, again, very simple controllers, almost rotating-drum type of controllers. Other companies who were in the business, Bendix, had some hydraulic robots, Cincinnati Milacron had some hydraulic robots. And again, all of those with very simple types of controllers. There were some other pneumatic robots out there that were driven by air cylinders, essentially. But there was no electric robot, there was no servo-controlled robot, and there was no language, and there was no robot that had the kinematic solution, running in a controller where it could literally move in straight lines and talk to sensors and communicate with vision systems and do repetitive structures and do loops and things and pick parts off of pallets without having every single program, every single motion explicitly taught. So the PUMA was different in both regards, both in the control system, being the first computer-based control system that was available. And then secondly, in being the first small, light to medium-payload electric robot that was available. And about that same time, another company, ABB in Sweden, came out with a small electric robot that they targeted primarily at arc welding. So just about that time, the mid-'70s, the '76, '77 timeframe, there were these two products that came into the market. There was the PUMA from Unimation and then there was this small electric robot, I think it was called the IRB-6, from ABB.

Q: And after that, a lot of companies then moved into electronic robotics?

Brian Carlisle: Yeah. And so the PUMA was somewhat of a watershed product in the sense that it became clear then A) that there was a market for small electric robots with General Motors buying these things, buying 40 million a year of these things. And then B) that the technology was mature enough to make small electric robots. So then everybody sort of piled on board. You had many Japanese companies kind of expand into the robot business, doing lots of electric robots, various European companies. A few years later, I think by 1983 or so, when Time Magazine had robots on the cover of Time Magazine, just in the US there were 34 US companies that I counted up at the time that were in the robot business. There were probably two or three times that in Japan in the robot business. And there were a good dozen or so in Europe.

So it was believed in the early '80s that robotics would be a really explosive growth business, that robots would replace human labor in things that were heavy, big, and dangerous, like spot welding, which in fact they largely have done, in hazardous environments, underwater sorts of things, which has also come about. But it was also felt that robots would do a lot of work in small part assembly. And that has been, I would say less ubiquitous than some of these other areas, because people can still easily do small part assembly until you get to the point where you're talking about very high precision. When you get down to thousandths of an inch or 10, 20, 30, 40 microns kinds of precisions, then it becomes very difficult for people to do it and then you find that robots or other automated equipment using various kinds of feedback is doing that. But there was this sense in the early '80s that robots were going to be everywhere and that humanoids were just a few years away. And so there was kind of this wild boom in companies investing in robotics. And that lasted for about five years and then kind of tapered off.

Q: Why do you think it tapered off?

Brian Carlisle: It tapered off for several reasons. One, a lot of the robots are not nearly, even today, as independent and sophisticated as a person is. And so many applications that were envisioned for a robot you just couldn't do with the technology. You couldn't send a robot in to clean the bathroom or put the dishes away or wash the windows or do many of these kinds of things that were kind of imagined in the early days. So people sort of took the science fiction view of robots and figured it was all going to happen in the next five or ten years, and the technology has taken much longer to develop. So I think that's kind of the bottom line. There are some things that robots are quite good at doing if they're very repetitive in a very structured environment, and you order the parts and the robot can go pick up the parts and that. But working in unstructured environments is still very challenging, even today.

Q: What were some of the big companies that were investing in robotics then?

Brian Carlisle: You had many of the large companies in the United States. You had General Electric, which had a big robotics program. Westinghouse, which then not to be outdone by General Electric, purchased Unimation in about the 1983 timeframe. And then you had IBM who had a big robotics program. You had Bendix, you had Honeywell had a robotics program. So quite a number of large companies had programs, and then there were a number of smaller companies as well, sort of startup kinds of companies.

Q: What led you to your next business venture?

Brian Carlisle: We had sold Vicarm out to Unimation. And the way that kind of worked out was that we were out here in California, being California kids, and Unimation was back in Connecticut. And so our working relationship with Unimation evolved into we became sort of an R&D group, a research lab, and they had the manufacturing and production facilities back there. And so we would develop new products and both controls and robots, and we had mobile robots rolling around and doing infrared navigation and a whole variety of things. And Unimation would commercialize those products back there. And that worked out quite well for about five or six years. And then Westinghouse, as I mentioned, acquired Unimation. And Westinghouse had a big robot research group in Pittsburgh. They were a number of years behind where we were in both technology and in software and in terms of the experience and some of the capabilities of the team. But there was quite a period of kind of integration planning that went on.

At the same time, Westinghouse reorganized. Just after this acquisition, they reorganized from three business units or four business units down into some smaller number, two or three business units. And they eliminated the business unit that had planned and executed the acquisition of Unimation. So all the managers who had done that were all let go or reassigned and Unimation was punted into this completely new group that had no clue as to why they suddenly had inherited this business. That new group, in their wisdom, went out and hired McKinsey, a consulting company, to tell them what they ought to do with this acquisition that they'd just spent $107 million on. And so we then had six months of young sort of consultants from McKinsey who didn't know anything about robots coming out and asking us in California, "Well what should we tell Westinghouse they ought to do with this business?" And that looked like it really wasn't going to have a very positive outcome. And so at the same time in this period around 1983, there was as I mentioned a great deal of brouhaha and euphoria about robotics being on the cover of Time and so forth. And so we were being regularly approached by venture capital investors, and I knew people in the venture capital community. And they said, "Gee, why don't you guys go start your own robot company?" So after watching Westinghouse thrash around for some six months or so with no clear plan, and then finally they hit upon the nice idea that they would offer us all the opportunity to relocate to Pittsburgh, which didn't go over terribly well with this bunch of people from Silicon Valley, we said, "No thank you." And Bruce and I went out and we raised some millions of dollars in venture capital to start Adept Technology. So that was in 1983.

And at that time, we looked at the market and we said while it's not a huge market, there still is an opportunity in this area of small part material handling and assembly. And in particular, it would be nice if the robots were more reliable than the robots had been in the past, because they need to run very fast and for a long period of time. So I'd been working with another company on a new motor design, a direct-drive motor, similar to a giant stepper motor, it was called a variable reluctance motor. And it was low cost but very high torque. But it was very challenging to control this thing to make it run smoothly and quickly. So we'd figured out a little bit of that while we were at Unimation, and I'd given Westinghouse the opportunity to invest in it and develop it and Westinghouse said, "No, we don’t think this is very useful." So they walked away from it. So we took that core technology and we cut this deal with Westinghouse. And we said, "Look, we'll give you 15 percent of this new company. You let us take this technology base that we have. We won't take any of the existing products, Westinghouse will retain the PUMA and all the existing products, but we'll go do something new and we'll get it funded. But we want to take the people, we want to have a license to certain bits of technology and particularly this motor and some other stuff, and we'll go off and do our own thing. And if you guys are interested in it, maybe you can sell it or distribute it at some point." So we funded this thing with venture capital and went out and hired a few more people.

But we started Adept with 27 engineers, 27 people, most of whom were engineers, and a facility and some ideas. And we went out to develop a direct-drive assembly robot, which we did in about 14 months and introduced it about a year, year and a half later. And it was a really popular product. Our first year of sales we went from zero to $14 million in revenue, which was much faster even than we had grown the PUMA product line with Unimation. And the Adept 1, as it was called, was bought by companies all over the world. It was very reliable. Some of the machines that we developed and delivered in 1984 are still running in factories today, many years later. And it was very well received and very well recognized. And so Adept over the next few years grew to sales of over $100 million. And we developed other products. We continued to develop. We believed then and as we believe now that much of the key differentiating technology for robots is the sophistication, power, and ease of use of the control system, the language in the controller. We invested quite a bit of money in integrating machine vision with motion control. And so Adept was one of the very early – in fact, we'd done that even at Unimation. This early robot here back in the Unimation days was actually a vision-guided demonstration. This had a camera and it was as six-axis robot with machine vision back in 1981, which was years before any of the other robot companies were really doing anything with integrating machine vision.

And so Adept, when we introduced the Adept 1, we introduced it along with a machine vision system at the same time. And Adept over the years and even today probably sells half its robots with machine vision. And we developed a number of technologies, some things called flexible part feeders which would allow you to just take a bag of jumbled parts and drop them kind of this vibrating conveyor which would spread them out under a camera, and then the robot could pick them up once they were separated. And that made it much easier to do small part assembly, because one of the big challenges was: how do you get the parts out of this bag of parts? So we did work in robotics, we did work in vision, we did work in part feeding, we did work in making all of that easier to visualize and to program. In 1996, I bought a company called SILMA. And SILMA was another Stanford spinoff. One of the founders was a gentleman named John Craig, who was another one of Bernie Roth's students. And they had concentrated on developing offline three-dimensional simulation and robot programming technology. So they could program spot welding machines and they could program coordinate measuring machines and they could program assembly robots. And you could develop all the software in the soft line environment and you could visualize it and move CAD models around and debug it and get the geometry sorted out and then download that program to your spot welding line or whatever you had.

Well, I had believed for some time, and still believe that as we go forward in robotics, we need to integrate the ability to model and reason about geometry with the robot control system. And so I acquired SILMA so that we would start to get that technology within Adept. And SILMA was about a five or $6 million business then at the time. And we started then to integrate some of the SILMA technology with some of the Adept robotics technology. And so we could do – I don't know if it's on here. Let me see if I have the next slide here. Yeah. So we could do things like this, where you could simulate an entire production line and you could simulate the robots at each of their stations and you could predict how quickly they could do a particular task. And then you could do line balancing along the line so that if workstation 1 took five seconds and workstation 2 took three seconds, you could move some things around and try to balance the cycle time for each of the workstations so that you would improve your throughput. And typically when you did that with the simulation tools you would improve the throughput of the entire assembly line by 30 percent or more. And when you're spending maybe half a million dollars or a million dollars on an assembly line, getting 30 percent more productivity out of it was a big deal.

We also developed technology to reason about the geometric stability of parts. If you dumped a bunch of parts onto a flat surface, what percentage of the time would they lie in these various stable states? And based on that, you could predict what the throughput of these flexible part feeders would be, how many parts per minute you could feed. And so we had some very sophisticated mathematics and reasoning that we were starting to build into the systems in the late '90s and sort of early 2000 timeframe. And it was my intent to integrate the offline geometric modeling and reasoning capability with the online control systems. Because what you ultimately would like to have is you'd like to be able to have a robot roll into a room and use its vision scanners and laser range scanners to make up a model of the room and know whether it can reach under the table or over the table but it can't go through the table. And so if it doesn't have a model already, you'd like to be able to create a model. You'd like to be able to reason about that model. You'd like to be able to update that model with sensory information. And that's kind of what people do and what higher level reasoning entities do. So that was kind of the rationale. And we never completed the integration of SILMA. We did a lot of work there, but the products were still sort of a separate simulation and separate motion control system by the time we left and started Precise. But that was the vision.

Q: Who was working on the vision systems during that time?

Brian Carlisle: Well, if we go back to kind of the original Unimation days, there was vision work that had started at Stanford also. It had migrated over to SRI, Stanford Research Institute. There was a gentleman over there named Bob Bolles who was well known in the vision community. He had done a lot of work, along with a couple of other people over there sort of commercializing some of the research that had been done at Stanford. And then we licensed some of the SRI technology at Unimation in the late, well, probably would have been in the early '80s, about the 1980 timeframe. And we hired a Ph.D. named Scott Roth from Cal Tech. And Scott worked with Bruce Shimano and essentially did our commercial version of that vision technology. And we developed patents for various things. And so he was kind of the leader both early on at Unimation and then subsequently at Adept in developing a lot of the early vision technology for us.

Q: What was it like working with Bruce and starting up that company, and Vic?

Brian Carlisle: Well the three of us are all very different personalities. Have you met Vic Scheinman?

Q: Tomorrow.

Brian Carlisle: Tomorrow. Well, you'll get Vic's take on it all. Vic's a very high energy guy with lots of ideas and a rather short attention span. And so he was great at generating ideas. He's very bright and he's very capable. But in terms of the back end of things, of really turning something into a commercial product, he kind of loses interest fairly quickly. And in some sense, that's why he hired me originally in the early days of Vicarm was to kind of make things into real products and supportable products and that. Bruce is a very, very bright guy. He's very methodical, he's very thorough. He's extremely detail oriented and never forgets anything. And his real love is software and mathematics and so he's a real programmer. And I'm sort of somewhere in between. I have lots of ideas, but I can also kind of work details and get through the process and get to the back end. And so I would say our relationship with Victor was when it was Vicarm it was Vic's company and he was coming up with a lot of ideas and Bruce and I were doing some of the execution. When it was our company, and I actually took over – Vic Scheinman was the original concept guy on the PUMA robot because Unimation had bought Vicarm and the PUMA was a derivative of some of Victor's work. After a couple of years though at Unimation, even Unimation was kind of too big a company for Victor. So Victor quit and went off to do something else, working with another company called Automatix, where he went and did some other new things.

And so I was running kind of then the research group there for Unimation. And then when Bruce and I started our own company, obviously all the ideas were essentially our ideas at that time. Bruce and I have a very good working relationship. We've worked together for, I don't know, more than 30 years. And I have lots of ideas. Bruce is very calm and he's sort of a low-pass filter. So if I can convince Bruce that one of my ideas is a reasonable idea, then usually it has some – <break in recording> So we work quite well. We kind of complement each other personality-wise. He has always preferred to live in Southern California. He was born down there, his family is down there. And they're Japanese-American, they were very close to their families, they like to spend weekends together with families and that. And I've always hated Southern California and I've always preferred to live in Northern California. I can't imagine why anybody would ever want to live in Southern California. So I've liked the mountains and skiing, and so I've lived in the Bay Area. Now I'm up here in the Auburn, sort of near Lake Tahoe, Squaw Valley Area. But having said that, we've worked together quite well for many, many years and continue to have a very close relationship.

Q: How were you able to coordinate over that distance?

Brian Carlisle: Well, starting in the mid-'70s, that was also kind of the birth of the ARPANET, which sort of morphed into the Internet. And so we've always just done lots of telecommunications and emails and phone calls and web conferences and all of that. And also, logistically, the work that we were doing was fairly well segmented. Bruce was doing programming and running a software group down in LA. And when I was running Unimation or subsequently running Adept or now running Precise, I was running more the hardware stuff. But the software stuff, you can kind of split off. So the software guys were kind of locked in an office and every week or two we'd slide a pizza under the door kind of thing. We tried to isolate them from distractions, from customers dropping in, from sales guys saying, "Can you do this? Can you do that?" And as a result, they were able to be very, very productive and they had a quiet sort of fairly intense working environment.

But Bruce enjoyed that and that's the way he liked to work. And the people that he hired to work with him also were those types of people. And so they've always worked very independently and it's worked quite well. Now there are periods when you're doing a robot where you have to do integration, where you have to bring software and hardware and mechanical stuff together. And when you do that, then people have to travel and we all get together in one place and try to make the robot work. But a lot of the development can be done independently.

Q: Where were the production facilities? Where did you actually build the robots?

Brian Carlisle: Well, in the Unimation days, they were in Connecticut. In the Adept days, they were in originally San Jose and then later Livermore, but in the Bay Area. We had about 100,000 square foot facility there in San Jose. And then we expanded even beyond that in sort of the 2000 timeframe. And then subsequently, Adept was contracted about the time we left, that was part of the reason we did leave, which we'll get to. So it's probably about half that size now, maybe 40 or 50,000 square feet, something like that. What we're doing with this company is we're now doing production at a company that's a friend of mine down in Los Angeles again, so the production is actually done down near Anaheim. Were you at Chad? Did you interview Bruce at Chad?

Q: Yeah, I was at Chad.

Brian Carlisle: So you saw Chad, yeah. Chad's where we're doing our manufacturing right now.

Q: Can you talk a little bit about Precise Automation and how it came together?

Brian Carlisle: Yeah. So we'd grown Adept by sort of the late '90s to about $100 million or so in revenue. We had $25 million in cash, we were profitable. So the company was pretty successful and we had gone public in 1996. And so we were sitting around at the board level talking about well, we've grown up to this point, how do we grow this thing to the next 100 to $200 million? And so we started or contracted or assigned three marketing people to look at three new markets. One was a semiconductor robot market, the second was the photonics, fiber optics market. And the third was the life sciences and kind of genomics market. Each of those markets was developing for robotics. And so we spent about a year or so doing these market studies in each of those new markets. And at the end of the day, we decided that we couldn't do three new markets. They all looked interesting, but now we selected semiconductor and we selected photonics as two that were close to home. Semiconductor, we were in the middle of Silicon Valley and so we had lots of semiconductor companies there. And photonics was exploding. At that time, JDS Uniphase, which also was a big presence in Silicon Valley, thousands of employees, had grown from 2,000 employees to 24,000 employees in just a few years. And everybody was wiring fiber all over the place and putting these fiber optic transceivers which convert electrical signals to optical signals under water and all kinds of places. And so it appeared that semiconductor and photonics would both be very interesting growth markets for us. And we went out and we did a couple of acquisitions to help us address those markets. And semiconductor, between sort of 1999 and then sort of 2000, we grew a business from basically zero to $20 million.

So we had a quite a nice business that developed there. In photonics, we got a very big program with JDS Uniphase, and we were doing $2 million work sales for them and they told us they were going to need hundreds of these things and that we really had to expand our manufacturing facility to be able to meet their needs, and how were possibly going to ramp up and scale up and so forth. And we had taken their first-pass yields on these little fiber optic transceivers, which required that you align an optical fiber with a laser diode to a tolerance of a few microns and then fasten them in place. And we'd figured out how to do that. Their first-pass yields had been about 30 percent for this product and they were selling it for thousands of dollars, in some cases $10,000 and throwing 70 percent of them away. And so we were able to take their first-pass yields up to 97, 98 percent with automation. So they were delighted about that and were just going crazy with this forecast. They even invested $25 million in Adept to support that whole development program. So in sort of the 1999, early 2000 timeframe, it looked like Adept was probably going to grow from 100 million to 200 million in the next five or ten years. So we went over and we leased a big new facility over in Livermore. We roughly doubled our space from about 100,000 square feet to about 200,000 square feet. And we did some acquisitions and we were scaling up.

And then in 2000, sort of the whole economy, at least the electronics economy, marched off a cliff. We had this whole Y2K thing, and so everybody who needed to buy a computer bought a computer in 1999 and they didn't need to buy any more computers in 2000. And so the computer market tanked. The semiconductor market as a consequence tanked. The disk drive market as a consequence tanked. The photonics market, as soon as the long-haul fiber was built out, that had been way over built and way over extended, and all the telecom communications companies tanked, so you had companies like Northern Telecom that almost went bankrupt, Lucent, that was sort of sold off, Alcatel, which had huge problems. I mean, these big worldwide 50, 60, $70 billion companies just cratered. And JDS Uniphase went from 24,000 employees back down to about 2,000 employees over the next three or four years. So they absolutely stopped building any new product and cut off their business.

So at Adept we saw our orders, our revenue, drop from 120 million down to something like less than half that, about 50 million, in a period of about 18 months. And we had just gone out and leased, signed a ten-year lease on this great big new facility, expensive facility, and the whole business vanished on us. So that was extremely painful. We essentially spent the three years between 2000 and 2003 downsizing the company. And we had multiple layoffs and we had to close sales offices all over the world. It's very difficult to lay people off in Europe, in France and Germany. It takes a year or more to let somebody go. And obviously, it's very difficult emotionally to take all these people that you've hired and they've grown with you and you've known for, in some cases, 20 years or more and tell them that they just can't work with you anymore. So as well as, of course, we were a public company. So we had tremendous pressure from investors and the board of directors. We were losing a lot of money and so forth. So we spent three years sort of going through huge write downs and layoffs and downsizing the company, which we finally sort of accomplished by the middle of 2003.

And we never ran out of money, which was good. But our cash was getting low. So at the end, sort the middle of 2003, we went out to raise some additional working capital for the company. And at that time, we had a reasonable story to tell. We had stopped burning cash, the orders were starting to improve a bit again. So the company was stable and not hemorrhaging. And so I went out and raised $10 million with a venture fund called Special Situations Fund in New York. So they put a person on the board and they said, "Gee, we're going to put our money in, but we really want to have somebody else come in and run this company because it's been so bad for the last three years that somebody else must be able to do better." So the board hired a new CEO who came in. And about three weeks after he arrived, he decided, "Well, I really have no interest in trying to work with a couple of founders here." So he just fired Bruce Shimano and I, just walked in one morning and fired us with no warning. And actually – well, we won't go much further there. So Bruce and I were out. And this new fellow had his opportunity to run the company. He was fired five years later. But he did last four or five years, but finally the board got tired of him. So our only sort of solace, I suppose, is that he certainly didn't do any better than we had done over the previous 15 or 20 years.

Q: Who was he? What was his background?

Brian Carlisle: He had worked in the automation industry but in a very different industry, in the paper industry. So he'd done paper mill automation. And he didn't really understand robotics, he didn't understand the market, he didn't understand the technology. And he didn't understand the rationale and history for why we had the products we had. And he wasn't a big listener. He was one of these fellows who was going to come in and do it his way. And so a lot of the very, very senior people left within six months to a year after he arrived. He really kind of decimated the company. But that's kind of what happens, or not always happens, but sometimes happens. Boards, when the business is bad have an obligation to the shareholders to go do something. And the one thing they can go do is they can go change the CEO. And so that's what the board did. And certainly it can be argued whether it was the right decision or not, but nonetheless, that's what they decided to go do. So Bruce and I then went out and started a new company, this company that we're currently running, called Precise Automation. And we decided this time that we were not going to give up voting control of the company to an outside board of directors. So we raised quite a bit less money this time around. I funded part of it and we have some outside investors and we have a couple of corporate investors. And so we've grown this company more slowly. But we've also done what we hope will be kind of the next generation of control systems and robotic technology. And that now is starting to get out into the marketplace. So this company is now starting to grow. We'll grow 100 percent this year and probably 100 percent next year. We're still small. We're sort of at the $4 million revenue range right now. But we should be doing six or eight next year, and we'll get up into the bigger numbers at some point. But this time, we will do it in a manner that doesn't require us to give up control of the business.

I still believe that robotics will continue to be – that the technology will continue to address many different areas. That it will get out of the factory, as it's starting to do, into service areas. There are already some nice models for surgical robots, which it can be argued whether they're robots or master-slave tele-manipulators, but certainly a couple, at least one company, has done very well in that area. There are good examples of some military, hazardous environment sorts of things, robots going into caves and looking for mines. And there are some toys and things like that now that are starting to come out with some of the technology, kind of low-end technology. And if you think about it in sort of its most general sense, people have lots of definitions for robots, but my definition is essentially an autonomous thinking machine that can sense and interact on its environment, interact with its environment. Computers have essentially been these disembodied boxes that we kept in a closet for the last 30, 40 years. And a robot is in some sense a computer that has some sensing, whether it's vision or a sense of touch, and the ability to act on the environment, whether it's just rolling around with wheels or flying a plane or running a cruise missile or doing surgery, that's sort of a very broad definition. And the types of technology that we have developed and will continue to develop can serve, if you take that broad definition, many, many different applications. And so I think as this company gets a bit more mature, we will have a lot of opportunities to spin this technology into several different directions.

Q: Do you think that the fact that robots are embodied also in a sense limits their ability to be general purpose like computers are?

Brian Carlisle: Yeah. I mean, in some sense. Obviously a human is an extremely flexible mechanism. But even humans pick up tools to do a lot of things. So we adapt the human body, whether we jump in an automobile or pick up a screwdriver, by adding various tools and so forth. And certainly, you're not going to have a general purpose robot that's going to be more flexible or even as flexible as a human any time soon. But you will have robotic technology that can be packaged into, whether it's a sentry that's rolling around or a drone that's flying around, the sensing technology, whether it's machine vision or terrain mapping or actuation, coordinating multiple actuators to move in a coordinate system, that core technology base can be packaged in different kinds of mechanical packages to address a lot of different applications.

Q: And what are the main applications you focus on at Precise?

Brian Carlisle: Well, at Precise, we decided we needed to build a business that wasn't terribly risky in the sense that we didn't want to spend 10 years doing R&D and have to raise tens of millions of dollars to go something dramatically new. And so we started by sort of packaging the technology and we're focusing on a couple of markets, one of which is life sciences. So we're doing robots for life science applications. That is a market that requires some sensing, it requires a lot of material handling, it requires motion control. There are both some dedicated machines where we're selling controllers into that market and then we're also making some various mechanisms that go into that market. And it's also one that's growing quite quickly.

With the focus on healthcare in the United States, we're doing more and more personalized medicine. There are companies out there trying to figure out how they're going to run a million drugs past your particular cancer and see which one actually does something that's effective, as opposed to hitting you with these broad chemo blasts that destroy your entire body.

There's a lot of genomic work going on. So there's a lot of R&D work going on in life sciences, and then there's also a lot of processing of just samples, biological samples, whether they're blood or urine or whatever. And all that's got to be handled and processed and so forth. It's a market, it's going to be a growing market, and there will be derivatives and spinoffs of that market. And it's not going to go to China, it's not going to go to Singapore or go overseas, it's going to stay here in the United States. So that's really where we're spending a fair bit of our time. We're doing a little bit of work with the semiconductor industry where we're selling controls to people that are building semiconductor robots. A lot of that is in Korea right now, a lot of that is in Asia because most of that market is overseas now. And we're doing a little bit of work in disk drive and most of those products are going to Singapore, are again going overseas. But I would say over half our business right now is in this life sciences area.

Q: That was the one that you ended up not doing out of the three.

Brian Carlisle: Yes, that's right. Yeah, it looked good 10 years ago and it still looks good. But we didn't know anything about it then. And I can't say we know a great deal about it now, but we know more about it now than we did then. And it's also matured a bit and developed a bit over that period of time.

Q: You obviously have had a lot of very successful technologies that you developed. Were there any paths that you took that were unsuccessful and that you thought would be interesting but just didn't work out for certain reasons?

Brian Carlisle: Well, yeah. I mean, you don't always hit home runs. And you hopefully learn as you go along. We had one product at Adept which was a real boat anchor, it was called the Adept 2. But we decided we were going to take these big direct-drive motors and make a very small robot with this that would go really, really fast because it would have these giant motors on it. But it turned out that it was just too big and too expensive and too heavy and we should have built something much smaller. So we probably spent a year developing that thing and it never went anywhere. And that was also a case of not doing a very good job of listening to our customers and our market. Earlier, at Unimation, we had high hopes for mobile robots. And we developed a platform that had these omni-directional wheels on it back in, I don't know, probably 1980, '81 timeframe. So it has these three wheels and it could move in any direction. And we put a robot on top of that, and it had portable battery power and it could go recharge itself. And we had infrared sensors on it and it could navigate around, and it could move around a factory. And the idea was that it could go service intermittently process stations that needed to be loaded and unloaded every few minutes, but then that you could move the robot around. And we thought that would be quite interesting for the semiconductor industry. And we had talks with TI and other semiconductor companies about it. And they said, "Yeah, gee, that is interesting."

But it wasn't interesting enough that they really wanted to buy it. And so we put probably a few years of research into that and made some nice videos about it. But it was probably 30 years too early. There just wasn't a real viable commercial market for it yet. And today, there are lots of automated vehicles moving both overhead and to some extent on the floor of semiconductor factories. But as the semiconductor ultimately evolved, most of the transportation is done on overhead rails to keep from cluttering up the floors. And a lot of the floors also are these clean room floors, and it's hard to put heavy loads on them sometimes.

Q: So you mentioned that with Adept 2 that you weren't listening to your market.

Brian Carlisle: Right.

Q: How do you usually integrate the voice of the market into your work?

Brian Carlisle: Well, it's always kind of a fine line. Because if you just ask the market what they want, they'll tell you sort of what they wanted yesterday. And if nobody is making that, that's an opportunity, you can go do it. But usually, you try to shoot a few years ahead because it's going to take you a few years to do something. And then secondly, you'd like to, when you introduce something, have something that not 10 other guys are doing exactly the same thing. So most of these activities involve some balance between trying to forecast what's going to be a successful product in a couple of years and doing enough homework that it actually is when you get it out there. We knew for the Adept 2 that for small part assembly that people wanted to go real fast. And they wanted to get higher throughput and do sub-one-second cycle times and things like that. We thought that they wouldn't mind a great big old footprint that was at that time about 14 inches in diameter for moving around these little tiny parts. But that we sort of blew it on.

And some people, if you listen to what people like Steve Jobs will say, they say, "Well, I envision the future and we go create the future." And if you're really, really good and if you time things correctly, you can do that. But even companies like Apple, they had the Newton, which was, if you remember, was probably 25 years ahead of its time and it was a horrible flop, but seemed like a good idea at the time. And so sometimes these things almost have to wait for the market to come around. I have believed for many years in using machine vision to do what we call flexible part feeding. And I flogged that for probably 15 years at Adept and it's starting finally now to gain more and broader acceptance. It’s not something we're doing at Precise. But there are some companies out there, and vision-based part feeders are becoming common now, much more accepted. So sometimes you just have to kind of wait for the market to come around.

Q: So how has the business of robotics changed over the years?

Brian Carlisle: --in the ‘60s and ‘70s and even ‘80s, and to some extent even today, robotics is driven to a large extent by the automotive industry. Probably 50 to as much as 70 percent of the volume, certainly in the early years, was spot welding and heavy material handling and so forth. And as such, the machines that were developed were these very large and very powerful machines. And the technology that was developed was primarily targeted towards just a couple of application areas. I think today, and then as there was, as the ‘80s came around, we got into these, you know, robots that would do smaller things, such as we developed at Unimation and then later at Adept and now at Precise. And so the robots have gone into new markets where the payloads were smaller and lighter and so forth. And secondly, I think, the evolution of computer technology now, particularly in the area of machine vision, has let the robots work in some, robots and other automated machines, to very high levels of precision in its almost microscopic environments. And so certainly a lot of what goes on today in the semiconductor industry and electronics industry would not be possible if it weren’t for the integration of machine vision and motion control, all of your circuit board assembly. You know, if you put together a circuit board you have these little surface mount devices on it and they all have to be lined up very precisely and things we mentioned earlier in photonics. You may need to align parts up to a few microns. Well, people just can’t do that. So I think we’ve seen the technology spread out into a number of areas, disc drives and electronics and similar things. Now what’s starting to happen is there’s been a lot of work in the last 5 or 10 years on trying to deal with much less or completely unstructured environments. You are probably familiar with the DARPA Grand Challenge, you know, over the last few years, which was essentially a machine vision exercise in terms of navigation. Well, sensing, modeling, building up a model, you know, from these laser range scanners and these vision systems. Planning based on that model, and navigation. And so that was considered an almost impossible thing to do, you know, 15, 20 years ago. And then in the last couple of years people are driving, you know-- not people, I should say-- completely automated systems are driving automobiles at 30, 40, 50 miles an hour through the desert. And then more recently in a city environment. So what’s happening now is we are beginning to develop the technology to build models, to begin to reason about models, to put in these heuristic sort of rule-based systems to tell you what to do when various things happen. And as a result of that, we will see a whole lot of new technologies become possible. It’s technically possible or will be in the next couple of years to have your car drive you to work. You know, you can go get in the thing and say, “Take me to work,” and it’ll do all the navigation and you can sit in the back seat and play video games or sleep. It is possible today to have drones flying around in the air doing military applications or underwater in which there are no supervisors. And they get instructions on a periodic update basis. And it will be possible in a few more years to give relatively high-level instructions for relatively mundane jobs. You know, go pick up the dishes off the table and put them in the dishwasher. That will be possible in the next 10 or 15 or 20 years. And that is all based on this integration of modeling, reasoning, motion control sensing and so forth. So that is going to allow the technology to just laterally explode in many, many different areas. It won’t be necessary for UPS to have human pilots flying, you know, cargo planes around anymore. It technically wouldn't be necessary to have human pilots flying passenger planes around, but I think they probably will be for the foreseeable future. There's no rational reason that other… No real rational reason that you ought to have human pilots in fighter planes anymore. We spent I don't know how many hundreds of millions of dollars for these incredibly advanced expensive fighter planes and you could fly a Drum missile around with much higher performance for a fraction of the cost. So I think that we will see the technology be used in many ways, some of which will be scary, some of which will be, you know, really enhance people's lives and add value to the society.

Interviewer: If there's a rational reason, what do you think the reason is that these things aren't being yet or won't be applied as quickly as they could technically be applied?

Brian Carlisle: Lots of people have done studies of the rate of acceptance of new technologies into society. And the sort of general rule of thumb is it takes about 25 years for a brand-new technology to sort of be broadly accepted in society. Whether it's a personal computer… Whether that will accelerate or not is not clear. But certainly even things that we view as being ubiquitous or almost overnight sorts of things like cell phones, you really look at. And cell phones it's been about 25 years from the time the first, you know, fairly big, clunky cell phones were introduced to the time that, you know, over 50 percent of the people actually have a cell phone. So there are these sort of, you know, rates that are in some sense driven by the ease of use of the technology when the things are big and clunky and heavy that they're not that much fun to use. In some sense driven by cost and economics, over time there's a learning curve and they get cheaper and more affordable. And in some sense driven by generational acceptance rates. You know, your kids usually know more about computers than the adults do. And so you have kind of this rate at which technology or society is able to absorb these new technologies. So I think that's certainly one issue. And then I think there are today and will continue to be cultural issues in which we need to decide, choose and figure out how we feel about completely automated systems. An example of that at the moment is the debate about, you know, should we have a man mission to Mars? You know, emotionally want to send people to go walk around on Mars. It makes very little scientific or economic sense to do that. You know, these robot missions, these little… Mars Rover that ran around for, you know, year and a half or two years and brought back all kind of great information. And it was a terrific success. You know, is a far more efficient way to go about exploring other planets than trying to get people there and back and all the water and all of the infrastructure and all the psychological issues of being locked in a box for two years. But still emotionally we have these things where people should be doing certain things, whether it's exploring, whether it's driving your car. We want to be in control. We want to lead. We don't want to give that up. So for certain applications I think that will continue to be a very strong driver. Will you be comfortable having the robot drive you to work? Are you really going to want to have your hands on the wheel?

Interviewer: And in the '70s and '80s, was there a lot of social interest in the problem of robots displacing workers? And how did that relate to your business?

Brian Carlisle: There certainly was in the late '70s and early '80s. There was the perception that robots were going to displace all the workers in the factory and that everybody's going to be laid off and every time a robot came in people were saying, "Hey, there used to be a guy doing that spot welding on that job over there. Now a robot's doing it." That sort of concern slowly faded. I mean, it never went away 100 percent, and I don't think will. I mean, if you replace a job with a machine or some kind of automation, whether it's a operator working at a switchboard. I mean, there are no switchboard operators anymore. Or farmers working in the field with a combine harvester. I mean, those things will happen to a certain extent, but they will only happen if they kind of make economic sense and business sense and social sense. And if people feel too uncomfortable about it they won't allow those machines to come in. And I think that the bigger question is whether the economy and the industries can adjust and remain competitive and continue to grow and provide opportunities for people as the work changes, or whether the jobs simply vanish. And there have been for some time arguments about, people have written books about the end of work, for example. But that has yet to come to pass, but we have migrated from an agrarian economy where 90 percent of the people were involved in farming, to a manufacturing economy, and now more to a service economy. So at the macroeconomic level you see sort of these long-term trends. But again, they tend to take 25 years, 50 years, while these things happen. So there's almost nothing that happens overnight.

Interviewer: I was also curious. You've done a lot of work with U.S. companies, but what about other international connections?

Brian Carlisle: Yeah. Well, you know, robotics has always been a very international business. You know, it started, the first robots were developed in the United States, but relatively quickly licensed in Japan and then Japan today you could say is probably the leader in terms of accepting, implementing, innovating in many robot areas. Many other countries, obviously, are also very involved in robotics. Certainly Europe has a huge effort going on and then if you actually look at the markets today, probably Japan and Asia is the largest market, followed by Europe, followed by the United States. And so United States is actually the smallest market in the world markets for robots, and in terms of acceptance. That's driven for a couple of reasons. One, the United States has been relatively quick and relatively accepting of just contracting out manufacturing. So instead of trying to keep manufacturing here in the States and keeping some jobs while you put in some robots, we sent it all to Asia. Europe, conversely, has done a lot of investment in manufacturing technology and has put a lot of robots and other automation in, especially in Germany and France and to some extent Spain. They have been much less ready to just export their manufacturing. Japan, of course, has used robots to gain a manufacturing advantage, and as have Korea and some other economies. And so there's sort of that kind of cultural thing going on. With respect to us, you know, I've been to Japan probably 35, 40 times.

At Adept we had an office in Japan. We sold maybe 8 or 10 million dollars a year of mostly controls, but some robots over there. At Precise we have some customers in Japan. We have a number of customers in Korea. We are just now starting to set up reps and distribution in Singapore and Southeast Asia. We have also some customers in Europe and I've been to Europe many, many times. And at Adept actually, 40 percent to 50 percent of Adept's business was in Europe. Adept had, we had offices, in Germany, France, Italy, U.K., Spain. And so I think Adept had four or five offices in Europe and very strong presence there. So it's always been a very international business and when you go to conferences and they're all over the world and I certainly know people all over the world in the industry. But not only in the industry, but also in the research community.

Interviewer: Have you had close collaborators that were from other parts of the world?

Brian Carlisle: Well, in some cases. We've done some research work with folks in Korea. We had a program that we developed there that I can't really talk about too much. We've done other projects with people in Europe. When you talk about collaborators there's sort of two ways. There's, you know, within your company and so there's, you know, your people in Europe that are working on things, and then there's sort of outside of your company with other entities. In the business community we've done, at least at Precise, we've done work with a company called SCHUNK, which, they make grippers and they more recently have been working on some service robot things and we've done control programs with them and cooperative, developed some controllers and so forth. And so they're using some of those in their business in Europe right now. We haven't participated in sort of international fundamental R&D programs. We don't really have the infrastructure to do that here at Precise, at Adept. We had some discussions about some of those sorts of things, but never really got involved. They tend to be long-term and complicated and difficult to get through the political process and so forth.

Interviewer: You mentioned conferences. What were some of the conferences that you've gone to over the years and especially in the earlier years?

Brian Carlisle: Well, I've been a member of various organizations and president of some. So one organization was the Robotic Industries Association, the RIA. And they have also Machine Vision Association there, or I guess they call it the AVA, the Automated Vision Association or something now. But we were members of that. I was on the board of directors there. I was the president of the RIA for three years. And then I've also been a member of IEEE for quite a long time, and yeah, so I'm a fellow of IEEE. And then so I've attended the ICRA, the ICRA conferences, some of the other IEEE conferences, the Robot Industry Association conferences. I've chaired some of those conferences. Oussama Khatib, who is a professor at Stanford, and I co-chaired the IEEE ICRA conference in 2000 in San Francisco, so that was 1100 attendees and from all over the world. And I was a general chair and Oussama was the program chair, so…

And that was pretty significant chunk of time to kind of pull all that together and host everybody. That was well attended. Had a good time with that. And I've been to conference in Asia, and I've given talks all over the world. So I've participated in the research community and kind of the conference professional societies for some time.

Interviewer: And when did the Robotic Industries Association form?

Brian Carlisle: I would say the late '60s. I don't know the exact date. I would say '66, '67, '68, back in there somewhere. You could call them up and ask them, but I don't-- yeah.

Interviewer: So they were already around when you were starting up your company.

Brian Carlisle: Yes. You know, they were started partly by Joe Engelberger. Joe Engelberger had started Unimation in 1960 or so. And developing his big hydraulic robots. So by the time we came on the scene, which was the early to mid-'70s, there was this robot industry, as I mentioned, but it was composed primarily of these, or consisted primarily, of these big hydraulic machines. And the Robot Industry Association was started-- I don't know how many members there were in the late '60s, but it was at that time maybe half a dozen companies that were doing robots. And they had a staff person and they started having some conferences and some robot shows and some things like that.

Interviewer: I'm curious. This is slightly a different direction, but with the development of robot industry, you mentioned this kind of like spreading out of the industry. And part of it, obviously, is industrial robotics, but then now there's a lot of push for more service-oriented robotics?

Brian Carlisle: Yes.

Interviewer: How do you see that as developing in the future? Is that a reasonable direction to go in or… <laughs>

Brian Carlisle: Well, I think you will see a lot of service robots. And they will start in environments in which they're not touching people very much. So you will have your cleaning. We have already automatic vacuums running around the floor. You will then start to see some cleaning and service and maintenance kinds of machines that are doing intermittent periodic kinds of maintenance. I think that there are today some robots that are washing airplanes and working in some things that are relatively difficult. There's obviously underwater sorts of maintenance activities and a lot of teleoperated stuff going on there. There have been maintenance activities in hazardous environments for many years, including nuclear reactors and other hazardous environments. Now starting to see robots in mines and mining applications. And then I think a lot of time when people talk about service robots they think about something in the house. Or possibly helping the elderly or possibly working in medicine. And so when you get into those environments, certainly I think the early applications, again, will be ones which don't provide a lot of physical contact with people. But you may have cleaning robots and maybe more sophisticated the vacuuming things. You may have some outdoor maintenance sorts of things. The gardening robot. And we will start to see eventually then-- and there's a lot of research going into sort of inherent safety, how we get robots to interact with people in a safe manner. There has been interest in lifting in hospitals. You know, how you have a nurse's aide that can come in and help turn and lift and reposition a person who's not able to do that themselves. There have been certainly work in elder care. Both in terms of sort of very simple things like reminding someone to take their medicine or doing some monitoring and determining if they're healthy. And then people are trying to build these structured environments in which the robot can go cook a meal or go get you a beer. But when you get into the details of elder care, there's a lot of, "How do you take a bath? How do you go to the bathroom?" I mean, these very personal sorts of things that the robot technology isn't really quite there yet and may not be for a while. That's not to say that it won't ever be. There are mixed schools of thought as to whether people would prefer to live semi-independently with a robot aide or go into a community where they have other people around and maybe get intermittent visits from a caregiver of some sort. And different people may just have different psychological make-ups and prefer different approaches, but some people may just want to be very independent and whatever, don't ever want to go into a home. And other people like a sense of community. So that may turn out at the end of the day to be kind of a sense of a personal choice. But those sorts of issues will become the interaction, the safety and then the psychological aspects of, "Do we make friendly robots? Do we make robots that try to mimic humans? Do we make robots we can have conversations with?" And what does that really mean in terms of society, psychology and social structure? Those will come up in the next 20 to 30, to 40, 50 years. There's been a lot of work more recently in robots trying to read and interact with human emotions. So MIT and others have programs of robots looking at the human face and figuring out whether you're smiling or frowning or happy or sad and trying to respond to you in an emotive manner. And that is… You can debate how good that is, but certainly the more response of if we're sitting here interacting and you're nodding or smiling or something, it's certainly more rewarding to have an interaction with something that's a responsive entity as opposed to talking to a computer screen or a microphone. So I think that you do elicit more natural responses in people, whether people ultimately decide that's the way they want to interact with machines probably is open to test of time here.

Interviewer: So do you think that the, I mean, is it really the social/cultural challenges that are big problems there? Because in Japan particularly they've been trying to develop different applications for these robots that are either more social or somehow exist in the home or in the general society, but it's not worked <laughs> so far.

Brian Carlisle: Well, you know, the Japanese have this fascination, this historical fascination. There was a guy that wrote quite a nice book that I have a copy of in the other room that sort of dates the history of robots. He wrote this about 15 years ago, but…

Interviewer: Is it "The Robot Kingdom"?

Brian Carlisle: Yeah. "Inside the Robot Kingdom".

Interviewer: Yeah. Uh-huh.

Brian Carlisle: Yeah. I met that fellow. An interesting guy. But he goes back and talks about kind of Japan's cultural and historical fascination with puppets and automatons and then cartoons and then anime and then how all that ties into robots and how there's this whole thing in Japan about these sort of animated cultural characters. And so that fascination has led the Japanese to try and go and develop these very humanoid type of robots, even though they don't do anything useful. So you can see these things at trade shows, and Honda has ASIMO that sort of clumps around. And Toyota actually built a marching band with robots playing musical instruments, and you can imagine the amount of effort that went into something like that. Unfortunately, all of that anthropomorphization, if I can get that out, has almost been counterproductive in some sense, because people see these things, they expect them to behave like a human or to have the capabilities of a humanoid, and they really don't. None of them have the sensing systems, the modeling systems, the control systems. Even the natural language understanding that you can have a conversation with them and tell them to go clean up the kitchen, the dishes, and put them in the dishwasher. So there's this wish or this idea that we're going to have these humanoids wandering around, and it's to some extent interesting as a mechanical engineer to watch companies develop and try to improve mechanisms and so forth to be able to have these multi-fingered hands that can pick things up and things that can walk around and work in these less structured environments. But we still have a long ways to go from a control standpoint. Japan, they're trying to get leverage. I mean, I think Stanford is-- I don't know if they actually have it now or not, but they'd talked with Honda about getting some ASIMO robots at Stanford and trying to get more controls people involved in running these things. So, you know, it will perhaps slowly evolve over time. The other point that I would make is that from the perspective of a mechanical engineer, we're still extremely inefficient in how we build these mechanisms relative to biological systems. If I'm sitting here sort of chitchatting with you guys and running my little brain here, I consume maybe 100 watts of energy. And if I'm pedaling hard on my exercise bicycle I might get up to 125 watts or 150 watts of energy that I'm putting out. So maybe a human running at full speed or riding your exercise bicycle is consuming 200 or 250 watts of energy. Well, you look at a robot or something like ASIMO, it's consuming kilowatts of energy and the battery runs out in 15 minutes and the thing falls over. You know, we're nowhere near as efficient in our mechanical systems as these biological systems are. And if you look at something like a chimpanzee, which weighs about, you know, probably little bit less than I do, but a chimpanzee, its muscles are six times stronger than my muscles. So a chimpanzee can chin itself easily with one hand and it can pop my fingers off one by one. I mean, they can pull thousands of pounds with their arms. The muscle tissue is six times stronger than human muscle tissue. So sort of where we are in terms of power to weight ratios and efficiency of designing these complex machines is still quite poor relative to biological systems. And so we don't want to build a bunch of stuff that's incredibly inefficient and sucks up all kind of power and runs the environment out of resources either. So there's other issues as to how quickly this technology will develop.