Oral History of Rodney Brooks

Interviewed by:
Hansen Hsu

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Hsu: So today is Friday, June 2nd, 2023. I am Hansen Hsu, curator here at the Computer History Museum, with Rodney Brooks. So to begin with, we'll start with where and when were you born?

Brooks: I was born in Adelaide, South Australia, in December 1954.

Hsu: Mm-hm. And you grew up in Australia?

Brooks: I grew up in Australia until I was 22 1/2 years old, and then I came to Palo Alto to Stanford University.

Hsu: Oh, wow. <laughs> What were your parents' background?

Brooks: My mother was a hairdresser until she got married, and then no more working, and my father was a telephone technician on relay telephones, and then later he worked as a technician on some rocket engines for a European launcher that was launching from Australia.

Hsu: Oh, okay. Interesting. Do you have any siblings?

Brooks: I have three siblings. One older brother, younger brother and sister, yeah.

Hsu: What were your interests, hobbies or favorite subjects as a child?

Brooks: Oh, I was-- from a very early age arithmetic was fascinating to me, and then mathematics, and, you know, about age eight I was trying to build computers. There were none, <laughs> so I had to build them, and I had a couple of How and Why Wonder books, American books on-- one on computers and giant brains and another on electricity, so the electricity [one] taught me how to build circuits and then putting [them] together to try and make computers.

Hsu: And so these kits or--

Brooks: Oh, no. No, no.

Hsu: --you built it--

Brooks: No, there were no kits back then.

Hsu: Okay.

Brooks: This was just whatever I could get my hands on and I'd refashion, whether it was switches from old manual switchboards in offices or whether it was relays that I made myself by winding--

Hsu: Oh, wow.

Brooks: --coils, light bulbs from flashlights, batteries, those sorts of things.

Hsu: So you're just sort of self-taught or just reading books that you--

Brooks: What I could get my hands on to read, and the rest I had to invent. Yeah.

Hsu: Oh, wow. So like what years was this taking place?

Brooks: That was during the early '60s, so by 1967 I think I'd built a machine that could play Tic-Tac-Toe and not be beaten.

Hsu: Oh.

Brooks: So I was just having fun. I had a lab--

Hsu: Wow.

Brooks: --which-- the old tin shed in the garden. I'd spent hours down there trying to build stuff.

Hsu: Yeah. <laughs> What sorts of books did you read or media did you consume?

Brooks: I read science fiction, and anything I could find that talked about computers, and there wasn't much in Adelaide at that time, so whatever I could find I would read. I went to the state library, found-- I remember finding a book on cybernetics, which was a bit beyond me, but I read it and studied it.

Hsu: Norbert Wiener's book or...?

Brooks: No, this was a Czech book, from Czechoslovakia.

Hsu: Oh.

Brooks: Yeah.

Hsu: So from behind the Iron Curtain. So--

Brooks: Yes, yes, yes.

Hsu: --Soviet style cybernetics.

Brooks: Yeah.

Hsu: Wow.

Brooks: Yeah.

Hsu: Interesting. <laughs> And what sorts of movies did you watch?

Brooks: Well, we didn't go to movies very often. I must say the greatest impact on me was "2001: A Space Odyssey," when that came out. I was a mid-teenager by then, and I just loved "2001." I loved the computer. You know, it was a murdering psychopath, but apart from that small problem...

<laughter>

Brooks: The idea of artificial intelligence, which I was sort of aware of A.I. by then and seeing it put into this movie in this vision of the future of these-- this intelligent computer was just fantastic.

Hsu: Mm-hmm. Who were your mentors or favorite teachers or heroes growing up?

Brooks: Yeah, I had two math teachers in high school who took a special interest in me and tried to cultivate me and help me get more materials that they could get their hands on that I couldn't, and they were very, very helpful, Tom Bauerochse and John Gaffney.

Hsu: Uh-huh. So you did your undergraduate first in Australia?

Brooks: Yeah, I was at the Flinders University of South Australia, and I did a degree in Pure Mathematics. I took 1 physics course, 1 chemistry course and 39 courses in mathematics.

Hsu: Wow.

Brooks: That was my undergraduate.

Hsu: <laughs> Wow. That's serious math.

Brooks: <laughs> And it was a fairly classical Eastern European education because it was a brand-new university and a lot of the math faculty were refugees from the Prague Spring, and so it was very, very continuous mathematics, analysis, et cetera.

Hsu: Wow, okay. And who were your biggest influences in college?

Brooks: I think it was one faculty member, Bill Cornish, who, again, you know, took me under his wing, and it was very much in abstract algebra, but there was also the mainframe computer for the university. Now, when I say mainframe, it had 16 kilobytes of RAM. The disk was one megabyte, and normally during the week there were operators and you'd put punch cards in and you'd get one run a day of your punch card program, but there was one professor, Jerry Kautsky, who was a Czech refugee, who really took an interest in me and he arranged that I could have that computer to myself for 12 hours on every Sunday, and then I got the computer myself. I built a-- I built file systems, I built virtual memory for it. I built languages for it. I just had the greatest time teaching myself, mostly. I'd read a snippet somewhere in some book about some technique and then try and see if I could make it work.

Hsu: Hm. Wow. What was the first program that you ever wrote?

Brooks: The very first program I ever wrote was in FORTRAN and it was a simulation of a neuron talking to another neuron, a ma-- you know, a continuous math sort of simulation of pulses going down the axon and then into the next neuron.

Hsu: Was that during undergraduate or graduate school?

Brooks: No, that was in high school.

Hsu: Oh, in high school?

Brooks: Yeah. I managed to get access to something.

Hsu: Wow.

Brooks: And yeah.

Hsu: Wow, that's amazing that you were doing neurons, neural simulation.

Brooks: Well, I had actually built a physical neural network that could learn. It was electrodes in a copper sulfate-- it was on a-- in an ice crea-- ice cube tray. It was small ice cubes, so lots of little, you know, cubic spaces. Copper sulfate in each one, and then electrodes made from nails in each one, and when there was a conjunction, when both things were operating, it would start to build up a copper bridge between those two electrodes, so it was sort of Hebbian learning, and I had this network of these things that taught it sort of to add very small numbers, so...

Hsu: Wow.

Brooks: So when you don't have anything, you use what you've got.

<laughter>

Hsu: Yeah.

Brooks: And I think that was really helpful for me because I didn't have big things. I just had nails and ice cream-- ice cube trays, so yeah.

Hsu: Wow. <laughs> Okay, I'm-- we're going to sort of switch gears a little bit and get to the overview questions, so--

Hsu: Okay. So describe in layman's terms your contribution to your field of work.

Brooks: My main field has been robotics, and in the '80s people were trying to build robots that could move for the first time. The [Stanford] Cart is on exhibit here at the Computer History Museum, and that was at the Stanford A.I. Lab. I was an officemate with Hans Moravec when he was working on that, but it took the mainframe and 15 minutes of computation to move every meter, and then I was looking at insects, and insects could fly around and avoid things and attack each other and find a human and suck their blood and they didn't have that many neurons, and I was thinking, "Okay. Maybe we're organizing our computation in a much more difficult way than real insects operate." So I started to try to figure out how to make simple creatures that could do simple things in the world but I-- in real-time, make them fast, and out of that came something I later called the subsumption architecture, which was a way to couple sensory data to actuators in very tight loops, and there was no one place that had a complete understanding of what was going on but these whole-- many, many loops operating at different frequencies stacked on top of each other gave overall behavior from tiny amounts of computation, and so I was able to build robots that moved around cluttered environments or robots that could walk, or even robots that could go and find things with very simple vision systems with almost no computation, and that direct interaction between the world and the robot has then been adopted, modified, changed over the decades, and some of those early systems I built, behavior-based systems, then later became behavior trees, which is what people use to program videogames these days.

Hsu: Wow, thank you. What is the underlying passion or focus that has driven your work?

Brooks: I think it was from my childhood, trying to build things that moved and, you know, I just love it when it actually works, when it operates in the world, when it's doing something in the world. <laughs> Once a philosophy professor visited my lab at MIT and he saw what I was doing and he said, "You're just reliving your childhood," and I said, "Yeah, I am. It's great."

<laughter>

Hsu: I'm very curious about that possible philosophy professor. I'll get back to that later. Can you tell us a story about a major challenge or a dark moment in your career and how you overcame it and turned it into a success?

Brooks: Can I just have a minute to think about this one?

Hsu: Yeah.

Brooks: In the late '80s, I wrote a paper which was published in the *Journal of The British Interplanetary Society*, and it was called "Fast, Cheap and Out of Control: A Robot Invasion of the Solar System," and the idea was instead of-- as people were then working on trying to build a big rover that was going to be a many, many billion-dollar mission, I suggested that we send small rovers to other planets, to Mars in particular. Much cheaper mission, maybe send multiple copies, if one fails the other will operate, et cetera, and we-- Colin Angle, who was my undergraduate student, and I, had worked with JPL, and we had started a project there to build small rovers, and it soon became clear that, ah, there was no way that was going to be put on a manifest to go to Mars. So we looked around. We teamed up with David Scott, who had been commander of Apollo 15, and then we worked with-- and once we had someone who'd been to the moon we could talk to anyone we wanted-- and we teamed up with the Ballistic Missile Defense Organization, and they were going to send a satellite to the moon called CLEMENTINE, which they did do, and we worked with them and we built a prototype rover for the moon, which was small enough that it could-- they could have ejected one of their Brilliant Pebbles when in lunar orbit and it had enough delta-v to get this very small rover that we built down to the surface of the moon, and we were going to land it next to Apollo 15, which was David Scott's lunar module, and do some metallurgy on something that had been on the moon for 20 years at that point. So we did a test flight out of Edwards Air Force Base with them simulating landing, being out of communication for four days, and then, ugh, NASA was very upset with us. "You can't. You can't-- that's our job," and out of that the little project we'd started at JPL and wasn't going to go anywhere, got added to the 1996 launch, which landed on July 4th, 1997, and that was Sojourner, the rover that we all-- the first rover on the surface of Mars, which was from a project we'd started a few years before. So we started it, realized it wasn't going to work, tried another one, and that influenced NASA to actually put it on the-- in the launch and get rovers to Mars. That was pretty good.

<laughter>

Hsu: So I guess the part that was the challenge and overcoming was the part that...?

Brooks: For a while it looked like we could not possibly rely on NASA to have a launch, so we had to go look for other launch partners and we talked to lots of companies that were going to build launches. We talked to some other nations that had launches, and then coupled up with the Ballistic Missile Defense Organization, which was a separate thing from NASA which had launches, and the promise of them doing something then pushed NASA into doing it after all.

Hsu: Okay. Okay. Thanks. Regarding the current state of the field that you pioneered, what outcomes have surprised you the most?

Brooks: When during the '80s and '90s we were building robots and we'd started the company which became iRobot, that was actually started as a space exploration company, we were thinking of one robot or two robots or six robots, but then the Roomba is in [the] tens of millions of robots, so I think that's sort of a surprise. I think-- build something that turned into that many things? That was pretty exciting. Now, on the other hand, you know, I started life out as a pure mathematician, and then I sort of ended up as a vacuum cleaner salesman, so there's ups and downs.

<laughter>

Hsu: What's the biggest misunderstanding about your field?

Brooks: I think today the misunderstanding is that you just need more intelligence or more learning and robots'll be able to do anything, and you know, that's just not so. Things take a long, long time. The hands we have on our robots today are not very different from the ones on the robots at the Stanford Artificial Intelligence Lab when I got there in 1977. There's lots of simulations of complex hands learning to do things, but in practical terms we don't have complex robot hands, and we're not going to have robots, humanoid robots, that can walk around and do everything people can do, and I think that, you know, it's part of the hype cycle of, "Well, that's what's going to happen next. We're going to have humanoid robots doing all factory work or all warehouse work," and it is so much harder than people believe.

Hsu: Uh-huh. Thank you. So we're going to go back to the main part of the interview now. So--

Hsu: So what led you from Australia to come to Stanford for graduate school?

Brooks: I was really interested in artificial intelligence and I was in the mathematics department but there wasn't really anyone who knew much about artificial intelligence, and I was trying to do a PhD with an advisor who was being very helpful, but it wasn't really his field, and I realized after a while that I needed to go somewhere where there were people working in artificial intelligence to learn from them. So at the time the-- what I knew about was the three major places in the United States where artificial intelligence work was done was MIT, Carnegie Mellon and Stanford. So I applied to all three places. I did not get into MIT. I got into Carnegie Mellon and Stanford, so I went to the library and got an atlas and looked up where they were. I had no idea, and Stanford was close to Australia so I thought, "Maybe that's the one to go to." <laughs> And I must say, if I had applied two years later I don't think I would've gotten into Stanford. I was just so lucky. I was at a point where computer science and artificial intelligence was not important yet so there wasn't a lot of people applying, and I had a good background in mathematics. I'm assuming that's what got me in, but I didn't know anything about computer science particularly or artificial intelligence, and I think that would've been much harder just two to four years later.

Hsu: Oh, wow. So you entered Stanford at what year?

Brooks: I entered Stanford in 1977. I was 22 1/2 years old.

Hsu: Wow. Okay. And your advisor was...?

Brooks: My advisor at Stanford was Tom Binford, who was a [computer] vision researcher, a research scientist, and he led the hand/eye group at the Artificial Intelligence Lab. John McCarthy, who's founder of artificial intelligence, was the head of the lab, and there were a few different groups, and Tom Binford led the vision and robotics group.

Hsu: Right. And you mentioned earlier that Hans Moravec was another student in the lab that--

Brooks: When I got to the Stanford A.I. Lab Hans Moravec was already a student there. He'd already been there for a while and he had the Cart, which was a mobile robot, and he was trying to operate it with computer vision, and he actually lived in the ceiling. That's where he slept, and so I rode my bicycle up to the lab every day and rode home late at night, but we had so many great late-night conversations about all sorts of things. It was tremendous.

Hsu: <laughs> And your thesis was a machine learning thesis or...?

Brooks: Back in Australia when I--

Hsu: Oh, that was in Australia.

Brooks: Back in Australia when I terminated my PhD program I wrote up the results I had as a master's thesis and it was a really bad thesis on machine learning, <laughs> but that's what I knew about. When I got to Stanford I started working on computer vision. My PhD thesis was in computer vision.

Hsu: Oh, okay. At this time, were you working sort of with like the blocks world type of paradigm in A.I.?

Brooks: When I got to Stanford I worked on a DARPA-funded program. The DARPA had at that point a big program at many universities called the DARPA Image Understanding Program, and it was really about how we could interpret satellite images or high-altitude images for all sorts of purposes, and my thesis, it's-- the data that we had were pictures of airplanes at San Francisco Airport and trying to, you know, which were unclassified, and we're trying to pull out, "What is an airplane?" "Which is not an airplane?" and "What sort of airplane is that?" So it was extracting a geometric model enough to match to a pre-input model of the length and ratios of everything, you know, different airplanes, and determine what sort of airplane was being seen in the image. I was able to process three images for my PhD thesis. <laughs> Each one took a couple of weeks on the mainframe to run, and then Moore's Law took care of that over the next 10 years and things were completely different.

Hsu: Yeah. What mainframe was that?

Brooks: That was a-- the computer we used was a PDP-10, DEC 10, but it was a hacked version at the Stanford A.I. Lab with all sorts of extra peripherals and all sorts of stuff that regular commercial Digital Equipment Corporation computers did not have.

Hsu: Mm-hm. So then after you finish your PhD you went on to CMU?

Brooks: After my PhD I went to CMU to work with Guy Steele.

Hsu: Oh.

Brooks: I had been working with him-- in the summers at Stanford we had been working with Lawrence Livermore National Lab building a LISP system for the S-1 Mark IIA supercomputer, because that was intended ultimately to run artificial intelligence algorithms, and LISP was what was used in those days, and so I spent a summer at CMU working on that LISP system getting it closer to reality, and then after that I went to MIT for two years as a post-doc in Robotics.

Hsu: Mm-hm. And then after your post-doc you came back to Stanford?

Brooks: Yes, the-- yes, in 1983 I came back to Stanford and joined the faculty. Just two years after I'd left.

Hsu: Right.

Brooks: And that was a pretty interesting time. I'd been using LISP machines at MIT, which were special-purpose machines built just to run LISP, but at Stanford there was the SUN project, Stanford University Network, and the Sun Corporation had started, and we had some of the very early workstations, which were general purpose workstations, and so I immediately built a LISP system for the SUN machine, because I was building planners and reasoners for-- at that point for robotics and I needed some way to program that.

Brooks: I had a great year at Stanford but there was a big push into robotics at MIT and I didn't want to miss out on that, so I moved back. I was fortunate enough to get a faculty offer at MIT in '84, and I moved back to MIT then, and that's where I spent the rest of my academic career.

Hsu: Mm-hm. And I want to jump back to, you know, you mentioned earlier being influenced by HAL from 2001. You know, it's not uncommon, I find, that like A.I. scientists, being in-- taking inspiration from HAL, despite the fact that it's a murderous device. So what is the, you know, what is that that-- why is that, even though there's such a negative part of the--

Brooks: I think I and lots of other people, when we saw the movie "2001," it was an eye-opener because the imagination that had come from people like Marvin Minsky, who was a consultant, and the magic of the filming, you know, it had computer graphics in it. There were no computer graphics at that time and they couldn't use computer graphics to show them. All those screens which look like LCD screens, were actually back-projected from film running on it. It was before there were screens that you could have graphics on, but there was graphics, there was language, there was computer vision. There was all these things coming together, and people had talked about little pieces of that but here was a vision of how it might all come together and what the world might look like in the future in terms of devices and interaction and it was pretty prescient, I think, and it inspired a lot of people. I was not, at that point, trying to build super-intelligent robots. I was trying to build robots which were, you know, sort of an insect level intelligence, but still it was inspiring to me to see how the pieces might come together, and by that time we were sort of aware, *sort of* aware, of the impact of Moore's Law. It wasn't as formal as it got in the '90s and in the 2000s where everyone talked about Moore's Law but we knew computers were getting bigger and faster very quickly. We didn't realize what a factor of a million or billion would actually mean, but-- and so that sort of fit what "2001" was showing us, and it seemed like a serious movie. It wasn't, you know, a-- it wasn't cowboys dressed up in space suits. It was something deeper to think about.

Hsu: Mm-hm. Yeah. So 1984, what was the state of the field of A.I. and robotics, you know, when you joined MIT?

Brooks: When I joined MIT the second time in 1984, I decided to shift to mobile robots. At that point Moravec's Cart, Hilare in Toulouse, France, was sort of where things were, state of the art. They were very slow, and this was when I was really thinking about insect-level intelligence and trying to put that into mobile robots. So I started working on robots which moved at speeds which you could see them moving. You could walk around them, you can interact with them, and they had to be aware of their surroundings enough at least not to hit things and maybe to interact with it.

Hsu: Mm-hm. So we touched on earlier the origins of your-- of the behavioral based robots. You know, what maybe, you know, what was really the issue with the symbolic approach that really led to you basically taking a whole completely new approach?

Brooks: In the mid-'80s, people were thinking that robots should use the Sense, Model, Plan, Act [methodology]. Sensing had to get what was out there in the world quite possibly in 3D, Model, turned into a three-dimensional model. Then Plan within that model and then Act, and the acting was sort of blind. It got the instructions from the planner, which had what had been built as the model, but in a dynamic environment that wasn't very helpful because the world was changing at the same-- well, faster than you could plan and act, so there had to be a way to short-circuit that, and not building that complex world model was the easiest way to do it. We still have this problem today. People will want to build a complete world model and then decide what to act in it, you know, and they may be using machine learning and all sorts of things, but they're still thinking that way. And I always argue that you have to have both. You have to have the reactive aspect of, of interacting with the world *and* the world model. And by the way, when you go back and you read the early papers about Shakey the Robot--

Hsu: Mm-hmm.

Brooks: It did the same thing, although they didn't publish all those details because it didn't seem like that was the important part. It was the planning, the STRIPS planner was the important part. But if you go and look at how it was implemented in some of the, the more technical things which weren't published in journals but were issued as reports at SRI International, there were the intermediate level actions which were the, the glue between the, the squishiness of the real world and the rigidity of the internal model. So Shakey had actually, and I didn't know about this till later, Shakey, the people working on Shakey had had to solve this problem in some way to make even Shakey work as a robot.

Hsu: And really what-- what, what led to sort of the insects as, as the inspiration?

Brooks: I-- <laughs> My kids are half Thai and my-- their mother is Thai and we would go and spend time in very rural Thailand with her family and no one else spoke English and, and everyone was busy speaking Thai. So I would just sit there and contemplate the world. And I started watching a lot of insects and that got me thinking, "Well, what are those insects doing? How are they doing that?" And so it was really, you know, in a-- in a house on stilts in a river that I came up with this approach with my notebook.

How-- how could it-- how could the, the stuff inside the insects be organized to produce these fantastic behaviors with not many neurons, so likely not much computation?

Hsu: <laughs> What were the reactions of, you know, people like Minsky, Allen Newell, Herb Simon, McCarthy at, you know, this approach?

Brooks: I got a lot of pushback from just about everyone. I remember I was at a conference in 1985 in just outside of Paris where I first talked about this work. And two senior people were in the back of the audience, one saying to the other, "What is this young man doing, throwing away his career?" Of course, that was just red meat to me. Okay. Game on.

<laughter>

Brooks: Let's-- let's see how far I can push this. And so I-- That, that really got me excited. I just started building more and more robots, showing them, doing more and more things that other approaches couldn't do. It doesn't mean everyone was convinced. A lot of people to this day say, "That's not how robots ought to work." But I sort of plead victory by the number of robots based on these ideas that are out in the world.

Hsu: What-- Why was it so important for the robots to be embodied and situated in the environment?

Brooks: Within my group, the-- the I-- We, we sort of had this slogan within the group, you know, "simulations are doomed to succeed." Because if you're simulating, if you're building the simulation and you're building the intelligence, you want to make something that you can publish. So you get the simulation and the intelligence to interact in some way which shows some interesting result. When you're using the real world, you don't get to change how physics works or anything like that. You can't simplify it. You got to deal with the real stuff. And so that always, I thought, led to a more honest, to use a word, system because it wasn't-- there was no place to hide the fake stuff. It, it had to work with the real world.

Hsu: And also the importance of building from the bottom up.

Brooks: I really had this thing of building from the bottom up because I was actually influenced by Hans Moravec's argument about how, you know, animals can do all sorts of things without being able to do really smart things. And it turned into, in my case, it turned into a paper titled "Elephants Can't Play Chess" where elephants can do a lot of stuff, but they can't play chess. They can't reason in that way, and simpler animals, less of that reasoning. So I was also in a way trying to see how could this have come about evolutionarily, how can you start with simple stuff and eventually get complex behavior? And how-- how is it built piece after piece after piece? So that was an auxiliary question that was in my mind, which meant that in my group, we always started out with nothing and built on top of nothing to build up because it was how does this relate to evolution?

Hsu: Right. And that affects the way-- So, you know, so subsumption architecture in the way you've described it is based on that evolutionary sort of metaphor?

Brooks: The subsumption architecture was based on a cartoon version of, of evolution, not a real version, but a cartoon version of how over time you'd have a creature with some nervous system and when you add more stuff to that nervous system and it can do more stuff. It is a cartoon. It's not the whole thing by any means. But it was a-- an organizing principle for us.

Hsu: Right. Was there any influence on this approach from cybernetics?

Brooks: When I was a kid in Australia, I had read Grey Walter's book. It was about electrophysiology, but he had a chapter about his robots he called tortoises. And they, they were also, and I didn't see these till later, there were also a couple articles he had written for *Scientific American*, which were much more succinct. And these tortoises were very simple systems. They had two vacuum tubes-- two vacuum tubes. It's like two transistors-- but got an amazing number of behaviors by using the non-linearities in the vacuum tubes and coupling them together. So I had seen that when I was younger. I had tried to build a transistor version of it. Transistors didn't have as many non-linearities as vacuum tubes, so it was a little-- it was harder, but I had a little robot that I had built as a teenager that could go around the house, bump into things, avoid them, follow a light. It tended to get stuck under four-legged chairs or would get-- get in and then could never get out. But I, so I had that background which was non-computational in the way it was thought about. So that was an aspect that influenced me in this, in the subsumption-based artificial insects.

Hsu: Was Lucy Suchman's book, "Plans and Situated Actions" something that was influential?

Brooks: We, we were very well aware of Lucy Suchman's work and other people, there were a whole bunch of people, who were coming at it from not building robots, but studying humans or human psychology or human behavior, also a whole range of-- of things. And, and there were a couple of you know, intellectual groupings during the nineties. There was the Simulation of Adaptive Behavior Groups mostly based in Europe. And then the Artificial Life groups, mostly based in Santa Fe in, in the U.S. Both of them had strong participation from Japanese researchers. And there these ideas were all circling around each other. And it was a-- it was a very rich time and it was very distinct from mainstream AI at the time. The mainstream AI people did not go to those conferences in general.

Hsu: Right. Okay. I also want to, you know, bring back the-- So you mentioned a philosopher earlier, so I don't--

Brooks: Unfortunately, I don't-- He was Japanese and I don't remember who he was.

Hsu: Okay. So I have a different philosopher in mind.

Brooks: Okay.

Hsu: So you probably-- So, I know Hubert Dreyfus was a big critic of traditional symbolic AI. And you know, you've written that your approach is not German philosophy, is not-- You're not doing phenomenology, but you had a few students who were engaged with that work.

Brooks: Yeah. That actually goes all the way back to when I was a student at Stanford. I could start there.

Hsu: Oh yeah. Yeah.

Brooks: Back when I was a grad student at Stanford, Terry Winograd--

Hsu: Yeah.

Brooks: Had Fernando Flores as a guest professor. He had been in Chile, had run into political problems. He had been part of the group that interacted with Stafford Beer who was an English cybernetician and they had put a lot of his ideas into information systems [Cybersyn] within Chile. And then there was a coup and--

Hsu: Yeah.

Brooks: He was on the wrong side of things. And he, he taught a class that I took on German philosophy, on, you know, Heidegger and Husserl and all those people. So I, I read a lot of that. It was-- It made my head hurt.

<laughter>

Brooks: It's hard-- hard-- hard-going. But I was aware of that philosophy.

Brooks: ~~Okay, so I would say,~~ so with Flores, I read a lot of this philosophy and there were many ideas that I liked. The ready at hand idea, which was very similar to the affordances idea of J.J. Gibson, a psychologist at-- at Cornell, which-- where we build things that tell a person how to interact with them and they, you know, that is a grabbable object; that is a closeable door, et cetera. And that seemed to me to fit in with my approach of a very direct coupling between perception and action telling you what to do. Meanwhile, Searle at Berkeley, I thought was arguing almost, you know, although he referred to the German philosophers, he was a philosopher himself, I felt that he was arguing an in principle idea that a machine could never do anything, could not be as rich as a-- as a biological thing. But I was of the opinion, still am of the opinion, we are machines. There's nothing-- there's nothing-- You know, we don't when we talk about molecular biology, we don't say, "These two molecules come together and then God intervenes and makes them couple." We talk about it in terms of forces and Van der Waals and etcetera. So I thought he was going too far. I thought his argument was weak because it was unless it's a real being it can never have real understanding. But to me, that was missing, I thought-- or relying on something higher order that isn't, in my view, [is] not there and is not viewed as being there by modern science. I, you know, some of his criticisms of the techniques not being able to get there might be reasonable, but he was in principle against the idea you could have true intelligence in a non-biological entity. I don't think that's the case, whether we humans are smart enough to make such non-biological entities that are intelligent is a different question. But in principle, I don't think there's any argument that it shouldn't be possible.

Hsu: Right. So, so then going back to sort of the phenomenology, so you were already engaging with phenomenology as a graduate student. So you're saying that there is some connection from that to your insight that, you know, perception needs to be coupled directly to action?

Brooks: I found phenomenal-- <laughs> I found phenomenology to be a way of thinking about how perception and action could be in the world without being-- going to the central world model, which is a simulation of the world-- because then you have a model of the model in the simulation of the simulation-- but it was how you coupled those. And so to me, that was a bit of an inspiration. It didn't turn-- it didn't, it didn't turn into a technical piece of code that tried to implement it, but it was an inspiration of how this might work.

Hsu: Right. Yeah. And then you had your students, you had Dave Chapman and Phil Agre who, who did take up that in a stronger way.

Brooks: David Chapman was my student and, and Phil Agre was Mike Brady's student. But Mike moved to Oxford and Phil was left with me and for most of his Ph.D. The two of them were very good friends and they had really taken these pheno-- phenomenon-- phenomenology ideas to heart and pushed through them and built their Ph.D. theses around them in an interesting way. It was, and they were engaged in that Simulation of the-- of Adaptive Behavior Group and in the Artificial Life groups. They were really part of that intellectual ferment across-- across three continents, really.

Hsu: Yeah. Okay. How much did you engage with Artificial Life and with the Simulation of Adaptive Behavior in your work?

Brooks: I wrote many papers for both Simulation of Adaptive Behavior and Artificial life. I wasn't at the very first Artificial Life conference that was held at the Santa Fe Institute, but I was there for the others. I hosted the fourth, maybe fourth, Artificial Life conference at MIT. Pattie Maes and I co-edited the-- the proceedings. I was very much part of the Artificial Life community in the United States for many, many years. And then I would go to every Simulation of Adaptive Behavior meeting in Europe.

Hsu: Yeah, so very engaged. How do you define intelligence?

Brooks: People always ask, you know, how do you define intelligence? And, and we see this play out in, in modern debates, modern-- modern hype cycles.

<laughter>

Brooks: Patrick Winston, who was former Director of the Artificial Intelligence Lab at MIT would say intelligence is something that that if you see a person do it and call it intelligence-- that if you had seen a person do what the machine did and called it intelligent behavior from the human, that would be intelligent behavior from the machine, which actually was not too far off Turing's approach to it, with the Imitation Game, which then became weirdly the Turing Test, which was not the point of Turing's argument at all. We don't have a good definition of it. And I think that was why the European group that called Simulation of Adaptive Behavior, tried to get around, you know, having to define intelligence. It was how does the behavior adapt to the situation to achieve whatever it needs to achieve? And we still don't have a good description of intelligence. You know, I think if you go back to 1956 with the founders of Artificial Intelligence in the Dartmouth Workshop and even in the proposal from 1955, they were all trying to figure out how to make an intelligent system, which was human level equivalent. A few years ago, some group of researchers decided, okay, we'll-- we'll call artificial general intelligence and that's-- we're going after the real thing. But everyone else was already going after the real thing. That's what they were trying to do. And so that was a marketing exercise. And now we have AI and we have AGI for Artificial General Intelligence. And we have ASI for Artificial Super Intelligence. It's all research groups marketing themselves. It's all about how do we do this stuff that people do?

Hsu: <laughs> So how did you come up with the names of a lot of the robots that you and your students worked on? You know, Genghis and Attila, but also, you know, named after famous AI people. And--

Brooks: Yeah. My early-- my early robots were sort of a, you know, <makes raspberry> to the artificial intelligence workers, naming my robots after the famous AI researchers. And then we built this six-legged robot which clambered over everything. And, and one of my students who hadn't worked on it, saw it and said, "Wow. That's like Genghis Khan, the way it can just walk over everything." So we called it Genghis. And then we started naming our robots after-- after marauding conquerors because these robots would go anywhere. <laughs> And then when we started building a humanoid robot, it was sort of meant to be able to do cognition. And Cynthia Breazeal came up with the name Cog, you know, and which was great. It's a mechanical thing, cog, gear-- and cognition. And so that was a great name for it. We had fun naming our robots.

Hsu: <laughs> Yeah. Earlier, you mentioned the article that you wrote, "Elephants Don't Play Chess." Talk about the impact that that article made.

Brooks: My early papers were quite controversial at the time. “Intelligence without representation,” which was a sort of a real stick it because AI relied on representation. I said, "Let's get rid of the representation. Intelligence without representation." It took a long time to publish. The reviews were terrible, but I held on and eventually got published in the *Artificial Intelligence Journal,* unchanged from what it was, and it has some amazing number of citations now. And it quickly became required reading in many AI and psychology courses all across the world. Then I-- I'm still stunned. I won the Computers and Thought Award in 1991, which was a bit of a surprise to me because I felt like that was so mainstream and they'd give it to me? But the-- I got to write a paper for the proceedings of the International Joint Conference on Artificial Intelligence where there was a, I think a 5-page limit, but there was no limit for me. So I wrote a 27-page paper, 2 columns, and I tried to relate the ideas of cybernetics, the history of AI, how all the ideas came together about embodied and situated, et cetera. And I called it rather provocatively, "Intelligence Without Reason." So I now I had a pair of papers, "Intelligence Without Representation," core part of AI, and then "Intelligence Without Reason," the other core part of AI. I was enjoying myself, I must admit.

<laughter>

Brooks: I was enjoying inflaming the world. And then "Elephants Don't Play Chess" was to point out-- really to riff off of Moravec's Paradox of what was hard and what was easy. And the names of those papers made it easy for people to remember and talk about. Another working paper I'd done in the late eighties, which I still see around now, was "Planning Is Just a Way of Avoiding Figuring Out What to Do Next." And the answer, the argument there was planning tries to take this long term thing and but then you have to divide it into smaller pieces and smaller pieces. What is the next--? It's sort of like that half and half and half paradox. What is the thing you have to do next? And my subsumption architecture was about finding out the thing you have to do next without worrying too much about the steps later. So that was the contrast there. I did enjoy making up provocative titles for my papers.

Hsu: <laughs> Yeah, you write in the paper that, you know, I guess this goes back to what you just said about Moravec's argument, was that, you know, survival in a changing physical environment is the harder problem for evolution to solve rather than reasoning or language. And this kind of goes against centuries of Western philosophy and theology centering on reason, right, as the unique thing that separates us from human, from animal consciousness. So, you know, is-- was-- is this this entire sort of cultural, Western cultural thing that you're arguing against, is that one of the-- was that one of the biggest hurdles that your approach was facing?

Brooks: You mean the argue-- making the argument or--?

Hsu: Or, well, that, you know, that main line AI with its focus on reason was following centuries of western philosophical tradition. So do you think that's one of the reasons why your approach was so radical or had such a hard time?

Brooks: Yeah, okay.

Hsu: Uphill battle?

Brooks: I think the approach that I took was counter intuitive to a lot of people, so that made it hard to accept. It also, I think in a deeper way, got at people's view of themselves and self-worth. I've said that the early work in artificial intelligence, and if you go back and you look at the Ph.D. thesis-- theses at the AI Lab at MIT and at Stanford in the sixties, what were they about? They were about the things that smart students, mostly white males, found difficult or competitive, like playing chess, geometric reasoning, all sorts of things like that, that ordinary people don't even think about most of the time, but that to them was the essence of intelligence. But to me, the essence of intelligence was how we are in the world, how a dog is in the world, how an ant is in the world. That is how evolution evolved in some sense. So I think I was poking away at the things that was [part of] people's self-worth of them as super intelligent, "I got my Ph.D. at MIT" type thing, and that was-- that was hard for people to say, "No, it's the stuff that any 2-year-old can do is the-- is the hard stuff." Which was Moravec's, again, Moravec's Paradox. So I think that was part of what made it difficult. I'm still of the opinion that we got it completely wrong and I need to spend more time on my book about what that is.

Hsu: <laughs>I mean, it, it does seem to, you know, given that behavior-based AI is kind of all about not having the need for a central brain, the implications for intelligence is rather unsettling.

Brooks: I'm going to say something which I think will surprise many people. The fact that, you know, subsumption was about not having central reasoning, but still being able to act was unsettling, in the same way I think to me is unsettling, that ChatGPT 3, 3.5, 4 can produce stuff which seems coherent where there is no reasoning. It's a rehash, some complex hashing function, with billions and billions of parameters. But there is no linking apart from the symbols or the tokens that they have in the token buffer, and that it can produce convincing language which fools people totally about what it's talking about and what it knows, to me it's part of the same paradox. There isn't-- I'm not and I'm not saying that we are ChatGPTs. Maybe our dreams are ChatGPTs, I don't know. But I'm not saying that. I'm saying that it's not as built in a computational way as we think it is. And that is unsettling because since roughly in the period 1945 to 1965 we had-- we came up with the computational metaphors for neuroscience, computational neuroscience, for Artificial Intelligence, for Artificial Life, all became products of computation. And it was Turing computation which itself was based on looking at how people produce-- do arithmetic on paper. That's, you know, what, first, those people were called computers. Wait, computers are people and now people use computation? Wait, people are computers? It's a circular argument that we in our modern mid-20th century have gotten into and I think will not stand the test of time. And when I mean the-- when I say the test of time, I'm not talking 10 years, I'm talking 300 years.

Hsu: Hmm. Yeah. Discuss--

Brooks: It's not a good thing to say at the Computer History Museum, but--

Hsu: Yes.

<laughter>

Hsu: We're trying for that 300, 500-year lifespan. Discuss the importance of emergence as a theme in AI.

Brooks: Some people take-- Certainly, when I was talking about emergence, some people took great umbrage at emergence. "What do you mean emergence? You know, it just, it's just magic, it just comes out?" And no, I don't mean that. A gasoline-driven car, it can drive from San Jose to San Francisco with a human in there. But there's no place in the car, which is the, the thing that is the go on the freeway thing. It goes on the freeway, but it's a combination of the wheels turning the suspension system, the motor pushing the wheels around, the steering mechanism being-- being turned in the right direction to stay on the freeway. A car driving on the freeway, the fact that it drives on the freeway is an emergent property of a lot of other little coupled systems working together. There is no thing--this is the drive on the freeway box. It comes out of other stuff. And that's one of the things I was trying to push, that that's how all systems work. They emerge out of interactions of subsystems which are not directly generating the thing. The thing gets generated as a, as a-- out of a totality in a whole. And the engineering by reductionist methods has to encode that somehow in that tree reduction that's done. But it is an encoding that's being done to get the emergence out and to do the analysis. And when you see a natural system, you may decompose it into parts based on maybe how the neurons stain with a particular chemical. "Oh, this is that subsystem. That's that subsystem." No, that's-- that's where that chemical migrated through the-- through to stain that part of the system. It doesn't show you everything, you know, in the-- in the way that neuroscience for a long time completely forgot about the cells that are holding the brain together. And it turns out they have a big role besides the neurons. It was all about neurons, neurons, neurons, but there's other stuff there because it was a different structure and it wasn't-- it was thought of as structural rather than part of the process. So the fact that things are emergent, I think, and they all are emergent. But you have to understand that how you do the decomposition and your understanding is biasing how you think that these things can emerge.

Hsu: Hm, wow, fascinating.

Brooks: Yeah, almost gobbledygook. <laughter> But I truly believe it.

Hsu: Yeah. <laughs> So, in your view, how did the field of A.I. research change between 1990 and 2010 before the rise of deep learning? So, which approaches were dominant and which fell by the wayside? What was getting funding and what wasn't? And how was your particular behavioral approach faring in this landscape?

Brooks: There's always been a lot of churn and ideas for intelligence or perception. So, ideas come and go. The most famous of course is neural networks, which came and went three or four times, depending how you count. But other, you know, during the '90s and into the 2000s, the were lots of new learning mechanisms, which are not neural based, support vector machines, others of that nature-- some very mathematical, some based on Bayes' Rule. So, lots of new learning techniques. Which eventually sort of got swamped by deep learning. Surprising most people. I-- if you look back at history, every idea gets swamped by something else eventually, so I expect other things to come along. I think the most recent surprise of course is the generative A.I. and the large language models being so successful. That was a surprise to many people, including me. I don't think just because it's the latest that it's either the greatest or the ultimate answer. And I mean, time will tell. So, there was more emphas-- another sort of learning, of course, reinforcement learning, which became quite popular in the '90s and into the 2000s, has been very successfully applied by Deep Mind. But reinforcement learning, the first papers were back in 1960 about reinforcement learning. It's been around for a long time. And the basic idea, the computation idea, and then Christopher Watkins' Q-learning approach in the '80s, which was critical to Deep Mind's success for all the Alpha programs. So, these ideas are around for a long time, and they ebb and flow on what's the most important one. There's always been a bias towards the newest idea. "Oh, this is the big idea." And now we're in this echo chamber of where it's taken over the whole technical press and the whole of science almost. To me, it's just another cycle, except it just got louder this time because more voices are jumping in looking for something. We'll see.

Hsu: <laughs> Let's see, we got that one. Oh, so we-- you mentioned Cog earlier, so Cog was after the Genghis and all the insect-based robots. How did you jump suddenly all the way up to doing a humanoid robot?

Brooks: Yeah, people were very surprised when I went from insects to humanoids. And I've got two stories about it. One, it had taken so many years to do the insects and I looked at how much time I had left in life if I was going to get to do little tiny mammals, or lizards, and then mammals, and then monkeys. You know, I didn't have enough time to do all those cycles, so maybe I should go straight for it. That was one aspect. The other aspect was on January 12th, 1992, I had my grad students over and we watched *2001, A Space Odyssey*-- and in either the book or the movie, I don't know which-- it's different in the two places-- that day was the birth of HAL. And we're like, "Where the hell is HAL? HAL isn't here. What, what?" So, that was actually what prompted me to think, "Okay, let's try something. Let's do a big jump and let's try and look at human level intelligence. What can we do there using the techniques we've developed over the last ten years, what can we do?" And that's where the humanoid robots came from, and Cog was the first one of them.

Hsu: Right. I mean, that segues directly to my questions about some of the students you've had over the years. So, Cynthia Breazeal? [Mispronounces]

Brooks: Cynthia Breazeal. [Pronounced like "brazeel"]

Hsu: Breazeal, Breazeal. So, she was one of your students that started on that project?

Brooks: Cynthia actually started, her master's thesis was with the robots Attila and Hannibal, which were six-legged walking robots. And it was how to be aware of parts of the body that are broken down and adapt to that and be able to operate in a broken way in the world. Then she was part of the original Cog team and worked on Cog for a while. And then she was-- got much more interested in the human interaction part of it, and so she built her robot Kismet, which was just a head, and you know, didn't do anything in the world but interacted with people socially.

Hsu: Right, yeah, Kismet has gotten a lot of exposure because it has like the eyes and the mouth and it seems to emote. And I guess it's not really a question, but what do you think is the role of emotion or affect in robotics?

Brooks: I think affect pulls people in. How much of it you want in a practical robot, in a practical system situation is, I think, a very much more open question. I think people are more comfortable with robots that show deference to people. But it doesn't have to be emotional, no. In the robot, Baxter at one of my companies, we introduced, it was an industrial robot, and it had a screen, which was also used to program it, but then when it was operating it had two eyes. And the eyes glanced where it was about to move. And we didn't have to train people. You'd ask someone in the factory after being there a couple of days, "What's up with the eyes?" And they'd say, "Oh, it looks where it's going to reach." Because that gives a cue to the person. The robot's going to reach over this way just as another person does. A person normally looks where they're about to reach, and so that you know what's going to happen. You're not so surprised. Some people were very angry with that. People who weren't using the robot, but I got so many things, "Why do you put that smiling face on the robot?" There was no smile. It was just two eyeballs looking at where it was about to reach. People overinterpreted it. It wasn't trying to show emotion in any way.

Hsu: Hm.

Brooks: So, showing emotion I think is part of a more general problem. I say that the appearance of any robot is making a promise to how it's going to behave. So, I've said, "If your robot looks like Albert Einstein, it ought to be as smart as Albert Einstein, or it's going to be a disappointment." So, if your robot shows some sort of emotion, that should be consistent with how some model we would have of how emotion works. It shouldn't go from wildly happy to wildly sad in microseconds. It's got to be consistent with how it's behaved-- what it's experienced in the world, which is much harder than just showing emotion. So, I think it's very hard yet to have a robot showing emotion in the way which is genuine enough for acceptance.

Hsu: Right. Talk about Daniela Rus.

Brooks: She was not my student.

Hsu: Oh, no, okay. But she was in the lab, though.

Brooks: Daniela Rus had been on the faculty at Dartmouth and then joined the faculty at MIT.

Hsu: Oh, okay.

Brooks: And she has been the Head of CSAIL, Computer Science and Artificial Intelligence Lab, for 11 or 12 years now. She's really run that lab for a long, long time. But I never worked beside her. She's not my student.

Hsu: Oh, I'm sorry. I guess I got that wrong. I'm sorry. But did you or your lab do work with like multi-agent robots as well?

Brooks: During the early '90s besides the humanoid projects, there were two projects on multi-agent robots. One by Maja Mataric, with a group of robots. And one by Lynne Parker, with a group of robots. And both of them worked on different aspects of group dynamics of robots interacting with each other. And really their publishing was in the Simulation of Adaptive Behavior groups in Europe in those journals. Both have gone on to do many other things in the world. Lynne Parker was Deputy CTO of the United States until recently.

Hsu: Whoa. <laughs> Was Andrew Ng ever a student of yours?

Brooks: No, Andrew was not.

Hsu: Okay.

Brooks: I interviewed him for a faculty position. <laughter>

Hsu: How did you get involved in Errol Morris' film, *Fast, Cheap, and Out of Control*?

Brooks: One day I got a call from someone from Errol Morris'-- maybe from Errol himself-- his wife had seen a half-page description of me and my work in something called *Gentleman's Quarterly*, and it was by a journalist who usually worked for *Science*, but he'd done this side thing talking about me. And Errol Morris' wife had seen it and said to Errol, "This guy looks interesting. You should think about him for this movie you're working on." And so, that's how Errol found me. And we talked and because I used to always say "Yes" to everything, I said "Yes" to being part of his movie. We did the filming, I think in '91 or '92. And then the movie came out. Well, late '97, he called me up and said, "I've sold the movie!" and I said, "What movie?" He said, "Oh, I finished it." <laughter> And he'd sold it to Sony Classic Pictures. And he sent over a version of it that still had the little counters running on it. And the graduate students and I got together and it was a VHS tape, we put it in, and we were watching it. And I was just appalled. <laughter> Because it was five years later, and what I'd been talking about back in the movie was still what I thought were my newest idea. I hadn't had a new idea in five years, I realized. <laughter> I'd just been talking about the same ideas again and again and again. But I thought the movie was okay. It was an experience and I enjoyed it. <laughter>

Hsu: So, let's move to talking about your leadership of the department at MIT. So, you're responsible for merging computer science and artificial intelligence into what is now CSAIL. How did that come about? What was the driving need for that and what have been the consequences of that?

Brooks: Back on July 1st, 1963, Project MAC had begun. Project MAC was Computer Science and Artificial Intelligence, everyone working together. And it was a new research lab for people to work together. But there was a falling out within a small number of years where the A.I. Lab, Artificial Intelligence Lab, separated from the labs of Computer Science. They were in the same building, there was always turf wars. I joined the A.I. Lab first in 1981, which was more or less than 20 years later. By the late '90s, we were going to have a building on campus. We never had been on campus before. And I had been involved in the planning committee for that building since the early '90s, and then we chose Frank Gehry to build it.

Hsu: Oh, that's that Gehry building.

Brooks: Yeah. And we were going to move the Lab for Computer Science, and the A.I. Lab into it, and it was built in two towers, so we'd each have our own tower. So, it was sort of elbowing people at the same time. And then there were a couple of changes. Patrick Winston stepped down from running the A.I. Lab and I took it over in 1997. And then I really enjoyed working with Michael Dertouzos, who was the head of LCS, and he was older than me and took me under his wing in many ways. And we worked together on raising funding from industry, from Europe and Asia. And we were very successful. We would travel together. And then he just-- he passed away in 2001 unexpectedly. So, as we're moving into this building, then it became, "Well, maybe we should change from being competitors, or different, to being jointly together." And we sort of decided that as a group. But then who was going to lead it? And what was it going to be called? I was fortunate to be chosen to lead it. And then we had to name it something, and a lot of people just wanted to call the whole thing Lab for Computer Science and not separate out A.I. as part of it. I really thought the name A.I. was important for the-- my smaller group, it was about half the size of the Lab for Computer Science. Took a long time, but we eventually came up with a name. We had LCS, Lab for Computer Science and we had A.I. There were five letters. But eventually we got together in the Computer Science and Artificial Intelligence Lab. And at the time many people were unhappy about that. But I talked to some recently who were really against having A.I. in the name. Now they say, "We're so lucky to have A.I. in the name," because of what's happened since. And then we merged and I was the head of it. And it was as uncomfortable I think for the A.I. people as for the Computer Science people that this, you know, someone had been this crazy young guy, you know, throwing bombs everywhere was now the leader. <laughter> But I think they got calmed down a lot and was able to help everyone work together and be productive. <laughter>

Hsu: And you know, even while you were there you helped foster a lot of industry collaborations.

Brooks: Yeah, we-- there was a time when there was a pullback. I would say in the early 2000s, there was a new President, and some of his advisors were very skeptical about academia. And they sort of pulled back military funding, which would've been very important to both Lab for Computer Science and the A.I. Lab at MIT. And we had to find new methods of funding. And so, we went out and talked to industry all over the world, and you know, the irony is that we more internationalized research rather than the U.S. owning the research in some ways, because of skepticism about academia. If they hadn't had that skepticism, it would have been more U.S.-centric. But it became more international. And you know, we see the ups and downs, you know, the political spectrum and the popular spectrum of who should people in the U.S. work with or not. It continues to happen to this day and it will continue forever; and the internationalization of science and engineering is scary for many people.

Hsu: Hm. Right, especially because there's-- I mean, now we're in this perceived A.I. cold war with China, so there's--

Brooks: I'm not going to talk about it.

Hsu: Okay. <laughter>

Brooks: I think I got the message across--

Hsu: Yeah.

Brooks: -- with those words, yes.

Hsu: So, talk about your first startup, Lucid.

Brooks: I was on the faculty at Stanford, and I had built a LISP system for the Sun workstations. And as I was leaving, we decided to do a startup in 1984 here in Silicon Valley. We called the company Lucid. It was decided that we would use my compiler for the first six weeks and then they'd be replaced by another compiler. It was still there eight years later. <laughter> As always these things never happen. And so, we got venture funding. I was moving to MIT. I had sold a book about LISP for a $20,000 advance. And I used that as a down payment on a $140,000 house in Lexington, Massachusetts. And in that, I had a $100,000 Sun workstation, which had a megabyte of RAM. It was $100,000 then.

Hsu: Wow.

Brooks: For two-thousand--a megabyte of RAM. And I worked, you know, while I was being a junior Professor at MIT and doing subsumption and all that other stuff, I continued to work on the compiler for eight years. And I would put my latest work on a cartridge tape and ship it FedEx across the country and then back here in Silicon Valley it would get all merged together. And back then there were many more architectures for computers than now. And so, we made the compiler be able to target lots and lots of architectures. And we were running on 19 different machines because the market was so fragmented at that time. And we operated for a few years and then the investors said, "This LISP business is not going well enough. You should do something. The interactive debugging environment, maybe you should do that for C, because that's a real place where things can happen." And so, we built a system and I think the seeds of the failure of the company can be seen in the internal code name for the system. It was called Cadillac. Which meant it had everything. <laughter> And we were competing with really Borland, which was a very small system, scrappy. They sold seats for $100; we sold seats for $20,000. You can guess what happened. We went out of business. I learned some lessons there about pricing and customers.

Hsu: Right. So, let's move on to the founding of iRobot.

Brooks: iRobot was originally founded, it was called IS Robotics. It was a space exploration company. It was trying to take the ideas we had for small rovers and send them to other planets. And we worked with lots of people and eventually with the Ballistic Missile Defense Organization, and eventually that led to NASA taking out our older project and putting it on Mars. So, we had to change. That wasn't a real business. And we went through a lot of business models over the next few years. We didn't take any venture capital this time. After my experience with Lucid, I didn't want to be beholden to venture capital. So, we did it with no funding. Everything was, you know, "What can we get a contract for now, which will keep the payroll going, and somehow we'll turn into a company later?" And so, we worked on lots of projects. We built research robots that we sold to universities. We got a contract with the Japanese government and worked on nuclear power plant inspection robots. We eventually did a partnership with Hasbro and built robot toys in Shenzhen in the very, very early days, in the '90s. And then we took some venture capital at the same time that we were getting quite a bit of money from the Defense Department and building up a Defense Unit, which was building a robot called PackBot. And we also then started to use the techniques [that] we'd developed to build toys to build the Roomba robot. And in 2002, both of those had success. One for a very sad reason, the military robots we had gotten to the 9/11 site in New York within 24 hours of it happening and had our robots there trying to look for survivors in nearby buildings that had partially collapsed, sending the robots in with infrared sensors. And then they got sent off to initially Bagram Air Force Base in Afghanistan to look for weapons caches. And then for a whole long period during the Iraq conflict, our robots were there in Iraq, about 6,500 of them being used by bomb diffuser-- bomb units where there were roadside bombs, going and trying to diffuse them and keep the bomb techs out of harm's way. But also in 2002, we brought the Roomba onto the market and then that grew rapidly and then we went public and so that was a great success.

Hsu: Yeah. And the PackBots were also used at the Fukushima nuclear plant?

Brooks: We sent-- the tsunami happened on March 11th, 2011, and on March 18th, we sent six robots. They were put into Fukushima, operated by Tokyo Electric Power Company personnel, who we trained. And they were able to go while-- they were decommissioning and trying to shut things down, but it was an analog-- a 40-year-old analog system. And there was no digital communication. So, the only way you could find out the pressure or the temperature somewhere was to go and look on an analog dial. So, we sent the robots-- or they sent the robots, one to be a Wi-Fi hotspot, the next one to go out and then put its camera-- you know point the camera on the tele-op at the pressure gauge or the temperature gauge and send back an image. And now they knew what was-- something that was happening out there, because it was so toxically radioactive. You couldn't send anyone to go and look at that. When I visited Fukushima in 2014, those robots were still there, plus new ones still being used to go into the more radioactive parts of the power plant. And I must say it was a-- of all the things I've done, I feel very good about that. I thought we really helped in a bad situation.

Hsu: Yeah. How did you come to the decision to step away from iRobot in 2011?

Brooks: I'd been with iRobot for 21 years at that point. It was now a big organization. I was running a big organization at MIT. I enjoy being in there -- you know, at the coal face. I couldn't do it at MIT because I was running a big organization. Could no longer do it in iRobot, so I started another company, where it was just less than ten people, and I'm there, I'm doing it, I'm talking, I'm having fun. So, I like that.

Hsu: Right. So, that brings us to Heartland, or renamed Rethink, in 2008. So, how did that begin?

Brooks: Well, I had spent a lot of time with iRobot in manufacturing facilities in China. I also, as part of our international effort to raise money at MIT, had worked with a lot of Taiwan-based manufacturers who did a lot of their manufacturing in China. And around 2005, they were starting to tell me-- they were telling me they were having trouble getting enough labor in China, and at iRobot, we would see things like after Golden Week, a lot of the workers wouldn't come back to our production facility and we'd have to cut down by one shift and we had production problems. So, I was seeing that the days of infinite supplies of labor in China were changing. And why is that? Well, you know, China had raised its standard of living so much that what had been a lucrative job in the early days when most people were still on farms, was no longer a lucrative job. They were doing things just like people in the United States. <laughs> There were accountants and designers and engineers and there just wasn't that really large supply of labor. So, I was thinking, "Well, when you look at those factories in China, you couldn't just replace all the people with robots. You have to do it incrementally. So, how could you have robots and people working together?" and then, "Wow, that could work in the U.S. too. And we can put robots into factories in the U.S., increase productivity, do things locally." So, that was the theme of what we were trying to do.

Hsu: Mm hm. And then so you came out with first Baxter and then Sawyer. Could you discuss those robots?

Brooks: Yeah, those robots were both-- two features of them. One, they were safe so that a person could be within their reach. Which at that time, all industrial robots were behind cages, or the people were behind cages, you couldn't mix people and industrial robots. We made the robots so that they were safe, they could sense if they were going to hit you, as they were hitting you, it was completely safe. So, that was a change we made to how robots were thought of in factories. And that was really I was thinking about those Chinese factories where there are lots of people side-by-side, you're going to replace some of those people with robots. You're not going to be able to have a big open space around them. They have to be in close. The other thing was that the way we programmed them was teach by demonstration. Then and still today a lot of robot programming for industrial robots is based on Pascal, and languages from the '80s. It's really archaic systems. And we started to show the robot what to do, and then on the screen, which also had the eyes on it later in the operation, tweak things, make things work and so that someone didn't have to be programmer to get them to do stuff. They could show them what was needed to be done and then have the robot do it. We failed. I think we were a complete artistic success; we were a financial failure. And I put that down to my fault. I let costs get away from us and the robots became too expensive.

Hsu: Hm.

Brooks: And I won't let that happen again. <laughs>

Hsu: Right, because I think it was-- your original idea was that it would be kind of like a PC, but for robots, right? That like every factory would have one.

Brooks: Well, originally, I was thinking it wasn't even factories. It was for places that didn't have robot arms. But then I was targeting three-to-five-thousand dollars for the robot arm. But I remember the critical meeting where I let a mechanical engineer overrule what we were doing, and that, through a chain of events, led to much more expensive robots. And then to our sales team selling into conventional manufacturing instead of manufacturing that didn't have robots. So, now we had to do the new stuff and the old stuff in the same unit, and it just became way too expensive. And then we were mostly selling our robots in China. We were building them in the United States, shipping them to China, but the trade war started, and we got retaliatory tariffs put on us, which increased our price in China. So, what had been a great business for the United States, building robots and selling them in China now became impossible.

Hsu: Right, yeah. So, that shut down in 2018.

Brooks: 2018.

Hsu: Yeah. But you had retired from MIT in 2010?

Brooks: In 2010 was when I became Emeritus, yes.

Hsu: Okay, right. So, what led to that decision?

Brooks: Well, you know, I had been a professor, I'd been very successful. And I'd been an administrator, and by the way, one of the things that I felt very strongly was that a lot of people had given me a lot of encouragement, a lot of chances during academia, I thought it was everyone's duty to give back and do part of that. And I did it in spades. I did a lot of it. But after that, I thought, "Okay, I paid back what I owed for what I was given as a young faculty, I think I've done that." And I, you know, again, was wanting to be on a small team. The same theme, a small team. And so, that's why I left.

Hsu: Hm.

Brooks: Well, for a couple of years, I was working at Heartland/Rethink Robotics and not teaching at MIT and I thought we had a perfect arrangement. I didn't teach and they didn't pay me. <laughter> And then the President said, "Look, you got to make a decision, guy. Are you coming back or not?" <laughter> And I didn't want to go back.

Hsu: Right. <laughs> You also joined the board of Toyota Research Institute in 2016?

Brooks: Yes, that was just as it was getting started, some people had come to see me and I'd connected them to both MIT and Stanford. And I think I had some impact on how they thought about who and how to connect in a way which would not have happened in Japan. It was a different structure, and so I was on that board for a while, and then the Toyota Research Institute became much more mainstream key part of Toyota and didn't need a little American board overseeing it. It was part of the-- it really became successful within Toyota.

Hsu: Mm, okay. And discuss your latest venture.

Brooks: Yeah, my latest venture's gone through some changes. It started out in 2019. I was only half time, and <laughs> one of the reasons I, you know, I became a co-founder was, well, I wasn't having a lot of interaction with other people. I thought, "Well, okay. This'll be a way to do it," and COVID came and so we're all remote, <laughs> and we haven't really talked about this, but when COVID came, we-- and we didn't-- no one-- it's hard to remember now, but for a while we didn't know that COVID was airborne. We thought it was on surfaces. Remember we had to wash our hands all the time but we didn't have to wear masks, and so we developed some robots based on a commercial platform to go and use infrared to disinfect, to kill bacteria on places. We thought that might be a real part of helping with COVID, having these robots wandering around initially in hospitals and then in cafeterias and places, but that whole model got blown up when it was realized it was airborne and not surface borne. So we kept having to change, and we eventually settled on robots in warehouses, fulfillment centers. The vast majority of places where goods are fulfilled, either for retail outlets or [direct] to consumer have zero automation in the U.S. They're 5 percent highly automated, 15 percent somewhat automated and 80 percent with 0 automation. Have incredible labor problems. Just can't get enough labor, and so we're building robots that are human centered. They know about humans. They are easy for humans to use. You just grab them, move them, and try to make them a tool which the floor associates in those warehouses find useful and find that they want to use. Not to be a replacement, because frankly, all those places need every person they can get. The robots are there and help people. They don't have to-- make their jobs much more-- it makes their jobs much more ergonomic and lets them be more satisfied in their jobs, so that's what we're doing. It's still early days. These things take a long time. You know, the popular press thinks, "Oh, the new A.I. technique will get deployed and next year--" it takes a long time to get these things right, so that's what we're working on.

Hsu: Yeah. What's the name?

Brooks: The name of the company's Robust.AI., which was from an earlier incarnation of it, but we're building robots that we call Carter right now.

Hsu: Right. Because they're carts?

Brooks: They look like carts. They look like a shopping cart. They've got a handlebar and if you grab the handlebar, you can move it however you want. It's like a block of ice, and they cart stuff around.

Hsu: <laughs>

Brooks: They can go autonomously. They can follow a person. The person can send them off somewhere else. They go by themselves, et cetera.

Hsu: Mm-hm. What is your connection to Marc Raibert?

Brooks: Marc Raibert's been a friend of mine for a long time. Before he came to MIT I knew him. You know, we would go to robotics conferences together. Then he came to MIT. He was in the A.I. lab. He had a lab, a sublab called the Leg Lab, which was down in the basement of the building, and he was building hopping robots, and then around 1992 he started Boston Dynamics, and it-- originally it wasn't building robots, it was using his control methods to solve problems for other companies, but he couldn't stop himself. He had to get back to his legged robots.

<laughter>

Brooks: By the way, when he left, Gill Pratt took over that Leg Lab and he then went on to become-- he's chief scientist at Toyota now, as part of Toyota Research Institute, so-- and I've known Marc the whole time, so good. We've been friends for a long, long time.

Hsu: Yeah. <laughs> Is something like subsumption architecture being used in any self-driving car projects today?

Brooks: I think there's things related to it, yeah, but there's a big planning layer on top. But, you know, the glue, some aspects of it, but, you know, anywhere where behavior trees are used it's related. They're used in lots of robotics projects now besides games, so...

Hsu: Right.

Brooks: It's related, but times change.

Hsu: Right. Yeah. I guess they combine all sorts of different methods. They still use like the search algorithm from Shakey and...

Brooks: Yeah, there's a long history of pieces. You know, my company, we use behavior trees to do subsumption-like things. We also use simultaneous localization and mapping. We use classical planning at the high level. We use optimization techniques for where the robots need to be when. We use neural models to-- on the cameras to know, "That's a ladder. You don't want to hit ladders." <laughs> "That's a pallet on the ground." "That's a person." So we're using lots and lots of techniques. Whatever makes sense, whatever's cost-effective.

Hsu: Right. So for a lot of your career you've been sort of the contrarian, and you call yourself an A.I. realist. You've been trying to temper the hype around the current sort of A.I. fad. We've talked about, a little bit about the GPTs and large language models. What is your view of GPTs and deep learning more generally and why they're not as-- maybe not a route to general intelligence?

Brooks: I think all of these things provide useful tools, but to think that, "Today, today we've got the right thing," is a bit arrogant, quite a bit arrogant, and we have such a hype cycle, and we've seen this with autonomous vehicles. You know, if you go back half a dozen years, all the major car companies were saying, "They're going to have autonomous vehicles on the road by 2020, '21, '22." None of that happened, and it's sort of a problem that's happened repeatedly for the last 60 years, except it's now happening at a bigger scale. So I like to ask people, "When do you think the first vehicle will drive on a public freeway," and I told in U.S. units, "drive on a public freeway at more than 55 miles an hour for more than 10 miles with no human touching the control, being surrounded by other cars driving with humans in them?" And I ask people, "When do you think that first happened?" They say, "2007," "2009." Well, it actually happened in 1987 in Germany at the Bundeswehr-- Ernst Dickmanns did it, and people were excited at the time but they didn't think it was going to, you know, be generally on the roads in five years. They knew it would take a long time, but today people see a research result. It gets hyped up so much they think, "Ah, now it's going to be deployed instantly." But these things take a long, long time. We've been able to drive autonomously on freeways for what is that, 36 years now. We're not doing it yet <laughs> in terms of real deployment, and then it gets obfuscated by the companies doing it when they've got a demonstration. Maybe they don't tell about the, you know, in the earlier days of the vehicle which followed each autonomous vehicle, just in case, with a Stop button. They're trying to show that it's further along than it is and there's a lot of over-hype and over-promise, and I think it's led people to not be able to estimate things well and every new A.I. result at the moment is super news. I think, you know, I've written a lot about what I call the seven deadly sins of predicting the future of A.I. and I think the two that we're suffering from most at the moment are we as humans can see someone do some performance, intellectual performance or mental performance, and we can generalize to what competence they have, but that same generalization doesn't work for machines. They may be doing that thing in a very narrow way, and the other thing is when a technology's sufficiently different from what you understand, you can't distinguish it from magic, so you start attributing all sorts of capabilities that may not be there yet. So LLMs, ChatGPT, et cetera, have become magic. "Oh, they're so powerful. They'll soon be able to do this. They'll be able to do that," without any connection to the underlying technology and what the real problems are going to be in doing that, and we're in that feeding frenzy phase right now of those models.

Hsu: Right, yeah. I guess one of the things though is that ChatGPT is actually being deployed, is available, for average people to use, which is at least allowing people to see limitations of it.

Brooks: So some people see them as limitations and some of the people think, "Oh, then we'll get fixed soon," because the companies are spending enormous amounts of money with humans to fix problems. Just recently, I think in the last few days, as we're recording this, something came out about one of them being able to do mathematical reasoning, but it turns out they had deployed thousands of people annotating mathematical proofs in order to teach it that. So it's a good technique to take human annotations but it's not because the thing is smart, it's because it's told this, this, this and this, and then it's really able to do a remarkably good job at generating smooth English. So I have used ChatGPT for help with some of my personal programming problems, and I ask it questions and it's better than a Google search because it has so many tokens in its search parameters, but it keeps tricking me. It comes back so definitely positive about what the answer is that I, "Oh, that's what I have to do," and I go and work on it for while and then I realize it's not working. I say, "That's not--" I say, "That's not working," and then it tells me something else <laughs> that's more relevant. So I get fooled by it. Everyone's going to get fooled by it. We have to box it around-- box around that language generation, language understanding capability, to make it useful, and it will be useful. We're going to have better language interactions with machines as a result, but it's not general intelligence.

Hsu: Right. Do you think AGI is possible, and in what timeframe?

Brooks: AGI, A.I., all the same to me. I think certainly in principle it's possible to build machines that are as intelligent as humans. We don't know whether anything can be more intelligent. We don't have any data on that yet. In what time frame? I think, yeah, pretty-- I'm pretty sure within 300 years we'll make some progress.

Hsu: <laughs> So what's your opinion of the singularity?

Brooks: Oh, the singularity.

<laughter>

Brooks: I'm sorry. To me, the singularity is technologists being able to have eternal life without the inconvenience of believing in God.

Hsu: <laughs> What do you think consciousness is?

Brooks: Ah, in my lab we used to talk about-- we had a word for consciousness. It was the C word. The C word shall not be spoken.

<laughter>

Brooks: Because it is so not well understood that any, you know, people come up with all sorts of wacky theories. I don't know what consciousness is. I don't know that we have the right language or the right concepts to talk about it. That's at least 280 years away.

Hsu: Okay. <laughs> So what should we actually be concerned about with current A.I. systems like ChatGPT?

Brooks: ChatGPT will make it easier, is making it easier to generate a lot of bogus stuff that sounds good. Full of bogus references. It will make it easier-- you know, as all technology. All technology gets used by bad players. It will provide new avenues of scamming people, as email, as text messages. Providing new avenues, and often there's so much scamming going on that overwhelms the usefulness of the channel. You know, I don't answer my phone anymore unless I know who the person is calling me because of that, so it pollutes the atmosphere. So we will get more pollution from that but there'll be plenty of other technologies causing more pollution. It'll be used by bad actors. It will-- it may produce so much stuff, data, words, that it sort of is an echo chamber that diminishes the good stuff because it all gets turned into a middle mush by these large language models. Are these disasters for humanity? They're not good, but all technologies come with bad parts. Are they malevolent? Not on the part of those systems? They're malevolent, you know, in that they can be used by malevolent human actors. So I sort of say to everyone, on the hype side and on the doom side, just calm down. Yes, be aware. Yes, we shouldn't-- we should, as we do regulate many things, we shouldn't let hypesters build some system with ChatGPT and say, "This is your artificial doctor. Pay the subscription. This doctor will look after you," when it has no actual knowledge or ability. It requires regulation, which we use in so many aspects of our life, and regulation makes the world work because there are, you know, everyone-- so many people out there willing to transgress in order to make some money. Should we ban research on it? Well, what would that look like? That to me makes no sense. But we certainly should subject the products of it to the same regulation that we already subject drug companies and other people in places that can cause harm to people.

Hsu: Right.

Hsu: What good do you think can come from ChatGPT and other generative A.I.?

Brooks: I think with the right boxing around it, because of its large buffers of tokens, it can be much more useful search, as long as you don't let it hallucinate around it. I think it will provide, you know, just as over the last 10 years we've gone from speech interfaces being really crummy to pretty good. You know, I talk to my car, I talk to appliances at home and they're okay, but for each one, I sort of know what language it can understand and I know how to couch what I want to say. I think that's going to become much more general because of these language models. We get to talk to all devices in a much more natural way over time, so continued ease of interaction certainly something that's coming.

Hsu: Right. What do you think we can learn from studying the history of computing?

Brooks: There's a view, I think, that computation is a thing which is, you know, a basic kind, but as I, and I've spent a lot of time in the last few years reading old books, and especially old prefaces. What we call computing is a social construct that we as people have decided, "Well, this looks right." "Ah, not sure about this. This..." It's not a natural kind in the way that we have come to think of it, and I think going back and tracing where certain ideas come from tell us what assumptions were made back then and what may have been missed and what those other opportunities around that we just don't have because this was the way it unfolded. It didn't need to unfold this particular way. If two or three people had gone off and done a different thing here we may have a very different unfolding of history. Now, computation is unique, computers are unique, because of Moore's Law. There's never been an exponential that's lasted that long. We've had lots of exponentials but they peter out after a smaller time. Computation didn't peter out because essentially you're asking, "Is something there or not?" and it was a voltage or electrons, and if you halve the number of electrons or halve the voltage, is it there or not, you still get the same "yes/no" and you keep halving and halving and halving until you get down to just a few atoms, which is where we are now. So Moore's Law had the, you know, an incredible run in history, which I think probably overwhelmed any misgivings that we had about whether we were on the right technological path because Moore's Law would outrun any other sort of development, which is why I think today is sort of, as I see it, the golden age of computer architecture, because you can't just rely on old-fashioned Moore's Law to get there anymore. You have to be smarter. You have to do different things, and the companies that are doing different things are producing different sorts of silicon in ways that we never would've thought of until recently. So as Moore's Law peters out or Moore's Law has to get spread out in another way, you have to solve things in another way, it's not just the physics anymore, I think there's lots of opportunity, and by studying the history and really looking at how the ideas develop, we can find the adjacents which never got explored and maybe, maybe some of them will be duds, but maybe there'll be some really interesting stuff there that turns into something great.

Hsu: So what does it mean to you to join other pioneers as a CHM Fellow?

Brooks: I must say I was shocked when I was told that I was going to be a <laughs> Fellow of the Computer History Museum. You know, you look back at Grace Hopper as the first one, you know. Ah. <laughs> I'm so honored. I think maybe you guys made a mistake <laughs> but I'll go with it. I'm very honored. I think looking at the names of the other people and the things they've done, it's just, you know, such an-- you know, I've been a fanboy of computers since I could read. That's been my whole life, understanding computers and what they can do, and to be part of this is really an honor.

Hsu: Thank you. What would you like your legacy to be?

Brooks: I think my early days when I was, you know, labeled as the crazy, out-there person, I was enjoying that. I enjoyed building real organizations. I think now I get to play a role of-- this is tricky but I get to play a role of having seen so much that I can inject that in the current discussions and try and put realism into them. What often happens is I get, you know, I'm now often being called "You Boomer," <laughs> you know, which is a derogative to someone whose time has left behind, but I think I can offer some perspective on things and I'm enjoying trying to do that. I'd like to think I haven't yet done my best work and so I'm really trying to understand how computation came together into A.I., neuroscience, artificial life, et cetera, where those ideas came from and where they may be wrong or not appropriate or missing something by looking back at the early work and seeing what people were trying to do, what was motivating them. Often someone's really trying to answer one question, they answer it and someone else sees it and says, "Oh, that's this," but it wasn't this, and sometimes it gets transplanted in a way which is missing some of the context and perspective, and so I really want to uncover that, but I better-- because I'm not a singularity believer, I better work really fast.

Hsu: <laughs> Right. You won't be living forever and ever. <laughs> So this is a longer one. As you consider the challenges facing people and the planet, what new technology innovations are you most optimistic about making a positive difference, and why? That's part one. What are your hopes for the future of technology for the benefit of humanity? And what technologies are you excited about for the future?

Brooks: Okay. That's three. I got to keep three in my token buffer here.

<laughter>

Brooks: We are the largest population of humans that the planet has had to support until now, at the same time as climate change is changing things radically. Until fairly recently, our food production has relied on the time tested method. You go out, you put some seeds, you look at the sky, you complain about the rain, it's too much rain, too little rain. You don't really have control over things, and you may cause tremendous side effect pollution. I'm excited today about new farming methods which involve technology, indoor farming of all sorts, involving genetic engineering to couple the systems together to be less wasteful, to use much less water by cleaning the water with biological mechanisms, but producing food in ways which are not as inherently hard on the planet as they have been. I think it's really important for our future. At the same time, we still need to work on energy, and so whether that is just solar and wind and tidal and renewables in that way, maybe that's all we need. Maybe we need some other things but it's got to be different from our traditional ways of producing energy, which have been very polluting. So I think there's excitement there on the energy front. I think as a society, over the next 80 years we have real problems in the fact that the population, we're changing to an elderly society and how the elderly amongst us, and I'm a leading indicator of this, how we get to have dignity and independence as we grow older and happy lives is going to be a real challenge, because younger people, they got their lives to lead and now they have to support a whole lot of old-- whole lot more older people than anyone in the past has had to do. So that's another critical place where I think there'll be such a pull that there will be technologies developed. We're not quite yet at the really critical pull stage but it's coming. So there's a bunch of areas that I think technology can be really helpful. Some of it's already happening; some will happen.

Hsu: Yeah, thank you.

Hsu: Okay, what-- drawing on your wealth of life experiences, what advice would you give to a high school student who is interested in technology?

Brooks: Is this the one-word question?

Hsu: No. This is--

Brooks: <laughs>

Hsu: --similar but we're getting to the one word. But this is-- this one you can just freely talk about what advice you would give in a longer answer.

Brooks: I think for a high school student, the most important thing is to get out and work with other people and, you know, see them working, in action, see how they solve problems. Learn how to be part of a team. Now, you may-- that high school student may end up being the leader at some way, some time, but I think it's really helpful to see how to be part of a team, how to have empathy for others in the team, how to interact in a socially useful way with other members of the team, see how technology and science can be used, how it can be shared. So go, go find a way to work with other people, most of whom are going to be older than yourself at the moment-- you're only in high school-- and you'll learn a lot and see a lot and then, you know, both know how to work better but also figure out what sort of-- what aspects you like and what do you want to spend your time on?

Hsu: That's great. So we will finish with a one-word question. So what one word of advice would you give to a young innovator or entrepreneur?

Hsu: So what one word of advice would you give to a young innovator or entrepreneur? What is the word and can you tell a story that illustrates why you chose this word?

Brooks: So my advice is to be fearless. Now, doesn't mean to be rash. It means when you're confronted with something which sounds scary, don't reject it just because it sounds scary. Go and analyze it. See if it's possible to do it after all. Now, if you do the analysis and, you know, physics doesn't let it happen or something else, then get rid of it, but don't react out of fear, and so I guess my story of that is when I realized that we were going to have to manufacture in China in the '90s and I didn't know how to do that, I didn't know what we're going to do, how, how to get into it, how to start it, how to connect. I found a person and I went and hung out with him in Taipei for weeks and learned at his feet how to do it and then we started manufacturing in China and we built millions of products, in a way that I couldn't imagine that's how you build products just two years before, three years before. So being fearless about it let me do it.

Hsu: Great. Thank you.

END OF THE INTERVIEW