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Joel Burdick

An interview conducted by
Selma Šabanović
with
Peter Asaro

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Selma Sabanovic: If you could tell us when and where you were born.

Joel Burdick: I was born in Rahway, New Jersey on May 22nd, 1959.

Selma Sabanovic: And where did you go to school?

Joel Burdick: Up until the time I went to college I was in seven different schools – my family moved a lot – so mainly in the eastern seaboard. And then after that I went to Duke University as an undergraduate where I majored in chemistry and mechanical engineering, and then I went to Stanford for grad school where I have a master's and Ph.D. in mechanical engineering and then I came straight to Caltech. So I've never had a real job in my life.

Selma Sabanovic: So how did you get interested in mechanical engineering?

Joel Burdick: That's a kind of interesting story because when I started as an undergraduate I actually started as a chemistry major. I thought I was going to cure cancer and that's – as I went along I decided to take, for fun, one engineering course and really liked it, so I ended up then finishing my undergraduate work primarily in mechanical engineering. And why mechanical versus electrical something else, I'm not sure but I always liked to build things and so the mechanical part intrigued me more than the electrical part.

Selma Sabanovic: What are some of the early things you've built?

Joel Burdick: So in my graduate-study days, especially the first half of the graduate-study days, I worked with a guy named Oussama Khatib when he was a post doc at Stanford and now he's a professor there. And so I worked on robotic force control with him. So there we didn't build so much as we sort of used existing robot technology and worked on algorithms to improve the ability of robots to do what's called force control, to be able to monitor and control the forces the robot applies to the environment. And the latter part of my graduate career was primarily theoretical, but once I got to Caltech that's when I really started building things. And so one of the earliest things I did here with my first graduate student – Gregory Chirikjian. He's now at Johns Hopkins University. Gregory and I were interested in these hyper redundant or highly redundant robots or snake-like robots. And so in addition to working on the algorithms or theory – and I'm probably more of an algorithm person than I am a mechanical engineer per se – we built a variety of snake-like robots. So the first kind of full-scale construction project I did in robotics was actually – how many degrees of freedom? Thirty degree of freedom snake-like robot.

Selma Sabanovic: And how did you become interested in those particular types of..?

Joel Burdick: Well, in the latter half of my Ph.D. career, I was working on a class or robots that were hot then called these redundant robots. So these are robots with more than six joints in their arms. And quite frankly they didn't pan out as well as we'd hoped at the time, but it was a fairly natural extension to think of these hyper redundant, as we called them, which means lots of redundancy. And so I already had some exposure to that and fortunately my first graduate student, Gregory, when he arrived here for graduate school, he was interested in the topic also. He had thought something about it, so it was kind of a natural marriage. I was interested, he was interested, so we said let's dive in and just do it.

Selma Sabanovic: So what were the hopes for redundant robots?

Joel Burdick: Well, in those early days, the thought was by adding these extra degrees of freedom, that you could make the robots much more agile and able to do more things. And while that's true, it also means that the robots are very expensive and more difficult to design and build because they have that much more complexity to them.

Selma Sabanovic: And what were some of the other robots that you worked with when you were at Stanford?

Joel Burdick: Like I said, at Stanford primarily was just with robot arms, these robot manipulators, and doing this force control work. Occasionally, because the lab I was in was one of the first labs in the field of robotics, had a long, noble history. Certainly we were exposed to lots of different robots that were there at that time in the field, including some mobile robots. And actually, now that you mention it, I forgot. The first JPL Stanford hand, built by Kenneth Salisbury, I actually helped build some of the electronic interfaces for that, and so that could actually be used in the early days.

Selma Sabanovic: So you worked with Kenneth?

Joel Burdick: He was just finishing his Ph.D. when I was a first-year graduate student. I can't say I worked with him closely 'cause he was frantically trying to write his thesis and get out. But the arm, that hand was there for a while and so I helped people – in particular Ron Fearing, who is now at Berkeley, was a junior graduate student like I was and he sort of inherited that mechanical system. And so while it was Ron's main work, certainly we had discussions and I occasionally helped with interfacing and doing a few other things. But he did most of the work.

Selma Sabanovic: And who are some of these other people you worked with there?

Joel Burdick: So people who went on and still work in the field of robotics, or related things; so that group was both the robotics group and a computer vision group. So there are lots of computer vision people also. So not necessarily in order of importance: David Kriegman, who went on to Yale and then Illinois and now UC San Diego, was a co-graduate student at the same time. Ron Fearing, as I mentioned. Brian Armstrong was my office mate and actually I'm still in contact with Brian these days. He's up in Wisconsin now, a professor of electrical engineering. Jean Ponce was a post-doc back then. He went on to be a professor at Illinois for many years in the computer vision area. He's French by birth and so he went back to France to one of the top schools there as a professor. Some other notables in the field of robotics: He was certainly earlier than me but after he went in post-doc at MIT, Rod Brooks came back to Stanford for a while, and so I knew Rod a little bit then. This is a name not in the robotics field but it's kind of funny. Bruno Olshausen was a master's student then. He went on to become a very prominent biological vision researcher. He's now at UC Berkeley. So that's one of the things which was exciting at that time is you were in one of the few labs that had a long history of robotics and you knew that the other students around you were very talented and were likely to go on and have impacts in the field. I completely forgot. I didn't know you were going to ask this question ahead of time so I'm thinking here. John Craig, who was important in the early field, I knew him quite well at the time, and for many years after grad school maintained casual contact with him. I've lost contact in the last ten years or so. Someone who didn't necessarily play a big role in academia but was quite active in the robotics field for many years was Jeff Kerr, so we were sort of contemporaries and we had the same Ph.D. advisor. Another student then was Sunil Agrawal, who's now a professor at the University of Delaware. It was kind of a funny story. He wasn't working in the lab with me day to day, but he had the same Ph.D. advisor, so we ran across each other. I just saw him last week, as a matter of fact, so we're still friends and colleagues. And probably during the interview more names will pop up. I hope you don't mind if I free associate when things come to mind.

Selma Sabanovic: Not at all.

Joel Burdick: I'm sure I'm missing someone important. Just some other ones, because of the dual nature of the lab there is a whole vision side that I wasn't much involved in, but Jitendra Malik, who went on to be a very prominent professor at Berkeley – was even chair of the Berkeley SC Department for a while – came out of the group just a few years before I left as well.

Selma Sabanovic: Who was your advisor?

Joel Burdick: It was a complicated story. So when I went to Stanford I went to do fluid mechanics because I was a mechanical engineer and a chemistry major. And then I decided that was just going to be very boring, so I just happened to take a control course in my first year and liked it. And then Thomas Binford's lab, who at that time directing the kind of lab which had the long history at Stanford in robotics. And so he was my first advisor for a while, but then fairly late in the game I eventually switched to a guy named Bernie Roth who was my final Ph.D. advisor, so I really had two advisors in that period: Tom, a more CS vision person; and then Bernie Roth, a real mechanical engineer.

Peter Asaro: What were they like as people to work with?

Joel Burdick: Bernie Roth was my second advisor and in large part I'm in academia today because of Bernie. He sort of showed that you could be both a researcher and a good human being while being in academics. He's kind of this terrific sort of Zen guru master type and I can't say enough positive, wonderful things about Bernie. I think certainly if you haven't interviewed him you will, but certainly he's a mentor to a whole generation of people that have had a big impact on the field. I think it's due to his mentorship and his personality and his force of nature that he had the impact that he had.

Selma Sabanovic: And what were some of the big discussion or challenges that people in the lab were very interested in at the time?

Joel Burdick: I have to think back. Certainly it's kind of surprising how many of the issues we were dealing with back then are still prominent issues today. I think what happened is in those early days we could foresee a lot of the important problems, but we didn't necessarily have all the technology then to really tackle them. So we spent a lot more time then worrying about the computational complexity of algorithms because computers were so slow. If you couldn't get them to implement it on the minimal hardware we had, then they just didn't work. Those issues have almost completely gone away these days. But all the kinds of things, there were just different flavors, so the computer vision people, for example, studied all the same problems that are being studied in vision today but they just didn't have the tools that we have today, not only in terms of hardware but in terms of the principles and theories and algorithms. As I mentioned, I was only tangentially involved in this sort of grasping a little bit. In fact, actually a couple years after I came here I got involved in grasping. I still work in grasping today. And so we were thinking about it back then but it was much more trying to discover what are the basic principles that should be used, formulating some of the first mathematical or algorithmic problems. And so those problems are now well understood but not necessarily solved today, so I think we're just starting to formulate more of the basic problems back then. And so certainly in the force control area, I wasn't one of the first people with Oussama to work in force control, but we were pretty early in the game. And so we were able to at least, I hope, elucidate some of the key problems and a couple of solutions, which people of course have built upon or advanced or come up with new ideas since then.

Selma Sabanovic: And how was Oussama to work with?

Joel Burdick: Oussama was a lot of fun. It was kind of a funny story then. He was a post doc. He's Syrian, I believe, by birth. So then he went and did his graduate work in France and then came to the U.S. and so by the time you come to the U.S. it had been a long time since he spoke Arabic. His French was pretty good. It wasn't a native language. English wasn't his native language and so we used to actually, in the early days, converse by Pascal. We'd send each other Pascal programs and that's actually how we did a lot of our early conversations. But then his English advanced very rapidly. He's an incredibly sweet and gentle guy and so I learned a couple of big things from him. So the one thing I learned from him that I still pass onto my graduate students today is if you ask the right question, then that's the most important problem in research is asking that good question. 'Cause once you can formulate the question properly, then you can do the hard work and roll up your sleeves and find the solution to it. He was a very, very gentle and sweet guy and so that made working with him very pleasant.

Peter Asaro: What years were you actually at Stanford?

Joel Burdick: Eight-two to eighty-eight, or to early eighty-eight.

Peter Asaro: What did you do after you graduated?

Joel Burdick: I came directly here. And so my graduate career was a little bit longer than average, longer than I hoped, 'cause I switched advisors fairly late in the game. And so the downside of that is I spent more time in graduate school. The upside was I had a lot more experience than the average graduate student and that, in some sense, helped me land my position here. I had more breadth of skills which made me attractive. And there's actually kind of a funny story how I got my job here. So Caltech was quite interested in hiring John Craig, that we had mentioned before, and John, at that point, had also had an offer from Berkeley and was also working with one of the companies, Silma, that he helped found. So he's trying to decide between academia and Silma, but he knew he wasn't going to take the Caltech job. But he said, "I have this friend who's gradating soon. You should talk to him." And so that's actually what led to me getting my position here 'cause they weren't really advertising that position. So I can thank and curse John for my job here.

Peter Asaro: What was the engineering department like and were there any other robotics…?

Joel Burdick: At Stanford or here?

Peter Asaro: Here.

Joel Burdick: No, mechanical engineering group here, when I first came here, up until maybe two years before I arrived here it was all thermodynamics and fluid mechanics. There was very little in the way of mechanical design, mechanical systems, control theory; the kinds of things which go into robotics. And so they hired another faculty just two years before me, Eric Antonsson, who was in the mechanical design area; and then just a few years after me Richard Murray, who you talked to earlier today, was hired. And so for a while we formed this mechanical systems group and it was a lot of fun. Richard kind of drifted off, first into the control and dynamical systems and actually I'm now part of that program also; and then into bioengineering, and actually I'm part of bioengineering. We sort of shifted the department away from a total focus on fluid mechanics and heat transfer. Although, in some ways, sadly we're kind of back in that mode again. I'm the only person left in ME that doesn't do some sort of continuum mechanics, which is now why I'm sort of more closely affiliated with the control and dynamical systems program. So I don't know if it's a topic we'll talk about too much here, but just six miles away is a jet propulsion laboratory and they have 40 some researchers in the field of robotics and so I have done, off and on, with them collaboration. In fact, right now pretty much all of my robotics research at the moment is done in collaboration with JPL and so there's a bigger activity here than you might imagine.

Peter Asaro: Who are some of the people you collaborate with at JPL?

Joel Burdick: A whole bunch of people over the years. And so I'm going to actually work backwards. So my two active collaborations right now – there's a whole bunch of names but I'll give sort of the senior people. And so the senior people would be Larry Matthies M-A-T-T-H-I-E-S. He's a computer vision person. A guy named Paul Backes, B-A-C-K-E-S. He's more from the mechanical side. And then a very fun collaboration I have with Issa, I-S-S-A Nesnas, N-E-S-N-A-S. So we're working on some cliff-climbing robots. In fact, we were just out in the Arizona desert last weekend testing these robots. And other people, in the earlier days, a person who's risen up in the ranks there is Carl Ruoff R-U-O-F-F. He's been involved in robotics from the very early days. And so if you haven't interviewed him you should. Samad Hayati is another person I worked with in my earlier days and he's risen in the management ranks also. Hayati is H-A-Y-A-T-I. Another name I like to mention is Homayoun Seraji, S-E-R-A-J-I. I worked quite a bit with him in my first couple of years here and the reason I mention it is because he unfortunately died of cancer a few years back kind of prematurely, which was a big loss. But I enjoyed working with him.

Selma Sabanovic: When you came here, since there wasn't really a focus on robotics, but they obviously wanted to hire a robotics person, so you know why that was?

Joel Burdick: I think in large part you can trace that to two people: One was Carl Ruoff. Carl had his master's degree – and I apologize. I don't remember where he got his master's degree from. But then wanted to come back and do a Ph.D. and so there's a program so that JPL researchers can do their Ph.D.s at Caltech in a not too painful way. And Fred Kulick was a professor here in the thermo sciences area and propulsion area, and so it really was Fred – and in some sense working with Carl who first taught some robotics courses here just to sort of see what it was all about, and then really pushed the department to kind of hire in the non-fluid mechanics area, and in particular in robotics. I really owe, not only John Craig for making the contact, but also really Fred Kulick for pushing the department to think about that.

Selma Sabanovic: And so what was some of the early work you did here in robotics?

Joel Burdick: As I said, the first thing I got involved in, 'cause my first student was just a terrific student. I, in some sense, owe him my career. It was Gregory Chirikjian. So we worked on these snake-like robots and the reason I mention it is because I was very motivated to do this work by the terrific work of Shigeo Hirose. I don't know if you're going to interview him. He's a huge name in the field of robotics, and justifiably so. He's just an incredibly inventive man. And he had done some beautiful mechanical design work on these hyper-redundant robots, and so my interest was to try to contribute to the algorithmic side of these robots, so to develop a theory of how to plan the motions and do sensing and do lots of operations with these redundant robots. And the reason I mention that is, even though I dropped that work six or seven years after I got here, research goes in phases. The pendulum swings back and forth, and so it was not an area where I could sustain long-term funding. On the other hand, the problems that I worked in in those early days actually spawned pretty much most of my research that I'm doing today in many ways.

So with these redundant robots, you want to send them into very unstructured environments, so these snake-like things, we were thinking about using them to crawl into collapsed buildings or into difficult-to-reach places and therefore you'd want to do a lot of sensing and be able to plan your motions using sensing. And so for many years, and still even to this day, I worked on sensor-based motion planning for robots. With Gregory we kind of, as a fun thing, we looked at actually how these snake-like arms could grab stuff and manipulate them and that really kind of got me started on grasping, which I still do to this day. And then because these snake-like things were one of the modes of operation as to locomote to move, for a decade or so I had several students working on various aspects of robotic locomotion. And kind of indirectly then, also one of the early applications we had envisioned – and we weren't the only ones. For example, Professor Yokota in Japan was prominent in this area, thinking of using these snake-like robots for medical operations. And so I didn't really become a prominent person in the medical robotics field, but I did a little work in the area which opened me up to starting to work with neurobiologists about 12 years ago. And so basically, for the last 12 years, almost half my group, and now half my group, has been working in different technologies related to paralysis. And many of the technologies are motivated by robotic technology. A lot of the algorithms of technology that have been used in robotics we've been finding ways to transform them and bring them to bear upon some of these problems of paralysis. And so that's a very active area in my research group today. And actually I found also that the paralysis work, the algorithms we developed there have actually had a positive impact on the robotics side. We've actually first developed things in the signal processing for reading neural signals that we've actually found great applications in robotics as well.

Peter Asaro: What kinds of applications?

Joel Burdick: So I have a crazy project right now, which is winding up. It's funded actually by the Korean Military. So we're building little sensor pods with radars on them to sprinkle all over the demilitarized zone between North and South Korea to actually find and track people as they enter the demilitarized zone. And so it turns out that the mathematics of finding and tracking these people is absolutely identical to the mathematics that I had to solve for an earlier project where we had to put electrodes in the brain, and I sort of introduced a new concept of a robotic electrodes, which would drive around the brain and optimize the signals which were recorded. It's mathematically the same problem. So we had to find and track these neurons inside the brain and they give off signals that are exactly the same as the signals given off by ultra wide-band radar reflecting off of humans.

Peter Asaro: Within the neural stuff, have you been able to get robotic control from <inaudible>?

Joel Burdick: In a different way. Our goal isn't so much that. And so in the early days when I was working on this process problems, we were working on neuroprosthetics. So the idea is you would put electrodes in the brain, and again I developed some robotic electrodes, get the signals out and then use that to move a cursor on a screen or a robotic arm. And other groups have gone on and done that. I've been putting that work aside because about eight years ago I really started working very actively on spinal cord injuries and so there the goal isn't to move the legs mechanically. The goal was to actually tap into the nervous system and find a way to rehabilitate the nervous system so it can actually move the person's legs in a fairly natural way. And so that work's actually gone very well, so we actually had our first human studies this year. You may have noticed two weeks ago there was a big press release about advances in paralysis. That was us and my colleagues at UCLA and also University of Louisville.

Selma Sabanovic: And how did you get into that line of research?

Joel Burdick: Well, going back this neuroprosthetics work, because I'm kind of the robot guy on campus as well as Richard Murray, a guy named Richard Anderson, who's a very famous cortical neurophysiologist here at Caltech, called me up must be 12 years ago now and said, "Hey, I want to hook a monkey's brain up to a robot arm." And I'm like yeah count me in, sounds great. And so that's how it started. At that time the leading primate neurophysiology research labs were reviving an idea which has been around for a long time, this neuroprosthetics, implanting electrodes into the brain, trying to bypass the broken circuitry to get information out of the brain and use it in some competent way. And so he was thinking about hooking the brain up to a robot arm and he has live monkeys in his lab, and so we worked together for nearly a decade doing that work. And there's still a lot of exciting work to be done in that area. I'm just focusing more on spinal cords because it's an area where there aren't so many other techniques that are working right now, and so we're hoping to make better progress.

Peter Asaro: What are the biggest challenges, both for the interface with the monkeys and for the prosthetics you're working on now?

Joel Burdick: There's an infinite number of challenges. And so certainly moving from the mechanical to the algorithm theoretical, making a long-lasting interface with a nervous system has proven to be a challenge and many people are working on that, and I've had my working contributions to that area. Certainly another one which I focus on is the algorithmic aspect. So the nervous system is incredibly complex and we don't have anything like Newton's Laws of Mechanics to tell us what is the model. And so it's very complex to come up with a good model so that an engineer like me can either build a mechanism or build an algorithm to interface with a nervous system. And so just developing the models and developing the theory of how you interface is still an emerging art and science. We're not done yet. We have a lot more to do. And then a part which I didn't appreciate until more recently until our human work started is just dealing with human patients and all the issues that they have are complex. So just to give you a brief example: So in the paralysis work, you would think that the number one thing that most people want to recover after a major spinal cord injury is the ability to walk. It's not. So for example, most people with a major and high spinal cord injury have difficulty regulating their blood pressure, difficulty breathing, they can't control their bladder and bowel; they have all these problems. In fact, that's actually what they want solved first. And so part of our work has actually been aimed, not only at restoring the locomotion, but restoring these additional functions as well. And as I said, yeah, going from a laboratory animal to a human is a big jump.

Selma Sabanovic: And you mentioned that this was feeding back into your work in robotics as well.

Joel Burdick: Absolutely. Some of the feedback is just serendipitous, it's just lucky. Some of it's more deliberate and that is, I'm not the pioneer of this – I'm sure you're talking with Sebastian Thrun up at Stanford – and so certainly he's pioneered the idea of probabilistic robotics and what we know is all of our work on interfacing with the nervous system, the nervous system is very uncertain; it's a plastic or adaptable, as we call it. And so treating it as a kind of probabilistic system has been the right way of doing it and I'm not the only person to do that; other people treat it exactly that way also. But it's really opened up my eyes to bringing probability in from my neural side to play or to bear upon all the work I do on the robotics side as well.

Peter Asaro: And in terms of the multi degree of freedom, hyper degrees of freedom, what are the biggest challenges in controlling those?

Joel Burdick: Well like I say I don't, I haven't worked in that area for quite some time and certainly in the early days the big issue was how do you deal with a large number of degrees of freedom? Because the kinds of algorithms that I and the other people looked at during my Ph.D. days are there's redundant arms, they didn't scale very well once you started to add a large number of degrees of freedom. And so that's why with the work with Gregory Chirikjian and we were trying to come up with a different way of doing that and we had some successes there and it had some impact on the field. And then I think still the, one of the key issues is that now you have this incredibly complicated robot, if you can build it, and we're pretty good at now designing algorithms to control its shape and its motion but still trying to put sensors all over this robot and make the response much more adaptive based on the kinds of sensory information that comes in is still an open challenge in that area and that's a problem in robotics in general. So in some sense that early work got me involved in thinking about sensor processing and algorithms for planning that rely upon sensory data and assume that you don't know about the world ahead of time and that what you can find out about the world is uncertain and noisy and dirty.

Selma Sabanovic: What kind of different sensors have you used?

Joel Burdick: You know I'm not a vision researcher but we use vision. I don't necessarily per se do research on tactile sensing but we use tactile sensors. We've used lasers, like everyone else in the field of robotics does. The unusual thing is I mentioned we've been using ultra wideband radar. In fact we're looking now at using ultra wideband radar for mapping buildings and things as an alternative or as in conjunction with vision and radar. You know, force-torque sensors, even from my early days, even now. So one of my big projects right now I'm working with a team at JPL as part of the national kind of DARPA grasping challenge. We're one of the six teams that we've got hardware given to us by DARPA and we're every month having to solve a different manipulation challenge; so pick up a flashlight and turn on the light, pick up a key and put it in a keyhole and turn it and unlock a door. And so there we integrate all kinds of sensors; lasers, vision, tactile, joint sensors, force torque. And so a lot of my current interest is how to fuse all that information together in an interesting way.

Peter Asaro: What were some of other robots you've worked on through the JPL project?

Joel Burdick: Well, and so at JPL and here I've built several generations of these snake-like robots. As I mentioned I worked on locomotion for a long time so we built this little fun robot called a snake board that actually, it's one of the most highly referenced papers I ever wrote even though it's just a cheesy little conference paper. You know, built fish-like robots, built hopping robots. So I had a lot of fun for a couple of years with Paolo Fiorini at JPL building little hopping robots, with some visitors from Japan, little walking robots. So pretty much most, different morphologies except for humanoid robots I've built one of them sometime in my career.

Selma Sabanovic: And were they for a particular application for JPL or…?

Joel Burdick: So some of the, this is not unique to me but typically either you would build the robot for an application – so one of my students, Tom Lee, was a JPL employee and so motivated by the earlier work we did in snake-like robots he and the team up at JPL, with the assistance from us, built a snake-like arm which is meant to be picked up by a larger arm to use for inspection inside the space shuttle when it was down on the ground. So that was one that was motivated by an application. Other ones like the early snake-like robots I built, we didn't necessarily have an application in mind; we built them more as a demonstration device. It's like look, if you want to build a robot that's crazy like this we can build it and we have the algorithms to sort of control it, so most of the time for me the mechanisms are more a vehicle for demonstration of the ideas rather than particularly for a specific application.

Selma Sabanovic: And have you, with JPL have you worked on any of the rover missions or…?

Joel Burdick: Yeah, indirectly. And so one of my first students, who did her Ph.D. up at JPL, Sharon Laubach, who's now actually risen up to quite some prominence in the current Mars missions, she actually took some time out and actually was a rover ops person. So in the Sojourner Mission, the Sojourner vehicle on the Pathfinder Mission, in the latter days she actually was one of the persons that actually all the control commands went through her and she double checked all the commands. And I think she actually even got to drive the rover one day. And she's gone on, as I said, to play an important role in the Mars activities on the flight side at JPL. Sam Feaster, another one of my grad students, took off about a year during his graduate time and sort of with some input from me worked on the current Odyssey and Spirit rovers that are on JPL. So in particular all the camera pointing and sun angle estimation and orientation and body estimation with the vehicle Sam wrote while he was a graduate student here.

Peter Asaro: What was that like working with Paolo Fiorini?

Joel Burdick: Paolo and I are old friends and so we still collaborate in indirect way. In fact I just saw him in China two weeks ago at the big conference. And so I met Paolo when I was a graduate student. So, because at Stanford we were one of the labs that figured out how to break into these Unimate 560 PUMA robots and so they were a prominent device used by many research labs. So I had sort of knowledge of actually how to break into the system and hook up computers so I came to JPL to just do a little two day consulting job to help them make it interface to their research PUMA robot and that's when I first met Paolo. Then after I came to Caltech, at that time I didn't know I was coming to Caltech, we just sort of kept casual contact and then we found a way to collaborate together with these hopping robots and Paolo is just a terrific gentleman and a scholar and a dear friend of mine. And so then after he left JPL I went and spent sabbatical time with him in Verona and I still, we send email back and forth so we're personal friends.

Peter Asaro: Have you gone to other labs for sabbaticals over extended periods?

Joel Burdick: I spent some time also in a lab called Inria, I-N-R-I-A, which is in the south of France in Sophia Antipolis. So Inria is a big national French organization of research and at that time I wanted to learn more about computational geometry and so a guy named Jean-Daniel Boissonnat, who actually played in robotics for a while, was a host. I didn't know him that well, I knew mainly through my French mafia contacts, Oussama Khatib and Jean Ponce, so they really helped set it up and just coincidentally happened to be in the Côte d'Azur. So it was a great place to spend sabbatical time so I spent a summer there with them and learned a lot about computational geometry. I actually made a contact there with a nice guy named Subir Ghosh; we actually ended up writing a few papers together. And I had a great time living in the south of France; it was a real life changing experience.

Selma Sabanovic: And you also worked with the Japanese more closely?

Joel Burdick: I can't say I've had a detailed collaboration with them, no. But obviously Japan is a very important country in robotics and I've kind of gone out of my way to make visits there and so I've met many people there. I actually had a small collaboration with a guy named Omata who was another grasping researcher so we wrote a paper together. So Élan, Ramón and I have worked together for 20 years now on grasping, it's kind of a hobby. We had one student together and now we actually have several students working on grasping now, now that grasping's hot again. So Élan and I were motivated by some of Omata's work and so we asked him to be a coauthor on a paper that was motivated by his earlier work. He made some nice contributions; it was a great pleasure to work with him. And you know it was mainly just I met people in the years over there. And there's also a National Science Foundation Joint Japan activity that graduate students can go spend a summer there so I've had at least three, maybe four of my graduate students go spend summers there. And then the main activity I've had is also the Japanese government has a, kind of a sabbatical program for young researchers. They don't necessarily have to be in academic labs, they can be in government labs and so I had two researchers come over; one was Nobuaki Takahashi, who actually I just saw last week as a matter of fact, come over and spend a year in my lab. And he, that was during the days in which I was doing snake-like stuff and so he made some terrific contributions in the technology in my lab and was just a lot of fun to have around. And then another researcher that you may run across, Shuuji Kajita, K-A-J-I-T-A, he was working in the lab which at that time was called MEL, Mechanical Engineering Laboratory, which later got folded into the now AIST. So he got one of these sabbatical grants and then spent a year and a half here and we worked on some walking robots together; he built a terrific little walking robot. And so with him I co-authored my only publication in the Japanese language, he had to write it of course; I can't speak or write Japanese.

Selma Sabanovic: He's on the HRP project now, right?

Joel Burdick: He's on the HRP project, yeah. Yeah, yeah, yeah. So he kinda heads up the locomotion part of the HRP project. And so he's a funny guy; we had, it was really a great pleasure to have him here.

Selma Sabanovic: I'm curious, could you tell us a little bit about your funding sources over the years?

Joel Burdick: Oh, I think I have most of the typical funding sources that most researchers do. They've changed over time. In the early days of my career more of my work was funded by the National Science Foundation and to some extent the Office of Naval Research. And that was really valuable funding because when I finished up in robotics in the late '80s, it was right at the peak of the sort of first wave of explosion robotics and so I was lucky that's what got me this job here was that was a good time. And then robotics crashed and went through a hard time; boy, that was not fun. And so I was very lucky to have support from NSF and ONR in those early days. And then off and on I've had support either from NASA or joint work with JPL either for NASA or for other sponsors. I've had Department of Energy funding. These days, because of all the biomedical work I do, the majority of my lab is funded by NIH. And then I've had little odds and ends like this Korean funding right now. I've certainly had some very pleasant collaborations with a number of companies; Toyota, Denso, another Japanese car company, Yamaha, another Japanese. So actually I've had more Japanese collaboration than I guess, than I told. And so, let's see, Department of Energy, ONR, NIH, NSF, DARPA of course; I've had several DARPA grants, I have one right now with JPL. So those are the main funding agencies. And then also some of the medical work there are nonprofit foundations and so my lab per se hasn't received funding from Christopher Reeve Foundation but people I collaborate with do and so I benefitted from the Christopher Reeve Foundation. And also some, the Beckman, there's a Beckman Medical Foundation as well.

Selma Sabanovic: How did you get in contact with the Koreans?

Joel Burdick: So I was working with Denso and they were interested in being able to detect pedestrians at a distance. So car manufacturers have reached the point where there's lots of great safety technology for the drivers and passengers but pedestrians, particularly in the newly urbanizing Asia, are getting killed at a horrific rate and so they first came to us because of all my sensor based planning work. It's like, "Okay, here's someone who knows about sensing and a broad range of sensing and can also integrate it into planning." And we looked at a number of things and eventually decided, "Hey, vision, radar, we have researchers in our labs that can do that. Why don't you look at this ultra wideband radar?" and I didn't know anything about ultra wideband radar. And so fortunately my Japanese collaborator – so Denso actually sent someone to sit in my lab for a whole year, Dr. Mitsumoto, who's another great guy who spent three years in my lab. And he actually helped me find a postdoc named SangHyun Chang from China, or not China, excuse me, Korea. And so we were working with Denso and then SangHyun, because he was Korean, had contact with Korea and they were finding out about the work we were doing. And then when the financial crisis hit then so I had to drop out but it was perfect timing; that was when actually the Korean military and government wanted to advance this ultra wideband radar technology. So it was really because of the postdoc and he's, not only is he a terrific guy but he's made this all possible because he can speak to the sponsor in Korean so it's made things much easier.

Selma Sabanovic: And for the first time, sorry to be jumping around, I just want to…

Joel Burdick: No, no, no. It's okay. I know you'll edit this later.

Selma Sabanovic: <laughs> Yeah, yeah, yeah we will. So you mentioned that there was kind of a downturn in robotics around the '90s?

Joel Burdick: Yeah, early '90s.

Selma Sabanovic: Could you tell us a little bit about…?

Joel Burdick: Well I'm sure other people have told you about this. Well here's the stock phrase that everyone says, and there's, this is primarily the truth, there's some nuances though. So I think what happened in the early '80s everyone got excited about robotics and there was a big push and advances were made. But I think again the cliché is there was sort of, people pushed robotics too much and there were sort of more expectations than could be really delivered with the technology and science at the time and so many of the funding agencies and companies then got frustrated that these robotics people told us we could do all these great things and none of it came true or very little that came true. So I think the field had to lay fallow for a while because the funding agencies and the corporate sponsors got frustrated that all this money wasn't seeing too many results. There were results; they just weren't necessarily results leading right to factory or to other economic implications. And so funding in large part dried up and certainly on the corporate side and even within the government the amount of money put into robotics didn't disappear but it was certainly lower than that first blush. But in some ways it was good for the field to have that hard time; it sort of shook out a lot of the people and only the kind of die-hards remained and then we kind of started rebuilding. And so certainly I would say now we're in an area of much more active robotics funding. It's not the giddy rush like the early days but that, it's good; it's much more sustainable now. Robots are working, computer vision works now; it just wasn't working outside of the lab before.

Selma Sabanovic: And could you compare kind of some of the funding agencies since you've had contact with so many?

Joel Burdick: So I, so there's a joke I tell and so the funding agency is going to be mad at me about this but it's true to some extent. So when my junior students or finishing Ph.D. students go to academia and they want to know how to write a proposal I say, "Well you got to know your funding agency. And so NIH loves innovation as long as you can guarantee no failure and NSF you just got to make sure to refer to everyone in the field because if someone's on the panel and you don't refer to their paper you're dead. And DARPA…" I used to tell them, "Tell the biggest lie that you can think you can get away with." Now I tell them, "Tell the biggest lie you can imagine." And so you know that gives you some character of the different funding agencies.

Peter Asaro: In terms of students, you mentioned several that went on to work at JPL. Are there other students in academia that you trained?

Joel Burdick: Yeah. I actually, it's kinda funny, I did a count last year so between the number of Ph.D. students I finished and also the number of postdocs in my lab I've actually had 50 people come through my lab so far. And I have probably, I have to count this but you can send me an email and I'll count it up, but especially in the early days a large fraction of my students went out to academia so I have at least 15 that I can think of postdocs and Ph.D. students who've gone on to academia all across the country. If you want I can try to name them all here or I can send you a list later. But so, particularly in the early days as I said it was popular and I was lucky to have students go on to academia and so hopefully when my kids go to college they'll have lots of ins at different places to help my kids get into school.

Selma Sabanovic: If they want to do engineering.

Joel Burdick: Yeah, if, yeah. Mm-hmm.

Selma Sabanovic: <laughs> So would you, if you were giving advice to somebody who's in the future interested in robotics or, what would you tell them?

Joel Burdick: Yeah, you're kind of catching me flat footed on that one. I don't, I'm sure you've heard these clichés from everything but certainly robots are computer controlled, electromechanical devices and so one thing, which is both an advantage and a disadvantage from the field of robotics, it's a very multi-disciplinary field. And so it's good to sort of pick one area that's of your interest that you can go deep in but you need to actually have kind of broad exposure to a variety of things to be effective in the field of robotics. So I would encourage people yeah, that if people like to do only narrow-minded research robotics isn't the right field for you. It's something where you have to have a fairly kind of broad interest. And any other advice I have is the same for any research field which is find something you're passionate about and do it as well as you can.

Peter Asaro: What do you see as the big outstanding problem for robots in the near future?

Joel Burdick: Well here's my take on why, why don't we see robots everywhere today and other people have different opinions on this, but in my mind there's sort of five things you can take off. So as, if you go back and think about robots or computer controlled electromechanical devices in the early days computing was awful; now that's kind of getting solved. And so sure, for some of the really difficult things we want to do computing still is a limitation but it's just getting much, much less to be a limitation so that one's falling by the wayside. The other one is if we wanna put robots in the real world they have to use sensing and again that's been one of my interests. And sensing technology has come a long way both in terms of quality and also the cost, particularly with kind of the, and again as computing gets better and also as micromachining and other kinds of fabrication techniques get better, sensing is getting close to being solved. Yeah, there's still a lot to do but it's not the, the real bottleneck that it used to be. There's still two real practical bottlenecks why we don't see robots everywhere. So one is power; we don't really have a great way to store a lot of power on board a robot so they're kind of like tethered to a power source, they can't get too far away from a power source and power engineering is always a hard one. Another one is if you want robots to be cheap the kind of DC servo motors that we have right now to drive robots, they're just still too expensive. They're coming down in price and they get incrementally better every year but that's still a bottleneck. And then the last one of course is what all of us researchers worry about which is the intelligence part of the algorithmic part. That's going to be with us for decades. And so, but we're hoping soon, in my own opinion, is if those other two, sensing needs to move about another decade further and we need to move actuation and power another quite substantial leap. And then what's left is just trying to make these robots smarter, and that's going to be an outstanding problem for a long time.

Peter Asaro: And what are the big challenges for integrating sensing into planning and decision making?

Joel Burdick: I'm speaking as an academic, not necessarily as a battle hardened industry veteran here, and so anyone can come up with an algorithm. What's hard is can you come up with an algorithm where you can provide some property about it? So what you'd like to know is if I send a robot to Mars and it's been in the, it goes in this environment where it's never seen things before you'd like your algorithm to have certain properties so that you know that it'll either be able to solve the problem, if a solution exists, or come back and tell you the problem can't be solved. So this is a classic idea we call completeness in motion planning. And so with sensor based motion planning, because you're dealing with things where you don't have much prior information and there's a lot of noise, you assume there's noise in your sensors and uncertainty, how can you make these very robust, reliable algorithms, not only being able to prove things as an academic, but also make it practical, reliable and robust in the real world is still a real challenge.

Peter Asaro: Great. Is there anything else you'd like to add?

Joel Burdick: I think you guys are doing a great service and so in fact I was almost thinking that someone should go around and try to capture all of this stuff. So I'm not, I don't know how, you guys may see it differently than I do but you can think there's sort of different generations that have sort of come out. I'm like the third or fourth generation; I'm not the really early guys. So there's a funny, an interesting story. So Stanford was one of the first places that did robotics research starting in the early '60s and so they used to have a place called the Stanford DC Power Lab and it wasn't to study DC power; it was named after a guy named DC Powers. And so the, I may have that wrong; still, check your sources on that. But there's no doubt that some of the really early I know Ph.D. students that had important impacts in the field used to work in this lab up in the hill behind Stanford and it attracted a pretty, by today standards, curious kind of eccentric crowd. And so when I was a graduate student, right at the tail end of my graduate days, they were actually tearing that lab down and so they actually had a reunion of all the people who used to work there and it was a, just a great adventure to meet kind of the really early pioneers of robotics. Because they did this not knowing if there'd be a future or not; they just thought it was exciting. And they, those people, even though by our standards today the tools they had to work with and the technology was incredibly primitive, they really kind of figured out a lot of at least the problems to tackle and they were surprisingly good at sort of figuring out what should be solved, but it took a long time to figure out how to solve it.

Selma Sabanovic: Who were some of the people?

Joel Burdick: Oh, yeah. This is, now we're going to have to – the canonical person that I'm sure is on your list, actually I saw it on your list, is Victor Scheinman; has been in and out of robotics and was a grad student in those early days with Bernie Roth. Russ Taylor, who's now at Johns Hopkins, I'm sure you're going to talk with him. Here's a name that probably has not been on your list at all and he's actually here in L.A. at Cal Poly Pomona: Barry Siroka, S-I-R-O-K-A. And I see Barry occasionally here. He's a funny guy and he would actually have great insights into those really early days. And Bernie Roth would also give you great insights into those early days and a list of students. Dan Piper, one of Bernie's first students. So there was, actually at Bernie Roth's 70th birthday they had a reunion at Stanford, I went to that; it was a lot of fun. I'm just trying to remember some of the early people that used to show up there. Kenneth Waldron of course has had a big impact on the field and also was in the early days and is a great storyteller too and so he'd probably give you some great stories. What I'm trying to think about is some of the more esoteric ones that sort of left the field of robotics soon after that that you might not run across; like I said Barry is one of them.

<pause>

Joel Burdick: You know that's all that comes to mind right now. Yeah, it's a shame. Yeah, I feel like I should've written down all those names there for posterity sake.

Selma Sabanovic: Well if another one pops up you can let us know.

Joel Burdick: Okay, okay.

Peter Asaro: Did you ever run into Hans Moravec when you were there?

Joel Burdick: No, I never met Hans while I was there. He left long before my time. But certainly yeah, that's a character, a known character in the field of robotics from those early days.

Peter Asaro: Great.

Selma Sabanovic: Yeah.

Peter Asaro: Good.

Selma Sabanovic: That was all we had…

Joel Burdick: Okay.

Selma Sabanovic: …unless there's something that you can think of that would be important to add that we haven't come across.

Joel Burdick: No, I think you covered a lot.

Selma Sabanovic: Okay. <laughs>

Peter Asaro: Great.

Selma Sabanovic: Thank you so much.