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Jim Bobrow

An interview conducted by
Selma Sabanovic
with
Peter Asaro

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Selma Sabanovic: So, could we start by having you tell us where you were born and a little bit about your family?

Jim Bobrow: Okay. I was born in Newton, Massachusetts. I moved out to California when I was one and I had one sister and we grew up in a suburb of Los Angeles. And I went as an undergrad to Cal State, Long Beach, which is the closest college to where I grew up. Then I went as a graduate student to UCLA and I've always been interested in machines. Motorcycles are sort of what got me the most excited about mechanical engineering. I like machines that go fast and have high performance. So, I've had lots of fast motorcycles and cars and things like that. So, then I started learning about dynamics because that's always interested me. And then, at UCLA, there was an interest in robotics, and that was fun because it was a new field. It seemed like I could make a contribution in that.

Selma Sabanovic: So, do you remember when you first came across these exciting, fast, powerful machines?

Jim Bobrow: When I was kid, starting with my mini bike. I supped it up and raised the compression on the Briggs and Stratton engine, took it apart, figured out how to make it go faster.

Selma Sabanovic: How did you learn how to do those things?

Jim Bobrow: Well, my dad had a lot of tools and I liked playing around in the garage. So, I enjoyed doing that and just learned by doing.

Peter Asaro: What would you say was your first robot, or your first robotic project?

Jim Bobrow: I didn't really get involved with robots until I started doing my Ph.D. work. And even at that time, we just had some really sort of prototype crummy ones at UCLA. So, we never even had a commercial robot when I was doing my research for my Ph.D. So, it was more of a mathematical study.

Selma Sabanovic: What kind of prototypes? Were they built in-house?

Jim Bobrow: Yeah. Yeah, just some of the students. Steve Dubowsky – I had two advisors; Steve Dubowsky, after I finished at UCLA, he went to MIT and Steve Gibson is more a mathematician. I studied with both of those guys as my co-advisors. Steve Dubowsky had

some master's students building robots and I would work with them. So, I got some exposure to the machines through them.

Peter Asaro: It was a mechanical engineering program?

Jim Bobrow: Yes, mechanical engineering, but I've always enjoyed electronics and computers.

Peter Asaro: Your undergraduate work is also –?

Jim Bobrow: Mechanical engineer, yeah.

Selma Sabanovic: So, the kinds of robots that you had the prototypes for, were they focusing on any specific thing like manipulation or mobile robots?

Jim Bobrow: My Ph.D. work was mainly on manipulation, but how to make to make robots move as quickly as possible. So, that was sort of my main contribution was I had an algorithm that would produce the fastest possible point-to-point motion for a machine. That algorithm is used in a lot of robot controllers today. There is no way to make a machine go faster than what was done in my Ph.D. So, that was – you can use it for any kind of machine. It's been used for mobile robots and other machines after that, but the focus was manipulation, point-to-point motions.

Peter Asaro: Is there a name for the algorithm?

Jim Bobrow: A what?

Peter Asaro: Is there a name for the algorithm?

Jim Bobrow: No name. Some people made up names, but I don't have a name. Sorry.

Peter Asaro: And so, after your graduate work, did you decide to go into robotics, or just –

Jim Bobrow: Well, that was when CAD/CAM was starting to become a big deal. So, I went to work in the CAD industry and actually published a paper on machine tool path generation for automatically creating motions for cutting parts in CAD systems and then I decided that I didn't like working in industry as much as exploring things in the university. I thought maybe I'd have

more freedom. So after about a year and a half, I got a job here at UCI. I've been here ever since then.

Peter Asaro: What year was that?

Jim Bobrow: It was 1984 is when I started working here.

Peter Asaro: So, you finished UCLA about '82.

Jim Bobrow: '82ish, yeah.

Selma Sabanovic: So, before you went UCLA, how was working for McDonnell Douglas?

Jim Bobrow: Yeah, that's the CAD system. They had a Unigraphics CAD system.

Selma Sabanovic: So, what was the workplace like?

Jim Bobrow: It was great. Programmers back then – I had worked at Hughes Aircraft and TRW with engineers working on satellites, but it was refreshing to work with programmers at McDonnell Douglas Automation because they're sort of younger people. They've come to work in cutoffs and they're just a good group of guys to hang with. So, I really enjoyed that.

Selma Sabanovic: How big is the group?

Jim Bobrow: Well, there's probably a hundred people in this division. I mean now, it was purchased by Siemens and it was purchased for $4 billion. So, it grew to be a pretty big thing.

Selma Sabanovic: And so, how did you decide that you wanted to go into academia?

Jim Bobrow: Well, I liked working with the CAD software, but like I said, I wanted to have more freedom to work on my own projects. Rather than working on a project that would make them money, I'd rather work on my own stuff if I had the opportunity to do that.

Peter Asaro: Was there anybody else working in robotics at Irvine when you came here?

Jim Bobrow: No, I was the first person. This department was mainly thermal fluids. So, they didn't have anybody that did dynamics and controls and that sort of thing.

Selma Sabanovic: So, how was it starting, the robotics angle here?

Jim Bobrow: Well, it's been fun. It's been a lot of work, but it's kind of nice to go to a place and if you're the first one, you get to make the choices that affect what's going to happen for years afterwards. So now, it's been 26 years or so since I've been here and I think we made some good decisions and some decisions that weren't so good, but I've learned a lot.

Selma Sabanovic: Hopefully you'll tell us about some.

Jim Bobrow: Really? I don't know. Maybe I'll tell you.

Peter Asaro: What was the first robotics project you got going here in the lab that you started?

Jim Bobrow: Well, I started with pneumatic robots because I didn't have any research money and motors are very expensive. So, it turns out that air is cheap. An air compressor, every gas station you can fill up your tires with air and air actuators are just pistons that you can buy for $20. I'm sitting on this chair that's actuated by air. There's some pistons on the side. And so, this is a flight simulator chair. I just turned it on. If you went to buy one of these if it were electrically actuated, it'd probably cost you $5,000, but this thing cost closer to about $100 or $200 and you can hear the air actuators running. So, the actuators themselves are very cheap and it's a fun way to work on things without having to worry about melting your electric motors and $5,000 bites the dust. It's more like $5 bites the dust if you wreck your actuator if it's an air powered machine. So, that's what I started when I was here mainly because I couldn't afford the expensive actuators. The other thing about air is that pistons are very light. It would be nice to have a lightweight robot. And so, I have lots of machines that we've made since I came here that are powered by air, and they have some really great advantages over other robots. And so, we're probably the leader of all the researchers that build pneumatically actuated robots. We started it and it's still being done today. So, a lot of that work was evolved to rehabilitation research. I should probably turn this off now that it's making a hissing noise. Okay. I'll turn it off. That's the power right there. I turned it off. So anyway, I think that blue robot is the first generation of air powered robots and the actuators are actually part of the structure of the robot and the whole is light. The advantage of air is that it's kind of spongy. So, when you're interacting with people, you can't hit them with hard forces. It's more like hitting them with a sponge. And so, a lot of my work to start with was figuring out how to control the force from the sponge accurately and safely. And so, we made a lot of machines doing that.

Selma Sabanovic: Where you doing rehabilitation in the beginning or did you have other applications?

Jim Bobrow: No. No. When I first started, I just wanted to make a fast robot because I had this algorithm that said this is how you make them go fast. I wanted to try it out on my own machine. So, I wanted strong actuators and air seemed like the way to get strong actuators without a lot of expense. And so, that's why I was sort of motivated to make these air powered robots.

Peter Asaro: A lot of the early investor robots were hydraulics. So, how does the pneumatic compare to the hydraulic?

Jim Bobrow: Yeah, hydraulic is great. I mean it's the same kind of advantages in the sense that you get a lot of force in light and very low weight package, but for that, you need to compress the oil. So, you need a power source – a oil compressor. So, that's usually a noisy thing, and the biggest disadvantage to oil is that if you're assembling the robot or disassembling the robot, you get oil all over the place. It's just, overall, in general, it's not a pleasant to think to work with whereas if air leaks, everything is air. That's fine. If oil leaks, you get a big mess. I've built my share of oil powered machines as well, but it's just not as fun. In general, you're always getting squirted with oil and I'm a grease monkey, but I don't like to be a grease monkey all the time.

Peter Asaro: But in terms of precision and control, it's pretty similar?

Jim Bobrow: Well, no. Because you can get higher forces from oil systems, you can typically make them more accurate as well because air, there's a problem with the amount of friction compared to the force on each joint. So, it's more difficult to make an air powered system accurate, but we've been able to do pretty well. I've had companies approach me about commercializing these products and usually, they want to get venture capitalists involved. I've met with them and I've decided that it wasn't something that I wanted to do.

Selma Sabanovic: Why not?

Peter Asaro: But, you've worked with a lot of smaller companies over the years.

Jim Bobrow: Yeah, I've worked with small companies that have used air power for specialized applications. But, what I was talking about with the venture capitalists was more like general robots that they could mass produce and sell to huge businesses and things like that. But, the companies that I've worked with are more specialized in rehabilitation, things like that.

Peter Asaro: How did you get involved with the rehabilitation?

Jim Bobrow: Mainly through one of the faculty we hired, Dave Reinkensmeyer, that was his research area and he's interested in helping patients after they've had a stroke or any neurologic injury. And so, the robots are a good way to automate the therapy. I like designing robots to do different tasks. So, it was a good match and I'm still building robots with him today.

Selma Sabanovic: When did you start working with him?

Jim Bobrow: Probably about 15 years ago, 10 or 15 years ago.

Selma Sabanovic: And I'm curious; so, since you were the first person who was interested in robotics here, when you were getting hired, was that something that was of interest to the department as well, or is it something that came on later? How did people here, react to the robotics direction?

Jim Bobrow: I think back in 1984, robots were sort of new and they needed somebody that knew the kind of core of material that I know, dynamics and control, and the application seemed interesting to them. So, they seemed pretty receptive to having a faculty in that area.

Selma Sabanovic: How about students?

Jim Bobrow: Students loved it. They always love it. I always have students that want to come and build these machines, usually too many of them.

Peter Asaro: Have you had a lot of Ph.D. students in robotics, or is it –

Jim Bobrow: Well, I've had – I don't know. I've had about 15 of them. It's not a big number compared to other places, but it's been fun. A lot of master's students, a lot of specialized products, which end up being master's degrees. Most of my Ph.D. students have gone to work for places like Jet Propulsion Lab; a couple of them in academia.

Peter Asaro: Any names of people that have gone to JPL?

Jim Bobrow: Well, Bryan Martin, Garrett Sohl, Scott Ploen; those three are at Jet Propulsion Lab. Those are the only – then there are several master students and stuff like that. Eric Wolbrecht is at Idaho teaching and then another bunch of them floating around.

Peter Asaro: Before you got into the rehabilitation robotics, were there some other systems you developed in – I mean obviously, it was almost a decade.

Jim Bobrow: I've worked on a lot of different things - hydraulic systems. I've worked on software to solve some problems in robotics, but as far as actual machines, it's sort of been a slow progression for some of the machines, the blue machine to the upper extremity rehabilitation machine. So, I don't know. It seems like there hasn't been any like big project that you'd want to know about. There's a lot of little ones.

Peter Asaro: And mostly in task control, or did you expand to other problems and eventually –?

Jim Bobrow: You mean for making them move fast? Is that –?

Peter Asaro: Right. Right.

Jim Bobrow: Oh. No. Yeah, I sort of moved – there was a lot of people that sort of went farther into they call it time optimal control of robots. I did a little bit more work in that and then I sort of lost excitement about that and wanted to do other things. So, I kind of – one of the projects was this weightlifting robot, which is not – we sold it I guess. We sold it on eBay. I'm interested in finding motions for machines that maximize how much they can carry for example. So, rather than moving them really fast, what's the biggest weight a machine could lift. So, I had a PUMA robot in here. There's a video on my website where we show that we can make it lift three times more than what the manufacturer says it can lift by finding the motion through my algorithm. So, that's an optimal control problem, different than minimum time. It's minimum effort optimal control. So, I have reliable algorithms for doing that.

Peter Asaro: Yeah. What's the general strategy for doing that?

Jim Bobrow: The general strategy is that you have to write a function, a mathematical function that describes as best you can your desire to maximize the payload and minimize the joint torques. And so, they call that an optimal control problem. And then, the next step is to find a solution reliably. And so, I've published three or four papers on good ways to solve that problem and applied it to both sort of simulated machines and real machines like the PUMA robot and also to rehabilitation as well.

Peter Asaro: Have others been using that algorithm?

Jim Bobrow: Pardon me?

Peter Asaro: Have other people been employing that algorithm to –?

Jim Bobrow: Other people have made similar algorithms to solve their own problems, but I don't think as many have done it. They haven't gone as far as I have, solved as many realistic problems.

Peter Asaro: So, tell us about the rehabilitation robots. What were some of the challenges you found in trying to design those systems?

Jim Bobrow: Well, the first one we built was a gait rehabilitation machine and the challenge was to – I need to stand up. I don't know if you're going to get this, but the patients have a severed spinal cord or partially severed spinal cord and they don't have the ability to walk, they're paralyzed, but if you support them on a treadmill, therapists, they can drive the patient through a normal gait cycle and this is how they would regain the ability to walk if they were trained to walk again. So, first, we solved an optimal control problem, which said if we were supporting the patient at the hips, could we swing the hips so that the patient would take a step on a treadmill? We were able to use the programs that I wrote for weightlifting and things like that for hip swinging. So, we published a paper on how you swing a hip in an optimal way. And then, we built a machine, which parts of it are back there. I don't think you can see it. That's our hip swinging robot, and we actually tried it out on some patients at UCLA. So, the challenge is not only to find these motions, but also to create the machine that can do them. Of course, the machine is pneumatic because that's what I like to do and it's cheap, but you could do it with electrically actuated machines, but finding the motion is an interesting problem because there's no motors for the patient that has no control of their leg. Yet, if you support the patient by the hips and move the hips just right, it'll swing the leg like a pendulum and that turns out to be helpful for the patient.

Peter Asaro: So, you need to know the mass and like the weight.

Jim Bobrow: Yes. It's good to know all the mass properties and things like that. So, that's another little challenge. That's system identification problem. So, we've worked on that as well.

Peter Asaro: How do you address that in that kind of rehabilitation system? Is it automatic or do you have to calibrate it or--?

Jim Bobrow: How do you do system identification?

Peter Asaro: How do you do it?

Jim Bobrow: How do I do system id – so, system identification is that you have equations of motion from Newton's laws and unfortunately, for robots, the equations are really nonlinear and ugly. So, we end up doing a big least squares problem where the coefficients, the unknown things that you're trying to figure out in a least squares problems are the mass properties or whatever's unknown about the machine. So, mathematically, it's just a big least squares problem, but the challenging part is writing out the form of the equations in an efficient way. And then, you can do motion capture to actually find the input to this big least squares problem. You can sort of shake the patient or have similar humans walk, which we've done. There's lots of different ways to do it.

Peter Asaro: So, the patient actually becomes part of the robot system.

Jim Bobrow: Yes. The patient becomes part of the robot.

Selma Sabanovic: Did this ever become applied?

Jim Bobrow: Yeah. Well, we're trying. We're still working on that and like I said, we had a couple of patients that we tried our gait robot out on at UCLA. And then, we moved onto upper extremity rehabilitation. So, arm, we have an arm robot over there; actually, two of them. It's an interesting problem for them, where patients need to move their arm kind of like an exercise you would in a gym, but ideally, they – I think the lights.

<crew talk>

Jim Bobrow: I forgot what I was talking about.

Selma Sabanovic: You were talking about –

Jim Bobrow: Oh, upper extremity, yes. So, for upper extremity, physical therapists would guide patients through motions normally, but a robot can do that as well. They try to get the patients to exert as much force as they can and try as hard as they can. If you just attach a robot and guide a patient through a motion, the patient won't be rehabilitated because the patient just lets the machine do the work for them. So, the challenge is to have the robot sort

of push the patient like a therapist would, say, “Try harder. Try more.” And so, we have one of the few robots in the world that will actually learn what the patient is capable of doing and not ask the patient to do too much or too little, just enough to get them to do the motion and to learn what they’re capable of and it can tell if they’re slacking off. So, we call it a slacking controller and it lets up on the forces that it applies to the patient if it senses that the patient is slacking off. So, it’s kind of a neat adaptive controller.

Selma Sabanovic: So, does it actually speak to the patient?

Jim Bobrow: No. Usually, there’s a therapist there that’s speaking, but getting the patient engaged is a big deal and any kind of cues that you can give to the patient, audio, visual, are really important.

Selma Sabanovic: So, how have you been figuring out those cues?

Jim Bobrow: We have them play games. We get the games. We’ll try to encourage them to try harder. We’ll give them applause. There’s just many different ways to do it. It seems like the therapists that are in the room with the patients do the best job. They’re sort of like cheerleaders and we don’t have a cheerleader robot. But if we did, it might help.

Selma Sabanovic: There are a lot of people who work on the kind of socially assistive side of robotics.

Jim Bobrow: Yeah, that could work, yeah, if we had a socially assistive robot in with the patients. It might work. It might help.

Selma Sabanovic: Have you worked with any psychologists, or were you talking to the – I’m just curious how you picked like what was happening in the game, or were there other people that you were collaborating with on that?

Jim Bobrow: Yeah. I collaborated with other people and it turns out that we have a good programmer who has made some games to work with patients in the past. So, that programmer is helping us figure out the games, but the games that the patients play need to encourage certain function for the patients, certain motions. And so, we’ve designed a lot of different games just to get different movements from the patient. And yeah, Dave Reinkensmeyer and Steve Cramer is an M.D. that works on that.

Peter Asaro: But in terms of finding just the right amount of force to feedback, is that a feedback control system where it's trying to learn?

Jim Bobrow: Yes.

Peter Asaro: So, it's a control control how much pressure to apply–?

Jim Bobrow: Yeah. It's a feedback control system that looks at an error measure. The patient typically has some goal; they want to reach to a certain point, or follow some trajectory. So, there's a measure of error from the trajectory. The controller will try to push them to the desired trajectory. The feedback is how it knows how far off it is from the trajectory. And then it senses these errors. If there's – it also knows how hard it's pushing because pneumatics allow you to measure the air pressure and force on the patient because you can accurately measure the force. And then knowing how far – how hard it's pushing on the patient, it knows what it's contribution is to the motion and the patient's contribution and it can also detect if the patient isn't doing as much as they could and it can then sorta back off in a sorta nice continuous way and give the patient higher – more work for the patient to do and less work for the robot or vice versa. If the patient isn't able to do anything, then it'll help the patient more.

Selma Sabanovic: What are some of the problems of actually working with people as a part of the loop?

Jim Bobrow: Well, the – that's why we have therapists who are great with working with people and it's kind of fun to have engineers and therapists because they both – the engineers usually are in the room with the patients and they're Ph.D. students of ours that have built the machine and the controller. And there's kind of a neat interaction that happens between the therapist, the engineer and the patient – to have all three of them in the room and – but the engineers are typical – typically care most about getting their machine to work and the therapists want the patient to be comfortable and doing what they're supposed to do. So the challenges are – for these handicap patients, is just, you know, helping them into the device and making sure it's not rubbing them the wrong way and just sort of practical things like that.

Selma Sabanovic: Put that in terms of the technical side. Does working with people effect how you think about the mechanism or the kind of problems that you have to solve when you're developing the mechanism itself?

Jim Bobrow: Yeah, and I'm not as good at that as the people that I work with so that's why I work with these other people. I like building the machine but the machine has to work with patients and the patients need to be motivated to wanna work through the therapy and it can

be a challenge and I've been – I'm just the engineering geek. You know, I say, "Okay, here. I wanna – I'll fix this machine." But the patients, they – well, they love robots. In general, they see a robot and they're like, "Oh, I want – I like that robot." And then you try to figure out, "Well, did the robot really help 'em?" Turns out the main thing that helps is attention. If the therapist is helping, 'em they get – they do well with recovery. If the robot's helping 'em, they do well with recovery, but not that much better. No, there's no real big difference between whether the therapist did it or the robot did it. They need the attention and they need to be motivated. If they're motivated, I think they'll – it helps 'em. So I didn't answer your question. I'm not sure how to answer your question <laughs>.

Peter Asaro: Have you thought about other kinds of systems technologies, exoskeletons or other things for people who have lost capacities in their body?

Jim Bobrow: Yeah, exoskeletons are really hard. I don't know if you interviewed Hami Kazerooni up at UC Berkeley.

Peter Asaro: No.

Selma Sabanovic: What's the name again?

Jim Bobrow: Kazerooni. He's got – he built an exoskeleton for the – for soldiers, for military application so they can carry big backpacks. But now they're being used for – they started a company and they're selling them for paralyzed people as well. So they can help with their gait. And those are a big challenge 'cause the need to be really light and really powerful. So that's – he's using – he's – I think he's used electric motors. He's used hydraulics. He uses anything he can. But I haven't – so our – we – our arm robots are exoskeletons but they're not mobile exoskeletons. In other words, they fit around the patient's arm but it's not like they can carry 'em with 'em in their house like you might wanna do. Kazerooni's are mobile ones. They go out in the field and...

Selma Sabanovic: In working with therapists and doctors, have there ever been moments when the engineering goals, the therapeutic goals and the medical goals might come at cross-purposes?

Jim Bobrow: Yeah. I mean, I think engineers are not too cognizant about how a patient feels about the machine and they're mostly focused on the design itself and so you have to be – make sure that you say, "We don't care about the engineering performance measures," which might be, like, how fast it can move, how much force it has, how accurate it is. You have to make sure that they worry about how comfortable the patient is and comfort comes in a lotta

different ways. A lotta these interfaces between the machine and the patient have – they have to be soft enough yet firm enough to hold the patient. And those are the kinds of things that we don't teach, you know, engineers how to do. So – and also they might wanna make a machine that moves an arm past its joint limits and that's not a good thing if the machine – 'cause most of my machines go unstable when we're designing them, meaning that they don't do what they're supposed to do. They do something really bad and – which is fun. It's exciting for me. So we all – a lotta times we break stuff but we wouldn't wanna do that when we're working with patients. So we have a lotta safety measures and just all the safety measures are a big pain in the butt and it's kinda necessary for this kinda work. So that's a big problem. I mean, problem in the sense that it's not the thing that our students wanna worry about.

Selma Sabanovic: It seems also it's an interesting progression from wanting to build things that are fast and have a lot of efficiency and then now actually having to build things that people like to be in or that motivate them <laughs>.

Jim Bobrow: Yeah, that is a big change but I s – what I wanna do is have, you know, really light cool ones that people wanna be in and move fast anyways. So we're getting into other kinds of machines that might be more fun, like Wheelie – like some of these patients in wheelchairs. We're gonna try to make some that will pop wheelies so they can go upstairs and things like that in a fun way, try to get 'em engaged.

Selma Sabanovic: How old are the patients you work with? Is there an age range?

Jim Bobrow: I work on – work with all age ranges, so – exce – usually not really old ones but – less than 70 for sure.

Peter Asaro: Do you have any other good stories of catastrophic failures?

Jim Bobrow: Catastrophic failures?

Selma Sabanovic: Or awesome successes?

Jim Bobrow: <laughs>

Selma Sabanovic: <laughs>

Jim Bobrow: Well, I do remember the first year I was teaching, I had an undergraduate project where the students built a pneumatic robot and it was just a big arm and I wanted it to be big. And so the students brought their parents. It was displayed day – final, you know, graduation day and the group of 10 students brought their parents into my lab and they turned on the machine and it – and they didn't have it – the control parameters set just right and the arm just flailed up and hit the lights on the ceiling and broke the florescent lights, right down on the – on top of the parents. That's was a – one of our first fun experiences. Let's see we've had lots of – we had another student have a cable break while they were filming a commercial for Rockwell and they were – Rockwell was supporting 'em as PhD work and they were trying to show, "Well, Rockwell is supporting this," <laughs> and here he is working with this robot and a cable breaks and the robot almost hits him in the head <laughs>. But it didn't. It was okay. There was probably – there's probably a lotta others but I can't think of anything.

Peter Asaro: And the big successes?

Jim Bobrow: Well, the big successes are, I think, the gait robot, taking it up to UCLA and actually making it – hooking it up to a patient and watching the patient automatically take steps. It's a pretty big deal.

Selma Sabanovic: What was that like? People may be a little more used to the notion of robots in every day circumstances now. And even that is maybe, I would think, pretty recent. So how did people react? Was there a crowd of people that wanted to see or was anybody at all trepidatious about them having to interact with this robot?

Jim Bobrow: I think, overall, people like robot – like to interact with 'em. They think it's kind of engaging. It's, you know, kinda fun. So I don't think it's – they see it so much on TV that they're like, "Okay, a robot. Cool," you know.

Selma Sabanovic: What about the therapists and nurses? Has there ever been a discussion of whether the robots would be changing their work in positive or negative ways?

Jim Bobrow: Yeah, you know, there's always the question, "Well, are the robots gonna put me out of a job?" but it actually – if you saw the physical labor that these therapists were doing for gait rehabilitation, that's not something you'd wanna do. You'd want a machine to do it if you could and then you'd want – you could watch, you know. So it's – just changes their focus of their work from actually having to do physical work to more mental work and let the robot do the physical work. So I think, overall, it's been a positive thing for the – for everybody. I mean, robots are more expensive and are more complicated and that's the biggest downside to them.

Selma Sabanovic: Who were some of the people that you collaborate most with over your career?

Jim Bobrow: Over my career?

Selma Sabanovic: Mm-hm.

Jim Bobrow: Collaborated with a lotta people. I guess with some of the dynamics stuff that I've done for th – related to the weightlifting robots, that's been – Frank Park started. He's a Seoul National now. Steve Dubowsky I said, still work with him. He's at MIT. Worked a little with Oussama Khatib. Did you interview him or...?

Selma Sabanovic: He's actually advising us on this partly.

Jim Bobrow: Oh, yeah. Okay.

Selma Sabanovic: We will interview him, yes.

Jim Bobrow: I've worked with Mike McCarthy. He's – I share this lab with him. I mentioned Dave Reinkensmeyer. A guy in my department, Athanasios Sideris. That was the optimal control problem that we were solving. So these guys are probably not your mainstream robotics people. They're more specialized in different areas of – related to robotics. So I think that's all I can think of right now.

Selma Sabanovic: And you were a visiting professor at MIT or...?

Jim Bobrow: Yeah, yeah, yeah. That's Ste – that was Steve Dubowsky's lab.

Selma Sabanovic: Okay, and…?

Jim Bobrow: And I also worked with a couple other people at MIT.

Selma Sabanovic: And also at Stanford, right?

Jim Bobrow: Yeah, that was with Khatib, at Stanford.

Selma Sabanovic: Okay, so when did you go to Stanford/MIT. Could you tell us a little bit about the atmosphere there or who you found there, what it was like, what was different?

Jim Bobrow: No, it's fun. Well, that was – I mean, Oussama's lab is in computer science so the – there's a – more of a machine – making smart machines with, you know, more of the focus on algorithms. And I'd say they had a bigger robotics operation. So it was, you know, they had more machines and I'd say overall it was neat to hang out up there with 'em. But I'm not sure what you're...

Selma Sabanovic: I was just curious what it was like as a place to be. Who was there? How did you interact with each other?

Peter Asaro: The different research cultures between UCLA, MIT, Stanford...

Jim Bobrow: Yeah. I – I mean, I guess I've – all the places I've been at: MIT, Stanford, UCLA, here, as long as you have a core group of guys that are really interested – guys and gals that are interested in the problems that it's fun. And, you know, I like working with everybody and I learned at all those places, learned a lot. So I don't know. I'm not sure how to compare 'em. Actually, I can't compare 'em 'cause they, I mean, they have a personality that's related to the people and I – I don't go to work with somebody that's not fun. Just wan – you know, I wanna do something fun so...

Selma Sabanovic: Were they fun in different ways?

Jim Bobrow: Oh, yeah. Everyb – yes.

Selma Sabanovic: So what are the different ways <laughs>?

Jim Bobrow: Oh, no <laughs>. Well, Oussama likes sushi. Yeah, I don't know – I'm not sure how to answer that.

Selma Sabanovic: Or at least <inaudible>...

Jim Bobrow: I mean, I like to drink beer with all those people if I can <laughs>.

Peter Asaro: Over the years, where did you look for funding or gathered funding for your various projects?

Jim Bobrow: Well, I've mostly gotten funding from National Science Foundation but for the rehabilitation that's the National Institute of Health. And that has been easier for me, lately, to get funding than National Science Foundation so it's been a transition, sort of – I think NSF has backed off from funding the kinda stuff that I have done over the years and they're more into computer science type stuff. So that part is – for me has dropped off.

Selma Sabanovic: So they're lessening funding building of actual machines?

Jim Bobrow: Pardon me?

Selma Sabanovic: What have they kind of gone away from? Is it the building of...

Jim Bobrow: Well...

Selma Sabanovic: ...actual mechanisms or...?

Jim Bobrow: They never funded building of mechanisms, at least the kind o – least the proposals that I've written. They have funded, in the past, some of the mathematical aspects that I was interested in looking at. But more recently, they're not – they haven't been interested in that so the – I've noticed that it's more on computer science programming stuff that I – there's other more qualified people to do that and they haven't funded my proposals in that area. So I've been doing more of this rehabilitation stuff and there's a whole buncha problems that are still out there to be solved for this, so.

Peter Asaro: So what are, in your opinion, the big outstanding problems in your area of robotics that you'd like to see solved during the next 10 or 20 years?

Jim Bobrow: Well, I think – I mean, the biggest problem for robots is the actuators. That's – they're too heavy. They're too expensive. So it makes it so you can't design machines that will – can work with humans easily and they're too expensive. So that problem hasn't – it's always been a problem with robotics and it hasn't been solved yet. And it's – if – unless that problem gets solved, they're not gonna – robots aren't gonna evolve to the point where you see 'em on – in any of the movies that you watch. Those robots that you see in movies are strong and they're light and they look cool and the robots that we have today are never gonna be that way unless we can make the muscles strong and light. And there's lots of different actuators out there but none of 'em are strong and light. So that's the biggest challenge in my mind. I think the computational computer science aspects of robotics has come a long way and it'll still – it still has a long way to go. But it's gonna get there because computers just keep getting better and better and more powerful and cheaper and that's been a huge boost for robotics. The cost

has come down. But the machines themselves are gonna need these muscles. So if they can get 'em, then they're gonna, you know – if somebody designs a good one, then there's gonna be robots washing your dishes and doing everything you'd want 'em to do and they won't be too expensive. But if they can't, then robots are just – they're not gonna – they're gon – it's gonna be a very slow progression and they'll get smarter but they'll still be really expensive and people aren't gonna be using them in their household and stuff like that.

Selma Sabanovic: Where do you see these things being developed currently? I know in Japan it seems like they develop a lot of pneumatic systems...

Jim Bobrow: Pneumatic or – I mean, everyth – all the robotics are electric really. Pneumatics is a very small fraction of 'em.

Selma Sabanovic: Or at least some of the humanoids. I've seen that are particularly at Osaka University and some at ATR that are the crazy baby <laughs> – CB2, for example. I don't know what they're called but also there are some places in KV University that are developing different kinds of, in a sense, muscles or different types of actuators that are more, you know, biologically inspired in a sense. So where do you see these developments currently taking place, if at all?

Jim Bobrow: You know, everybody's working on 'em and none of – they all are – they all suck. Yeah, I mean, you – when I say they suck I mean that they don't have a lotta force. They take a lot of power to run 'em. They get hot. They – there's just all kinds of problems with 'em. So it – and that – and everybody realizes that actuators are important so they try different things but, so far, the best ones are electric motors. They're, you know – if you look at any of the commercial machines out there, they've got good electric motors and they're also really expensive. You know, 'cause motors themselves have a certain amount of copper in 'em and magnets in 'em and they need power amplifiers and all that stuff. So, yeah, there's lots of people trying different things, biologically inspired ones. But so far, I haven't seen anything that's gonna work, that's gonna really be the – I mean, if I play with my cat and I watch my cat jump up, you know, five feet, that – my cat's actuators are just beyond belief compared to what's out there for robots. So – and then there's people that try – actually trying to take muscles from animals and turn 'em into actuators for robots but that doesn't work too well because you need to – you know, nutrients for the muscles. Keep supplying 'em. But something like that might have a chance, you know, of some biological – a real biological muscle.

Selma Sabanovic: Have you ever worked with people internationally at all? It seems to me that robotics in the U.S. is more focused on the software side. Whereas, for example, in Japan they're very much focused on building so they build a lot of interesting mechanisms.

Jim Bobrow: Yeah, I think you're right, yeah.

Selma Sabanovic: <laughs> I'm just curious if you you've had a chance to kind of...

Jim Bobrow: No, I, you know, I don't know anybody that well in Japan so I haven't – I've worked with – Frank Park is down in Korea so he's got a pretty big lab. But it's kinda strange. You know, people tend to keep their stuff close to the vest. Is that the right way to explain? I don't know. It doesn't seem like there's that much interaction and collaboration.

Selma Sabanovic: What about at conferences? Do you find that conferences are generally more international or is there still, in a sense, segregation among things that are very popular with perhaps one group?

Jim Bobrow: Well, every – it is a little bit of competition between all the researchers. They're all trying to get their papers published and get their work funded and perhaps start a company. So I think, you know, in general – I don't think – I think that there's always isolated groups and so for me it's more fun to sorta have a open dialog about ideas but not everybody is that way. So I don't – and I don't think one – I don't think Japan is more close-minded about it than China or anywhere else and the robotics conferences are big international conferences and they're a lotta fun overall.

Selma Sabanovic: Where you trying to cha-- I was just curious...

Jim Bobrow: And...

Selma Sabanovic: ...about what is like work with...?

Jim Bobrow: But I can say that – like, for example, for the pneumatic robots, when people realized that I could make these relatively cheap machines that are pretty accurate, there was interest and there still is today. And this one venture capital firm created a business plan. They would hire 10 engineers and a whole salesforce. I would be the – sort of the technical leader but they'd also have a business leader. So they had a business plan. They had – this was 10 years ago. They had $20 million that they figured they could get and they wanted me to sort of lead this operation from the technical side and I was supposed to do that while I'm in the university. And in the end, they said I'd get 5 percent of this company and they expect it go from $20 million investment to $200 million and then I'd have 5 percent of $200 million. But it – that sounds great but it would take a huge – it would've taken a huge amount of work for me to try to push that along and I just wasn't – I didn't believe enough that they would meet the goals of the business plan and it didn't seem like, you know, 5 percent of this whole effort was

that big of a reward because if they didn't meet the goals, I wouldn't get anything. So it seemed like – even if they only partially met the goals, then I wouldn't get anything. So there's – they all basically, these venture capital guys, are not called – they're nickname is vulture capitalists and it's for very good reason. They basically want your company and if you don't meet the goals, the milestones that they put in the business plan, then they could basically take whatever your investment is and dilute it down to nothing. So, to me, I'd rather teach my classes and do – work on my projects and...

Peter Asaro: So in terms of students and <inaudible> energy, what's your recommendation for young people who are interested in a career in robotics and how should they go about it?

Jim Bobrow: How should they go about it?

Peter Asaro: Yeah.

Jim Bobrow: That's a good question and I don't know the answer to it <laughs>. I don't – there's not too many companies in the U.S. that are hiring in robotics. There's not that many companies. So there's a lotta things related to robotics and automation and some companies are – they have specialize applications, medical industries and things like that that might hire these students. So they...

Peter Asaro: What do you recommend that they study in order to...

Jim Bobrow: Well, they need to – for robotics – that's what's cool about robotics is that you get to do mechanical engineering, computer science, electrical engineering. You get to do all of it. And they need to learn those fields and it's challenging for students because usually you focus in just one of those three things. But for robotics it's a general field, then you need to do a good job at all of them. So I tell them to be as general as they can, learn as much as they can in all these areas and I think there's a demand for any student that can sort of put together concepts from electrical engineering, mechanical engineering and computer science. Not just for robotics for automation in general.

Peter Asaro: What would you say are the growth areas for robotics in the future?

Jim Bobrow: I think household robotics is a big deal and medical robotics, both of those things. But, you know, like I said, it's gonna take cheaper, more accurate machines and right now the limitation is the actuators and it has been that way for a long time. But I believe that, even with electric motors, they're getting to be cheaper and so I think any household robotics in general

are – they're getting to be a bigger deal and so are medical robots. We're building our own medical robots and – think that's gonna continue that way.

Selma Sabanovic: Great...

Peter Asaro: Okay, thank you very much.

Selma Sabanovic: ...thank you.

Jim Bobrow: You're welcome.