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Sabine Hauert

IEEE RAS Interviews

Q1: It would be great if we could start with your name. And then if you want to tell us a little bit about your early days experiences, where you were born, your family, kind of early schooling until you get into robotics.

Sabine Hauert: I'm Sabine Hauert. I'm Professor of Swarm Engineering at the University of Bristol in the UK. I've had a fun journey into robotics. I was born in the US and lived there for 10 years and then moved to Switzerland. And in Switzerland, very early on, you had to choose if you were going to do a more scientific career or a more language career. So I was one of the few girls, actually, in my class who chose to do a more scientific career. And that just meant we had more maths as we were studying all the way up until the end of high school. And then at that point, you have to choose where are you going to go after high school. And so we had a really nice university in Switzerland called EPFL. And I was looking at all the subjects. And amongst the subjects, the one that got me excited was computer science. They all sounded excited. Actually, I was trying to pick the only one that didn't have chemistry. For some reason, I didn't like chemistry and computer science. I didn't have any chemistry in the curriculum. And so I went for computer science. And then throughout the studies in computer science, that's really where I got excited about robotics because we had a wonderful class by Dario Floriano that was called Bio-inspired AI. And that's really what piqued my interest.

Q1: And did you have, as you were kind of exploring your interest in the sciences, did you have any prior exposure to robots? What was the first time you became aware of robotics as thing? Was it in class? Did you have any other experiences?

Sabine Hauert: My early exposure to robotics was mostly computer science and programming. So when I was in secondary school, we learned very basic programming, which is, in fact, called basic. And we can make little games of things like that. I thought it was quite fun to implement something and to immediately see the results of that implementation, even though it was just on screen. And then really, the robotics only kicked in at university level. It felt quite new, actually, at the time that people were going and programming robots. And what I was lucky to do at Bio-inspired AI was to really see all the different ways in which biology can inspire new designs of robots. And that got me excited about going on a master's exchange year. So I actually applied for a bursary to go to Carnegie Mellon University. And I spent one year over there. And they had so many robots. And for one year, I joined a competition called RoboCup that made robots to do robot football. That was with Manuel de Bellusa's team. And really, we'd spend time in that basement just programming the robot dogs to go and kick balls and then compete in the US championship. And I thought, goodness, robots in the future will need to work together in really smart ways, just like those robots on the football field were coordinating so well. And so based on that excitement for robotics, I came back to EPFL with Dario Floriano. I did a PhD then on swarms of flying robots.

Q1: So what were some of your first research projects in robotics?

Sabine Hauert: My first projects were really around swarms. It's always been about how do you coordinate multiple robots. So my master's dissertation and PhD project were looking at a swarm of flying robots. We had quite small ones that were actually-- they were built in-house. It was quite new to have these fully autonomous drones at the time. And I was interested in how they could be used for search and rescue. And so the whole project was, if you're in an environment, there's been a disaster. Communication has been knocked down. Can you send these flying robots so that they autonomously cover the area? And that can then serve as a communication relay for the rescuers of the victims on the ground so they can send messages through those drones to each other. And so we had all these interesting questions like, "OK, if there's no GPS, how do the robots coordinate?" Oh, well, let's use communication a little bit like a leash so that they always stay connected. And then we're like, how do we discover these swarm algorithms? Because that's one of the big puzzles we need to crack in my area, swarm engineering. And so we thought, well, let's use artificial evolution. But again, this bio-inspiration automatically discovered controllers. And so my master's was that, was automatic evolution of controllers for swarms of robots to create these relays. And it was just the early stages. And then that led to a full PhD project. So I did that for the next four years, all the way to the point of being able to go to farm fields. We'd drive over to farm fields. We had an authorization to do experiments on a kilometer by kilometer farm field in Switzerland. And I would sit there, throw my robots in the air, also with my colleagues who designed them, and watch them flock or watch them swarm. And we had 10 of them in the air, which was really quite novel at the time.

Q1: What were some of the particular typical challenges that you were interested in, also taking things into the field? So it seems like it would be quite a different experience to have them in a more controlled environment and then out there in the elements.

Sabine Hauert: The technical challenges were both algorithmic. So what algorithms allow these robots, when you throw them in the air, to coordinate efficiently? And in the world of swarming, that's quite a challenge, because everything is decentralized. The way it works is that every robot has a series of simple rules. They react to the local world around them. And if every robot within that swarm does that, you get beautiful emergent properties or self-organization that emerges from them. And you want those properties to be useful for a task. So for example, when we were doing exploration of environments, creating communication networks, we always had to figure out what the individual does, its local interactions, so that we get those desired collective behaviors.

So the bulk of my work was trying to crack that puzzle, those algorithms. But then the fun thing is when you try to put things in reality, it really grounds things. You can't go nuts with your controller. It needs to be something that you can put on a flying robot. And so because we were doing evolution at the time of neural controllers, those are black boxes. And we weren't quite comfortable putting that on a flying robot. And so we also spent some time learning from

what learning taught us from the evolutionary algorithms to reverse engineer the controllers. So we understood them really well. And then we could put them on the flying robots. And so once we were comfortable with that, the question is how do you get them on flying robots? And so I had a wonderful colleague, INAUDIBLE, who designed the robots at the low level. If you tell it to go in this direction, it will go in this direction. It will adjust its speed, all that technical stuff. And I was living in a much more high level, algorithmic level. How do the robots communicate and coordinate?

But getting it to work takes a couple of years to get one to work reliably. And once you get one to work reliably, two to work reliably. And when you get two to work reliably, you start realizing you can't micromanage your robots. So you need to trust them. And you need to make sure they're doing the right thing when you send them in the air. And so then you have to get three in the air. And that leap really from two to three is when you need to have real confidence in your system. And so the challenge in getting into the field is what are all the safety mechanisms? So if GPS drops, your robots don't just crash. Or if one of them has a bad algorithm and flies away, or worse, 10 of them do that, how do you make sure that they don't escape a box, that you're comfortable experimenting within your environment? And so we had all these safety mechanisms that we had to learn on the go, usually because we made a mistake. We were like, whoops, the robots aren't quite doing what we were expecting. And then it works. And then you can do 10. And actually, I think it was quite unique. I'm not a pilot, my colleagues were. At least the drone pilots, also real pilots. That's another story. And I could go in the field pretty much by myself at the time, because we had this authorization, and throw lots of flying robots in the air, and they would work autonomously, and I would have confidence that they would come back and land at the end of the experiments. So it takes a lot of working together, really.

Q1: So you mentioned working with colleagues that were pilots and colleagues that were building the hardware. What kind of collaborations would you typically have in one of these projects?

Sabine Hauert: Swarm engineering is very cross-disciplinary. First, there's the bio-inspiration. So sometimes we work with biologists. In my current research, we work with people who study ants, or we might work with people who study fish or birds to understand the inspiration, or actually cell biologists, because those are beautiful small behaviors as well. So the biology side is really important. And then there's the algorithmic side. So how do you go about designing these programs? So there's machine learning, there's computer science, and then there's the hardware, because what we're discovering is, as we design our robots, we build all sorts of robots within my current laboratory, is that you need to build lots of them. You need these special capabilities that allow them to interact really nicely. And so we always end up designing new hardware that works for our swarm questions. And so that requires people who can do hardware, who can build robots. But what I've also learned is that you can learn all of these different skills. And so we have people who haven't designed hardware to start out, who design our great robots.

And so I think it's also very flexible. And increasingly, we're doing much more work with social scientists and human factors, because now that we're reaching a stage where I personally feel swarms are ready to enter these real world applications, we need to understand how humans will interact with them, how they'll be the operators of these systems, how they'll be the users of these systems, how they'll encounter them in their daily environments. Because if you have robots everywhere, if you have swarms everywhere, what does that look like? Is that something people want? Or maybe that's not the right use of these robots.

Q1: So can you tell us a little about how your research developed after your PhD, after the one by one kilometer of space experiment?

Sabine Hauert: During my PhD, it was fun to have 10 flying robots in the air, and we were really excited about that. I mean, I had loads of fun doing my project, but I thought 10 was not enough. And so I spent the last year of my PhD studying cancer research and nano medicine, and realizing that, at those tiny scales, you could scale up the numbers. And so in the field of nano medicine, they were looking at injections with 10 to the power 13 nanoparticles for cancer treatment, because these nanoparticles, because of their size, are interesting vehicles to deliver drugs or diagnostics to tumors. And so I emailed a professor at MIT, Sankeetavaty INAUDIBLE, and I was like, "Hey, I do swarms of drones. Can I come do swarms of nanoparticles in your wet lab?" And she didn't answer right away. I sent a little reminder, basically saying, "Hey, I'll be in Boston." Which wasn't quite true. I was in Alaska for a conference, but it was somewhere on the way. And she's like, "Okay, come to the lab." And I gave a talk, and then I ended up talking to lots of people in her lab, and she gave me a chance, basically. And I secured a grant called the Human Frontier Science Program Fellowship for cross-disciplinary research. And they basically let you do this wacky stuff.

And so I spent three years in a laboratory that does nanomedicine, learning both how these nanoparticles work, how we can't program them in the same way as the flying robots that I was throwing in the air. So we needed to figure out how to control them. And how you do that is by changing the design of the particle, its size, its shape, its coding, its material, what you load it with, and all of these knobs that you can turn on the design of the nanoparticle. When you inject 10 to the power 13, that's going to change how they move to the tumor, how they penetrate a tumor tissue, where they accumulate in the cells. And so I spent quite some time both understanding the particles and then simulating these complex tumor tissues to understand what the collective behavior of the nanoparticles would be. And then again, applying evolutionary algorithms. So the same tools is for the drones to automatically turn the knob on the design of those particles so that they would do what we wanted them to do in that context. And also learning how to do chemistry. So it's funny, that whole, I don't want to do chemistry, I'm going to do computer sciences. I needed to go back and then relearn chemistry because I hadn't done that at university so that I could at least do the mixes and do some basic sort of bench top chemistry so that I could try some of my models in reality.

Q1: So when you are kind of designing, controlling nanoparticles, do you think of them as a kind of robot in some sense? Or do you see those two things as separate? And really it's the swarming and the kind of coordinated collective behavior that brings them together.

Sabine Hauert: What I've discovered with the nanoparticles is that you can, what I've discovered with the nanoparticles is depending on how you design them, these particles can sense their environment through their surfaces, for example. They can act on their environment by releasing something in the environment like a chemical or heat. And they can then use that to interact with another nanoparticle, so they can have forms of communication based on those release mechanisms. So those are a lot of the things that we have within the swarm robotics world that I was using for my swarm algorithms. Now what's challenging with nanoparticles is you can't tell them to go left or right like my flying robots. But you can tell them to speed up or slow down by having them self-assemble and disassemble which makes them bigger or smaller, then changes their dynamics. So they have a lot of the things that we have in the robotics world. The only difference is the way we control the robots is we preset a program and then they react to their environment, they communicate, they sense. And in the case of nanoparticles, it's how you invent that intelligence in the design of a nanoparticle. So is it a robot or not? That's a constant discussion but I feel, in terms of what it allows you to do, a lot of the mechanisms are there. And actually in some of the reviews we've done in nanomedicine, there's really clever behaviors that behave a little bit like the robots that we have where they recruit each other to a site of a tumor so they can amplify delivery, they can synchronize like fireflies do, and that we've used for inspiration at swarm robotics. And I personally think a lot of the algorithms, and I have simulations of this, could do consensus formation. So decision-making but in a chemical way, not in a programmable way.

Q1: So can you tell us a little bit more about the main questions that are driving your work and any other projects that you wanna bring up?

Sabine Hauert: For the past 10 years, I have my own laboratory, University of Bristol, and we do swarming across scales. So from nano-medicine for cancer treatment to cellular-sized systems, looking at how we control swarms of skin, for example, to help in the wound healing process, or with my colleagues in synthetic biology to design de novo swarm behaviors based on these engineered bacteria, for example. And then at the larger scales, we're really keen on robots for people. So I think what we've discovered is over the past 20 years, we figured out how to design many of these algorithms. We know how to design lots of types of robot hardware now. And the push is how do we get these out into reality? And so at the larger robot scales, we work both conceptually with kilobots. So we have a thousand of these quite sized robots. And that still helps us explore the science of swarm robotics in large numbers, but we have more implied platforms too. So we've designed a big platform, it's not big, it's called the DOTS. And those

ones are sort of the state of the art swarm system for logistics, and those have high spec perception, they have a lot of computation, they have the ability to better receive the local world around them so that we can start to think about if our robots are more capable, and it understands the world around it, how can it do swarming in a more realistic setting?

We also work with big drones. So we currently have a project that's looking at how can we find wildfires over huge areas, for example, the size of the state of California and the drones and the company, INAUDIBLE, their robot is a 10 meter width spanned robot that can travel a thousand kilometers and carry a hundred kilos. And so that allows you to actually do 24-7 monitoring with not a huge number of drones to find these fires before they go out of control. And because they have a payload, you can drop an extinguishing payload. We have other robots that are like screens on wheels, we have a hundred of them that we use to interact in social settings, in crowds to help crowds think about climate change or just to do education, puzzles, all sorts of fun things with those platforms. And yeah, and anything, really, where robots could be useful. We actually feed back to biologists too. So we have this really cool project, called Human Frontier Science Program, looking at swarms to monitor basket sharks. And so we were recently in Ireland with these robots with underwater imaging things that we can better understand. And so anything where robots work in large numbers, but across scale and how do we get them out to people?

Q1: So in your experience, you've mentioned a number of application areas where you find these swarms might be helpful. Are there any areas that you've found where you realize like it seems like they're not the answer or it's not appropriate to use swarms?

Sabine Hauert: Swarms makes sense in messy environments, in places where you need decentralization, where you need scalability, the ability to increase or remove robots, depending on the demand. And where you need a bit of robustness and adaptability. So we have this example, it's a toy scenario that we used to sort of compare what a decentralized swarm approach can do and what a more centralized approach can do. And I'll walk you through that because I think it helps understand where these systems are useful. So it's a cloakroom. So you go to a conference and everyone brings their suitcase or their jacket and they need to leave their items in a cloakroom. If you were to do this in a more classical centralized way, what you would do as the operator of the swarm cloakroom or the robot cloakroom is that you would arrive and you would map the environment, and then you'd put a central computer and then people would arrive with their jacket to that central computer. And then they would say, okay, pick up my jacket. And that central computer would say, robot 324, follow this trajectory, pick up this jacket, follow this trajectory again, store it in this location and that will end up in a database. And at the end of the day, you would come back and you would request your jacket from that central computer and the same thing would happen again. That required a map. It required communication. It requires that central computer to always be working and that database needs to be up to date. So if someone moved your item, you won't be able to find it at the end of the day. That's a centralized approach where basically a central system controls or coordinates all the robots.

In a swarm approach, in a decentralized approach, the way you'd use it is that you'd put a line on the floor and then you'd take your robots out of the box, however many you think is useful, and people would arrive with a Bluetooth app at the edge and say, I've got a jacket. And any robot would come, pick up their jacket and drop it off anywhere in the cloakroom environment. And at the end of the day, you'd come back with your Bluetooth app somewhere along the cloakroom and say, has anyone seen my jacket? And there's enough robots to look around that the nearest one to your jacket finds it and brings it back to you. In that setup, there's no map, there's no central computer, there's actually no global communication in that system. And if you wanted to pick up the jacket yourself, that would be fine, there's no database. It's always real-time lookup. But it works in this out-of-the-box, messy environment without all the infrastructure. And so if you're a big company like Amazon, do a centralized, perfect system because you can invest in the infrastructure, you can really perfect the performance. But if you're looking at how you deploy in all these areas where we don't see robots yet, that's where I'm hoping swarms can shine because their whole thing is to react to the environment, and to build up from there.

Q1: As you mentioned, kind of developing robots yourself, have there been technologies or other kinds of developments, not from your lab, but from the outside, that have kind of transformed your work or made things easier or opened up a new area of potential exploration?

Sabine Hauert: We build our robots using off-the-shelf components. So every time hardware progresses, that helps us build robots. Every time the price goes down, that helps us build robots because we're thinking of hundreds, thousands of these robots. And so that matters when you're thinking of those scales. So, you know, raspberry pie, it's really easy to get cameras. Now we have GPUs on boards, lots of CPUs on boards, our robots, laser scanners. So we just have so much more perception and computation that we didn't have in the platforms just five, six years ago because that's all readily available to us. So that's a real piece of progress.

Now, what I'm excited about, and we haven't quite tapped into that yet, is the improvements in perception due to advances in AI. So up until now, we had all these toy scenarios in the lab and we didn't need that good perception. We could kind of fake it, or, you know, we're trying to push a blue frisbee and so it's really easy to understand. But now I think we're having the ability to look through your vision or other systems at the local world around you and make sense enough of that, that you can react to these real-world environments. And I think for me, that's going to be the next stage in getting these systems into realities. That they have just enough perception for those local understandings and interactions that all those things we've been designing in the lab I hope will break free.

Q1: Okay, going off on a slightly different direction, we're also curious in terms of funding. How has that kind of helped guide your work? Where you mentioned a few different kinds of different tiers, grants? Like are there, what are areas in which you can kind of find funding for this both interdisciplinary and novel exploration?

Sabine Hauert: Being cross-disciplinary is both a blessing and a curse in the grant world. So what's wonderful by being cross-disciplinary is you can tap into many types of funding. So for example, Human Frontier Science Program funded two of our projects that really had more of a biological component. So that really allowed to get outside of the box of what we usually do. European projects have been wonderful in pushing the frontier of what we can do from a research theoretical perspective. So now we have a real fun project on emerging awareness for minimal collectives. And so we're thinking about how do these collectives become more aware of their behavior so that they are better at doing their behaviors, but also can communicate that to the outside world by saying, you know, we're aware of the tasks that we're doing and we're trying to do it better. This is information you need. And that could also allow robots that are heterogeneous or systems that interact with other systems to work together. And that's quite blue sky. And so that type of European project has really helped us push the envelope at what's possible.

And then because we do nanomedicine, because we do work on a more biomedical setting, we've tapped into Cancer Research UK, we've tapped into funding from the medical side, where we're really bringing that understanding of complex systems just within another context. So it takes, you know, learning the language, which is what I did when I was in Boston for three years, and then understanding how your tools are useful in other disciplines. And then finally, one other area we've had nice funding in is the more translational pipeline. So for example, working with that aerial robot company is a more translational grant to really think about how do you do swarms to fight wildfires? And so that's a different pipeline. So I think you need to know how it works and what funds what, and just try it. Just keep trying and trying and trying, and then some come through, which is really fun.

Q1: Are there any kinds of things, challenges or things you've wanted to explore, but you haven't been able to, and kind of what's the challenge or barrier to that?

Sabine Hauert: There's loads to explore. So that's one of the challenges, is there's always new ideas, and especially as we write these grants, they don't all get funded, but they still are there, and there are new ideas and things we want to explore. So there's two frontiers, I'd say, that I'm really excited about. One, as I said, is getting these swarms into reality. And so what we're learning is that we need to understand how to make them more trustworthy or worthy of trust, or understanding how do we actually deploy a system in a way that's maybe verifiable, and that we can validate a little bit like an airplane, but not like an airplane, because they have emergent properties, and so we have a whole different set of challenges. And to get them into reality, I'd love to have more living labs where we can try that. So my neighborhood is actually on board with me trying our logistics robots for hand-to-hand delivery within that setting. There's around 400 households. But are we allowed to do that? How do we do that? And so those are questions that I'd like to see more of, because that opens up a whole suite of questions about how you design these systems in reality.

And then there's the really futuristic, what do swarms look like in the future? Are they biodegradable? So we actually have this whole compass system to try biodegradable swarm materials that would jump around just to see how do we make new materials with these very large-scale deployments in a way that's more sustainable? And how does that interface maybe with new technologies like engineering biology or synthetic biology, so that we make the best of the biological world and the robotics world so that we can do some of these interesting deployments and maybe discover new ways in which systems, the micro and the nanoscale, can coordinate in smarter ways. I think we have instilled intelligence at those scales, and the same with the robotics scale. So yeah, I'm interested in the fundamental and the translation, which is sometimes a juggling act, but I think you can't get really fun translation if you haven't explored some of the fundamentals.

Q1: And that also kind of points to potential societal impact of the work. And so when I looked at your website, one of the things I noticed is that you are also interested in kind of communicating science to the public. And so I was wondering if you could tell us a little bit about that aspect of your work and also how do you see the societal, how does societal impact kind of play a role in your research?

Sabine Hauert: There's two aspects to this. One is that, from my research perspective, we really need to understand how to deploy swarms in a responsible way and understand what people want to see from these systems. And so we've done quite a few use case studies now. So I was talking about the firefighting robots. We spoke to 50 firefighters across the world to understand would they want to be swarm operators? What is it they value? Didn't we learn, for example, that they would love to have the search, they would love to have information once the fire is found, but they are the experts in firefighting. So they want to say how that fire gets extinguished. So that type of insight on what people care about and what parts they need support in are really areas that are interesting to us. And we've done use case study in logistics, infrastructure monitoring. And I'm learning that it's not just use case studies that almost comes further down the line. Once you've developed a technology, you're really trying to test it. But I'm also part of the ESRC Center for Socio-Digital Futures. And I lead the robotics portfolio there, and it's mainly social scientists. And they've really taught me that it's a much earlier level at which we need to engage with communities to understand what would be useful, even before mentioning robots, to understand if there's a need and whether those needs can be met by sometimes non-technology and sometimes robots can play a role in that.

And so that better integration of social scientists and technologies is very important as well as the ethics around it. So how do you make safe swarms? That's a question we've also been exploring, for example, within that field. Then on the communication side, I lead, and I'm executive trustee of a charity called the Association for the Understanding of Artificial Intelligence. And we have to make websites, aihub.org and robohub.org, and we've been building these for the past 15 years. And it's driven by our desire to communicate robotics and AI to a general public. And, really, what we've realized is that researchers have the knowledge about how this technology works. They're the ones who know in what direction it's going. And it's really important for us researchers to spread the word about what we're doing, but also to

listen. Listen, so it's not just broadcast, but to hear what people want from the technology as well. And there's a reason that doesn't necessarily happen. One is that many researchers don't know how to communicate their research. Very often they don't have time, we're all very busy. And then even if they communicate, they're a little blip, right? And so they don't have a common portal by which to communicate. And so what we've been trying to do is address those three challenges by doing science communication training, editorial support to help them shape their message, and also to make it easy for them to communicate, and then to provide them with a common website so that gets more visibility when they finally have something to say. And really, it's not just because we should be doing it. When we did a study with the Royal Society, most of the news people get about robotics AI. It's from mainstream media and usually science fiction, which is not quite a good portrayal, or a correct portrayal of the way this technology is going. And so I think we need to have more meaningful conversations by communicating with them.

Q1: Have you had any kind of feedback in terms of these new loads of communication that you're trying to help scientists find either from the scientists or from the public about how, you know, is it improving communication, are people getting a different perspective on robotics, maybe a richer understanding of what's possible?

Sabine Hauert: It needs a lot of work to break into the mainstream. So I think what we're learning as well is, when you have this thing to say, how do you reach mainstream media so that it has that impact in terms of reaching people. In the conversations that we have with the science communicators, with the roboticists, often it helps them improve their messaging. And that could be useful just to get their word out to the public, but it also helps them with future groundbreaking, it helps them shape their ideas. So it does a lot more for them than just, you should go out and communicate to the public. So there's an added benefit to learning how to communicate. And for the public, every time we do an outreach event, every time we write an article or a blog post, it's much more grounded, and then we can have meaningful conversations. So we've done really nice use case studies with the Royal Society, and we were in these small group discussions and we were asking them about machine learning in that context. It was a few years ago. And we didn't go in saying, "what do you think of machine learning?," because that is so broad, and then that brings in all the science fiction and all the things you were thinking sort of on the top of your head. But we were like, okay, an education, do you think this could be useful? Oh, you're a doctor, how do you think this could be used in a clinical setting? And it just made things very grounded and very real. And so I think we're missing a little bit more of that realness, again, these systems for people so that it becomes more tractable and probably what we need is more robots in everyday environments. And that's how we're gonna move the dial in terms of people's understanding and perception of these systems.

Q1: So you've talked a little bit about kind of how you've experienced those shifts in robotics. When you think of the field maybe as a broader whole, what do you think are some of the main changes that you've seen in your career? And what do you think are some exciting opportunities that are around the near corner?

Sabine Hauert: It's quite a fun time to be in robotics. We're seeing breakthroughs at the individual robot scale. I feel like robots have gotten quite good. And usually the fancy robots where people are, they see them, they're like, wow, that's doing an amazing thing. Usually it's a single robot system. And so it's quite a fun time for swarm roboticists or multi robots systems to really think about, what's the end number of robots deployed and how do they work together? So for me, that's an opportunity, is taking all these breakthroughs that we've had at the individual robot level at the intelligence level that we're seeing now and thinking about, okay, that enables us now to think of large scale deployments because these robots are working individually. And so we need to scale up for many applications. Most applications, they have to do with scale, like large scale agriculture, construction, large scale environmental monitoring, logistics at local city scale, but also at larger scales. All of those are questions that rely on many robots to work together. And there's a reason we don't quite see them other than in controlled environments. It's because we haven't made that jump from single to multi. And so for me, that's the excitement right now.

Q1: Great. So we often ask this as well, just thinking about students, and folks who might be interested in getting into robotics, what kinds of things would we recommend or what are the things they should know, things they should consider, how do they approach the field?

Sabine Hauert: I've been very lucky to just follow my passion and it's worked. I don't know if that is always the case, but I've always gone for interesting questions that felt like they were at the frontier, that felt like they weren't going to be an application anytime soon. For example, the flying robots early in my PhD and five years down the road, companies everywhere doing flying robots. And so I think first of all, it's worth thinking about the next frontier, but the next frontier is not that far. Actually, if you start working on it to be part of that journey of making these next frontiers happen. And then sometimes what I get is PhD students will have done a blue sky project or they'll have done a post-doc in a blue sky area and actually they want to go into industry or they want to do something else than academia. And then my advice is to find someone who has the job that you want and talk to them. Because at that stage, sometimes they'll tell me, I want to do art and robots and medicine or something that's a beautiful combination that goodness I would love to, and actually that I get to do within my research world, academic world, but they want to find that job elsewhere and sometimes that doesn't exist. So I think it's also a lot about networking with all the amazing people who have really fun and interesting jobs to understand what the other opportunities are. That if it's not about academia, there aren't other areas that are just as exciting.

Q1: Wonderful. Thank you for sharing all of that. Is there something that you want to have as part of this that we haven't covered? Anything that you want mentioned but haven't we haven't mentioned?

Sabine Hauert: No, I think that's good. Thank you.

Q1: Okay!