Makers of Pervasive Systems and Crafts

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***Abstract*—We recently had the pleasure of interviewing researchers in electronics and materials for pervasive systems, as well as researchers, practitioners, and digital tool builders in crafts such as music and food. We have separated the conversations into two interview digests. The first highlights important topics for future research in pervasive systems and provides guidance for new investigators and entrepreneurs interested in the area. The second focuses on the interaction between crafts and new pervasive technologies to discover the ways technology is amplifying tradition or helping to create new hybrid crafts—crafts that combine the physical and digital.**

PERVASIVE COMPUTING SYSTEMS

Here, we present an interview digest from conversations with researchers across various aspects related to making pervasive computing systems. We aim to highlight important topics for future research as well as guide new investigators and entrepreneurs in finding their way to make pervasive systems.

Professional Beginnings and Motivations

JS: I have been fascinated about new materials for computer interfaces. I came to learn that these materials offer very interesting characteristics: their rich haptic properties, visual properties, and aesthetics. It is so much richer and more expressive than the typical materials that we commonly use in computer devices, which is essentially a touch device, at least a planar display made of glass, rectangular, and rigid. And if we compare it to the richness of the real world, we see that there is so much more we can offer and integrate with computing, to make use of our senses, physical manipulation skills, and, as well, the way we as human beings interact with the real world. The idea is to break out of the box of conventional form factor and materials of computing devices, to seamlessly integrate computing with the richness of the real world that surrounds us.

JV: I am a hardware engineer who develops and designs technologies for constructing electronics—electronics assembly and electronic circuits specifically. Best known today are rigid and flat polymer boards with component interconnections made of copper tracks. In this era of the

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Pervasive Computing Systems: The Investigators

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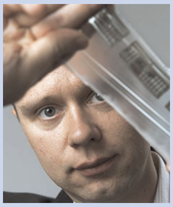
Jan Vanfleteren (JV) is a principal member of the technical staff of the Center for Microsystems Technology (CMST) of IMEC, based in Leuven, Belgium, and a part-time Professor with Ghent University, Belgium. Jan received the Ph.D. degree in electronic engineering from Ghent University in 1987. He develops novel interconnection, assembly, and polymer microsystem technologies, especially for wearable and implantable electronics, biomedical, microfluidics, cell culturing, and tissue engineering applications. He is the coauthor of more than 200 papers in international journals and conferences and holds more than 20 patents and patent applications (for more, see: https://www.cmst.be/staff/jvf.html).



Matti Mäntysalo (MM) is a Professor of Electronics at Tampere University, Finland, where he works in the Laboratory for Future Electronics (https://research.tuni.fi/lfe). Previously, he was a Visiting Scientist at KTH Royal Institute of Technology, Stockholm, Sweden. Prof. Mäntysalo was a recipient of the Academy Research Fellow Grant from the Academy of Finland in 2015. His current research interests include printed electronics materials, fabrication processes, stretchable electronics, sensors, and the integration of printed electronics with silicon-based technology (hybrid systems).

Benjamin C. K. Tee (BT) is the President's Assistant Professor and National Research Foundation Fellow and leads the Sensors AI Systems Labs. He is a prolific inventor with over 15 patents filed and several being licensed. Numerous prestigious international awards recognize his contributions, including the World Economic Forum Young Scientist of the Year in 2019, the Singapore Young Scientist Award in 2016, and the MIT TR35 Innovators Under 35 Award in 2015. He believes in a cross-disciplinary and design thinking approach to tackle grand research and technological challenges (for more, see: http://www.benjamintee.com)

Internet of Things, in many cases, these large printed circuit boards (PCBs) do not fulfill the requirements, for example, consider comfort. You do not want to carry around rigid and flat PCBs. And so, we look at ways to change these stalwart technologies into something that is more suitable for implantable, wearable, portable circuits. Thus, you go from rigid to flexible electronics, where substrates can be bent. The main technology is well-established already: It consists of a polyimide substrate, again with the copper tracks, on which you can solder components. The copper, which is normally etched away to form the pattern, can be replaced by printed conductors. So, you start from a plastic substrate and apply screen printing or technologies from newspaper printing, for example, offset printing.

MM: I came into printed electronics during my Ph.D., looking for ways to miniaturize electronics by printing. And then, during my postdoc at KTH, we were able to implement a new project on health sensors. There are wearable electronics today, but when we started, many wearables were still rigid and bulky devices. Flexible electronics has a huge potential for wearables, and when we looked deeper into alternative materials, we found that we can even do stretchable electronics. And that is, I think, the most interesting thing. Human skin is stretchable and soft. So, this is the one reason why printed electronics fits really nicely in the context of wearables.

BT: I joined Stanford University and found Professor Zhenan Bao's group. She was one of the early pioneers in the field of organic electronics. I thought, "Oh, this is interesting. Now, if we can make devices sensitive to the environment, we can make them intelligent," right? If you think about human intelligence, we become intelligent because we can perceive the world at a very high resolution. So I started working on skin-like devices. I see my work as a convergence of different disciplines. So, more specifically, I think I am on the intersection of materials science, as well as computer and electronic engineering, to create new forms of sensitive computers and human–machine interactions.

> Healthcare costs are continuously increasing, and we want to provide even better healthcare with lower cost than what is possible today.

Current Technology Opportunities

JS: The human body is not homogeneous. It is not planar. It is not rectangular. It has, on the contrary, an irregular geometry, varying elasticity, and varying sensitivity. And this, in turn, could at first be seen as a disadvantage. But quite the contrary, you notice that this offers interesting affordances for interaction. So, for instance, we can make productive use of what we call body landmarks; these are tactile cues and visual cues that are present on the human skin. What drives us here is to ease interaction—to make interaction more expressive and more human-like, and at the same time, to make interaction more mobile. The benefit of using skin rather than a classical rigid wearable device is that, first, we can make use of a soft malleable surface: the human body's skin that is always with us. This allows us to interact in more economical ways.

MM: For wearables, there are several application domains. For example, glasses or smart watches, but those are still rigid devices. If you could fabricate on a soft substrate that can take any form, then you could integrate electronics on textiles. And the next step is small temporary tattoos, which are easy to attach and to use to measure vital signs. Healthcare costs are continuously increasing, and we want to provide even better healthcare with lower cost than what is possible today. We need reliable data from patients 24/7. Printed electronics and flexible hybrid systems are the technology that can achieve sensing and computing at low cost. For example, we collaborated with an innovation center in India and other colleagues to build a monitoring device for respiration rate, activity, and 3-channel ECG. The basic idea was to measure vital signs, wherever people can connect to the Internet via mobile phone. The data were collected and analyzed for patients and doctors to make decisions going forward. However, at the moment, printed electronics is not ready for making a huge computational circuits: transistors made by printing are not performing as well as their silicon counterparts, so we are not competing with those. Whenever we need computing, we rely on silicon. Thus, there is a small part that is still rigid. But you can use technologies like direct chip bonding on the stretchable electronic substrate so that package size is minimized. This integration of the printed world and the silicon world is called a hybrid system.

BT: We are making devices that are much like rubber, but yet, when there is a cut or damage, it actually can sew itself back. So what we are trying to make are self-healing, skin-like devices that can sense the world. For example, a touch screen would be able to heal its cracks by itself, as if it were new. Self-healing touchscreens you would never have to replace again.

Prototyping and Translation to Industry

JS: Inkjet printing is a versatile technique for prototyping and uses a digital printing process. Now, our main problem with inkjet printing is that the variety of functional inks that one can use with common inkjet printers is heavily restricted. For this reason, we do a lot of our work with screen printing, which involves more manual steps and is more time-consuming. We have just finished work on how we can print many different functional materials in multiple layers, using just ordinary inkjet printers. And this will help us, and hopefully the community too, to dramatically speed up design.

MM: At the moment we see growing interest in building piloting and demo lines in different research facilities that can make printed electronics or hybrid systems. This is a really fascinating time in this industry sector. Do I believe that this will be mass manufacturable? For sure, yes. There are always laboratories or technologies that are not so scalable. But we can print fast, with the same technology that is already used to make magazines and T-shirts. We usually print functional inks on thermoplastic polyresin, which can be heat laminated on the textiles, and in a normal textile manufacturing process used to make clothes. It is really important for the industrialization of the technology that all parts can be combined and the value chain and the logistics are functioning.

JV: Fiat was one of our partners, interested in making a new glove box for the Fiat 500, where the mechanical opening knob should be replaced by a touch sensor and a lighting element inside it. So, in order to realize that, we could not use flexible electronics alone. Why? In order to make it in the industry today, you first have to make your surface on a flat substrate to be compatible with industrial standards. Then the flat surface was formed into 3D. So, we stretch the interconnections, of course, not the components, which are normally rigid parts. If it is only a flexible circuit, you can roll it like a piece of paper into a cylinder or into a cone. But it would not easily form into a spherical shape, for example. If you do that, it will wrinkle. Thus, the shapes that can be created from a flat surface, a cylinder or cone, are called developable surfaces. But to realize a spherical surface, for example, starting from a flat surface, you need not only flexibility, but you need stretchability—actual deformable surfaces.

Tools, Digital Tools, and Missing Tools

JV: When we embed circuits in a thermoplastic material, and heat and deform the polymer, and let it solidify again, we end up with a 3D-formed rigid surface. But one of the big challenges is to go through the transition: where do you put the component on the flat surface so that after deformation it ends up in the right position in this 3D surface? That is still a challenge to overcome. So, we would need a tool that can model the thermoforming process. There are some basic tools for the modeling of homogenous stacks of circuit layers, but they do not consider electrical components and deformation yet.

BT: We use computing to simulate some of the molecules and try to figure out which ones will work better, and we partner with people who have experience in dynamic molecular simulations. With molecules and polymers, the design space is very large, so computer programs that allow us to simulate interactions between atoms and molecules are important. Then, we have to actually synthesize and test new materials. We stretch them, damage them, punch holes in them, and see whether they recover. When we test these models and make them into real-life devices, then this knowledge feeds back into the simulation tools. It would be nice to have a suite of tools that can characterize soft, stretchy, and rubbery materials better, both in terms of the mechanics as well as the electronic properties. I am very interested in applying newer machine learning concepts to our material science and electronics engineering problems. We are just starting to leverage machine learning and cheap computing power to apply them in material development.

> We stretch them, damage them, punch holes in them, and see whether they recover.

JS: We do designs that relate to interaction design and to material design, for instance, stretchability or stiffness of the material, or its 3D geometry. Then, we have design aspects that come from electronics, because, after all, the sensors, displays, actuators, and circuits get embedded inside those materials. Now, in each of these areas, separately, of course, there is a tradition of design tools, and design tools do exist for all of these areas. But we bring the designs together here and this creates a big challenge. Because it means that we are currently lacking design tools that allow us to realize those types of interfaces. So, I think an important next step is to develop new principles for design tools that integrate material properties with electronic circuits. Because after all, these individual design aspects influence each other, so it is difficult or even impossible to design each of these aspects separately. We would like to make these approaches more accessible to a wider variety of users by abstracting from low-level technical details. For example, with LASEC, we abstract from the details of how a surface can be made stretchable, allowing the designer to specify the high-level properties, essentially, just how stretchable the surface should be. Using algorithms, the design is then automatically specified.

Open Challenges and Ideas

JS: The point that keeps surprising us is that many things are already possible, thanks to rapid advances in materials and fabrication technologies, such as things that a few years ago we had not even dreamed of in the HCI community. But of course, there are a couple of really hard challenges that have not been solved yet. One example is materials that are very thin and at the same time are very robust and long-lasting. We clearly see this with the skin interface. We can select from a wide range of materials, some are ultrathin. For temporary tattoos, these materials totally conform to the skin, even to the finest wrinkles, and you cannot even feel that you are wearing an interface on the body. So, this is exciting. But at the same time, given these materials are so thin, they are not very robust. The interfaces that we deploy would last for a few hours and up to one or two days. Conversely, we can go for thicker materials or stiffer materials, such as PDMS and medical-grade silicon. Those devices are much longer lasting, and we can even remove and reapply them.

> Do not be afraid to just learn and always try to do something that is more difficult than what your current abilities are.

MM: Our big dream is that we could fabricate everything by printing and we could do it on ultrathin foil that could be embedded everywhere or used as a temporary skin tattoo. It means that we need to print semiconducting material, which does not exist in large scale today. There are prototypes and some pilot lines testing this. But still it is a big dream and will probably take quite a long time to come true. But in the short term, we need to better understand materials and their performance. Hopefully, we are able to find materials in the future that are recyclable, preferably compostable. Materials like carbon or materials we find in nature, nanocellulose or something like that, and that would bring sustainable development.

JV: There is a tendency to put electronics in any material, in plastics, wherever. But you always have this problem at the end of life of the product: How do you disassemble it? It gets more difficult because the electronics are so well embedded in all kinds of materials that they are difficult to separate again. PCBs are the best example. At the end of life, you have incineration, where the PCB material is burned to get out the noble metals and all kinds of metals. But of course, PCBs are an epoxy material that when burned creates, for example, dioxin. I would like to see activity in trying to replace PCB material with something more bio- and ecofriendly so, it is at least cleanly combustible. Even better would be starting from biomaterials and a biodegradable carrier substrate.

Recommendations for Young Investigators

JS: All that is required is some interest in looking beyond the horizon of today's technologies and to get inspired and learn about what the materials community and mechanical engineering community is doing. The interesting point here is that for a wide range of applications, a commodity inkjet printer will do, alongside commercially available materials. And then you can print your own flexible or even stretchable circuits.

MM: I came from the electronics side, but used a lot of time to understand other disciplines, for example, materials, mechanics, and bioinstrumentation. My recommendation: do not play in one corner of the sandbox only. Talk to and work with experts outside of your field and boldly combine different disciplines. It will be much more rewarding.

BT: Do not be afraid to just learn and always try to do something that is more difficult than what your current abilities support. The Internet is an amazing information source, right? So, nobody can say that they are unable to learn something. One thing I do advise is always to try to be a bit uncomfortable. The more uncomfortable you are, the more likely you will learn a lot, and that is my algorithm when I make decisions.

JV: Very often we work in multidisciplinary consulting areas, together with doctors, material specialists, animal specialists, etc. So, it is very important to be open for the language that others use and to their challenges, and to understand what they need. I think that is really the future of research: its interdisciplinary and multidisciplinary collaboration.

CRAFT AND PERVASIVE TECHNOLOGIES

Music and food are traditional crafts that remain fundamental to the human experience. Here, we talk to experts in their fields to explore the interaction between these crafts and new pervasive technologies to discover the ways technology is amplifying tradition or helping to create new hybrid crafts—crafts that combine the physical and digital. All four interviewees are involved in their fields because they are passionate about the importance of the craft. They all perform the art or craft themselves, although the main focus of their participation ranges from being a master artisan who employs some digital tools (Guichon), to creating via combining digital and traditional elements together (Cavdir and Zoran), to producing digital tools to help others combine those elements (Michon).

Professional Beginnings and Motivations

AG: I always wanted to work with my hands, creating and adding value in my life. The earliest I could do it was right after graduating from school in France, when I was 14. I started first as a cook, because I knew it was an easy way to start working with my hands, but I guess I could have picked any other such craft, like woodwork. I did two years of cooking, which was interesting. However, I knew it was not what I wanted to do in my life. When I started a two-year pastry apprenticeship in Switzerland, I really fell in love with it.

Now my day-to-day job is mainly teaching and sharing with professionals in the industry my input on elaborate pastry—how to be creative and how to achieve what they would like to do with their pastry—new techniques, good recipes, textures—but also the science of pastry, which is important to me.

Also, there are two sides of me. There is the pastry side, but there is also the chocolate arts side. It adds another sense into the arts. You have the smell, the taste, the appearance, and the texture. You have most of the senses in one art. A traditional sculpture is beautiful, and with your eyes you can see it, and you can touch it, but it has no smell and no taste to it, so my work is like adding some value to the art itself.

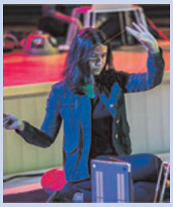
> You have the smell, the taste, the appearance, and the texture. You have most of the senses in one art.

DC: I started out playing music but ended up in engineering school with much less time to play music. Then at one point, realized that I was not enjoying that and ended up combining those two things. I was in Turkey, and there were not a lot of computer music or music technology programs. I ended up doing an internship with Xavier Serra at the Pompeu Fabra University in Barcelona about automatic vibrato detection. I thought, “Wow, this is so cool, and so different from what I do right now.” But now I do not even do research in that area and I prefer the more creative artistic aspects of computer music.

RM: I started making my own audio circuits and stuff like that when I was in Middle School, and at the time, the thing I really liked was being a DJ. That was my first vision of the field. When I arrived in college, I met Laurent Pottier, who became my Master’s thesis advisor, and he introduced me to computer music in general. And then I was, like, “Oh, it’s actually way more fun than just doing electronics or being a DJ.” Then I became oriented towards contemporary music, because that was Pottier’s background. But

Craft and Pervasive Technology: The Investigators

Doga Cavdir (DC) is a graduate student at Stanford University's Center for Computer Research in Music and Acoustics (CCRMA). She focuses on design, manufacturing, and composition for movement-based digital musical instruments and humansonic interaction. With a background in music performance, dance, and electrical engineering, Cavdir is driven to incorporate movement into instrument design and performance. For more on her background and current artistic works, see https://www.dogacavdir.com.



Romain Michon (RM) is a Lecturer and Researcher at both GRAME-CNCM, Lyon, France, and Stanford's CCRMA. His research explores hybrid lutherie, especially augmenting mobile devices to become musical instruments. His work includes musical instrument design and programming languages for digital signal processing and computer music. He created the Faust programming language and other tools to help people build mobile-device-based hybrid (physical and virtual) instruments. For more information on his work and to access the tools he has built, see https://ccrma.stanford.edu/~rmichon/.

Amit Zoran (AZ) is a Senior Lecturer at the School of Engineering and Computer Science, Hebrew University. He studies integrating craft, design, and technology, harnessing digital machines for the control and capabilities they can bring in aid of a human crafter's intentions and expressiveness. Zoran works with many crafts, including joinery and pottery, but here we interview him about his work in the area of Digital Gastronomy (http://digitalgastronomy.co/). For more on Zoran's work, see http://amitz.co/.

Amaury Guichon (AG) is likely the world's most famous pastry chef and chocolate sculptor. He is certainly the most followed on social media, and if you have not already visited his Instagram site (https://www.instagram.com/amauryguichon) you are in for a mind-blowing treat. Check out the video of his making a ship's wheel, complete with chocolate "woodwork" he makes from a 3D-printed molding process: https://www.instagram.com/p/BtwQ5jFFYJM/. He currently spends much of his time teaching others and recently published a book "The Art of Flavor" to help lead others through the process of creating his desserts.

now I would say that I am shifting back to more of what I was doing in college. There is a little bit less contemporary music in my life and most of my work is more oriented toward technology and making tools, and a little less making music.

AZ: Its almost ten years that I have been working on craft, and hybrid craft, and integration of traditional craft with digital fabrication. I care to inspire people through new concepts and designs. For me, cooking is a form of craft, and honestly, I got tired of making artwork and craftwork, and then putting it in a box or in a gallery. I was looking for some traditional creative medium that is still alive and still relevant to each of us. At the same time, I was exposed to 3D food printers and robotic chefs and so on, and it was obvious that something is starting to happen, and it is a great time to bring my knowledge about hybrid craft and hybrid design into the kitchen.

An important motivation is that food systems are currently the biggest challenge humanity has, because food systems are the major cause for our environmental crisis. Many techno-optimists believe the solution will come from technology, in the form of heavily processed food, so you can eat formulas of dry ingredients, where you get the exact nutritional value that you need, maybe based on your personal diet, and health record, and genetic record, without any waste, because you consume the exact amount you need, and the shelf-life is infinite.

I believe it will fail if it is not led by chefs. If we do not find a way to connect it to culinary tradition and our food culture, people will reject it. So, I see it as a very important challenge to convince chefs to lead this revolution, and the way to convince them is not by telling them, “We are getting rid of you by robot.” It is the opposite that we are telling them computers can be important from the creative point of view, and you can do new things with that. And so, this is what I am doing.

Views of the Field

AZ: For me, digital gastronomy stands for the integration of digital fabrication technologies into the kitchen. I am not the only one that is doing that, but I am a bit unique because I focus on the edible medium, on the food itself.

> For me, digital gastronomy stands for the integration of digital fabrication technologies into the kitchen

RM: There are many ways to approach the computer music field, and it really depends where you start. From my perspective, our field is about technology and research in service to music creation and music understanding. So, we make tools for composers and musicians, but the thing is, our field is not just limited to that. Our field is also everything that is related to audio in general. So many people in our field also do acoustics, signal processing, and machine learning. So, I would say it depends from where you start.

DC: I want to add that in computer music there is still room in this area to explore your own interests, and it can get even more interdisciplinary. For me it is creating a space to express yourself using music technology and whatever interests you have right now.

AG: For me, a good pastry chef needs to know a little bit of the science of the ingredients. We learned some of this along the way in school, but it was not much. I think if you are interested in it, you do your own research, and you can directly apply it to the recipe, and you will understand what you are working with.

In the pastry industry in France, taste matters so much, it is the very focal point, where people will first make their recipe and build a cake, and then say, “Okay, what shape can I give to that cake in order for it to look good?” But, I think in a different way. I sketch the final result of the dessert. I am creating an empty shell, then I fill it with a recipe and work the texture as I go. I think it is smarter that way, because I have always thought that the first thing you do when you eat pastry is you eat it with your eyes. Only then will you give it a chance at eating it with your mouth.

Tools, Digital Tools, and Missing Tools

DC: Mechanical engineering is not so well integrated into computer music. We design instruments, but we do not have tools to run any analysis on the mechanical aspects or material changes and their effects. The other thing is that there is a lot of overlap in biomechanics and teaching and music education, but we do not really know how to integrate the biomechanical tools. Although there is biomechanics involved in programs like OpenSim, the interaction with the musical instrument and the end result—the biomechanical end result—is missing.

RM: I think a tool that is missing, and that the language (FAUST) I worked on only partially solved, is a tool where you can execute low-level signal processing applications that can be run in real time and that are efficient, as good as what you would have in C++. At the same time, the tool should be very high level, something that is approachable and understandable by people who actually do signal processing like MATLAB.

AZ: For me, the problem with digital tools is not so much about technology but about its price. We learned that we would like to work with robotic hands because they are such general helpers you can do a lot of things with them. They can also wash the dishes at the end! But for high quality they are expensive. To make all this more realistic, the cost of these machines needs to be in the range of kitchen machines. Envision a kitchen with five robotic hands, for cutting, localized heating, etc. The good thing with robots, unlike current 3D printers, is that when one hand is working on one element on the plate, the other can work on the other side of the plate. They can work together. So, this is what I want to build in my lab, but it is a research project, not within the domestic kitchen budget.

Another problem is how to control these machines, and how we think about recipes and dishes. Consider making a carrot cake. You Google it, and you find a huge number of different recipes. And sometimes, it is very difficult, even impossible to interpolate between them, because they have been built in different ways. If you are not a skilled cook, most of the time, you just execute the recipe as is. However, theoretically, we can put all the recipes ever created into the same continuous space. Then using computer science, you can generate the specific interpretation that fits you. It is not a general carrot cake; it is the carrot cake that you like, the carrot cake that is healthy for you. It is the specific interpretation. Thus, we focus on the computer science tools too.

AG: I like to be a creative chef, and I try not to duplicate what has been done before. Sometimes, I will borrow a technique and give it a twist. Sometimes, I borrow a tool from another craft. I use a clay turntable and put chocolate on it and sculpt the chocolate. No one really has done this before. There are so many things that look like pastry—for instance, glassblowing is extremely similar to what sugar art could be. You can blow sugar. You can pull sugar. So, for the level of pastry I am doing, it requires a lot of very expensive and precise equipment. You must control humidity and temperature. Everything matters.

> The good thing with robots, unlike 3D printers, is that when one hand is working on one element on the plate, the other can work on the side of the plate.

But, lately, I have been turning to the resin 3-D printer that my wife gave me. I design and print a 3D copy of the creation that I want to use on my desserts, and then I make a hollow mold from this piece. Finally, I can fill that mold to create chocolate or mousse—whatever I want in that shape. I can also create a stamp. I print a stamp, and then I dip it into gold dust to leave a print onto a glaze, like onto my cake glaze. We also have a machine that cuts with high-pressure water. We can take a picture with our phone of a shape we want to have cut, and it goes straight by wireless network to the machine. We just say the size we want, and it just cuts.

Future and the Continuing Importance of the Craft

AG: Pastry is kind of exploding right now and changing. I think I have the chance to inspire newer generations, not in the way I began but more the way I am doing it now. But behind it, there is much more than just a guy who took on a piece of chocolate in his kitchen and had fun with it. There are a lot of hours of training and knowledge, and retraining, and breaking and frustration and sweat, you know? I feel very thankful for being able to do what I love every day, sharing my passion with others and guiding people into finding their own way. I would say advice number one is to be willing to work very hard, but even with hard work sometimes not everybody can achieve what they want to achieve. It is very important to be true to what you do. It is like at first you learn how to do things, so you replicate what you see and learn the recipe and the way of doing it. But, at some point if you want to become a pastry chef, it is important you follow your own path that comes from your own personal experiences.

RM: When the computer music field started in the 1960s, most of the people in the field had a very strong musical background. I think it was very clear to them that there had to be a link between music performance and music production and the technology that they were developing. But now, because the field is more mature and the research topics around it are also more mature and more specific, they sometimes require a lot of technical background and a lot of technical skills to actually do research. Very often, it is hard to be good at both, you know, it is hard to be a musician with an international career as well as a recognized researcher. So, as Doga said, the most important thing, no matter what you do in this field, is to remember you actually do it for music. Staying a musician, keeping the musical practice and playing music is definitely very important.

DC: I want to add that because it is getting harder to combine both the music and the technological skills, the mastery of it all, I think researchers should be open to collaboration, not just with electrical engineers and computer scientist musicians, but with other kinds of engineers, such as mechanical engineers, and other kinds of artists as well.

AZ: It is not about automation, not at all. It is not about getting rid of the human cook; it is the opposite. It is human-centered creative research, and the idea is to ask how a chef can enjoy digital technologies in the kitchen from the creative perspective.

We can take a correlation from digital photography, for example, the ability to edit, manipulate, and control, in a discreet way, the pixels of a photo. It is the same concept that we are trying to bring to cooking: what happens when a chef can control the flavor in each point of the dish? It brings the ability to start thinking about taste or flavor patterns and structures, and how they morph into each other. And how you take several ingredients and generate infinite variations to satisfy different requirements. With this perspective, it is about giving the chef entirely new vocabulary to think about cooking and food. And by that, to justify computers from the creative perspective.

I think the chef will be in the center of this future. Whatever it is going to be, we need people who are expert in the craft and are connected to the roots of it. They will lead it.