Report from Dagstuhl Seminar 18212

On-Body Interaction: Embodied Cognition Meets Sensor/Actuator Engineering to Design New Interfaces

Edited by

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Abstract

On-body technologies are emerging as a new paradigm in human-computer interaction. Instead of moving a mouse or tapping a touch surface, people can use whole-body movements to navigate in games, gesture in mid-air to interact with large displays, or touch their forearm to control a mobile phone. First promising applications are being investigated or have been demonstrated in mobile computing, healthcare, or sports.

Two areas of research have been contributing to this paradigm. Research on embodied cognition suggests that the body should no longer be treated as a passive actuator of input devices but as something that needs to be carefully designed for and as something that offers unique new possibilities in interaction. Embodied cognition has become a prominent candidate for outlining what we can and cannot do in on-body interaction. Research on interactive technologies for the body is opening up new avenues for human-computer interaction, by contributing body-based sensing input and output modalities with more body compatible form factors. Together, these areas allow the design and implementation of new user interfaces; however, they are rarely in direct contact with each other.

The intended outcome of the seminar was a research agenda for on-body technologies based on synergies between these two views. We therefore brought together a group of researchers from embodied cognition (including psychology, robotics, human-computer interaction, and sociology) as well as sensor/actuator engineering (including computer science, materials science, electrical engineering). These groups worked together toward outlining a research agenda for on-body technologies, in part using a bottom-up process at the seminar, in part using structured answers to questions in advance of the seminar. Key topics for discussion included (1) advances in on-body sensors and actuators, in particular how to drive the technical development from work on embodied cognition and the body, (2) cognitive consequences of on-body technologies, (3) how to take the peculiarities and possibilities of the body into consideration, (4) how to evaluate on-body technology, and (5) application areas of on-body technologies.

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1 Executive Summary

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Motivation

For the past 40 years, input to computers has been given with mouse and keyboard. Over the last decade, multi-touch has become popular for small devices (e.g., phones and tablets) as well as for large displays (e.g., interactive tabletops and wall-sized screens). All these forms of input require the user to hold or touch a device. Conversely, output has happened on large screens external to the body (e.g., a desktop) or small ones on the body (e.g., smartwatches). The field of human-computer interaction (HCI) has worked to understand these user interfaces (UIs) and how people use them, in addition to establishing principles of design and models of performance to help design them so that they are useful and usable.

Recently, however, HCI researchers have been interested in allowing new forms of on-body technologies. One vision is to integrate technology with the body so as to use and supplement its capabilities. In particular, researchers have focused on sensing users' movement and gestures, aiming to allow users to interact using their body rather than by using a device. Early work included Bolt's put-that-there system developed in the late 1970s, and recent advances in computer vision have allowed the tracking of users' hands, arms, and bodies, leading to a flurry of motion-based gaming controls and inventive, body-based games. The number and variety of research prototypes of non-device UIs have also exploded over the past few years, showing how movements in front of a large display can control navigation, how users can gesture in mid-air, how scratching or poking the skin of one's forearm can be a means of input, and how electric muscle stimulation can be used to move users' limbs as output. Further, HCI researchers have been exploring the theoretical opportunities in using the body for interaction, describing principles for whole-body interaction, embodied interaction, and body-centric interaction, as well as highlighting some of the philosophical and psychological challenges associated with using the body as an interface. First promising applications are being investigated or have been demonstrated in mobile computing, healthcare, or sports. A new UI paradigm seems to be emerging.

The main objective of the seminar was to explore on-body interaction through two research areas: embodied cognition and sensor/actuator engineering. The former has driven a lot of thinking and models around on-body technologies and the potential of body-based interaction. The latter has been behind many of the sensors and actuators that have enabled prototypes to be built and to demonstrate the potential of on-body technology. We did this bringing together a group of researchers from embodied cognition (including psychology, robotics, human-computer interaction, art/design, and sociology) as well as sensor/actuator engineering (including computer science, materials science, electrical engineering). Second, we had this diverse group of researchers outline a research agenda for on-body technologies, in part using a bottom-up process at the seminar, in part using structured answers to questions in advance of the seminar.

Topics

In line with the objectives above, the seminar focused on three areas of investigation:

- **Embodied Cognition**: Embodied cognition is a term covering research in linguistics, robotics, artificial intelligence, philosophy, and psychology (e.g., Anderson 2003, Wilson 2002). The core idea in embodied cognition is that our bodies shape thinking broadly understood (including reasoning, memory, and emotion). In contrast to most psychological foundations of HCI, embodied cognition argues that one cannot study the human as a system comprising input (senses), processing (thinking), and output (motor activity), because sensor-motor activity affects thinking fundamentally and, conversely but less radically, because our body reflects more about our thinking than is commonly expected. Thus, bodies and thinking are intertwined, as reflected in embodied cognition book titles like "How the Body Shapes the Way We Think" [2] and "How the Body Shapes the Mind" [1]. Embodied cognition has become a prominent candidate for outlining what we can and cannot do in on-body interaction.
- **Sensor/Actuator Engineering**: The engineering of technologies that transform the human body into an interface is a very active research area. A widely used approach uses techniques from visual computing for capturing body gestures and touch input on the body using RGB or depth cameras, while projecting visual output with a body-worn projector. Other approaches build on the transdermal propagation of ultrasound or electromagnetic waves to identify the location of touch contact on human skin. EMG can be used to capture human muscle movement, while Electrical Muscle Stimulation can generate muscle output. Radar is another technology that has been successfully demonstrated very recently for capturing gestural input. A further recent strand in research uses slim skin electronics for sensing and output on the body. These technologies are opening up new avenues for human-computer interaction, by contributing body-based sensing input and output modalities with an increasing resolution and more body compatible form factors.
- **New On-Body Technologies**: This area concerns how we can combine embodied cognition and sensor/actuator engineering to design on-body technologies. The design of on-body technologies was a key discussion topic, in particular, how to drive the technical development from work on embodied cognition and the body, how to evaluate on-body technology, and how to take the peculiarities and possibilities of the body into consideration. The application areas of on-body technologies were another consideration.

Activities

The first day of the seminar was reserved for presentations, to establish common ground for discussions. All participants introduced themselves, their background, and their vision in short position talks.

Four long talks reviewed the state-of-the-art and presented recent work in key areas. In his talk "Embodied Cognition: What does having a body gives us?", David Kirsh emphasized on four topics: Effectivity, Enactive perception, Interactive Cognition, and Experience. They all explore what having a body gives us that goes beyond just having a sensor in space. Katia Vega's talk, entitled "Beauty Technologies", focused on the possibilities to embed technology on and inside the skin. Nadia Bianchi-Berthouze gave a talk entitled "The Affective Body in Interaction", discussing the high-level principles of affective computing and creating body-affective-aware-computing technology, which involves sensing the affect and emotion of the users and using them for interaction. In his talk "Cosmetic Computing: Actions and

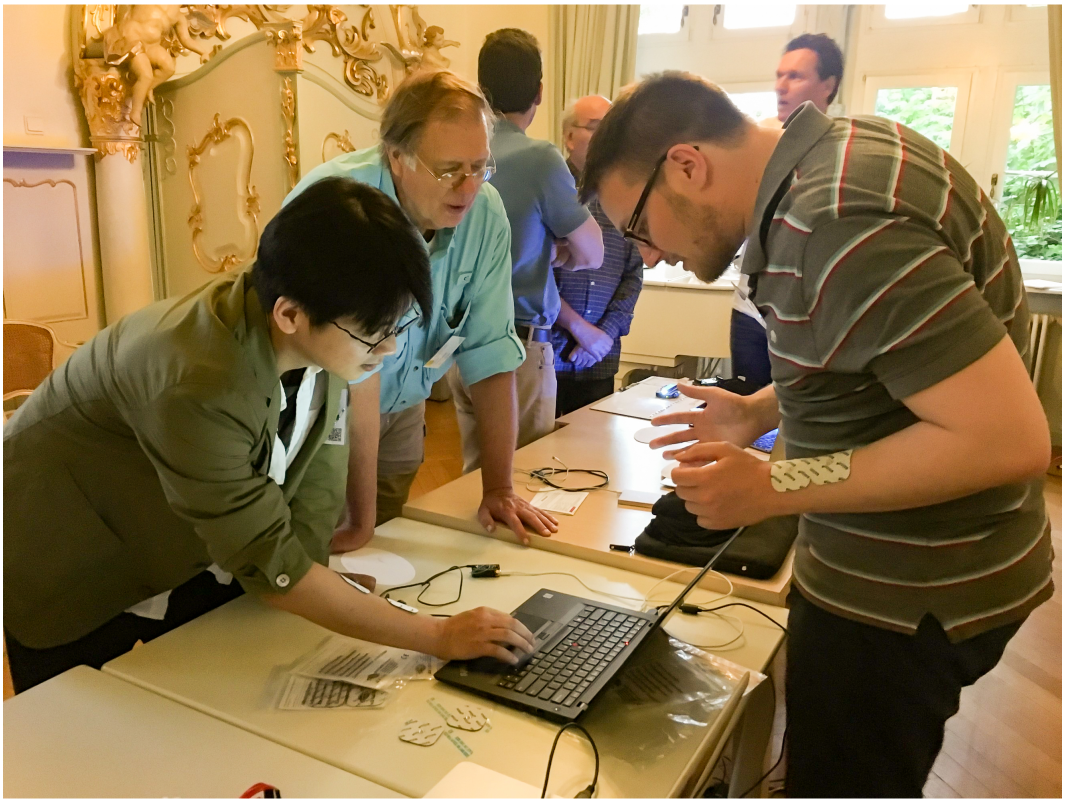

Figure 1 Demo session featuring latest body-based technologies, held in the historical Music Hall of Dagstuhl castle.

Urgencies towards an Inclusive, Equitable Landscape of On-Body Technologies", Eric Paulos urged the need for transdisciplinary and interdisciplinary approaches and proposed a framing around "Cosmetic Computing".

The evening featured a demo session. An impressive total number of 8 interactive demos and exhibits were demonstrated in the historical ambiance of the Rokoko-style music hall. Those demos comprised, amongst other, e-textiles, interactive tattoos and make-up, new bio-inspired materials and tactile actuation technologies.

The second day consisted of work in **breakout groups**. First, groups identified **challenges** for future work in the field of on-body interaction, grouped into four main areas: Integration of the body and the device; Cognition and Affect; Interaction; and Applications. Next, the participants worked together to identify **positive visions** of a future with body-based interfaces. Promising aspects that were identified include sensory augmentation of human body for graceful ageing, personalized medication and the idea of legal/democratic framework for controlling wearable technology.. To identify potential risks associated with body-based technologies and interaction, the group also developed **negative visions**. Key problems and risks that were identified include a loss of physical embodiment and substantial security risks of our bodies (and potentially even emotions) being externally controlled.

In an session, entitled academic speed-dating, we randomly paired two participants with each other. Their goal was to developed within 7 minutes an idea and a title for a paper they would write together. The format turned out to be very well-received and to stimulate research ideas at unforeseen intersections between the participants' interest and expertise.

Conclusion

The seminar set out to bring together diverse researchers to discuss the overlap between embodied cognition and sensor/actuator engineering. The group managed to cover advances in on-body sensors and actuator, some of the cognitive consequences of on-body technologies, and open issues in applications of on-body technologies. Further, a range of open questions and exciting research questions were discussed, which will likely foster future collaboration and serve as a generator of future research on on-body technologies.

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3 Overview of Talks

3.1 Haptically-enhanced Body Interaction

Liwei Chan (National Chiao-Tung University – Hsinchu, TW)

Body-based interaction should rely on the body, not vision and hearing though also not excluding them. The key challenge is to enable interaction loops centering haptic channel, if not alone. I consider the bandwidth of body-based interaction is limited by the imprecision of haptic sensation that can hider the user's input capability. Can we boost input capability with artificial haptic output that enhances our awareness of body motion?

3.2 Toward Extended Intelligence in Connected Environments

Clément Duhart (MIT – Cambridge, US)

Extended Intelligence is a new field introduced at the MIT Media Lab by Joi Ito which considers new cognitive dimensions as a fundamentally distributed phenomenon between artificial and biological intelligences. In this talk, we present an early stage of experimentation in which Hear There an auditive augmentation device with a visual attention mechanism interacts with Tidzam, a deep learning acoustic scene analyzer able also to classify wildlife sound like bird species. In such scenario, Hear There is able to detect where the user sight is oriented and so, able to play an audio stream from microphones close to the its region of interest which gives a kind of auditive super power. When combining with Tidzam which can detect that there is, for example, a canada goose, Hear There can play additional audio streams close to the right or left ear in order to invite the user to turn his head in another direction because there is other canada goose in his back for example. Depending of the user reaction, such system can refine his inference about user interest or learn more the acoustic scene. In this example, the intelligence is not in a particular system but more in their interaction in which the user is at the same time the subject and the actor.

3.3 Textile Interfaces

Michael Haller (University of Applied Sciences Upper Austria, AT)

The overall goal of this talk to show the possibilities for designing and creating an interactive knitted/woven textile sensor capable of sensing touch gestures and deformation input in real-time. Knitted/Woven Wearables combine tactile pressure sensitivity with conventional wearables, leading to an "Imperceptible Wearable Textile Interface". Its sensing capabilities enable the detection of pressure and deformation, and thus expands the potential gesture interaction space and possibilities for novel forms of expression. We propose a generic textile sensing platform, which includes the whole value chain ranging from material research and textile fabrication to hardware and software.

3.4 Textiles as Skin

Nur Hamdan (RWTH Aachen, DE)

In this talk, I propose textiles, garments, as an additional skin layer; one that can be digitally augmented to sense and actuate, and leverage our sense of proprioception. I describe two applications for textile-based on-body interaction. The first is a smart training shirt that enables runners to trigger actions by tapping at different locations on their upper body. The second is a seat cover with embedded vibration motors, specifically designed to send subtle messages to drivers to encourage mindful physical practices and breathing during a commute. I briefly demonstrate embroidered textiles sensors that can detect hover, touch, pressure, and fold. For actuation, I show how shape memory alloys can be incorporated in small monolithic structures and create rich tactile feedback on the skin, such as tap, stroke, twist, stretch, scratch, and pinch. I end the talk with a proof of concept prototype that proposers how textiles can add another dimension to our skin: sound.

3.5 Devices in, through or underneath the skin: Insertables

Kayla J. Heffernan (The University of Melbourne, AU)

The human body has emerged as a platform for devices—both for wearable wellbeing devices, and implantable medical devices (IMDs). IMDs include pacemakers, cochlear implants, deep brain stimulation for the treatment of Multiple Sclerosis and Parkinson's Disease, dental implants, orthodontics and implantable contraceptive to name only a few. Technological size and cost reductions, along with power and battery improvements, has seen items that were once strictly external become wearable, and even insertable. Instead of placing a device on the body when needed, and taking it off again when no longer required, it is now possible to augment the body in a semi-permanent way with an insertable device. This augmentation is typically not visible to others and is comparable to those who insert contact lenses rather than wearing glasses. In recent years, we have seen the emergence of non-life-threatening health products becoming insertable, such as female intrauterine devices (IUD) and sub-dermal contraceptive implants. As individuals become more comfortable with devices inside the body, as well as body modifications, we are beginning to see voluntary use of insertable devices outside of the health sphere. We define insertables as objects that go in, through, or underneath the skin. Our choice of the word 'insertable', over 'implantable', for these devices is deliberate. Implantable is used in the medical context to refer to an object fixed inside a person's body by surgery. Therefore, implantables are more difficult, if not impossible, to remove while insertables can be inserted and removed with minimal invasiveness. An implant is often something done to a person out of need, whereas an insertable implies a strong sense of personal agency and choice. Insertables are differentiated by their voluntary and non-medical nature. The arena of insertables has received little academic attention, particularly in the field of human-computer interaction (HCI). This project focuses on understanding the emerging field of insertable devices, looking as what devices people are putting into their bodies and why, classifying public opinions and propensity to insertables, and understanding how to design and develop for them. It will provide an understanding of the current state of insertables, and compare and contrast their design and development to implantable devices to identify why insertables are different. This knowledge will inform future use and design and position insertables as a device mode of choice for users and a legitimate category for hardware manufactures, HCI researchers and interaction designers alike.

3.6 Continuous Physiological Sensing for On-Body Interfaces

Christian Holz (Microsoft Research – Redmond, US)

Current interactive technology strives towards better understanding users and their contexts. I'm proposing continuously monitoring the user's physiological signals to get a sense of their state, using mobile and convenient form factors. I demonstrate how this work impacts the future of holistic and preventive healthcare in the wild as well as its implications for technology on modern touch systems.

3.7 Embodied Cognition: What does having a body gives us?

David Kirsh (University of California – San Diego, US)

The overview of embodied cognition that I presented focused on four topics, all explorations of what having a body gives us that goes beyond just having sensors in space. These included:

1. Effectivity: bodies give us capacities that come from having actuators and sensors tied to a single structure (the body) that enables performing action (i.e. agency), joint activity (i.e. doing things in a coordinated manner with others through shared attention) and coadapting to the built environment (i.e. having effects on the constructed world in a manner that is sensitive to the physical attributes of the local environment). Each of these potentialities is special and essentially requires a bodily agent with attention directing capacities, and effectors. An important point to understand about bodies is how the neural system determines the boundary of the body and how this 'body schema' can be altered by practice with a tool, such as a cane or hammer or even an articulated instrument such as nunchucks or violin.
2. Enactive perception: is the view that perception has evolved to pick up dynamic invariants that emerge from the way we interact with things. For instance, we have learned to identify a cup perceptually by having developed saccadic and eye movement strategies that continuously produce predictable cup sensations. Using this model of enactive perception we can ask how adding sensors to our body and adding actuators or tools that alter our behavioral repertoire can lead us to understand cups, other objects, processes and properties in a new way. With a hammer in our hands we can encounter nails and wood in a new way. Another thing to appreciate about enactive perception is that we perceive our environments in a goal and interest relative manner. If you smoke you see potential ashtrays or places to dump ash. If you do not you never even notice those.

3. Interactive Cognition: refers to the way humans and animals interact with things outside their nervous system – their body and other things – to facilitate cognition. A core interactive strategy that humans use – and arguably animals too – is to project future possibilities onto the world and determine whether that 'augmented' world has properties that interest them. A lion might project where a buck might be in a few minutes and scan that region for hiding places to go to now. What would the buck see from there? A person might imagine a diagram or constructions on a diagram in order to solve a geometric problem. Similarly people may projectively try out what performing an action might do to the environment prior to executing that action. There are many ways people project and many ways they alter the environment precisely to increase the power of their projection. This is means that we must design to support or scaffold projection.
4. Experience: having a body means you always have a point of view. It also means that our perception is sensitive to what we might do. We see things by unconsciously considering counterfactuals – what would I see if I look over there or there. Since most of the time we are not looking in those places but we nonetheless have expectations about what we would see were we to look, our current experience includes elements of these counterfactual expectations. We see the couch as having sides (upholstered arms) on both ends despite not really checking, or we see Andy Warhol's 'Wall of Marilyns' as being made up of facial images of Marilryn uniquely – no Jayne Mansfields, even though there might an image in there (Jayne) that is not of Marilyn. Another feature of experience is the way we experience our body as not being in space as much as defining the origin of space. This origin is not like a mathematical centroid; it is where my body ends. This has odd consequences. If I wear glasses I see through them, I never see them. They are part of me. The same for canes and other artifacts we absorb into our body schema. This sort of reflection is relevant when thinking about the consequences of adding actuators and sensory extenders to humans.

3.8 Devices That Overlap With the User's Body

Pedro Lopes (Hasso-Plattner-Institut – Potsdam, DE)

How can interactive devices connect with users in the most immediate and intimate way? This question has driven interactive computing for decades. If we think back to the early days of computing, user and device were quite distant, often located in separate rooms. Then, in the '70s, personal computers "moved in" with users. In the '90s, mobile devices moved computing into users' pockets. More recently, wearables brought computing into constant physical contact with the user's skin. These transitions proved to be useful: moving closer to users and spending more time with them allowed devices to perceive more of the user, allowing devices to act more personal. The main question that drives my research is: what is the next logical step? How can computing devices become even more personal? Some researchers argue that the next generation of interactive devices will move past the user's skin, and be directly implanted inside the user's body. This has already happened in that we have pacemakers, insulin pumps, etc. However, I argue that what we see is not devices moving towards the inside of the user's body but towards the "interface" of the user's body they need to address in order to perform their function. This idea holds the key to more immediate and personal communication between device and user. The question is how to increase this immediacy? My approach is to create devices that intentionally borrow parts of the user's body for input and output, rather than adding more technology to the body. I call this concept "devices that overlap with the user's body". I'll demonstrate my work in which I explored one specific flavor of such devices, i.e., devices that borrow the user's muscles. In my research I create computing devices that interact with the user by reading and controlling muscle activity. My devices are based on medical-grade signal generators and electrodes attached to the user's skin that send electrical impulses to the user's muscles; these impulses then cause the user's muscles to contract. While electrical muscle stimulation (EMS) devices have been used to regenerate lost motor functions in rehabilitation medicine since the '60s, during my PhD I explored EMS as a means for creating interactive systems. My devices form two main categories: (1) Devices that allow users eyes-free access to information by means of their proprioceptive sense, such as a variable, a tool, or a plot. (2) Devices that increase immersion in virtual reality by simulating large forces, such as wind, physical impact, or walls and heavy objects.

3.9 Inferring Emotion from Touch through analysis of On-Object Sensing

Karon MacLean (University of British Columbia – Vancouver, CA)

We've used low-cost, stretchy touch sensors and machine learning touch recognition to raise the 'emotional intelligence' of social human-robot interaction through bidirectional communication, by inferring changes in emotion state through sensed touch gestures and authoring believable emotional responses to them. This sensing, combined with simple outputs can transform a wide variety of interactions that are situated in the physical world rather than on a traditional computing device.

3.10 Towards Expressive Input Modalities for On-Skin Interaction

Aditya Shekhar Nittala (Universität des Saarlandes, DE)

The human body offers a vast, alwayas available, and quickly accessible real-estate for interaction. For these, reasons, interaction on body has received considerable attention in the HCI community. More recently, a new class of devices which we refer as Interactive Skin devices have emerged, which augement the human body with input and output capabilities. These devices are thin, flexible, can be easily worn on the body, are conformal to the body geometry[1, 2] and enable expressive ways of interaction on the body. However, the current state-of-the art Interactive Skin devices are only limited in terms of interaction and do not leverage all the natural affordances that the human skin offers. In this talk, I present the open challenges[3] and questions for enabling and understanding the new, expressive input modalities on the body, taking into account the various natural physical affordances that the human skin offers. Specifically, I focus on the deformation sensing(pressure, force, shear) on the skin leveraging the stretchability and deformability of the human skin.

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3.11 What is a Wearable?

Joseph A. Paradiso (MIT – Cambridge, US)

We have already witnessed profound and often unanticipated developments as IoT is built out and the world is mediated via mainly graphical wireless devices held at arm's length. But what will happen once the world is precognitively interpreted by what we term 'sensory prosthetics' that change what and how humans physically perceive, a world where your own intelligence is split ever more seamlessly between your brain and the cloud? In this talk, I outlined a few research initiatives in my group that anticipate the broad theme of interfacing humans to the ubiquitous electronic "nervous system" that sensor networks will soon extend across things, places, and people, going well beyond the 'Internet of Things'. I started by outlining a few projects we did sensing finger and wrist gestures for more direct manipulation, then described how we now use the voice channel for many things that soon won't be appropriate for it – IoT will evolve into more an extension of self vs. having a dialog with an 'other'. I gave an example of the 'Mediated Atmospheres' research project in my team, where we have an entire room transform (projection, lighting, sound) according to how the occupant reacts to the stimulus (as measured by an array of sensors), as an example of trans-corporeal actuation. I then shifted to perception, describing our Tidmarsh project (where we manifest sensor data from across a restored wetland in different ways), outlining the 'HearThere' device that gives the user sensory (auditory) 'superpowers', sensing with they are attentive, then enhancing sound (via a bone conduction headset) in the direction they are looking. Then I discussed dynamic wearables, that move across the user, pointing to our Rovables project, then introducing another new project in my team with micro-robots that walk on skin using dynamic suction, aimed mainly for medical purposes. I then posed some questions – first 'will we need to wear anything?', pointing to wireless sensing of people using RF (Katabe, Afib) and vitals from computer vision (Picard, Poh). I then posed a bunch of broader questions – Implantables vs Wearables (an issue in the next decades)? – What will be grown vs. what will be wired?(biology is good for some things, wires/silicon for others; can we grow the boundary instead of just wire it, including programming cells, etc.) – How will human presence generalize (when you can plug into ubiquitous sensing)? – What happens when everybody sees their own reality (look at the issues we have with 'fake news' already when it's still at arm's length)? – Where does 'self' stop and 'other' begin (as we physically couple more into the ubiquitous network)? My final question was 'Where are the Aliens?' – if life exists elsewhere (which we'll know in 20 years at most from atmospheres of exosolar planets), you'd think intelligence would be favored via evolution. Hence, why don't we see signs of life in other solar systems (you'd think advanced civilizations would do observable things). Answers include that either we're alone (my current belief due to the improbability of life – the universe is just a bunch of phase space for probability to play out in), intelligent life quickly self-destructs (highly dystopic view), or we retreat into noncoporeal (virtual) existence – e.g., we do our job too well, and people live in virtual rather than physical worlds (somewhere between dystopia and utopia perhaps, at least from our current understanding).

3.12 Cosmetic Computing: Actions and Urgencies towards a Inclusive, Equitable Landscape of On-Body Technologies

Eric Paulos (University of California – Berkeley, US)

The body as a site for new and exciting innovation. Through this presentation, I articulate a need for transdisciplinary and interdisciplinary approaches to advance the culture and state o the art within OnBody Interactions. Thinking back and building from a historical framing is essential and I present a list of body and performative artists starting from the Triadic Ballet by Oskar Schlemmer and moving through Rebecca Horn, Chris Burden, Yoko Ono, Stelarc, and others. I present an argument for a framing around "Cosmetic Computing" as a vociferous expression of radical individuality and an opportunity for deviance from binary gender norms. It is a catalyst towards an open, playful, and creative expression of individuality through wearable technologies. It's a liberation call across gender, race, and body types. Leveraging the term "cosmetics", originally meaning "technique of dress", we envision how intentionally designed new-wearables, specifically those that integrate with fashionable materials and overlays applied directly atop the skin or body, can (and should) empower individuals towards novel explorations of body and self- expression. Unlike many modern traditional cosmetics that are culturally laden with prescriptive social norms of required usage that are restrictive, sexually binary, and oppressive, we desire a new attitude and creative engagement with wearable technologies that can empower individuals with a more personal, playful, performative, and meaningful "technique of dress" – Cosmetic Computing. Throughout the talk, I presented exemplars of such on-body interactions through I wide range of materiality – hair, fingernails, skin, dynamic clothing, and beyond. Beyond the technical, the philosophical all to action is to operationalize the research through a lens that emphasizes a balance across the personal, performative, provocative, and poetic.

3.13 The Importance of Vestibular and Proprioceptive Signals on Perspective- Taking

Anastasia Pavlidou (MPI für biologische Kybernetik – Tübingen, DE)

The ability to adopt the visuo-spatial perspective of others is fundamental for successful social interactions. Here, we measured how vestibular (Experiment 1) and proprioceptive

(Experiment 2) signals influence perspective-taking abilities. For each experiment, participants completed the "dot-counting task": they evaluated if a number (0-3) presented at the start of each trial matched or mismatched the number of balls visible from their perspective in a visual scene of a 3D virtual room that followed. A task-irrelevant human avatar or arrow was also present in the center of the room that either shared the same or different viewpoint as the participant's. This allowed us to examine the likelihood that participants would implicitly adopt the perspective of the object even though they were not required to. In Experiment 1, participants performed the task while they received low-intensity (1mA) galvanic vestibular stimulation (GVS). Analysis of reaction times between same and different viewpoints revealed that GVS reduced the likelihood that participants implicitly adopted the avatar's perspective, promoting an egocentric viewpoint. In Experiment 2, we manipulated the congruency between the participant's body orientation (e.g. their entire body was facing the right side of the screen) and that of the avatar. When participants and avatars shared the same body orientation, participants were more likely to implicitly adopt the avatar's perspective, resulting in longer response times in the dot-counting task. For both experiments, the effects were not observed for the arrow. Altogether, the results indicate that implicit simulation of another person's viewpoint requires vestibular and proprioceptive signals.

3.14 The Body as a Casual Interaction Device

Henning Pohl (University of Copenhagen, DK)

Interaction with the body can be ubiquitous and subtle, yet is less suited for focused and complex interactions. For example, a body-based UI is likely not great for writing a novel, but pretty good for intermittent tasks or notifications. Interaction on and with the body can integrate and blend in. One variant of this integration is feedback that directly uses the body's own output channels. For example, itching skin is used by the body to steer our attention, but can also be repurposed as a channel for an interactive system.

3.15 Trying to augment the human experience

Joan Sol Roo (Universität des Saarlandes, DE)

This short presentation contains a brief overview of my previous work that led me to the field of body-based interaction. Rather than providing answers, it just frames my current hopes and concerns regarding this type of interfaces and their impact on how we experience our bodies.

3.16 Fashion motivated wearables

Chris Schmandt (MIT – Cambridge, US)

Our skin is the boundary between self and the world, and for millennia our species have decorated our bodies using many methods. We suggest that on-skin computing can benefit by means of design which builds on these existing "beauty practices". Examples include DuoSkin, which provides user interfaces based on metallic tattoos, NailO,which converts decorative finger nail paste on art to capacitive touch sensitive surfaces, and SkinMorph, which affords flexible body armor which stiffens when electrically heated.

3.17 Interactive Skin

Jürgen Steimle (Universität des Saarlandes, DE)

Using human skin as an interactive surface presents unique opportunities for body-based interaction: skin offers a large surface that is always available and easy-to-reach, even during demanding mobility tasks. Skin is inherently multi-modal and lends itself naturally to tactile and visual input and output. It is also a promising platform for continuous monitoring of physiological parameters.

We foresee a new generation of wearable devices, which we call Interactive Skin. These devices reside right on the user's skin and transform it into an input/output surface for computing. By seamlessly fusing natural functions of skin and computational augmentations, they shall enable interactions that are more direct, eyes-free, and more expressive than existing approaches.

However, turning human skin into an I/O surface is demanding. Skin is curved, covers complex geometries, can deform and stretch. This stands in stark contrast to conventional, rigid interactive devices. Skin also has a multitude of physiological functions, including tactile perception, thermal management and transport of vapor, which a skin-worn device must be compatible with. Last but not least, since every user's body is unique and body-worn devices have an important aesthetic component, it will be necessary to personalize such devices to a considerably larger extent than it is common with existing devices.

Together with my team, I address the challenges of Interactive Skin in the following main areas:

Fabrication and Personalization of Interactive Skin Devices: We have developed a suite of fabrication techniques to realize very thin interactive devices that are worn as overlays on human skin. With iSkin [1], we have presented a silicone-based approach for customized stretchable touch sensors that are fabricated using laser patterning. This approach enables new types of body-worn devices, including a) wrappables that are wrapped around body-parts, such as a finger, b) skin stickers that are attached on a desired body location, such as the forearm, and c) on-demand extensions for conventional wearable devices, such as a roll-out keyboard for a smartwatch. In follow-up work [2], we could considerably reduce the thickness of devices by using temporary tattoo paper and multi-layer screen printing with functional inks. The resulting devices are between 3 and 50 microns thick, which allows them to closely conform to the skin and its fine wrinkles.

Considering the complexity of designing the circuitry of an Interactive Skin device, it is of central importance to develop design tools for interface designers. These tools shall abstract from the low-level circuitry by allowing the designer to design an interface at a high level and then automatically generating the circuitry. We have presented a first design tool that automatically generates a multi-touch sensor for a desired size and shape that is specified by the designer [3]. This is only a first instance – considerably more work is required to investigate how to best support interface designers, to unleash the full power of personalization.

Multi-modal Input and Output: Our interactive skin devices contain various types of printed sensors. These include capacitive sensing of single touch and of high-resolution multi-touch input [3]. Further sensors capture squeezing interactions on the skin and flexion of joints using resistive sensing schemes. In addition, we demonstrated the fabrication of flexible light-emitting displays that are integrated inside temporary tattoos [2]. Arguably most demanding is to integrate tactile output inside the thin form factor of interactive skin. In our most recent work, we have integrated a high-density matrix for electro-tactile stimulation in a temporary tattoo. The tattoo [4] is thin enough to retain most of bare skin's tactile perception. This contributes a new type of tactile interface that allows the user to feel real-world tactile cues through the interface, while augmenting them with computer-generated stimuli.

New Interaction Techniques for Skin: Skin has unique features that present new opportunities for interaction. Skin covers complex geometries and offers numerous tactile cues. These form body landmarks, which can be used during on-skin interaction to provide eyes-free guidance. We have identified a set of landmarks that comprise skeletal landmarks, skin microstructures such as wrinkles, elastic landmarks, visual landmarks, and body-worn accessories [2]. We enable novel interaction techniques by augmenting the filigree geometry of those landmarks with very slim interfaces. For instance, this turns knuckles on the back of the hand into buttons. It can turn fine wrinkles on the fingers into an easy-to-locate slider. Interfaces on elastic flesh can support continuous pressure-based or squeezing-based interactions, etc. All these interactions suggest that future skin-based interfaces should make use of skin's geometry and stretchability, in addition to offering more conventional touch-based gestures.

With this line of research, we aim to contribute a "toolbox" for interaction designers and domain experts, allowing them to start investigating applications of Interactive Skin in various domains. While we expect the first practical applications to emerge in the medical field, we foresee beneficial use in many other areas, including industrial production, mobile computing, sports and fitness, games, and entertainment.

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3.18 Designing for and leveraging Active Perception

Paul Strohmeier (University of Copenhagen, DK)

Material properties of the world around us, are revealed to us by our interactions with them. It is tempting to think of the world around us as having fixed properties which we perceive through passive sensors, but various studies suggest that the pre-conscious mircointeractions between our body and the world around us in fact create our subjective experience of the world. This becomes particularly apparent when studying haptic perception. Let us analyze lifting up an object. When holding the object, the fingertips are distorted due to shear stress. This distortion of the fingertips while the object is being lifted leads to a perception of weight [1]. When holding it, there is an interaction between the compression of the fingertip and the corresponding displacement of the fingers through the object. This interaction leads to a perception of compliance [2]. When moving our fingertip over the texture of the object, the interaction between our fingerprints and the materials surface structure causes vibrations. These vibrations are perceived as texture [3]. We experience the world around us through our interactions with the world. This is relevant for HCI as it allows us to provide users with material impressions without recreating the entire material. Rather through studying the sensory modality one wishes to target, one can create the target material, by creating tightly coupled feedback loops, simulating the interaction rather than the material properties [4, 5]. This allows us to create perceptions of virtual worlds without needing to recreate the entire world, it also provides us with guidance of how to design completely new senses and experiences.

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3.19 Beauty Technology and Biosensor Tattoos for Interfacing on and inside the Skin

Katia Vega (University of California – Davis, US)

Can the skin become an interactive platform? This talk describes the possibilities to embed technology on the skin and inside the skin by the use of cosmetics and body modification techniques. In order to move forward traditional cosmetics to interactive ones, Beauty Technology extends the functionality of cosmetics by exploring them as skin interfaces, hair interfaces and nail interfaces. Conductive Makeup, Tech Nails and Hairware are some examples of Beauty Technologies. On the other hand, humans also embraced body modification as a deliberate procedure for altering the appearance and form of the body. The Dermal Abyss explores the possibilities of replacing traditional tattoo ink with biosensors that changes colors in response to changes in our metabolism. In this way, the skin is a bio-display that reveals information that is inside the body such as pH, sodium and glucose levels.

4 Working groups

4.1 Visions in human computer integration

Liwei Chan (National Chiao-Tung University – Hsinchu, TW), David Kirsh (University of California – San Diego, US), Pedro Lopes (Hasso-Plattner-Institut – Potsdam, DE), and Paul Strohmeier (University of Copenhagen, DK)

We discuss three scenarios in which a very deep & tight human computer integration results in new senses: (1) new modes of immersion (empathy) with other entities, other beings, scales; new methods of sensualizing complex entities (make sense of new things); and, new multimodal encounters can take place with new senses opening up opportunities to design whole new experiences (art). We finish with three necessary steps to achieve some of these ideas.

4.2 Interactivity: the problem of reading off control intentions

David Kirsh (University of California – San Diego, US), Liwei Chan (National Chiao-Tung University – Hsinchu, TW), Clément Duhart (MIT – Cambridge, US), Aditya Shekhar Nittala (Universität des Saarlandes, DE), and Chris Schmandt (MIT – Cambridge, US)

In our group we discussed the foundational question: how can people interact with devices that might be in, half way in, on or off our body. As befits a question as basic as this we started with some assumptions about devices. They have a set of control parameters (C1

... Cn) that a user can in principle change; they have a set of actions (A1 .. An) that they can in principle perform some of which at the direction of the agent, and they have a set of information display factors (I1 .. In) that they can manifest to reveal things about their own state, the agent's state, states of the world and so forth. How does the agent know how to manipulate those control parameters? The more devices we have the more we forget how to work with them. And people like to have their own personalized ways of controlling, though again they may forget what these are. Further, if we are augmented with a sensor we need to couple very tightly so that we can dynamically control it to pick up invariants that only show up through moving it in certain ways. Sensor control is thick. The solution we struck on may work for the control problem associated with thinner control though not for sensor control. Control of sensors is more like playing a musical instrument; it must be learned through practice. For thinner control problems we can think of the problem like this. First let's discuss it for a simple problem like remotely controlling a light that has two orthogonal parameters (intensity, color) without using voice control and without touching a switch. The problem is to read off our intentions without asking us. This is a fundamental problem. How can a system, whether on our body, or some contextual sensor system in the environment, read intentions? We can assume that we signal them in some way. But the signals may be implicit or explicit. We might signal them implicitly through implicit body language or by proceeding in a manner that assumes the system will adapt to our needs given the context. == or we may signal them explicitly by gesture using our hands, body or face or by eye movement. How do humans do this? It is not reasonable to hope that a system might do better than a human unless it has access to non-behavioral or non-contextual parameters such as brain states, or other inner bodily states. How then might a human proceed? They interpret the context, they see where we are gazing, and then interpret our gestures if we make any. Since the person may not read our intentions correctly each moment we can treat this problem as a type of iterative coordination game. If the person controls the lights they respond to our action by changing the lights in some way. If they get it right they must interpret our next actions as indicating we are satisfied. If we are dissatisfied we respond by acting to get them to improve their response. They guess, we react and if this game has an equilibrium then everyone is happy and the reader has done the right thing and knows it. We believe the future will involve our interacting with an AI middleware system that can read our intentions. This is a fundamental problem that will apply whether we are trying to control remote devices or devices on or in our bodies. And the more control states there are the more it is a serious problem.

4.3 Body Noir

Antonio Krüger (DFKI – Saarbrücken, DE), Kayla J. Heffernan (The University of Melbourne, AU), Eric Paulos (University of California – Berkeley, US), Chris Schmandt (MIT – Cambridge, US), and Katia Vega (University of California – Davis, US)

This group discussed and presented the negative visions for on-body sensing and actuation and provided possible solutions for these. The discussion involved various negative aspects such as using the body-based interaction as a mechanism for controlling users, their mind. Other issues such as constant tracking of the body-based private data was discussed. Lastly, body-based interfaces could devalue human dignity and can make user over-rely on technology making them not-opt-out of the technology. Some possible outcomes were to have government policies and regulations so that users can opt-out of the technology. Another possibility is to support critical design as valid respected research within the community and on the societal level, there should be technology -free parks and zones.

4.4 The Future of On-Body Interfaces

Joseph A. Paradiso (MIT – Cambridge, US), Nadia Bianchi-Berthouze (University College London, GB), Clément Duhart (MIT – Cambridge, US), Nur Hamdan (RWTH Aachen, DE), Christian Holz (Microsoft Research – Redmond, US), Kasper Hornbaek (University of Copenhagen, DK), Karon MacLean (University of British Columbia – Vancouver, CA), and Aditya Shekhar Nittala (Universität des Saarlandes, DE)

This group discussion led to the ideation about the positive visions for the future of on-body interfaces. The group presented the various avenues for the future of on-body interfaces: for e.g. how legal/democratic frameworks can bring about a positive change, similarly they discussed the various application areas for on-body interfaces which include, Graceful ageing, personalized medication also reflected on how on-body interfaces can bring about low energy consumptions. Some of the negative connotations were also discussed such as slavery that can be inflicted with on-body interfaces (though EMS), privacy issues which can give outsiders access to information about one's body and the excessive data logging that can be exploited by greedy organizations.

4.5 Challenges in Human Computer Integration

Joseph A. Paradiso (MIT – Cambridge, US), Nadia Bianchi-Berthouze (University College London, GB), Clément Duhart (MIT – Cambridge, US), Nur Hamdan (RWTH Aachen, DE), Christian Holz (Microsoft Research – Redmond, US), Kasper Hornbaek (University of Copenhagen, DK), Karon MacLean (University of British Columbia – Vancouver, CA), and Aditya Shekhar Nittala (Universität des Saarlandes, DE)

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