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From Toolmakers to Cyborgs

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Abstract Humans have an ingenious ability to shape the environment we live in. Twenty thousand years ago, this started with simple shelters and has now advanced to manipulation on a planetary scale. Human abilities are tightly linked to the tools and technologies we have at hand. Nearly nothing that surrounds us in a modern world can be created without sophisticated tools. The clothes we wear, the vehicles we use, the buildings we live and work in, and communication we rely on are only feasible due to tools and technologies humans have invented. Human evolution is inevitably linked to the tools we use. Our ability to survive and procreate goes together with technological advances. Early on, tools made survival easier and freed time for humans to advance their knowledge and create even better tools. Evolution and tool use are linked. Tools and technologies have long complemented and extended our physical abilities: from pre-historic spearheads to steam-propelled ploughs and high-tech prosthetics. We have come a long way. Human abilities have increased through technology; we can talk to people on the other side of the world, travel at the speed of sound, and lift loads that are many times our own weight. This past wave of innovation was mainly focused on our ability to act in and manipulate the **physical** world. With more recent technological advancements, however, the extension of our **perceptual** and **cognitive** qualities has increasingly taken shape.

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1 Introduction

Over thousands of years, humans have created tools to aid their cognitive and perceptual abilities. Writing-starting with cuneiform, one of the earliest systems of writing used by Sumerians in ancient Mesopotamia-and book printing have provided humans with a virtually unlimited and lasting memory. The development of optical lenses granted humankind insights into the micro- and macrocosms extending our perception and literally changing how we see the world.

For a human only 10,000 years ago, the achievements of today, the increased physical abilities and the augmented perception and cognition would appear truly magical. It would seem that people achieved god-like powers. And as history has shown these additional powers can be used to make the world a better place, but also to bring massive destruction.

Digital technologies are the next step in empowering humans. Digital technologies and their interlinking with the physical world change human abilities at an unprecedented scale. Sensors, actuators, networking, and processing—often summarized as ubiquitous computing—is redefining what humans can do. In this book, we aim to capture and share research that explores this massive change ahead. Much of the vision is still at a conceptual or prototypical stage, but we believe they give a glance into what will become feasible in the next 50 years. Enhancing our ability to capture information, to store and share it, to retrieve (or remember) it, and to act on it, is at the core of many ideas. We believe that the next 50 years will see a multitude of technologies that will increase, augment, and amplify our cognitive abilities, including memory and perception to a level that seems still magical, God-like, at the present day.

Besides technological advancements, the economic framework changes. Automation (from the industrial revolution onwards) massively changed the cost structure in manufacturing. Replacing manual labour by machines and automation, that happened in agriculture and production, will in the next decade fundamentally change white-collar work.

Information, software, and systems that build on artificial intelligence exhibit cost structures that are entirely different from physical goods. There is a massive start-up cost to create the initial version, but scaling it to millions or even billions can be done at marginal cost. One implication of this is that only things that scale (globally) are likely to work well economically.

Connecting the physical and the digital–the Internet of Things–ties the digital and physical world closer together. We can create environments that support us and respond to us. If such environments are well designed, we may not be consciously aware of the help we are receiving. It will appear natural that there is always a chair when we feel like sitting down, that there is always a coffee on the table, even before thinking about it. Creating such an environment is technically challenging, but for us, the question of what world this creates and who can decide about the features of that world is even more challenging. Hence, we find it essential for us—and probably

for humankind—to not delay the discussion of what kind of future of an augmented world we want us to create.

Already with current technologies available, ranging from automated driving cars to global-scale social media, we see the massive impact they have on our lives and society. We also see that enhancements, augmentations, and amplifications will become a part of our body. Already now, pacemakers, artificial joints, prostheses, and exoskeletons are moving closer to our body and have become part of us. So far, they are mainly used to replace and enhance 'broken' body parts, but it is apparent that there is a drive to use them as an enhancement, even if the body parts are intact, but 'inferior'.

We are already cyborgs–both in a physical and cognitive sense. "*Technology as the external organs of the body*" (Marshall McLuhan). Technology can provide already now superhuman powers. In this volume, we have collected examples that reflect on the trajectory towards augmenting human abilities in various ways. It integrates current research efforts, results, and visions from the fields of computer science, neuroscience, and psychology. It gives a glimpse into the state-of-the-art and future applications of how technologies assist and augment human perception and cognition by using applications and explorations straight out of various research labs.

2 Cognitive Enhancements in Memory and Learning

Simulating our environment allows us to experiment with reality itself. VR is a powerful tool to control aspects of our environment that we would not be able to manipulate in the real world. Therefore, we can use it as a tool to study the specific circumstances in which people perceive, process, and make sense of the world. We can dream up and design any condition that may become ubiquitous in the future. What if we were aware of our own brain activities? Could this help us understand our productive states better? Could we induce flow—the sought state of stimulation and challenge in balance—when needed? This volume starts out with a chapter investigating these technologies. By combining EEG signals and VR outputs, can we become more self-aware of our bodies and minds? What if we knew about our brain activities at the moment? Accoto and colleagues take us on a journey of using visual and auditory stimuli in VR to give us a glimpse into our own brain's workings. Such new ways of personal insights allow us to associate mental states with brain activation patterns to purposefully steer ourselves into productive states of mind: flow states on demand. Vivid learning environments in VR may become the future of education as we can design our surroundings to optimally support and motivate learners, help them keep their concentration while alleviating boredom.

Leonardo Da Vinci is often quoted as one of the most universal geniuses of all times. With his studies in arts, he became immortal as a sculptor, painter, architect, and inventor. His contribution to science cover anatomy, meteorology, geology, botany, as well as philosophy. His curiosity and perennial hunger for knowledge make him the prodigy of the polymath envied across centuries. A versatile mind, along with a

perfect memory, is a dream that has become ever more prevalent with our knowledge society. Lifelogging technologies, in their essence, help us document our lives by recording our activities and experiences to the point where a comprehensive lifelog complements and augments our innate memory. Not only does the vision of lifelogs encompass a searchable fundus of memories, but also the summary of our experiences. Digital recordings selected and summarized by algorithms create snippets of our lives that can help us strengthen those neural connections and improve our vivid memory. In Chap. 3, we dive into the use of lifelogs and the challenges of lifelogging technologies with respect to social norms and perceptual limitations. Dingler and colleagues built a series of prototypes that allowed them to investigate aspects, such as the positioning of on-body cameras, the implicit and explicit collection of lifelogging data, the effectiveness of lifelogging reviews, the automation of summary creation, and the effective navigation of multimedia lifelogs. This chapter highlights the potential of these technologies to augment human memory and discusses the obstacles of bringing memory prosthetics into the mainstream.

If we leave it up to algorithms, however, to strengthen certain aspects of our experiences, what happens with those that do not make it into said summaries? When we start filtering our memories, how much control do we have in selecting the filter itself? Photo collections, for example, are poor snapshots compared to the richness of the lived experience no matter how sophisticated the recording or all-encompassing the blend of modalities. Socrates himself insisted that with the adoption of writing, we risk the destruction of memory and the weakening of the mind. Lucky for us, his disciples disagreed and wrote down his words, which were passed down generations. But what are today's risks of our lives' recordings and reliance on technological gadgets to help our memory out?

Clinch and her colleagues go to the bottom of such risks by looking at the unintended consequences of our reliance on technology to be readily available and all-knowing. When was the last time you, dear reader, memorized a phone number of a friend or family member? Was there ever such a time? If so, we bet it was before the first smartphone made it into your pocket. What about your spatial memory and your first GPS navigation device? Does our reliance on technology increase or inhibit the capabilities of our memory?

Chapter 4 ventures into these questions by looking at technologies and their abilities to inhibit or distort our memory at three stages: the encoding of memories, their rehearsal, and retrieval. When we use memory prostheses, such as lifelogs, what happens to those memories that do not make it into our picture summaries? Those that are not actively strengthened through the process of rehearsal. Can memories be attenuated through selection and filters? Can technologies go as far as to implant false memories?

They certainly help us strengthening our memory when it comes to learning tasks. Especially mobile devices and the plethora of available apps allow us to fill gaps between our daily activities with short learning sessions, be they watching a course video on *Khanacademy*, solving a Math puzzle on *WolframAlpha* or rehearsing foreign language vocabulary using *Duolingo*. But with ubiquity and mobility come challenges to the undivided attention often required for complex learning tasks.

Mobile learners are inherently susceptible to interruptions, either from their surrounding environment (navigating on the sidewalk), from the device (in the form of incoming calls or notifications) or users themselves (through rising thoughts, feelings, and urges). In Chap. 5, Schneegass and Draxler investigate the nature of such interruptions and review strategies to guide users back to their task at hand. The resulting design space is an insightful guide for mobile app designers to augment mobile learning experiences with cognitive support and entice users to resume their learning where they left off.

This first part of the book is, therefore, all focused on memory and learning and the connection and interplay with technologies. Because cognitive performance plays such an important role in our knowledge society, the support and advancement of cognitive functions is a very active field of research and the subject of commercial endeavours. Gradually, we have seen an increasing variety of devices to capture and replay experiences, tools to support our memory and learning, as well as productivity tools that help us focus in a world of near-constant digital stimulation.

The second part of this book will look at how some of that stimulation itself has been changing. Technology inherently changes the way we look at the world: physically, through the invention of optical lenses, and perceptually through the information available at our fingertips. But while most incoming information is limited to one or more of our five sensory modalities, technology has the potential to enhance existing and even create new perceptual channels.

3 Sensory Enhancements

The idea of '*cyborgs*', who share organic and biomechatronic body parts, has inspired science fiction writers for centuries. In 1839, the poet Edgar Allan Poe published the short story "The Man that was used up" about a war veteran whom he described as made up of so many prostheses that he had to be assembled piece-by-piece. The fascination of partly human and partly machine inspires *transhumanists* to this day. With the goal of augmenting their bodies beyond '*human norms*' they seek to extend their senses, mental, and physical abilities. As prostheses become more sophisticated and equipped with technologies, such as predictive movement and haptic feedback, usage of bodily extensions is increasingly moving away from medical cases and hobbyists' explorations to early adopters, i.e., individuals who insert devices inside their bodies to enhance or gain new capabilities.

The second part of the book starts with a look at such people and their communities around their quest of becoming '*cybors*' of sort. Heffernan et al. explore motivations behind so-called *insertables* and their application beyond medical purposes. For some, these technologies are a mere convenience (e.g., opening doors using an implanted RFID chip) while for others they play such a central role that they become part of their identity. Magnets, chips, or LEDs are inserted for the purpose of artistic expression, presenting flashy gimmicks, and being at the forefront of blending with a world where technology dominates huge parts of daily life. No

longer limited to ‘cyber-punks’ and ‘transhumanists’, such technology enthusiasts see an inherent benefit or convenience of living with technology inside their body. Some even report about the thrill of gaining new senses: by placing magnets inside their bodies they are able to literally feel electromagnetic fields.

For those for whom the idea of sliding microchips under the skin seems less appealing, there are other options for upgrading the senses. In Chap. 7, Kiss and Poguntke present a range of technologies aimed at giving users superhuman senses by piggybacking on existing modalities. What if we could feel the tingle of an imminent rain shower? Or listen in on specific conversations across a busy conference hall? What about a new sense of direction when the waters get murky, and star navigation during a swim is less of an option? This chapter dives into a review of the human sensing condition and explores the possibilities of augmenting the way we perceive the world around us. Making the invisible visible, the silent sound, and the abstract vibrate.

As technology weaves itself ever deeper into our lives, under our skin, influences our attention, and augments our senses, careful examination of its capabilities, risks, and benefits is warranted. Clinch et al. bring up the threats of human hacking, of viruses targeting the technical components we increasingly tend to rely on. The need for secure augmentations is becoming a crucial priority. If we digitize our senses and cognitive processes, what kind of privacy intrusions do we potentially expose ourselves to? In Chap. 8, Khamis and Alt present a privacy framework as a result of retrospection on the technologies discussed throughout this book. Privacy, security, and safety concerns need to guide designers’ thinking throughout the entire design process rather than being added post-hoc. As we extend our bodily senses and capabilities by interfacing with technologies on an increasingly deeper level, security holes may compromise far more than locations and credit history. With new powers come new responsibilities.

This volume integrates current research and implications of technologies that augment human perception and cognition. Experts in the field explore how modern technologies both extend and disrupt the way we sense, learn and recall information in the emerging era of human cognitive augmentation. We hope this selection of cutting-edge research projects will inspire the reader, foster an understanding of and boost appetite for the exciting realm of human augmentations. We have come thus far as a species; now it’s time to take the next step.

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Albrecht Schmidt is a computer science professor at the Ludwig-Maximilians-Universität München in Germany. He studied in Ulm and Manchester and received a Ph.D. from the Lancaster University. In his research, he focuses on amplifying the human mind and he is excited about improving cognition and perception through information technology. In 2018, he was elected to the ACM CHI Academy. Besides his academic work, he co-founded ThingOS, where he is the Chief Scientist.