

Editor: Albrecht Schmidt ■ University of Stuttgart ■ albrecht@computer.org

# Augmenting Human Intellect and Amplifying Perception and Cognition

***Albrecht Schmidt,*** *University of Stuttgart*

In this first installment of *IEEE Pervasive Computing*'s new Human Augmentation department, I look at various technologies designed to augment the human intellect and amplify human perception and cognition. Linking back to early work in interactive computing, I consider how novel technologies can create a new relationship between digital technologies and humans. Forthcoming articles will provide examples of how digital systems can amplify human performance—in particular, human cognition and perception.

## A REVOLUTION IN THE MAKING

It's apparent that artificial intelligence (AI) is challenging humans in many established domains. In games such as chess and GO, algorithms have outperformed humans,[1] and autonomously driven cars have started to exhibit stunning performance.[2] In both the popular press[3] and articles from esteemed colleagues,[4] we see warnings of AI posing a risk to humanity. In fact, there's a website where you can plug in your profession and job title to find whether you're at risk of being replaced by computing technologies.[5] Some experts have painted a dark future in which humans are sidelined—or even made extinct—by machines. But I disagree with these bleak outlooks!

To me, this feels like history repeating itself, and people are underestimating human abilities and flexibility. From the 18th through the 20th century, power machines—such as steam engines, combustions engines, electric motors, and hydraulic lifts—revolutionized our world, from the workplace to family life. Power (that is, muscle power) was no longer an area where humans were superior to machines. Nevertheless, these advances in physical technologies led to the world in which we now live.

In the 21st century, computing, networking, and digital media, combined with sensing and actuation, are the new ingredients for fundamental change. We're likely at the dawn of another technical revolution that will question all we know about work, economics, social environments, family, and even ethics. I suggest reading up on the first industrial revolution and its wide impact, looking in particular at the opportunities it created beyond the workplace. An interesting starting point is *Energy and the English Industrial Revolution*, by Edward Anthony Wrigley (Cambridge University Press, 2010).

## THE BRIGHT SIDE OF THE FUTURE

Human history is full of technological advances that have changed how we work and live. A major talent of humans is our ability to develop tools and devices that help us adapt to different environments. The many machines invented in the last 200 years are examples of tools that have increased our physical capabilities, making humans stronger, faster, and more precise. This has inevitably changed what we value in individuals and how we structure our society. Tool use and tool making are fundamental to a species and linked to advances in evolution.

Tools for the mind and for augmenting the human intellect have been a central goal since the early days of computing (see the "Mandatory Reading: Past Visions of the Future" sidebar). Searching through vast amounts of information has become an essential tool for many professions (just try to write software without Internet access). Extending our memory and externalizing information is becoming commonplace, as media capture and access become more simplified. Tools for ubiquitous communication are providing value to people at home and in the workplace. There are many positive effects, but humans must learn how these tools fit into our lives, and it's apparent that new technologies affect how we think, sometimes literally changing our brains.[6] Evolution, however, is slow, even if the tools are quickly changing the conditions and requirements around us.

## AUGMENTING THE HUMAN INTELLECT

Amplifying human abilities follows Joseph Lickider's idea of a "Man-Computer Symbiosis"[7] and extends research



Published by the IEEE CS ■ 1536-1268/17/$33.00 © 2017 IEEE

## MANDATORY READING: PAST VISIONS OF THE FUTURE

Ideas of using information technologies to augment human cognitive and perceptual abilities have been stated by visionaries of the last century. It's exciting to go back to these powerful past visions of the future and read them with current technologies in mind.

In 1945, Vannevar Bush outlined, in "The Memex—As We May Think," a vision for making (scientific) knowledge widely available and for allowing for sharing and collaboration.[1] His vision was bold! Now, 70 years later, advances in technologies—especially in networking and capturing information—have created a world where information is readily available and where everyone can contribute with very little skill.

Joseph Licklider foresaw a close relationship between computers and humans. In "Man-Computer Symbiosis," he envisioned computers and humans working together with a high degree of flexibility, allowing for joint decision making and collaboration in solving complex (cognitive) tasks.[2] The way in which we now use computers as tools, and the seamlessness in human-computer interaction, underline that this has become the dominant way of working today.

Douglas Engelbart saw how interactive computing can augment the human intellect. He envisioned and explored experimentally how interactive applications can support humans. He coined the term of "augmenting human intellect" (see www.1962paper.org/web.html).[3] The idea was that computing technologies could increase human capability in dealing with complex problems by offering faster comprehension. Overall, he foresaw such systems solving problems that otherwise couldn't be tackled by humans.

Mark Weiser and his colleagues at XEROX PARC explored in the 1980s and 1990s how the ubiquity of digital computing, networking, and storage technologies would change our lives.[4] Technologies for networked mobile devices and large-scale interactive displays were experimentally explored from a wide range of angles, going beyond the purely technological questions, and looking at the impact on business and society.

### REFERENCES


1. V. Bush, "The Memex—As We May Think," *The Atlantic*, July 1945; www.theatlantic.com/magazine/archive/1945/07/as-we-may-think/303881/5.
2. J.C.R. Licklider, "Man-Computer Symbiosis," *IRE Trans. Human Factors in Electronics*, Mar. 1960, pp. 4-11; http://groups.csail.mit.edu/medg/people/psz/Licklider.html.
3. D.C. Engelbart and W.K. English, "A Research Center for Augmenting Human Intellect," *Proc. Am. Federation of Information Processing Societies* (AFIPS), 1968; http://dl.acm.org/citation.cfm?id=1476589.1476645.
4. M. Weiser, "The Computer for the 21st Century," *Scientific American*, vol. 265, no. 3, 1991, pp. 94–104.


by Douglas Engelbart on "Augmenting [the] Human Intellect."[8] Lickider and Engelbart understood early on how interactive computing technology could be used to augment the human intellect. The idea of ubiquitous computing, as described by Mark Weiser,[9] moved the vision forward to interactive computing technologies pervasively integrated with everyday environments.

The idea of externalizing cognitive efforts and the notion of *distributed cognition* is based on the fact that user actions are situated in place and time and are often a reaction to the immediate environment.[10] One important facet of distributed cognition is that cognitive capabilities are a combination of a person's cognitive abilities and their environment. Knowledge and skill are not only in our minds but also in the environment.[11] Another important example is the intelligent use of space for problem solving.[12] By creating dynamic environments that can change technically and adapt to the tasks at hand, we inevitably alter our cognitive abilities.

Many of these technologies, ranging from early work on development tools to remote collaboration, mobile computing devices, and (more recently) machine learning, have undoubtedly augmented the human intellect for the masses. However, looking at technologies currently in the making reveals that this is only the beginning. If we can amplify ourselves, we will stay ahead of machines. Once muscle power was no longer a central need, our intellectual abilities bloomed. If machines take over basic intellectual tasks, might we have the time to achieve new abilities in social, emotional, or moral domains?

## AMPLIFYING PERCEPTION AND COGNITION

The ability to see and to hear helps us make sense of our surroundings. Our perception and cognition determine how we experience the world, and human senses are incredibly powerful. However, with current and upcoming technologies, we have reached a point where sensors, databases, and algorithms can outperform human abilities compared to our raw capabilities. Imaging sensors have a higher spatial and temporal resolution than the human eye, and the amount of information we can store externally is much higher than what we can remember. Furthermore, algorithms are faster at picking out details from a vast amount of images than human observers.

The goal behind amplifying human perception and cognition is to create systems where we closely couple humans with technologies to provide us with super-human abilities. A key to such technologies is that they act like a natural extension of our own abilities, with no added effort or increased cognitive load required. Amplified perception is based on combining human senses with technical sensors. I envision new amplified senses that are seamless to use, and I'm confident they can be built with current technologies. Amplifying cognition includes a wide range of digital technologies. Examples are memory extensions and visualizations that help us take in information and enhance our short-term memory.

## HUMAN AUGMENTATION

**Figure 1. Prototype of a video see-through system that combines an Oculus with an RGB, depth, and thermal image and allows implicit control by different physiological sensors. (Source: Yomna Abdelrahman and Pascal Knierim, Project FeuerWeRR, University of Stuttgart; used with permission.)**

Basic technologies that implement these amplifiers for cognition and perception are already available. The missing, but central, piece is the seamless integration with our existing perceptual and cognitive abilities and effective mechanisms for explicit and implicit control. Physiological sensing could be the missing link, and I expect that using eye-gaze, brain signals, and muscle activity will be key to creating a seamless user experience for amplified perception and cognition.

### Amplified Perception

If we look at how to amplify perception, we see two major directions:

- enhancing and amplifying existing senses (such as vision, hearing, and touch), and
- extending perceptual abilities to domains where humans have no perception but technical sensors exist (such as sensors indicating magnetic north or solar radiation).

I expect that systems for amplifying perception could be seamlessly integrated with current perception such that, in the long term, a person wouldn't even realize the amplification.

A vision for such a system would be glasses (or contact lens, or even an implant) that let you seamlessly operate across a wide visual spectrum in which you can manipulate the focus, speed, and spectrum. Imagine you're walking along a path in the forest, and you see a squirrel in the distance. Once you look at it, you concentrate and can zoom in and see how it's nibbling on a nut. When it jumps from one tree to the next, you can, by holding your breath, slow down what you see and appreciate how it lands on the branch. Once you start walking again, you return to your normal view.

We're not there yet, but at the Human Computer Interaction Lab at the University of Stuttgart, we have experimented with different technologies for amplifying perception. Currently, technologies are still bulky—but the vision is that the technologies might be, in 20 years' time, embedded into your glasses or contact lenses. Figure 1 shows a prototype of a video see-through system that lets you have visual perception beyond the human visual spectrum. You can move between a normal color video and a thermal video, and you can add a depth view. With a similar setup, we have explored how to provide different perspectives (a first-person versus third-person view).

### Amplified Cognition and Creativity

You can amplify cognition and creativity in many ways. Examples include

- amplifying a user's personal memory through contextualized capture and repeated presentation[1] (for example, with a wearable camera, a user can capture pictures throughout the day and use them for memory augmentation—see http://recall-fet.eu);
- enhancing information intake of various media (for example, for speed reading or for nonlinear viewing of videos);
- offering a parallel presentation of massive amounts of information (such as presenting large documents on large and high-resolution screens); and
- presenting related solutions to amplify creativity (such as presenting hundreds of images of existing solutions in a room).

Consider the scenario shown in Figure 2. The idea here is to build on human perceptual capabilities and support them with technologies. Instead of searching within categories, (which requires significant knowledge), we narrow down the search space to a set that humans can easily perceive and match. In this example, let's say we have 500 plants in the book. By narrowing it down to blue plants that are approximately 30 cm high, we could probably reduce the set to 50 plants. We assume that a person could quickly pick the right plant from a set of just 50, shown on a high-resolution wall-sized display. By not fully automating the task, and by adding a human perceptual step, we can increase the person's knowledge as she sees what's around the actual match.

### Quantifying Cognitive and Perceptual Amplification

Even though there are now many tools that augment and amplify our abilities, solid metrics don't exist, and we, as a community, have made little effort

to quantify such augmentations and amplifications beyond single cases. For tools in the physical world, the effect is typically easy to quantify. A human without any technical support can travel about 5 km an hour; with a bike, that goes up to 20 km per hour, and with a car, up to 100 km. You can also clearly quantify the difference in using an electric drill versus a mechanical drill, noting the number of holes drilled and the increase in precision.

In the digital world, there's little scientific work on quantification. How much quicker can you develop software with a 50 mbit/s Internet connection versus a 1 mbit/s connection? What is the effect on the productivity of a software developer if she has access to the website stackoverflow.com compared to using a printed reference manual for the programming language? Is having an interactive 60-inch screen in the meeting room more effective than everyone having a tablet computer? How much quicker are you at solving problems when you can access YouTube versus using the manual provided with the product?

To scientifically validate the amplification of human capabilities, it's essential to understand how to quantify the amplification. Can we create metrics that let us state that using a certain digital tool will increase your externally perceived IQ by 5 points? Or that using another tool will allow you to perform (with the tool) as well as someone (without a tool) whose average school grades are 0.5 points better than yours?

Validating amplifications obviously won't be easy, and the methods will be disputed. Furthermore, validation will most certainly require complex, large-scale experiments, but such experiments are essential to making advances not just visible but also measurable.

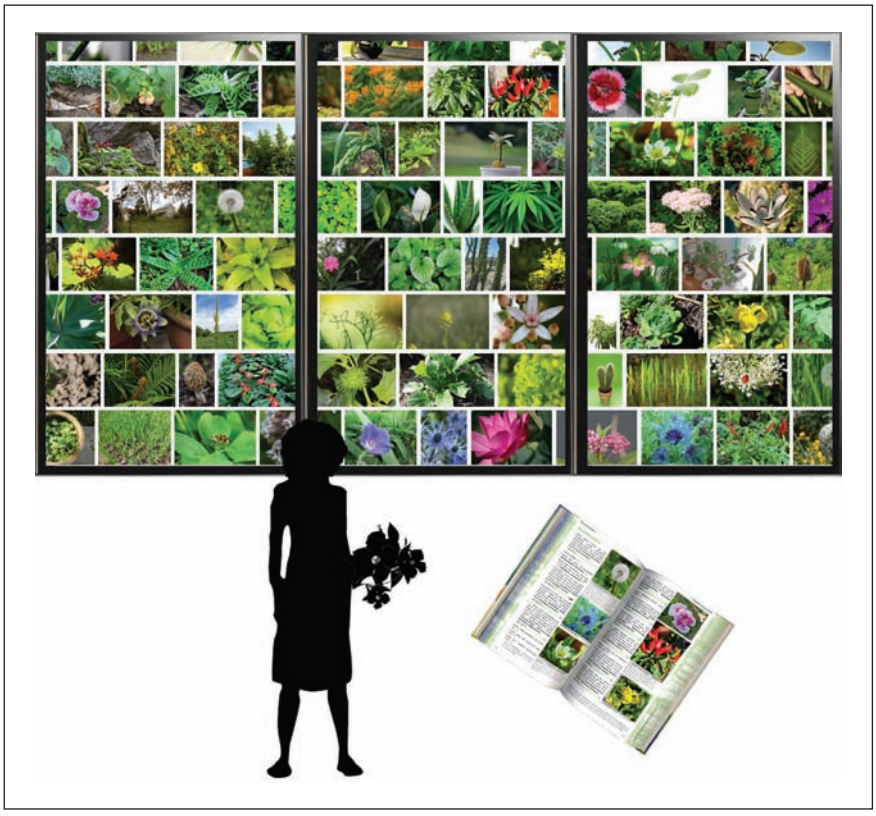

**Figure 2. A sample scenario—naming a plant. This examples illustrates comparing the usage of a traditional book based on categories with a large screen presentation. All potential candidates are shown at once, but filters (based on color, size, and so on) can be applied. Spotting the match relies on human perceptual abilities. (Artwork by Katrin Wolf; used with permission.)**

## TOWARD SUPER HUMAN TECHNOLOGIES?

It's apparent that many of these ideas will also question what we really want humans to be. Do we create (or at least attempt to create) technologies that make us smarter than the technology, or do we assume that technologies will take over?

Many are skeptical of technologies that amplify our abilities. There's a natural skepticism about creating super humans through technologies, but looking back at the machines that replaced human muscle power shows us that super human technologies aren't new. Humans move at great speeds (in cars) and lift amazing weights (with cranes). Technologies have and always will change our abilities. The introduction of written texts, book printing, and photography are just some examples that made us super human with regard to our cognitive abilities—compared to people who don't have these technologies. We also have perceptual aids (such as microscopes or thermal cameras) as well as cognitive aids (such as calculators).

So what's new? The difference now is that the upcoming technologies for cognition and perception are moving much closer to our bodies. Natural and implicit control will thus make us feel as though such technologies are a part of us—if we get it right. P

## ACKNOWLEDGEMENT

This work has received funding from the European Research Council (ERC), under the EU's Horizon 2020 research and innovation program (grant agreement no. 683008) and from the German Federal Ministry of Education and Research (BMBF) in project FeuerWeRR.

## REFERENCES

1. C. Moyer, "How Google's AlphaGo Beat a Go World Champion," *The Atlantic*, 28 Mar. 2016; www.theatlantic.com/technology/archive/2016/03/the-invisible-opponent/475611.

## HUMAN AUGMENTATION


2. J. Vincent, "World's First Self-Driving Taxi Trial Begins in Singapore," *The Verge*, 25 Aug 2016; www.theverge.com/2016/8/25/12637822/self-driving-taxi-first-public-trial-singapore-nutonomy.

3. M. Sainato, "Stephen Hawking, Elon Musk, and Bill Gates Warn about Artificial Intelligence," *The Observer*, 19 Aug. 2015; http://observer.com/2015/08/stephen-hawking-elon-musk-and-bill-gates-warn-about-artificial-intelligence.

4. S. Hawking et al., "Transcendence Looks at the Implications of Artificial Intelligence—But Are We Taking AI Seriously Enough?" *The Independent*, 1 May 2014; www.independent.co.uk/news/science/stephen-hawking-transcendence-looks-at-the-implications-of-artificial-intelligence-but-are-we-taking-9313474.html.

5. Q. Bui, "Will Your Job Be Done by a Machine?" *NPR*, 21 May 2015; www.npr.org/sections/money/2015/05/21/408234543/will-your-job-be-done-by-a-machine.

6. N. Carr, *The Shallows: How the Internet Is Changing the Way We Think, Read and Remember*, Atlantic Books, 2010.

7. J.C.R. Licklider, "Man-Computer Symbiosis," *IRE Trans. Human Factors in Electronics*, Mar. 1960, pp. 4–11; http://groups.csail.mit.edu/medg/people/psz/Licklider.html.

8. D.C. Engelbart and W.K. English, "A Research Center for Augmenting Human Intellect," *Proc. Am. Federation of Information Processing Societies* (AFIPS), 1968; http://dl.acm.org/citation.cfm?id=1476589.1476645.

9. M. Weiser, "The Computer for the 21st Century," *Scientific American*, vol. 265, no. 3, 1991, pp. 94–104.

10. L.A. Suchman, *Plans and Situated Actions: The Problem of Human-Machine Communication*, Cambridge Univ. Press, 1987.

11. J. Hollan, E. Hutchins, and D. Kirsh, "Distributed Cognition: Toward a New Foundation for Human-Computer Interaction Research," *ACM Trans. Computer-Human Interaction* (TOCHI), vol. 7, no. 2, 2000, pp. 174–196.

12. D. Kirsh, "The Intelligent Use of Space," *Artificial Intelligence*, vol. 73, no. 1, 1995, pp. 31–68.


**Albrecht Schmidt** is a professor at the University Stuttgart, Germany. Contact him at albrecht.schmidt@vis.uni-stuttgart.de