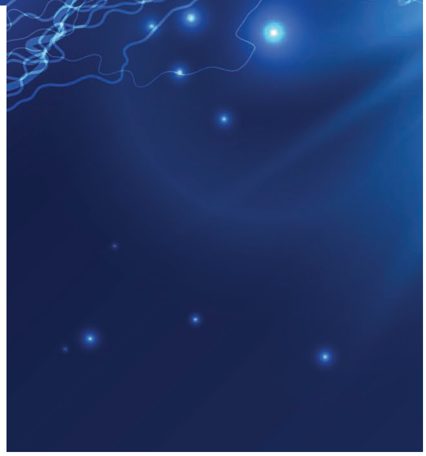
# Technologies to Amplify the Mind



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*By providing access to computing and offering intuitive control via users' physiological signals, new technologies can seamlessly amplify humans' cognitive abilities.*

With advances in AI, futurists and scientists have warned that humans might be sidelined or even driven to extinction by intelligent technologies. These warnings are commonly triggered by major achievements in AI, such as when, in the 1990s, IBM's Deep Blue defeated the best human chess player and, recently, when the best human Go player lost to a computer.

I argue that comparing "naked" humans' abilities to computing systems' is useless. We don't compare a marathon runner's performance to a car or an airplane. We should focus on symbiotic systems, in which humans harness technologies to amplify their abilities. (For more information on amplification types, see the "Metaphors: Glasses and Binoculars" sidebar.)

Human evolution and tool use are closely connected. Machinery has greatly increased humans' physical abilities, and the advances are stunning. For example, think of the transition from early Stone Age shovels to modern excavators. Mechanical and electrical devices such as power tools have augmented us by amplifying power. Support for tasks such as record keeping for memory—archiving knowledge and information about procedures in books and, more recently, using digital media—has evolved, improving human cognitive abilities.

Technologies can amplify all areas of human abilities, including physical power, memory, and perception. The "Concrete Examples in Amplifying Human Abilities" sidebar describes several use cases and technologies. Today's prominent drivers for amplification are the desire for

- improved capture and sensing technologies, for instance, cameras and sensors;
- in situ information presentation, for instance, augmented reality displays, ubiquitous displays, and projection; and
- technologies with implicit and adaptive control, for instance, gaze tracking, electromyography (EMG), and electroencephalography (EEG).

Many real-world applications will combine several of these to amplify user experience. In this article, I focus on technologies that enhance and amplify our mind.[1] I expect that, over the next several years, many cognitive and perceptual tasks will be automated and humans will not perform them anymore.

## AMPLIFYING THE MIND

There are three major areas in which digital technologies can amplify the human mind: perception, memory, and sense making. Our cognitive abilities and intellect aren't

just a function of our mind but rather related to our interactions in context; objects and artefacts, tools, and the physical and social environment can impact them. My work is inspired by the extended mind and active externalization,[2] distributed cognition,[3] collaborative knowledge and group cognition,[4] and the use of space and external representations.[5] Advances in sensing technologies, processing, communication, AI, and user interfaces (for instance, augmented reality) make it possible to implement these technologies.

Conceptually, human amplification extrapolates from the ideas of cognitive augmentation. Vannevar Bush introduced this idea in his article "As We May Think,"[6] even before the existence of digital technologies. Joseph Lickider's idea of a "man–computer symbiosis"[7] and Douglas Engelbart's research in *Augmenting Human Intellect*[8] expand on this vision with a broad range of application areas.

However, this field uses the term *amplification* rather than *augmentation* to highlight the creation of technologies that strengthen, rather than add, human abilities.

### Amplified perception

Human perception is complex; it includes the acquisition of signals from the environment (similar to sensing) and the interpretation of these signals. Again, on the sensory side, technological capabilities have surpassed human abilities: technical imaging sensors (cameras) have higher temporal and spatial resolution, allowing a wider spectrum than the human eye. Hence, we can capture events that wouldn't be visible to the human eye, for instance, a bullet hitting an object or a bursting balloon (see Figure 1). In the "Concrete Examples in Amplifying Human Abilities" sidebar, I describe a perceptual tool for firefighters that extends the spectrum the user can see.

## METAPHORS: GLASSES VERSUS BINOCULARS

Glasses are an extension of ourselves. They provide specific capabilities, and once we're used to them, we're typically not aware of wearing them. In contrast, binoculars are more like a tool that we use for a specific task: we pick them up to look at an object, and once the task is complete, we put them away. In this article, I focus on systems that fit the glasses metaphor, wherein amplification becomes transparent and doesn't add cognitive load to the user.

These metaphors are closely related to Mark Weiser's notion of invisibility. He envisions computing technologies of which users are not aware and argues that technology is most effective if it "is essentially invisible to the user."[1] In contrast, technologies that have had a major impact in the markets over the past 25 years—most notably the mobile phone—are still using the binoculars metaphor wherein users consciously and explicitly interact with the devices hundreds of times a day.

#### Reference

1. M. Weiser, "Some Computer Science Issues in Ubiquitous Computing," *Comm. ACM*, vol. 36, no. 7, 1993, pp. 75–84; www.cs.princeton.edu/courses/archive/spring99/cs598c/papers/p75-weiser.pdf.

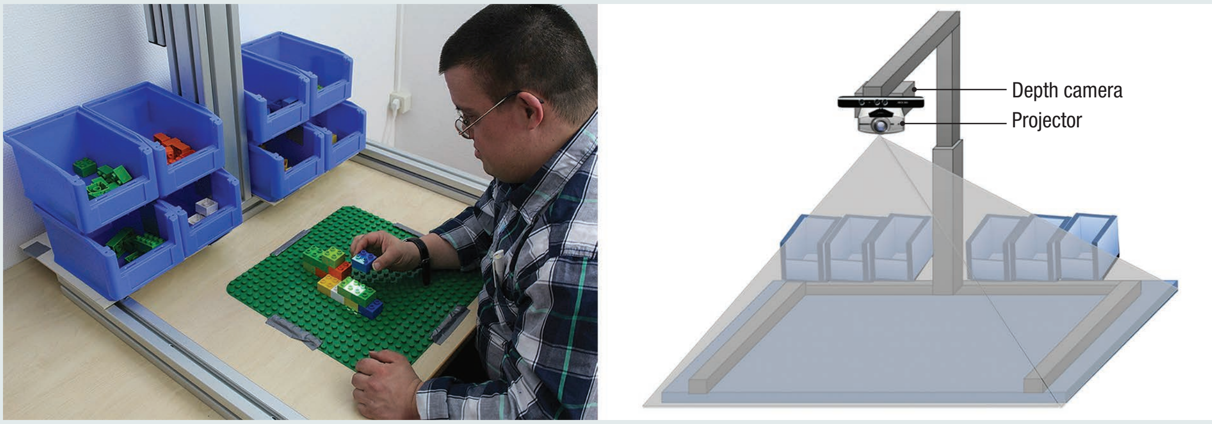
**Figure 1.** Example of photo that captures an event the naked eye could not see. Photo by tom_bullock, Water Balloon, www.flickr.com/photos/tombullock/24546629003 [CC BY-SA 2.0 (creativecommons.org/licenses/by-sa/2.0)].

## CONCRETE EXAMPLES IN AMPLIFYING HUMAN ABILITIES

A team at the University of Stuttgart and I are working on technologies to amplify human abilities in various domains.

### PROJECT MOTIONEAP

In the MotionEAP project, we explore cognitive assistive systems in the workplace. Assembly tasks typically require translating an abstract description into a set of complex motor actions, for instance, using a manual to build a LEGO car step by step (see Figure A). By decomposing the description into elementary steps and embedding the instructions into the work environment, we showed that the cognitive requirements remained constant even with more complex overall structures.[1] Users with lower cognitive abilities experienced amplified skills and benefited more from these support systems than highly skilled users.




(1) (2)

**Figure A.** MotionEAP project. (1) A worker at a sheltered work organization is provided with cognitive assistance in the assembly process. (2) The hardware setup includes an RGB and depth camera as well as a projector.

Currently, a team at the University of Stuttgart and I are developing camera-based sensing systems that can amplify visual perception, combining high-resolution sensors and machine vision that are implicitly controlled by users' physiological signals, including gaze, EMG, and EEG. The aim is to create an intuitive system that supports simple human interpretation and creates and effectively communicates new artificial senses.

### Amplifying human memory

Remembering how we solved a problem before—as an individual or on a societal level—is a key factor for success. In a similar way, the ability to store and pass on experience from one group to another or from one generation to the next is determining how well a society grows. Writing and book printing fundamentally changed humans' ability to remember and share experiences, and digital technologies are likely to increase human memory abilities even more drastically. Three areas play a major role in the amplification of human memory: media capture and production, distribution, and access.

**Media capture and production.** Today, we traditionally choose which experiences to capture and how to record them. For instance, when an event takes place, a person might choose to write it down and take some pictures of it. With future technologies, the default will likely be to capture everything. This would mean that everything an individual in a society does is recorded unless the person explicitly excludes particular activities. It will lead to an explosion of information and potentially knowledge about practices and operational skills ranging from everyday repair tasks, such as replacing a bike tire, to complex professional tasks, such as performing surgery.

**Distribution.** The transition of distribution methods is already happening. With digital storage, cheap global distribution of information with many

Such systems pose a variety of challenges ranging from computer vision problems in an interactive setting to plan extraction and understanding of the semantics of human actions.

## RECALL PROJECT

In the RECALL project (recall-fet.eu), we explored the creation of tools for human memory augmentation. Through different experiments, we looked at how life-logging technologies—basically, continuous capture with different technologies—can enhance, amplify, and attenuate human memory. This allows externalizing and augmenting human memory by using capture and search. Regularly reviewing captured media of an event users experienced can amplify their memory.

Often, it's challenging to create experiences in lab settings that reflect users' real-world experiences. So, together with psychologists, we created several studies in which we use wearable cameras, automated image processing, and interviews to assess the technology's impact on subjects' memory.

## PROJECT FEUERWERR

A prototype for augmented reality glasses for firefighters increases their perceptual abilities. This wearable device, which provides RGB and thermal stereo vision, allows users to switch subconsciously between the different views (see Figure B).

The only way to explore the effect of devices that introduce new abilities is through prototyping. In this project, we created a video see-through system, where the environment is recorded with thermal, depth, and color cameras, and the pictures are synthesized onto a wearable display. Users control the device using different physiological sensing modalities including gaze, electromyography, and electroencephalography. Besides image processing, a central challenge is to create a map of implicit actions (for example, concentrating, frowning, or narrowing one's eyes to a slit) to a natural and understandable system reaction.

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1. M. Funk, S. Mayer, and A. Schmidt, "Using In-Situ Projection to Support Cognitively Impaired Workers at the Workplace," *Proc. 17th Int'l ACM SIGACCESS Conf. Computers and Accessibility* (ASSETS 15), 2015, pp. 185–192.

**Figure B.** Feuerwerr project. To the front of the display, two RGB cameras, two thermal cameras, and a depth camera are attached. In the face mask, physiological sensors are built-in to allow intuitive user control.

replications is feasible. The means required for an unfiltered distribution are basically available to all Internet users, and an individual's reach is nearly unlimited. Immediate and global sharing—for instance, a livestream by one person—is already common practice.

**Access.** Finding information and media items is key to making use of information. Currently, we see mainly search-based access to find information on a specific topic. To more effectively support human memory, proactive mechanisms can find appropriate content for a user in advance and present it, potentially peripherally, to support external cognition. Advances in machine learning will support more efficient search and presentation of potentially relevant information.

### Amplified cognition—supporting sense making

Assuming unfiltered information will increase by several orders of magnitude, we need to support sense making. Already, traditional ways of discovering information, such as through search and sequential reading or by suggestions from recommender systems, create fragmented belief systems. Within each system are ample firsthand information and evidence (for instance, photos, recordings, and comments) to support a certain belief. However, because the information pool is already vast, there's little or no overlap between the evidence used in different systems. These effects, experienced as a filter bubble, are widely observed.

We need new means to amplify the mind's ability to deal with large amounts of conflicting and potentially biased evidence. Here too, machine learning and statistical approaches can amplify the human ability to process these vast amounts of information.

## RISKS AND SIDE EFFECTS

With technologies that amplify our minds, we become more prone to manipulation. Technologies are nearly always manipulating human behavior. Putting a paved path through the mountain will manipulate where hikers walk. Once we use digital technologies to amplify our perception, memory, and sense making, the risk for manipulation will increase massively, and it will be difficult to perceive it. Hence, it's important to ask what regulations we as a society expect for developers and providers of these tools and services. We must be aware that we cannot build technologies that don't impact people's behavior—or more simply: we cannot *not* manipulate with digital tools. Any design choice—conscious or unconscious—will impact users' actions.

Amplification of human memory does not come for free. Sharing experience will massively impact an individual's right to private information. With increased capture and improved access, realizing privacy will become harder and harder; societal discussions and decisions that draw boundaries to balance the many tradeoffs are required.

## A FUNDAMENTALLY NEW (SUPERIOR) CULTURE?

By combining perception, media, memory, and sense making, we can expect a fundamental transformation of our knowledge and information culture. In my view, this transformation is more radical and much faster than the transition from oral traditions to societies based on writing. This comparison highlights the risk as well as the potential. Few oral societies have survived, while books and later book printing boosted innovation. In a similar way, I expect societies that embrace the amplification of the human mind to outperform traditional societies. There might be no opting out!

Technologies such as wearable sensing and capture devices, ubiquitous displays, and augmented reality presentation, along with acquisition of human physiological information, will be critical to making this vision technically viable. With our current lab models, we can create prototypes that let us experiment with human amplification, but there's still a long way to go before the technologies are fit for everyday use.



## ACKNOWLEDGMENTS

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