Anticipating Widespread Augmented Reality: Insights from the 2018 AR Visioning Workshop

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Anticipating Widespread Augmented Reality

Insights from the 2018 AR Visioning Workshop

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PREFACE

In August of 2018 a group of academic, government, and industry experts in the field of Augmented Reality gathered for four days to consider potential technological and societal issues and opportunities that could accompany a future where AR is pervasive in location and duration of use. This report is intended to summarize some of the most novel and potentially impactful insights and opportunities identified by the group.

Our target audience includes AR researchers, government leaders, and thought leaders in general. It is our intent to share some compelling technological and societal questions that we believe are unique to AR, and to engender new thinking about the potentially impactful synergies associated with the convergence of AR and some other conventionally distinct areas of research.

ANTICIPATING WIDESPREAD AUGMENTED REALITY

The field of Augmented Reality (AR) traces its roots back to the 1960s when Ivan Sutherland built what is considered to be the first optical see-through head-mounted display system. Over the years, AR has developed a robust and growing research community. Advances in sensing and display technology have led to relatively turnkey AR outside of research labs, e.g., via the Microsoft HoloLens, the Magic Leap One, and a wide range of smart phones. Advances in digital projectors have led to commercially available systems for spatial augmented reality (SAR). The advances, largely driven by the smart phone market, include transformative breakthroughs such as robust active depth sensing, simultaneous localization and mapping (SLAM), processing, compact high-resolution displays, cameras, and motion sensing, coupled with seemingly constant improvements in size, weight, and ergonomics. The projected growth of AR has been compared to that of the smartphone market from 2007 to 2013[5].

> **What is Augmented Reality?**
> The most widely cited definition comes from Dr. Ron Azuma's 1997 article "A Survey of Augmented Reality," where he states "Augmented Reality (AR) is a variation of Virtual Environments (VE), or Virtual Reality as it is more commonly called. VE technologies completely immerse a user inside a synthetic environment. While immersed, the user cannot see the real world around him. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it." See also "Augmented Reality: Principles and Practice," Schmalstieg and Höllerer, 2016, Pearson Education, Inc.

The projected ubiquity of AR technology also brings the promise of compelling new uses in education, assistive technology, training and workforce development, healthcare, law enforcement, and entertainment.

> With the proliferation of AR technologies and content come new AR-specific questions and challenges. Some of the questions and challenges could be investigated *now*, while the technology and policies are still pliable or undefined, and the widespread adaptation of AR is relatively young or developing.

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[5] Laurits R. Christensen, Wes Marcik, Greg Rafert, Carletta Wong. The Global Economic Impacts Associated with Virtual and Augmented Reality. Analysis Group, Economic Impact Study, February 2016.

The U.S. military has been advancing AR research for decades, and more recently reaping benefits from the increasingly robust and turnkey systems as evidenced by the United States Marine Corps' adoption of the Microsoft HoloLens for their "Tactical Decision Kits," and the U.S. Army's announcement of a $480 million contract with Microsoft for AR systems.

AR offers the promise of novel assistive technology solutions, such as diagnosing and even compensating for impaired or lost senses—through body-worn transducers, adapting therapeutic feedback based on the measured ambient signals, eye tracking, or full body tracking. Future AR glasses based on light field technology offer the promise of compensating for many visual impairments currently corrected by today's corrective eyeglasses, while also mitigating the common issues of focus and convergence mismatch associated with existing AR glasses. For example, the Magic Leap One includes two focal plane distances for virtual imagery.

AR systems could someday provide "super-human" abilities or senses to users, e.g., allowing them to visualize otherwise invisible electromagnetic or physical signals such as radio, radar, or magnetic fields, or providing "virtual illumination" in scenes with little or no light. While such extensions of human perception could enable new ways of conveying and receiving information, they also present a risk of sensory overload. New regulations may be needed for the broader electromagnetic-physical spectrum, similar to existing control over radio frequency emissions of certain types of signals. This could include restrictions on the transmission and reception of special categories of signals, much like current restrictions over the use of police scanners or radar detectors in automobiles. One factor likely affecting adoption of AR is that there is a gap between common expectations for what AR can do, and corresponding conventional realizations. On the one hand, current AR systems fall woefully short of the magical visions depicted in science fiction books and movies. On the other hand, it is not clear that we are in any way seeing the large-scale dystopian effects portrayed by others.

A "KILLER APP"

Another factor seems to be the absence of an AR application that transforms the lives of users on an unusually wide or deep scale—a so-called "killer app." This could be a result of not having reached a certain threshold of cost and capabilities, despite the recent notable advances. This could also be a result of the way researchers, developers, and users have been thinking about the technology or its applications. For example, AR is sometimes marketed with flashy illustrative examples that are unrealistic from a technology perspective, or impractical examples that are not particularly well suited to AR. For example, the best AR devices today have a relatively limited field of view.

One particular factor identified at the workshop as an opportunity was the need for accessible but powerful content creation tools—tools that empower individuals who might be experts in some field, but not experts in AR, to create AR content and experiences, expressing themselves and their ideas with the equivalent of a simple and intuitive word processor. This empowerment is necessary to solve difficult domain-specific problems, and to unleash the ideas and creativity that could lead to transformative applications. The more people who are creating, the greater the chance for pivotal "black swan" events— transformative uses that the "experts" have not even thought about. Widespread, everyday use of AR has the potential for creating a whole new industry to support it—applications, systems, supply chains, jobs, etc.

CONCERNS AND OPPORTUNITIES

The ARVW organizers tasked the attendees with consideration of the six primary contexts depicted and discussed below.

Individual Health

As with many other new or developing technologies AR has the potential for unintended effects on the health and wellbeing of users, especially with long-term, frequent use. There are many unknowns about the long-term effects, both mental and physiological, related to

sustained AR use. Addiction and reliance could be serious issues, perhaps partially mitigated by age restrictions on use.

At the same time, there are many identified and likely unforeseen opportunities for improving individual health. For example, there exists the potential for leveraging AR as a learning tool—perhaps even to shape earlier brain development to facilitate or improve the use of the complex multi-sensory, spatiotemporal information channels later in life. AR may also provide a powerful mechanism for helping users improve themselves, assisting with behavioral issues such as diet and exercise, developmental issues such as amblyopia ("lazy eye"), and cognitive issues such as memory or psychomotor control.
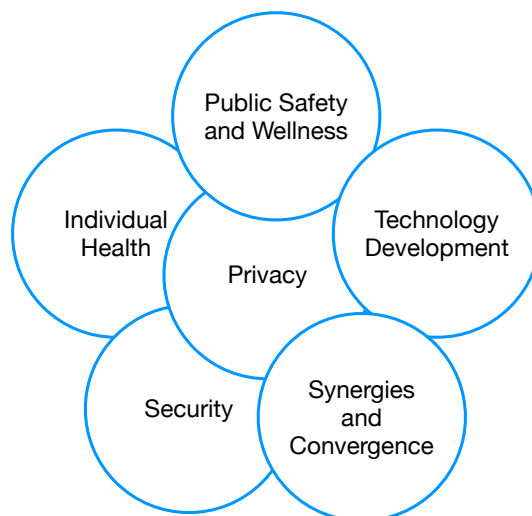
Sensors such as cameras and microphones are inherent components of AR. They are used continually for tracking the user, interpreting the surroundings, and rendering virtual items into those surroundings. As such, AR devices have the inherent capacity to collect huge amounts of behavioral information about the user. Such data, aggregated over long periods of time, could be used to benefit users via early detection or diagnosis of vision disorders (e.g., consider the handheld auto-refractor from NETRA), hearing disorders, and other medical conditions such as post-traumatic stress, heart disease, dementia, and neurological-motor issues. The ubiquitous sensing and sensory synthesis capabilities associated with AR could also offer new opportunities for treating some of these issues, e.g., by re-mapping information to different areas of the same sensory channel (e.g., different areas of the visual field) or even to different sensory channels.

The fusion and continuous analysis of environmental and egocentric sensing could be used to temporarily augment senses in times of need (e.g., when a distracted individual is about to step into traffic), or more permanently replace select senses when other senses fail with age or injury. The potential for continuous sensing and augmented perception could benefit Individuals in dangerous situations, e.g., first responders, warfighters, or every-day citizens. As with autonomous or driver-assistance technology in cars, there could be risks associated with over-reliance on such augmented sensing.

Privacy

AR sensors are not limited to capturing information about the user—they will necessarily also capture data about others in the immediate vicinity.

> The volume of shared data, and the fact that it could include identifiable information about unknowing bystanders, raises some unique issues related to privacy.

There are already similar existing issues with self-driving or otherwise heavily instrumented vehicles, such as those made by Tesla, or prolific traffic or surveillance camera networks in cities like London. Even today, embedded camera systems designed for telepresence at sporting events can lead to unexpected voyeurism, as individuals "privately" use their mobile phones, not realizing that thousands of individuals could be viewing and reading their screen contents "over their shoulders." There exists concern that advances in imaging, such as Gigapixel cameras, will soon enable someone to look into your house through an uncovered window, to capture a credit card you are holding in your hand. However the potential scale and pervasiveness of personal AR devices, including the presence in private places, along with the necessity of the kinds of rich spatiotemporal data generated and used by them, make questions related to privacy that much more pressing. Even if one implemented an "opt-in" mechanism, AR systems—by necessity—will collect data on others nearby. Different societal or political institutions, companies, and

even countries might adopt standards that are different compared to other entities, and perhaps different for different individuals. Such data privacy and security issues are being contemplated by world leaders (e.g., the World Economic Forum's "Data Policy in the Fourth Industrial Revolution: Insights on personal data"), however the potential for pervasive, personal, and invisible AR data collection raises the concerns to a new level.

Security

Some of these privacy concerns also give rise to potential security risks. For example, adversaries could use dense 3D reconstructions of sensitive areas or tracking and behavioral analysis of individuals to their advantage. AR tasks that rely on shared data or content to function could be compromised if the shared data is erroneous or even intentionally malicious. Now is the time to explore and develop frameworks that support the aggregating, sharing, distilling, and anonymizing of multi-resolution rich sensor data in ways that respect the privacy of users and bystanders, are robust to security issues, and provide a sanitized, processed data interface that is more directly useful and practical for applications.

There are also potential law enforcement and defense concerns regarding the use of AR technology related to adversarial detection of emissions or signals that might unintentionally advertise presence, location, or other critical information. Deliberate jamming or confounding techniques could also be employed by an enemy or unfriendly individual to disrupt or negatively affect various aspects of AR tracking, registration, or information collection.

Public Safety and Wellness

The widespread, dense spatiotemporal data associated with ubiquitous AR could provide a number of powerful benefits such as reliable records of events to help protect innocent users and bystanders. For example, AR systems could function much in the same way as automobile dashboard cameras or law enforcement body cameras, but with far more pervasiveness. They could also offer a source of real-time information for warfighters, law enforcement officials, or automated analysis systems about unforeseen threats or subtle anomalies in the surrounding environment or people.

However, ubiquitous AR could give rise to new forms of conventional societal problems such as bullying and even assault, if individuals are able to attach denigrating or even harm-inducing artifacts to others, e.g., a virtual "scarlet letter," a "kick me" sign, or a virtual noose. Previously protected public or private spaces could be invaded by virtual trespassers that give rise to real consequential individual or group behavior associated with the previously protected spaces. Individuals could gather on a public street in front of someone's home, and create AR scenes that involve the home and even the occupants, without anyone inside knowing it. The issues could range in scope from consumer protection to personal safety.

Technology Development

In support of longer-term studies about AR, there is an opportunity to establish standardized, comparable metrics for effective and meaningful evaluation of AR—something that has been largely missing thus far, even in terms of the fundamental technology for AR in general. This opportunity inherently involves questions about what the core aspects of effective AR comprise, and how they should be measured, in ways that are robust to the future of research and use in the field. This is also true for domain-specific uses such as in healthcare. For example, society will need standard practices and operating procedures for companies working with clinicians, including standards for the collection and measurement of data. Policies will also have to be determined related to when and where developers will need to get regulatory approval for products and processes.

Just as user interaction with mobile devices is significantly different than with traditional computers, interaction with AR is different from other common technology interfaces, including paradigms that are effective for mobile devices. Cumbersome gestures in front of a user's face are likely not the answer. Instead, the AR interfaces of the future should be intuitive and natural, context-aware, and with graceful fallbacks across different platforms, available information, or device capabilities. There is an opportunity now to establish best practices and even common shared technologies—something that organizations such as Mozilla are working on.

Finally, one crucial question spanning health, privacy, security, and on-going technology development and research is how users can be adequately protected from potential downsides without being disruptive to those users or stifling the creativity and innovation necessary to allow impactful, transformative uses of AR.

Synergies and Convergence

There are projections that AR earnings will eclipse VR as soon as 2021 (SuperData Research, "State of the XR Market," February 2018.) As with many technologies, it is only natural to continue to think about applying AR "just as AR"—advancing and using AR by itself without considering how the fundamental nature of AR is related to other advancing technologies. Indeed, if one considers the looming pervasiveness and technological advances of AR together with concurrent advances in other synergistic technologies, one can envision a wide range of potential opportunities to broaden the impacts of AR, addressing complex problems, and enriching our lives.

Some technology areas are naturally associated with AR, e.g., optics, displays, networking, localization, and sensing in general. Other emerging or advancing areas such as robotics, artificial intelligence (AI), and the Internet of Things (IoT) are less traditionally associated with AR, and yet there appear to be natural synergies with AR, and opportunities to go beyond transdisciplinary research where fields overlap and integrate, to the development of new fields with new directions for research that can attract and draw from deep integration of researchers in the different disciplines, leveraging their collective strengths to solve outstanding problems. Such "Convergence Research" is presently recognized by the National Science Foundation as one of the 10 Big Ideas for Future NSF Investments.

Several examples of potential convergence areas were discussed at ARVW. One example recognizes the synergy between AR and robotics. The field of robotics has made tremendous advances in recent years, with devices becoming more intelligent, robust, and portable, while demographic and economic factors continue to increase our dependency on robots. Yet a fundamental limitation of most robots is that once manufactured, they represent a singular embodiment with an appearance that is tailored to its use case. The

robot may be reconfigured but otherwise cannot change. Conversely, the appearance and behavior of AR entities today are flexible and versatile, and can be transformed into other entities right in front of us since they are not constrained by the laws of physics in the real world. The spatial appearance of AR entities is elicited through photons, which by themselves are unable to exert physical changes, while robotic devices are well-suited to manipulate and affect the real world by opening doors, moving furniture, or picking up objects. The capabilities and strengths of AR and robotics are largely orthogonal, which limits the fundamental paradigms of these fields if looked at in isolation. The ARVW attendees envision a new field of research and application aimed at the development and exploration of novel entities that comprise all of the real-world actuation and sensing abilities of robots with the richness and flexibility of AR entities.

Other examples of potential convergence discussed at ARVW include AR with computational and data-driven sensing in general (beyond just computer vision), as well as neuroscience and cognitive psychology. Open challenges include understanding how the human brain adapts or responds to existing multi-modal AR stimulation; how signals and data that are not perceptible to humans could be understood and transformed into existing human sensory channels, and how the brain might adapt to such unusual sensory stimuli; how such techniques might be used to stimulate early brain growth, or re-growth after damage, or behavioral modification associated with addiction or other negative behaviors; how collective sensing and cognition among multiple people could be combined and leveraged to understand or act in situations that are typically beyond the abilities of a single person.

ASSESSMENT AND ACTION

While there are a growing number of smartphone-based AR applications, today's head-worn AR display systems are primarily targeted at researchers, developers, and perhaps ambitious consumers. This is notably limited when compared to the readily available and inexpensive consumer versions of Virtual Reality systems from Oculus (Rift) and HTC (Vive) for example. However, this appears to be changing, with Microsoft and others continuing to evolve their AR systems, making them more capable and robust, and consequently

increasing consumer interest. Now is the time to explore questions and challenges, while the technology is developing, policies are undefined, and widespread adaptation of AR is in the future.

One question is what should researchers, developers, funding agencies, policy makers, and users do next? The ARVW attendees feel that several synergistic/convergent technology opportunities should be actively explored, for example via curated cross-pollination between conferences or symposia associated with different communities (e.g., AR, AI, robotics, etc.), joint special issues of journals seeking position papers or proposals, and even joint workshops on areas of possible convergence. If the cross-community efforts bear fruit, future visioning or convergent topic workshops could work toward specific recommendations for research programs that seek to engage researchers in new convergent areas to provide opportunities to inspire new researchers to explore convergent approaches to solving some of the difficult societal challenges identified at ARVW and beyond.