AUGMENTED REALITY + VIRTUAL REALITY

Privacy & Autonomy Considerations in Emerging, Immersive Digital Worlds

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FUTURE OF PRIVACY FORUM

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EXECUTIVE SUMMARY

Virtual reality (VR) and augmented reality (AR) applications can enhance entertainment, gaming, learning, and other experiences by immersing users in a digital world or adding images of digital objects to individuals' perceptions of their physical surroundings. VR most commonly employs headsets that rely on stereoscopic displays, spatial audio, and motion-tracking sensors to simulate a wholly virtual environment. AR layers virtual elements onto physical environments, typically via smartphones or displays mounted on specialized eyeglasses. VR and AR collectively fall under the umbrella term of "XR." Many XR technologies use headsets, but others employ advanced hardware – from heads-up displays (HUDs) on car windshields to full-sized virtual environments that feature haptic clothing, artificial wind, and dozens of cameras. Nearly all XR technologies rely on detailed information about users, their surroundings, and sometimes nearby individuals.

Today, XR technologies are used in fields including gaming, military training, architectural design, education, social skills training, medical simulations, and psychological treatment, among others. These technologies provide substantial benefits to individuals and society. But XR technologies typically cannot function without collecting sensitive personal information — data that can create privacy risks. Some VR and AR systems rely on biometric identifiers and measurements, real-time tracking of individuals' location, and precise maps of the physical world including the interiors of homes, offices, and medical facilities. XR systems also raise novel questions about how immersive technologies might increase or mitigate the risks of online harassment or impersonation.

Individuals and organizations are increasingly adopting XR hardware and software. In order to promote the benefits and mitigate the risks of these emerging, immersive technologies, FPF recommends:

- Policymakers should carefully consider how existing or proposed data protection laws can provide consumers with meaningful rights and companies with clear obligations regarding XR data;
- Hardware makers should consider how XR data collection, use, and sharing can be performed in ways that are transparent to users, bystanders, and other stakeholders;
- XR developers should consider the extent to which sensitive personal data can be processed locally and kept on-device;
- XR developers should ensure that sensitive personal data is encrypted in transit and at rest;
- Platforms and XR experience providers should implement rules about virtual identity and property that mitigate, rather than increase, online harassment, digital vandalism, and fraud;
- Platforms and XR experience providers should establish clear guidelines that mitigate physical risks to XR users and bystanders;
- Researchers should obtain informed consent prior to conducting research via XR technologies and consider seeking review by an Institutional Review Board (IRB) or Ethical Review Board (ERB) if consent is impractical;
- Platforms and XR experience providers should provide a wide-range of customizable avatar features that reflect the broader community, encouraging representation and inclusion; and
- Platforms and XR experience providers should consult with the larger community of stakeholders including, industry experts, advocates, policymakers, XR users, and non-XR users, and integrate community feedback into decisions about software and hardware design and data collection, use, sharing and user control.

INTRODUCTION

After decades of development, demonstrations, and improvements to hardware and software, immersive technologies are increasingly implemented in education and training, gaming, multimedia, navigation, and communication. Emerging use cases will let individuals explore complicated moral dilemmas or experience a shared digital overlay of the physical world in real time. As current technologies are more widely adopted and emerging technologies mature, virtual reality (VR) and augmented reality (AR) applications will likely converge into one extended reality (XR) category.

AR and VR need not be cabined to a single wearable device – full-sized virtual environments already exist, as do interactive heads-up displays and AR software on mobile phones. The most common type of hardware is a consumer-grade wearable headset, known as a head-mounted display (HMD); more powerful, less expensive HMDs are the most likely path to widespread adoption of immersive digital realities. HMDs are not as ubiquitous as mobile phones, gaming consoles, or laptop computers, but HMDs offer increasingly sophisticated XR experiences, with substantial support from leading companies and researchers.

XR technologies rely upon the collection of huge amounts of information and the processing of sensitive data, including users' biometric data, unique device identifiers, location, information about the interior of homes and businesses, and more.[1] Without this data, XR technologies cannot function safely and effectively. At the same time, these sensitive data categories have become flashpoints in ongoing data privacy controversies, prompting vigorous debate, regulation, and proposed limits on the ways organizations may collect, use, and share data.[2] As XR technologies become more popular, developers and XR platforms will gain access to rich new sources of information about individuals.

Further, the social mores and norms for virtual worlds and augmented physical space are only developing. HMDs raise many questions about privacy, free expression, and evolving digital norms. It is clear that new, high-volume streams of user data raise privacy issues.[3] The Future of Privacy Forum has long cautioned that the internet of things tests traditional notions of data minimization, but XR presents an even more visible and potentially sensitive confluence of sensors and connectivity.[4] Each iteration of AR and VR has improved in quality by collecting more information about users and the physical world. Future advances will rely on data from an increasing pool of users and locations. In addition, future, miniaturized HMDs will almost certainly collect data about non-users – individuals who have not adopted XR technologies and may not be aware that HMDs are operating near them, or that the devices exist at all. Organizations can

What types of data are collected in XR?

- **Sensor Information** — Devices can include cameras, motion and depth sensors to collect information about the immediate physical environment and physical movements.
  - **Audio Information** — Devices can include microphones that can capture audio of the user's voice, as well as acoustic sound from the device's surroundings.
  - **Biometrically-derived Information** — Devices also include inward-facing sensors that can track pupil measurements and gaze, as well as iris identification.
- **Location Information** — Devices can collect approximate location information using the device's IP address and may derive precise geolocation information and other location information from data collected from the device as well as location-based services including Wi-Fi and Bluetooth.
- **Device Information** — Devices can include log files that include information about hardware and software, device identifiers, and IP addresses.
- **Usage and Technical Information** — Devices can collect information about the apps used and purchased on XR platforms, including application telemetry, time spent using app features, and interactions with other users.

INTRODUCTION

take steps ensure XR technologies benefit users and bystanders, and that risks are appropriately mitigated. Such measures are typically most effective when they are implemented early in the development process.

Much of the information needed to fuel XR experiences is highly sensitive. An HMD collects biometric information about its wearer, knows its precise location in space, relative to its surroundings and other XR devices, and records the external world, potentially capturing other people and places. XR platforms and developers must comply with existing legal obligations. But many existing legal requirements were not drafted with XR in mind, and XR providers could benefit from agreeing on and articulating best practices and ensuring compliance regimes recognize the unique or heightened privacy risk raised by XR.

In virtual environments, individuals will increasingly have the option of adopting a realistic lifelike avatar or entirely novel forms of self-representation. Both options come with risks and rewards. Rewards include enhanced avatar customization leading to more nuanced self-representation better mapping to user identity, attributes, and preferences. Greater customization and realism will increase user "presence" and feelings that the user is inside and interacting with a virtual world. Potential risks include the ability to attach digital content to an avatar against a user's wishes in a way that may facilitate the worst of human behavior through digital vandalism resulting in individuals carrying permanent digital "kick me" signs on their avatar's back. Added realism will only exacerbate the negative consequences and feelings stemming from digital harassment and vandalism, as users feel a greater sense of identification and attachment to their avatars and immersive environments.

Immersive realities also have the potential to allow individuals to more deeply empathize with how others may view or understand the world. XR will also create whole new universes for individuals to express themselves, assemble, and share information. However, virtual freedom of expression needs to be balanced against inclusive and safe environments. Already there is an emphasis on developing respectful XR that is balanced with diversity and variance of community culture. However, the current community of developers and users does not yet reflect the diversity of the real world, so XR developers and creators will need to proactively include diverse voices and be especially mindful about how XR experiences will impact individuals' privacy and autonomy, particularly for vulnerable populations.

This tension between potential benefits and corresponding risks underlies many of the different technologies powering XR. This paper describes the current landscape of immersive technologies, their trajectory of development, and discusses the software and sensors that power their use. It distinguishes between several categories of XR use cases and how those applications intersect with how individuals communicate and interact with each other and the world. Finally, we explore how the technology and these experiences pose both data privacy and larger normative issues for developers, XR platforms, and society at large.

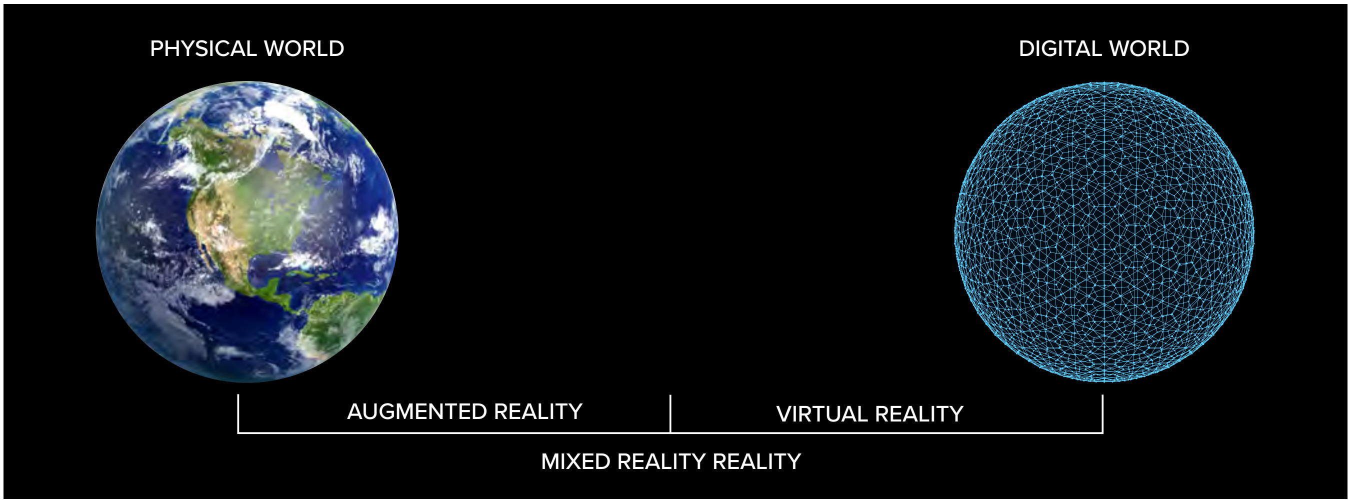
PART I: Virtual Reality & Augmented Reality Technologies Can Create Immersive Virtual Worlds or Display Digital Objects in Physical Environments

I think the relationship between [virtual and augmented reality] is similar to the relationship between film and television: They come through the same streams to the same devices, yet they're still distinct. They have distinct cultures, they're made in different ways, we have different expectations of them. Classical VR is ultimately more about you, it's more about the human body, human identity, human interaction. Mixed reality is about exploring the world.

—Jaron Lanier, Computer philosophy and "founding father of virtual reality"[5]

XR communications and interface technologies that blur digital and physical lines are powered by a combination of advancements in computer vision, graphic processing power, display technologies, and input systems. These systems require effective tracking, image rendering capabilities, and display technologies.

VR is not a new expression and AR has been popularized by gaming apps like Pokémon Go. These two terms have been joined by new buzzwords like mixed reality (MR) and XR. Researchers and computer scientists speak of a "virtuality Continuum"[6] and it is easiest to think of all of these terms as describing a spectrum of different technological applications.



PART I

There is no universal definition of different immersive technologies, but technical standards bodies like the IEEE and trade associations like the Consumer Technology Association have made efforts to clarify and define digital reality, as well as related technologies and functionality.[7]

Virtual reality (VR) aims to create a fully immersive user experience, replacing physical reality with a digital environment. VR requires specialty hardware and is most commonly achieved through headsets like the Oculus Quest that rely on stereoscopic displays, spatial audio, and motion-tracking sensors to simulate a "real" experience.

Augmented reality (AR) layers virtual elements onto real-world environments via smartphones or heads-up displays (HUDs). Rather than focusing on immersion, AR relies on software that extracts data from visual representations of the physical world to overlay and superimpose computer-generated sensory inputs such as sound, video, graphics, or other virtual content such as annotations or real-time commentary.

Mixed reality (MR) is sometimes characterized as existing on a spectrum between AR and VR, but it shares more in common with AR. The key difference is that MR aims to provide a more interactive experience than basic AR applications. While basic AR simply overlays information onto a physical environment, virtual content in an MR environment can interact with and respond to non-digital objects or content in real time.

XR, sometimes referred to as "extended reality," is an umbrella term often used to encompass AR, VR, and MR, as well as other future immersive reality applications, technologies, or experiences.[8]

A. Virtual Reality Immerses Users in Virtual, Digital Experiences that Can Include Interactive Graphics, Sound, Haptic Feedback, Wind, Water, and More

The dream of using technology to create an artificial, immersive environment went hand-in-hand with the development of the computer age. Computer researcher Ivan Sutherland is credited with starting the field that would become VR in the 1960s when he envisioned an "ultimate display" as a "room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked."[9] Research into the hardware needed to explore digital space would continue apace, but the term "virtual reality" would take another two more decades to emerge. Jaron Lanier of VPL Research first popularized the term in 1987, the same year that a "holodeck" debuted on *Star Trek: The Next Generation* as a photonic escape from reality for the crew of the starship Enterprise.[10]

VR is premised on the creation of fully immersive experiences.[11] "Presence is the *sine qua non* of VR," explains Jeremy Bailenson of the Stanford Virtual Human Interaction Lab.[12] In effective VR, individuals' motor and perceptual functions interpret virtual environments to be generally the same as physical reality. This psychological and physiological effect relies on technological inputs and outputs to immerse users within and provide them with control over digital experiences.

Inputs, such as a user's motion captured HMDs and haptic devices, allow a user to navigate within a virtual environment and include tracking capabilities to capture the user's movements and location. Input devices can range from traditional controllers, including mice and joysticks, to more advanced technologies that can capture hand movements and gestures for more precise control. Effective VR requires extensive data collection and processing activities. Internal and external inputs are also needed to do positional tracking and translate a full range of an individual's physical movements into a digital environment. Early models of the Oculus Rift headset, for example, were equipped with more than a dozen sensors including gyroscopes, accelerometers, and compasses as well as external infrared sensors and cameras to track the location of a user's head.[13]

Output displays allow the user to see and hear everything that happens in a virtual environment, while haptic mechanisms may provide a virtual sense of touch via tactile feedback.[14] Virtual sights and sounds, however, are generally achieved through two main technologies: (1) Cave Automatic Virtual Environments (CAVEs) and (2) HMDs. CAVEs are room-sized installations that rely on projectors to create a virtual environment against the walls and ceilings of the room.[15] HMDs, or VR headsets, are wearable devices worn by users that can generate realistic audio and visuals.[16] Recently released headsets are more affordable and higher quality than their predecessors; they have become the primary consumer-vehicle for in-home VR, including low-cost efforts like Nintendo's VR Kit Labo.

Accurate positional tracking and seamless 6DoF are features often associated with VR headsets, but these technologies will play an important role in making AR and MR more consumer-friendly and functional.

Degrees of Freedom in Virtual Space

HMDs offer different degrees of freedom (DoF) and movement to experience VR. Some systems only allow users to look around, while others provide full freedom of movement in a virtual space. There are six total degrees of freedom in 3D space.

Three degrees of freedom (3DoF) can track orientation—pitch, yaw, and roll—to register whether a user has turned their head, tilted it up or dawn, or pivoted it left or right.[17] These types of VR systems are best experienced sitting on a couch with a controller and can potentially be less immersive and disorienting.[18] While experiences that rely on 3DoF remain marketable, HMD platforms are rapidly embracing technology that permits six degrees of freedom. 6DoF creates a defined physical use space and includes tracking of translational movements like (4) moving forward or backward, (5) left or right, and (6) up or down.[19]

Positional Tracking

A VR HMD—as well other XR devices—needs to "know" its position relative to its environment. Positional tracking relies on a combination of software and hardware, as well as visual and inertial sensors to model a user's position.

6DoF once relied heavily on external sensors and cameras that were tethered directly to a computer. This sort of "outside-in" tracking requires careful setup and a dedicated space, but new VR systems can now do "inside-out" tracking via sensors on the HMD itself and use computer vision to track a user's position in real time.[20] To maintain immersion, tracking must be both accurate and low-latency. Some technologies support tracking with precision greater than a single millimeter and then use predictive algorithms to reduce latency (or lag) between physical and virtual movements.[21] These sorts of on-board external sensors can also facilitate VR hand-tracking, giving users more sensitive estimations of DoF in how they use their hands to manipulate a virtual environment.[22]

B. Augmented Reality Modifies Users' Experience of the Physical World with Computer Generated Images and Other Information

AR is closely related to VR. An AR experience displays all or most aspects of the physical world, but relies on technology to augment or modify the physical world with computer-generated information such as sound, video, or graphics. There is no universal definition of AR, but researchers at the University of Washington have posited that AR is comprised of a family of related technologies.

Specifically, technologies that deploy AR can sense properties of the physical world in real time, output contextual information to the user, and recognize and track physical objects.[23] While each of these elements is important, the real-time contextual nature of AR is what can make the technology magical. At present, however, the most common applications of AR are interactive filters that are superimposed onto a physical environment—often in the form of digital ads[24]—and dancing Pokémon and Instagram and Snap face filters are prime examples of rudimentary AR.

Many smart devices with a camera and a screen can output basic AR, and mobile AR via smartphones and tablets have been the primary way consumers have interacted with the technology. In some cases, mobile AR has the drawback of forcing users to hold out their devices as viewfinders reducing the feelings of presence a user experiences. However, vehicle-based static smart screens or HUDs largely avoid these presence issues, as they serve a narrower purpose of providing wayfinding and other digital information related to travel. Digital eyewear, allowing the user to easily move throughout an environment without sacrificing immersive elements, remains the holy grail of visual AR.[25]

The quality of AR depends upon the environmental understanding capabilities of the user's device. AR software uses a process known as concurrent odometry and mapping (COM) or simultaneous localization and mapping (SLAM) to understand the device relative to the world around it.[26] In short, mobile AR software relies on a device's camera and other onboard sensors like gyroscopes and accelerometers to build a map of the local environment and locate where the device rests in that world.[27] Frequently, environmental considerations like lighting and surface detection are important to ensure AR experiences are convincing, providing users with an immersive experience.

C. MR, like AR, Blends the Physical and Digital Worlds, But with an Extra Layer of Interactivity

Some AR experiences are increasingly more interactive and less passive when blending physical and digital worlds, moving toward MR experiences. MR is fueled by advances in AR combined with the immersiveness of VR, and MR promises to create a tangible digital environment that not only overlays the physical world but is persistent and interactive. Futurists as well as major technology companies view MR as a potential successor platform to today's ubiquitous mobile computing.[28]

While AR and VR also rely on differing degrees of spatial awareness and environmental inputs, MR incorporates an array of sensory inputs including device tracking, spatial mapping and scene understanding, and object recognition.[29] Comfortably controlling these experiences require advances in controls including hand gestures, voice control, and eye tracking to interact with virtual content.[30]

Some organizations are using VR and AR technologies as stepping stones to developing MR experiences, Magic Leap headsets and Microsoft's HoloLens are the most prominent products in this category. Both headsets are characterized by translucent displays that allow users to see—and interact with—a physical environment. Digital holograms, visible only through the HMD, are overlaid onto the physical world and can be manipulated via controllers or hand-gestures. Users get a hands-on ability to manipulate overlays and virtual content in real-time.

For MR to function, these devices require a local spatial map or create anchor points within the space the HMD will be used. These anchors represent important points in the world that the MR system will keep track of over time. While these maps can be created and stored locally, a shared world map may be needed to unlock MR's full potential. Both the Magic Leap and HoloLens headsets allow for these maps to be shared across devices and applications via the cloud. Azure Spatial Anchors and Magic Leap's Shared World facilitate multi-user experiences, location-based content and wayfinding, and persistent virtual content.[31] The data collected by these maps is extensive and can include horizontal and vertical planes, acoustic information, and other types of object data to create a 3D grid that can represent shape, position, distance, and volume of objects.[32]

D. Advances in XR Will Occur Alongside, and Are Dependent On, Other Technological Advances

Advances in XR are not happening in isolation. Improvements in artificial intelligence, for example, are most intertwined with the ability to develop more immersive experiences. AI aides in the mapping of the physical world and the creation of more realistic virtual simulations and independently acting avatars.

The evolution and widespread adoption of XR also may be dependent on an array of different technologies and telecommunications systems. 5G wireless networks may support the next generation of AR and VR experiences, but policy and technical issues surrounding a number of technologies will impact XR.

Related Technologies

- **5G** and **Edge Computing** are potentially vital infrastructure for XR experiences.[33] Fifth generation mobile networks (5G) will bring not just ubiquitous, high-speed connectivity, but also facilitate edge computing, which is a form of cloud computing that brings digital content and computing resources closer to a user.[34] This reduces latency, which is important for immersive XR, and could facilitate the introduction of lower cost, low-weight wearables like AR glasses.

- **AR Cloud** or **Point Cloud** is a persistent digital content layer that is mapped to objects and locations in the physical world, providing a digital legend to annotate objects and places in the physical world.[35] For example, Niantic, the developer of Pokémon Go, developed a shared "Real World Platform."

- **Smart Glasses** or **Digital Eyewear** is the holy grail of visual AR.[36] While mobile AR has the drawback of forcing users to hold out their devices as viewfinders and static smart screens or HUDs lack portability, a lightweight, fashionable, and always-on wearable promises to be the next mainstream digital platform.[37]

- **Spatial Computing** is an umbrella term for technologies that understand the physical world and can communicate and navigate through those spaces.[38] At a basic level, it can include basic location sensors like GPS and location-based services including Wi-Fi and Bluetooth, but XR requires highly precise location awareness to present real-time immersive digital content.

- **Computer Vision** is a field of artificial intelligence that trains computers to interpret and understand the visual world. In addition to mapping a visual environment, XR experiences will benefit from advances in facial recognition and characterization as well as object recognition.

PART II: XR is Increasingly Used for a Variety of Applications, Each Presenting Unique Benefits and Challenges

Imagine 10 years ago trying to envision the way we use cellphones today. It's impossible. That's the promise VR has today. VR at its best shouldn't replace real life, just modify it, giving us access to so much just out of reach physically, economically. If you can dream it, VR can make it. It's a medium for progress, not the progress itself.

—Matthew Schnipper, introducing the Verge's Rise and Fall and Rise of Virtual Reality[39]

Major technology companies, app developers, and investors are enthusiastic about the potential of XR to be the next game-changing user interface and technology platform. VR has applications in fields ranging from gaming, military training, architectural design, and education to social skills training, medical simulations, and psychological treatments.[40] VR "games" have been designed to treat anxiety, and virtual reality has potential to let terminally ill patients confront fears of death and for caregivers to express empathy. There may be many untapped forensic applications for VR for criminal investigation and prosecution.[41] The sensory and data collection capabilities of HMDs could even make them useful tools to assist individuals with disabilities.[42]

Although VR applications make headlines, AR may have greater potential utility and market share in the long-term than dedicated VR.[43] The economic stakes are significant with estimates pegging the entire XR market at anywhere from $35 to $550 billion globally by 2025.[44]

While there are numerous potential applications for XR technologies, today gaming is the primary driver of app development, but education and training applications also have seen significant uptick amongst developers.[45] Though there may be some audience overlap, these broad use cases raise different and unique privacy compliance issues and may fall under different legal regimes, particularly in the United States. For example, gaming apps are primarily directed to the general consumer market; educational uses typically involve schools; and training applications are often targeted to employers looking to reduce costs and improve training throughput and are experienced by employees in the workplace.

A. Gaming and Entertainment is XR's Most Popular Use Case

The majority of XR developers are working on video games. This should come as little surprise—gaming has been an important catalyst for technological advances in a range of related technologies, including graphic processing units (GPUs) and control interfaces like motion and voice inputs, and gaming apps can serve as a sort of trial run or tutorial for broader application. Video games and XR have gone hand-in-hand and have a long history. Sega announced an early VR headset at the 1993 Consumer Electronics Show, and Nintendo followed by launching its ill-fated Virtual Boy system in 1995. More recently, XR made its biggest headlines as a core feature of Pokémon Go, and Beat Saber, a VR rhythm game that brings dancing and lightsabers into the mix, is arguably the medium's first killer app.[46]

The larger potential for XR may be in new forms of games featuring social interaction. Echo Arena offers a glimpse of the potential of cooperative VR gaming experiences. Echo Arena involves players adopting an avatar and joining teams with other users with the goal of scoring a goal in a game resembling a zero-gravity version of ultimate frisbee by navigating and throwing a flying disc through various obstacles.[47] In-game success is often dependent on communication and collaboration with other players.

AR similarly could benefit from becoming more social.[48] Using AR to bring people physically together has been a core part of some apps' value. Pokémon Go developer Niantic encourages AR technologies that promote exploration and social interaction. One area that holds tremendous potential in AR is creating innovative new tabletop and board game experiences. AR board games offer a number of advantages over physical counterparts, eliminating the need to set up complicated boards and allowing play with friends and families regardless of whether everyone can assemble in person for a game night.[49]

XR and Children

Use of XR by children raises a number of specific privacy and ethical issues. The effects of immersive technologies on children warrants further study, but initial research suggests that the immersive aspects of XR do produce different physiological and behavioral responses. Some research suggests that children experience virtual environments less like traditional media on television and more like an actual physical experience.[50] This renews longstanding questions about the impact of violent or aggressive gaming experiences in VR; it also raises issues with "playable" virtual and augmented advertisements increasingly of interest to marketers.[51]

Further, another important consideration in game development is compliance with the Children's Online Privacy Protection Act (COPPA). The U.S. law applies to "operators" of online services directed to children under 13 or that have actual knowledge that they are collecting, using, or disclosing personal information from children under 13. Leading HMDs take different approaches:

- The Oculus Rift states the device is not to be used by children under age 13. Adults should monitor children age 13 and up who use the headset.
- PlayStation VR states the device is not to be used by children under age 12.
- HTC Vive provides no specific age restriction, but there is a warning that the "product was not designed to be used by children" and that if "older" children are permitted to use the product, an adult should monitor them.

While many XR companies have mature COPPA-compliance efforts, the data collection potential of XR devices should not be discounted. For example, advocates argue that companies developing devices that collect children's voice data are not obtaining parental consent as required by COPPA.[52] The FTC is currently considering whether biometric data or other information should be included in COPPA's definition of personal information. Looking forward, the merging of XR headsets with brain-computer interfaces (BCIs) involving sensors such as electroencephalogram (EEG) could permit app developers and game designers to make "personalized games" that respond differently based on whether a user is excited, happy, sad, or bored.[53]

B. XR is a Powerful Tool for Education and Training

The immersive and social aspects of XR make it a potentially powerful educational tool. AR and VR have been hyped by some as a "pedagogical silver bullet."[54] Digital overlays can provide step-by-step instructions, and the immersive aspects of XR allow for history to come alive. In 2017, for example, British artist Mat Collishaw digitally recreated the first photography exhibit held in 1939. The XR exhibition transformed a white room strewn with bookshelves and tables into a virtual space adorned with photos and artistic works now too degraded for public display.[55] This ability to step into history—and to interact with physical objects mapped and textured to replicate historical artifacts—has been a selling point of VR.

When the technology was initially introduced in classrooms, XR was presented as a tool to let students go beyond the walls of a school and experience places and locations too impractical to visit. Now, Google offers over 900 different AR and VR "Expeditions" for students.[56] But a virtual trip to the moon or an AR dinosaur rampaging around a classroom are just two applications of XR technologies. Even traditionally conservative educational environments such as law schools are exploring how immersive technologies and VR HMDs can augment legal education.[57] The prevalence of remote learning during the COVID-19 pandemic, only enhances the growing enthusiasm for the educational possibilities presented by VR. However, experts have pointed out that because longer XR sessions can result in feelings of disorientation and cybersickness, XR educational experiences could necessarily be limited to under 20 minutes—far shorter than many traditional class times and lessons.[58]

Further, the U.S. Department of Education is exploring whether VR can help support students with high-functioning autism and other learning disabilities.[59] VR-based learning modules are posited as a way to help students develop independent learning skills, practice social skills, build safety awareness, and navigate challenging community locations.[60]

Proteus Effects

Studies show that XR experiences can alter where users walk, how individuals focus and concentrate, and even basic social interactions, blurring individuals' physical and virtual identities.[61] Some of this is due to the ability of virtual environments to trigger behavioral modulations known as **Proteus effects**.

Artificial environments can be powerful therapeutic tools. Mirror boxes, for example, combine visual feedback and sensory inputs to resolve phantom limb pain in amputees.[62] The immersion of XR technologies can supercharge this effect. In virtual environments, an individual's avatar or digital representation can influence an individual's sense of self. Individuals may embrace attitudes and internal states based on their observation and experience of external cues—and these can translate into their lives outside of XR. Some studies indicate that the following scenarios can influence the ways in which users conduct themselves outside of XR.

- Studies show that racial bias may decrease when white users are represented by "darker" avatars.[63]
- Tall avatars can generate a more confident posture than users with short avatars in a negotiation.[64]
- Users who embody older avatars might take actions to better plan for retirement,[65] and other studies have looked at whether XR can help adults see the world through the eyes of a child.[66]
- An avatar's body shape can affect behavior. Some game players have shown increased physical activity in the outside of XR if they regularly play games with thin avatars as opposed to obese ones.[67]

These types of "body ownership illusions" suggest that XR could be used to not just generate empathy but also potentially modify behaviors and user habits. Deployed responsibly, these effects could help gamers show greater empathy, increase their confidence, and meet financial or fitness goals. Deployed irresponsibly, these effects could inappropriately influence individuals. For example, the use of an avatar resembling a member of the Ku Klux Klan has been shown to activate more negative thoughts and encourage users to participate more aggressively online.[68] Other studies show that sexualized avatars can lead to increased instances of sexual self-objectification, which could be risky and unsafe.[69] XR providers must ensure that immersive experiences benefit users and do not harm them.

These sorts of applications point to a future where VR is used as a sort of empathy-builder. There is a growing body of research that suggests that immersive environments can be a useful tool to simulate how others experience the world.[70] A number of XR developers and creators see potential in the technology to help individuals gain a new perspective on war, sickness, or other types of suffering. Chris Milk, a VR creator and filmmaker, suggests that immersive technologies could be the ultimate empathy machine.[71] However, some advocates suggest that younger children might not understand that perspectives other than their own exist and could struggle with developing empathy for others using VR.[72] Experts also caution that VR can be a powerful trigger for emotional and psychological issues, and it is unclear how exposure to these technologies affects childhood development and educational outcomes.[73]

C. XR Shows Promise as a Training Tool in a Number of Industries

While gaming and educational experiences have external consumer-focused applications, increasingly governments, nonprofits, and businesses see XR's potential in creating internally-focused experiences that have limited or no consumer application. Training applications may overlap significantly with educational experiences or may be substantially different, depending on the use case and audience.

A 2019 study found that individuals experience an 8.8% increase in recall when working in immersive environments,[74] and XR applications have also been found to increase collaboration among users. Thus, while Echo Arena makes for an entertaining immersive gaming experience, the game's emphasis and teamwork, communication, and strategy also points toward a future where XR HMDs are used for training and collaboration in the workplace.

Already, VR training solutions have been posited as a cost-effective replacement for physical nuclear power plant control room simulators.[75] Power plants spend millions of dollars annually to build realistic simulators for training purposes. Similarly, the Air Force has deployed VR to help with pilot training,[76] and collaborations between MR headset makers and medical schools promise to revolutionize medical training, diagnostics, and even surgery.

More typical uses, however, may be more mundane and pose some of the empathy questions at the crux of immersive technologies. For example, many employers are using VR for customer service training, placing employees in the position of having awkward conversations with customers and then switching perspectives to "become the customer."[77] Verizon has used VR simulations to train retail workers how to handle armed robberies, creating real stress responses for employees, while Walmart has highlighted how XR can be used to analyze job applicants to determine who are good fits for certain roles.[78] When employers use XR to evoke emotional responses in employees or otherwise use immersive technologies to make impactful career decisions, it's necessary to incorporate privacy and ethical safeguards and guidance.

PART II

D. Future XR Applications Include Enhanced Navigation, Smart Infrastructure, Communications, and More

XR developers, brands, and hardware manufacturers are seeking new use cases for immersive technologies. One recent survey highlighted the potential for XR technologies to improve smart cities.[79] Navigation, smart infrastructure, and urban planning are potential applications that could benefit from XR, and while incorporation into wearables has drawn more attention, AR may increasingly be incorporated into static HUDs.

Car makers, for instance, have experimented with projecting information onto car windshields since the 1980s.[80] Applications include mirroring dashboard information (e.g. speed or climate control info) on the windshield in the driver's immediate field of view and projecting "night vision" images collected through infrared cameras onto the bottom of the windshield.[81] More advanced volumetric HUDs—offering enhanced accuracy of distance perception—move beyond projecting flat information to creating interactive overlays like GPS arrows or object detection warnings that interact with what the driver is actually seeing on the road ahead.[82] Considering the existing external sensory capacity of newer connected cars, cars may be a unique testing bed for improving AR technologies.[83]

Thus far, these HUDs demonstrate a curated experience. Though excessive displays of advertising and user-generated content (UGC) could prove an HUD eyesore, AR promises tremendous utility to let businesses, governments, and individuals annotate physical space in real-time.

VR, on the other hand, could prove to have massive potential for improving long-distance social interactions. VR platforms are already enabling VR as a new social experience, and the immersion of HMDs could prove a powerful augmentation as remote and virtual conferences become a new normal. VRChat, which is a social app in which individuals can meet, hang out, and interact with others in VR, has remained a consistently popular VR application on a number of XR platforms,[84] and VR conferencing software is being offered as a novel approach to video conferencing.[85]

Many XR developers posit that VR could serve as a widespread communications platform, facilitating more natural telepresence with realistic avatars and holograms. While the social components of XR raise concerns about manipulation and user safety, developers are eager to embrace the collaborative and social aspects of XR.[86] Social experiences and annotative features may be what drives XR in the future, but these applications also raise some of the most important ethical and privacy issues facing the medium.

PART III: Current and Future XR Risks Include: The Vast Tracking of Consumers and Bystanders—Including Their Sensitive Information—Manipulation and Abuse of Digital Identities, Cyberharassment, and More

What are the five most important aspects of VR technology? The punch line: Tracking. Tracking. Tracking. Tracking. Tracking.

—Jeremy Bailsenson, Virtual Human Interaction Lab, Stanford University[87]

Technologies premised on data collection and tracking user behavior will always present privacy challenges. XR applications are dependent upon the collection and processing of vast quantities of information, some of it personal and highly sensitive. The data security implications of XR platforms are also significant. Researchers have identified a range of XR-specific security challenges from protecting inputs, outputs, user interfaces, and physical devices themselves.[88] Growing numbers of consumers report being worried about how the data collected via VR headsets and AR apps are used.[89] XR platforms and app developers have recognized this; a March 2020 industry survey found that consumer privacy and data security has emerged as one of the top legal risks when developing immersive technologies, topping product liability questions, health and safety challenges, and intellectual property and content guideline issues.[90]

XR raises traditional privacy and data governance concerns but also implicates questions of surveillance, social engineering, freedom of expression, and larger ethical questions. These larger issues were discussed at the 2018 VR Identity and Privacy Summit hosted by Stanford University. The conference, which brought together researchers, academics, and industry professionals across the VR, AR, and MR landscape,[91] identified several main areas of concern posed by XR technologies including loss of freedom and autonomy, reputational harm, and diminished opportunity due to the convergence of virtual and offline identities.[92]

Data collection concerns animated some of the initial privacy headlines involving AR and VR. For example, when it launched in 2016, Pokémon Go's account creation process erroneously requested full access permission to users' Google accounts, prompting congressional inquiries and a formal response from Niantic, the game's developer.[93] Oculus' acquisition by Facebook generated similar concerns,[94] and the privacy policies and data collection provisions of VR headset platforms have also been subject to scrutiny.[95] Developers and platforms have responded by updating their privacy notices and other consumer-facing disclosures.

The basic use of these technologies requires significant data collection and use, so collection limitations may be impractical, and use limitations must be carefully crafted to promote trust while ensuring the fundamental operation and safety of XR systems. In addition to account information collected directly from a user, XR HMDs also collect an array of sensor information about the immediate environment, physical movements, and the user herself. In the long-term, this collection can generate surprising insights about (1) users and wearers of these technologies and (2) individuals that incidentally come into contact with XR users. Both of these categories have the potential to create risks for individuals, communities, and society at large.

A. XR Collects a Vast Amount of Personal Data, Some of which is Highly Sensitive

Twenty minutes of VR use can generate approximately two million data points and unique recordings of body language.[96] VR headsets track a dozen types of movements upwards of 90 times per second to convincingly render a scene. Researchers have called for new protections for nonverbal behavior or biometrically-derived data such as posture, eye gaze, gestures, facial expressions, and interpersonal distance that is collected by XR applications.[97] Gaze or eye tracking and gait analysis have been singled out as especially sensitive.

Eye tracking, for example, will be an essential driver of improvements in XR, increasing the capabilities of HMDs and lowering the energy, cost, and weight of these systems.[98] Eye tracking lets headsets focus their graphic rendering capabilities on the precise area of the display where the user is looking. This technique, known as foveated rendering, will allow XR platforms to dynamically scale image quality.[99] More importantly, eye tracking could increase the capacity to direct and control XR content toward users. By making a device aware of what the user is interested in, eye tracking raises the potential of context-appropriate interactions with basic eye controls. The theoretical vision is akin to Tony Stark's ability to use simple eye movements to bring up or activate capabilities in his Iron Man suits.[100]

This increased functionality could come with potential privacy costs. Eyes may divulge information

about individuals' attention and perhaps even subconscious thoughts in ways that are difficult, if not impossible for individuals to control. Research has shown that pupil dilation, which is relatively easily measured by eye-tracking technologies, indicates an individual's level of interest in what they are looking at and can lead to conclusions—whether accurate or not—about a user's age, gender, or race.[101] Gaze can also be used to diagnose medical conditions; eye movements and pupil response can be used to diagnose ADHD, autism, and schizophrenia. Perhaps most concerning, eye tracking technologies can be used to ascertain conclusions about a user's sexual attraction.[102] With no real capacity to control this data stream, XR users will have to trust this information is used responsibly.

Eye tracking has been termed the holy grail of marketing.[103] While the targeted advertising potential of XR has not been lost on advertisers and marketing companies, eye tracking provides new—and effective—ways to measure how many actual human eyeballs viewed an advertisement and provide insights into the effectiveness of the advertising content. Advertising technologies have spent countless resources trying to develop advertising attribution and effectiveness; meanwhile, eye tracking serves as an unconscious "like" button for everything.[104]

The information divulged from eye tracking can be augmented with other sensors, including movement sensors, EEG and brain-computer interfaces (BCIs), and other pressure and fitness sensors. Bodily motions, and the relationship between different body movements and segments, can also serve as a tracking mechanism. Devices can increasingly understand who is carrying or wearing them based on their users' gait,[105] and gait-based digital fingerprinting presents real privacy concerns in XR environments. The unique identifiability of gait and widespread gait-analysis may undermine the ability of XR users and individuals generally to maintain anonymity.[106]

Researchers have suggested that motion data could serve as a reliable behavioral biometric.[107] Head motions and the distances between an XR headset and other devices or controllers are especially promising unique identifiers that could even serve as a potential authentication method. Spatial relations and motion data among hands, eye gaze, and head direction can be incorporated into identification models that outperform chance by a factor of ten, and this tracking data raises the same deidentification and anonymization concerns that exist around similarly granular data types like historical geolocation and genetic information.

This type of profiling, while potentially sensitive and derived from biometric information, was not contemplated by lawmakers when crafting many privacy laws; it likely does not fit squarely within existing legal definitions of biometric data under U.S. state privacy laws like the Illinois Biometric Information Privacy Act (BIPA) or frameworks such as the EU General Data Protection Regulation (GDPR).[108] BIPA, for instance, applies to "scans" of hand or face geometry, retinas or irises, and voiceprints and does not address behavioral characteristics or eye tracking.[109] While the GDPR applies to all information relating to an identifiable person, specific provisions around biometric data apply when that information is used to identify an individual. While stakeholders will continue to debate how existing biometrics laws apply to XR, early research suggests there are strong XR consumer preferences against expansive use or sharing of eye tracking and other biometrically-derived data.[110]

B. XR Can Collect Information about the External World and Bystanders

While much of the privacy discussion has focused on how extensive data collection and use directly impacts an individual XR user, these technologies will also have spillover effects. Bystanders outside of an XR experience may be affected, and the synchronous and persistent aspects of these technologies raise privacy and ethical challenges for members of an XR community and potentially bystanders who come into contact with the technology.

AR headsets have a long history of being portrayed as a potential privacy threat to an unknowing public. When Google Glass was announced in 2013, users imagined a future where someone's name, social media information, and Google search results could be pulled up simply by looking at them while wearing the smart glasses. These concerns have often gone hand-in-hand with generalized worries about biometric data collection, prompting Google to preemptively announce that it would not permit facial recognition applications on Glass absent strong privacy protections.[111] Many current developer guidelines restrict these sorts of use cases. For example, Magic Leap's Technical Requirements Checklist prohibits apps from using the device to identify a non-user.[112] However, other AR manufacturers are more aggressively exploring facial recognition applications. Reporting about Clearview AI, a service which surreptitiously scraped photos from social networks, uncovered code that identified a potential companion app designed by AR firm Vuzix.[113] Vuzix announced public partnerships to deploy facial recognition in its products targeting law enforcement, first responders, retail, hospitality, and banking.[114]

Facial recognition use cases draw headlines, but the sensors and connectivity tools of XR devices could be used on non-users in surprising and controversial ways that do not involve facial recognition. As the ACLU has highlighted,[115] video analytics software that can purportedly sense cognitive states or recognize emotions is developing rapidly, and the inclusion of this functionality in HMDs or AR headsets is likely. Instead of simply pulling up a name, social media profile, and list of search results, XR headsets could track eye movements, pupil dilation, and other contextual cues of non-users to help users navigate awkward first dates or job interviews, reshaping basic social interaction.

Government Surveillance and XR

A possible future in which XR technologies are widely deployed in public has already raised concerns about government surveillance and access by law enforcement agencies.[116] This is true both in the United States and globally. In the U.S., XR technologies pose further tensions for the Third Party Doctrine, which holds that an individual who voluntarily provides information to third parties, including Internet platforms, often lacks a reasonable expectation of privacy under the Fourth Amendment. As a result and as disclosed by all leading XR platforms, any information collected or processed in an AR or VR environment that is not processed locally could be obtained by police in response to a legal request.

While the Third Party Doctrine remains, a series of Supreme Court cases have begun to chip away at its breadth in recognition of the scale of information generated by electronic devices. Beginning with *United States v. Jones*, 565 U.S. 400 (2012), and *Carpenter v. United States*, 138 S. Ct. 2206 (2018), the Supreme Court held that granular geolocation data obtained from GPS devices and cell-site records required a warrant before being accessed—even though this location data was divulged publicly. In a separate case, *Riley v. California*, 573 U.S. 373 (2014), the Supreme Court noted that "a cell phone collects in one place many distinct types of information—an address, a note, a prescription, a bank statement, a video—that reveal much more in combination than any isolated record."

In other words, the Supreme Court appears to be acknowledging that technological advances may require extending constitutional protections over data that had previously been treated as non-private and accessible to government authorities. Privacy advocates have sought to expand this rationale further to additional types of sensitive information.

The data generated by XR experiences could prove a good candidate. Kevin Kelly of *Wired* has cautioned that "synchroniz[ing] the virtual twins of all places and all things with the real places and things, while rendering it visible to millions will require tracking people and things to a degree that can only be called a total surveillance state."[117] XR information that divulges a user's sexual identity could present real harms in parts of the world where, for example, LGBTQ status is legally persecutable. To the extent that XR data is processed remotely, the scale and sensitivity of this information—and its connection to real-world activities—could serve as a catalyst for further reconsideration of the Third Party Doctrine.

Beyond merely accessing consumer XR data streams, law enforcement officials themselves will demand using XR technologies in the field. Virtual reality's training potential has obvious law enforcement applications,[118] and vendors like Vuzix already are pitching facial recognition capable smart glasses as the "future of law enforcement."[119] HUDs and other wearable HMDs may have dramatic impacts on policing, with AR applications for patrolling, SWAT operations, criminal investigations, and training and supervision.[120] Some of these applications could challenge the Supreme Court's decision in *Kyllo v. United States*, 533 U.S. 27 (2001), which held that the use of a thermal imaging device to measure heat emanating from a private home was a search under the Fourth Amendment.

C. XR Can Lead to the Manipulation and Abuse of Digital Avatars and Identity

While the above concerns, in some respects, bring existing data protection discussions into the XR space, XR also raises tough new questions about individual autonomy and ownership in virtual worlds. Digital avatars, though not new,[121] take on a larger importance in virtual environments.

Future XR applications may provide a fully synchronous experience where individuals interact among users who are simultaneously logged into a digital environment. In some virtual environments, users need a way to interact with each other, and avatars provide needed context. However, it is an open question how realistic and representative digital identifiers can or should be. There are also current technological limitations. For example, when Facebook announced "Horizon," its social VR platform for Oculus, none of the avatars had legs. The primary reason for this is likely that convincing leg-tracking technology is harder to pull off than eye tracking or hand-tracking. Cartoony avatars also help avoid "uncanny valley" issues in VR. An uncanny valley can occur when artificial figures are not convincingly realistic, creating a sense of unease.

Facebook has demonstrated technology to create realistic digital representations of individuals through its Codec Avatars Project. This technology is still nascent—the Codec Avatars Project relies on an array of external sensors and monitors to replicate individual faces—and facial expressions—in tremendous detail.[122] Currently, this technology is far from the mass market. To create a single avatar, an individual sits in a dome fitted with 132 cameras and 350 lights aimed at them while their facial features are mapped over the course of an hour. However, developers believe realistic avatars of this degree will be necessary to achieve authentic telepresence in VR.

While developers work to improve the technology behind responsive and realistic avatars, the notion of prevalent, realistic avatars raises fundamental questions about an individual's ownership and control over their digital identity. With lawmakers and regulators increasingly interested in (1) "deepfakes" and other digital manipulations of audiovisual representations[123] *and* (2) how developers deploy nudges and other manipulative digital interfaces suggests,[124] the rules and norms around avatars could become a potential flashpoint in widespread acceptance of XR technologies generally. Further research and increased adoption of XR will illuminate how the feelings of presence when using immersive technology influence the attitudes and behaviors users have when interacting with one another in XR.

XR and Immersive Gaming Litigation

To date, litigation involving XR and immersive gaming is limited. Much of the litigation focuses on misappropriation of likenesses in immersive gaming. These cases are of limited predictive value, since they involve celebrities and athletes' likenesses.[125] Moreover, the courts' decisions in these cases hinge on Copyright issues and First Amendment concerns outweighing celebrity's commercial interests—a dynamic that is unlikely to apply to most XR users' concerns about how their likenesses are represented in virtual space. However, in November of 2020, New York state passed legislation[126] making it the first state in the nation to explicitly extend an individual's publicity rights to digital replicas, while extending a right to sue to a "depicted individual" when their likenesses are portrayed in an unlawful "sexually explicit" manner.[127] Whether the passage of this—or similar future—legislation results in increased litigation is yet to be seen.

Future litigation regarding XR avatars as virtual property is equally uncertain. The court in *Doe v. Epic Games, Inc.* ruled that virtual currency does not fall within a good or service under the Consumer Legal Remedies Act (CLRA).[128] Conversely, the Dutch Supreme Court held that virtual property from the immersive game Runescape was considered goods under Dutch law, and theft of such property was subject to criminal enforcement.[129] The Court determined that virtual property could be exclusively owned and therefore stolen because of its economic value. Even though the objects had no tangible value, they had intrinsic value to the young gamer who they were stolen from because of the time, energy and effort he invested in order to acquire those goods while playing Runescape.

Time will tell if future cases are brought based on privacy violations, online harassment, manipulation of digital identity, and other potential harms.

Realistic digital avatars are likely to be inexorably intertwined with emerging challenges involving deepfakes and audiovisual manipulations of individuals. Facebook has called deepfakes an "existential threat" to its telepresence efforts. Experts fear that XR environments can amplify the harm caused by sexually exploitative use of online technologies. Policymakers, platforms, and law enforcement currently struggle to police circulation of non-consensual pornography recorded using mobile phone cameras. Increasing adoption of XR technologies could make non-consensual sexual content more invasive and offensive. For example, a growing community of 3D graphics hobbyists are developing—and selling—avatars of real people in order to satisfy clients' sexual fantasies.[130] Existing legal regimes are not well equipped to address these harms.

Further, the gender dynamics at play are undeniable. The vast majority of these avatars are representations of women's bodies created by men.[131] This is representative of the gender gap in XR use generally. Women are vastly outnumbered in social VR, and early reports suggest rampant harassment in virtual environments.[132] In the absence of effective anti-harassment tools, some women employ self-help, choosing non-gendered avatars like robots to disguise themselves and avoid harassment.[133] While some XR developers are integrating anti-harassment controls such as user reporting and setting boundaries around avatars to prevent others from violating personal space,[134] companies must actively address the gender disparities around virtual harassment.

The integrity of digital representation and identity raises important questions in XR: in VR, individuals can use an avatar to broadcast how they wish to be seen by friends and strangers alike. VR applications do not typically permit users to alter the appearance of fellow participants in a VR space. AR, meanwhile, may give users the ability to see other people how they wish. Augmented digital filters are often presented as a novelty, and users can employ a variety of AR technologies to alter their own appearance—individuals can give themselves bunny ears, don a particular type of hat, or swap faces. But one can imagine AR filters that alter the appearance of others—permitting a user to ride the subway with a train full of bunnies or attend a sporting event where all the other fans wear team-branded hats. AR filters can change a user's hair color or make them appear thinner. The same filter raises serious ethical questions when applied to others who the user encounters on the street. Such filters could create new avenues for users to empathize with or be cruel to others.

Previous AR-related controversies are perhaps instructive. Snapchat, for instance, has offered a Bob Marley selfie-lens to promote April 20th, raising questions about digital blackface and promoting weed culture stereotypes.[135] The Sephora Virtual Artist technology allows users to try on makeup in a virtual or augmented environment, providing a real benefit to consumers while raising questions about the impact of digital makeup as part of an individual's self-image.[136] AR augmentations or filters may have spillover effects on users' physical bodies and sense of self—"Snapchat dysmorphia" is a new term to describe the trend of people getting plastic surgery to look like the versions of themselves that appear in social media filters.[137]

These effects are not merely hypothetical. Studies have shown how humans can succumb to Proteus effects, which manifest physical changes in attitude and behavior as a result of identity cues experienced in virtual or digital environments.[138] This psychological phenomenon raises difficult questions about how individuals, companies, and even complete strangers may be able to manipulate human behavior through XR experiences.

Another way of thinking about this challenge is to consider where the boundary between reality and fantasy should lie in immersive environments. Transforming sidewalks or dangerous plots of land into digital lava akin to the childhood game "The Floor is Lava" is one innocuous application tailormade for XR HMDs and mobile AR,[139] but this suggests a more fulsome conversation of whether there should be limits placed on how the world may be augmented is warranted.

D. XR Can Lead to Digital Vandalism, Doxing, and Cyberharassment

AR technologies offer promising ways to interact with public and private spaces. But the same technologies that can facilitate immersive games and educational annotations could also create an augmented world full of intrusive pop-up ads, garish virtual billboards, and real-time streams of unbidden information from passing strangers. It is unclear what constitutes digital graffiti or how unwanted virtual content in public spaces and even private homes should be policed. Private "digital" spaces in VR can operate similar to existing public and private groups on social media, with different searchability options or visibility into group members,[140] but this is complicated in AR and MR. As Pokémon Go and similar phone-based AR experiences demonstrated, there may be sensitive physical locations that should not be mappable, annotatable, or otherwise tagged in XR.

XR companies are creating digital twins of physical reality. Magic Leap's Shared World, for example, creates a collective spatial map in the cloud, but there are some locations, objects, or entities that may not desire to be mapped or augmented.

Furthermore, what becomes of a Digital Banksy in an XR world? These issues are already manifesting themselves. In 2018, a group of renegade artists modified the Jackson Pollock gallery at the New York Museum of Modern Art via an AR app. A MoMAR Gallery app framed a Pollock painting in an interactive representation of a smartphone running Instagram, while another painting was overlaid with right-wing conspiracy theories peddled by QAnon.[141] At the Isabella Stewart Gardner Museum in Boston, an independent effort used AR technologies to re-insert digital representations of thirteen stolen paintings into the museum.[142] These examples are relatively innocuous but point to a future where some augmentations of reality are unwelcome or outright hostile.

XR threatens new dimensions for existing doxing practices where intimate, private, or personal information is broadcast in order to be weaponized against a target individual, group, or organization. Stakeholders have posited what solutions will exist when biometric identification makes it possible for anyone, XR user or innocent bystander, to get tagged with a permanent digital "kick me" sign attached to their digital back. Society may be forced to moderate different "digital layers" that can be turned on or off with a toxic "public" XR layer. The alternative is to provide legal protections.

These issues will become more complicated when the augmentations—and annotations—are done on people. Tort law, which governs assaults and battery, intentional infliction of emotional distress, tortious interference with contract, and, in some jurisdictions, invasions of privacy, may be relevant. Professors Mark Lemley and Eugene Volokh have explored how tort law could apply to XR and are skeptical of their effectiveness or applicability in governing virtual worlds.[143] However, litigation may be inevitable, and courts will be required to address whether virtual activities can lead to real tort claims.[144]

Traditional Privacy Torts

- An intrusion tort involves the physical or electronic intrusion upon the privacy or solitude of a person.
- A private facts tort involves the public disclosure of private facts about an individual that the public has no right or need to know.
- False light torts involve the publication of false and offensive representations of people.
- An appropriation or "right to publicity" tort involves the use of someone's name or image without their approval.

XR will test how these privacy torts will apply in digital spaces. Policing digital misbehavior, however, has already proven difficult. Individual users who violate these torts or otherwise engage in unlawful or harassing activities can be effectively impossible to track down, and XR platforms are largely shielded from liability for defamatory user-generated content or the activities of their users under Section 230 of the Communications Decency Act. However, while this is the existing legal status quo, a failure to effectively police the sorts of harmful abuses that XR invites may invite lawmakers and courts to recalibrate legal protections.

Part IV: A Mix of Technical and Policy Solutions Will Maximize Benefits While Mitigating Risks

Mixed Reality opens the door to the application of common sense rules that have very effectively mediated the tensions between corporation and consumer, citizen and state. Mixed Reality need not be a dystopian vision. It may be the method by which we can restore balance to the law.

—Joshua Fairfield, Mixed Reality: How the Laws of Virtual Worlds Govern Everyday Life[145]

For XR to become a revolutionary communications platform on the scale of the internet and mobile phones, XR stakeholders must articulate a positive vision for how technology, law, and policy can shape these services in a way that is beneficial and privacy protective. The challenge ahead is significant on multiple levels. Because XR remains an emerging technology, as well as a game-changing user interface, establishing unnecessarily strict privacy rules may stifle the development of beneficial new services. Existing frameworks that rely on data collection limitations will likely be frustrated by the data demands of XR. Some mixture of policy interventions and technical mitigations are necessary to address the concerns identified in this paper and elsewhere.

Law and regulation will also play a role in guiding privacy expectations in XR. Platforms and developers already need to comply with existing sectoral privacy laws regarding health, biometrics, communications, and education. They must grapple with new privacy laws that mandate additional data use disclosures and mandate consumer choices. Courts will also play a role, and future litigation involving XR and state tort claims is likely inevitable. General privacy and data protection laws may establish baseline privacy compliance obligations on XR, but the development of a broadly-used collective virtual space implicates myriad different legal regimes.[146] What suite of meaningful privacy rules should apply to XR remains unclear, but uniform application of common sense privacy rules is necessary to ensure trust in these emerging technologies.

XR and the CCPA and CPRA

Since going into effect in January 2020, the California Consumer Privacy Act (CCPA) has been a key compliance priority for data-driven XR companies. As with other industries, VR companies that provide HMDs are offering a mixture of California-specific disclosures,[147] general purpose access and opt-out portals,[148] or relying on generic privacy policies that do not specifically reference the provider's immersive data processing.[149] As XR technologies evolve, platforms and developers will need to give serious thought about complying with the substantive rights in the CCPA, the California Privacy Rights Act (CPRA)—which goes into effect in January 2023—or other frameworks like the EU General Data Protection Regulation.

- **Access Rights:** The CCPA and CPRA give consumers the right to request access to personal information collected about an individual. The depth and breadth of how companies respond to access requests varies generally. Access rights also bring questions about what sorts of logs or technical information may need to be produced and generated about users, as well as how to securely and responsibly verify that an access request is coming from the correct individual entitled to make a request.
- **Portability Rights:** The CCPA's data portability requirements are related to access rights, and where information is provided electronically, the law requires it be provided in a portable and readily-usable format. The CPRA expands these rights by giving consumers the right to request that a business transmit their personal information when technically feasible. What that means for the vast quantities of telemetry generated by XR platforms is unclear, but one could imagine that some types of eye tracking, external sensory information, and components of avatars could prove useful for potential future data models for the open source, industry-supported Data Transfer Project.[150]
- **Deletion Rights**: The CCPA and CPRA also grant individuals the right to request that businesses delete their personal information subject to various exceptions. Most, if not all, XR platforms provide mechanisms for users to delete their accounts—and erase any information tied to those accounts in the process—but VR and AR, in particular, may warrant considering more granular deletion options or functionality.
- **Opt-Out Rights:** The CCPA gives consumers a right to opt out of the sale of personal information. This right does not precisely match EU law's rights to object to data processing, but both regimes reflect lawmakers' concerns about unrestricted data sharing and disclosure. Some XR platforms provide options to limit and restrict how personal information and data generated by HMDs, mobile AR, and other sensory inputs can be transferred to third parties. The CPRA expands these rights by giving consumers the right to opt out of automated decision making technology when used for making decisions about a consumer's personal preferences, behavior, location, movements, and other categories. The CPRA also provides consumers the right to limit the use of sensitive personal information to what is necessary to provide goods or perform services reasonably expected by the average consumer requesting the goods or services. Sensitive personal information includes categories such as: biometrics, geolocation, genetics, race, religion, union membership, among other categories.
- **Correction Rights:** The CPRA grants consumers the right to request that a business correct their inaccurate personal information. Like with deletion rights, companies may consider more granular correction options given the vast tracking necessary for the functioning of XR technology.

Neither the CCPA, CPRA, nor more comprehensive legal regimes like the GDPR describe what an optimum level of privacy should look like in XR. Instead, stakeholders and policymakers should explore technical and policy choices that can shape social norms around XR and public trust in the technology.

A. Technological Solutions Include On/Off Switches, Local Processing and Storage, Automated Blurring of Bystander Faces, and More

Technological controls that safeguard user privacy and limit XR data use may be the most privacy protective measures that can be deployed, but there is not consensus regarding current best practices for HMDs and other XR devices. Implementing technical controls is particularly challenging in this context, since XR devices need to constantly collect and process sensitive data to provide the core service. The types of cutting-edge privacy enhancing technologies (PETs) that are often discussed may not be easily deployable in XR absent further research.[151]

Previously, the Future of Privacy Forum identified a number of technological mitigations for "always listening" technologies like Internet-connected speakers, televisions, and mobile devices.[152] These recommendations called for considering whether data processing and storage can occur locally or is cloud-based, creating hardware on/off switches, and providing visual (or potential audio) cues to indicate recording and data transmission.

These recommendations are relevant in the XR context, but not dispositive. Privacy protections for VR headsets might take cues from best practices for gaming consoles, and "always on" AR technologies could benefit from strategies that have promoted privacy for mobile phones. Some aspects of XR will force developers to rethink traditional data minimization strategies. For instance, with Google Glass, Google established default recording periods of only ten seconds and built explicit signals into Glass to help non-users and pedestrians aware that the device was in use.[153] Sensory cues to other individuals may be necessary yet unwelcome as more individuals adopt wearable devices that constantly sense and read their surroundings. Future advances like wearable contact lenses also raise fundamental questions of whether sensory cues will even be possible.

Hardware-based hard on/off switches were presented as an important privacy protection to ensure smart speakers could be easily and completely disabled. Similar functionality could be offered in XR wearables, but that would not address the ability of these technologies to impact non-user bystanders. One solution would be to control AR and VR functionality through geofencing. While geofencing is frequently viewed as a way for advertisers or businesses to direct content to visitors, the same technology could be used to disable annotative or object recognition capabilities in intimate environments such as medical offices, houses of worship, or courts.[154] Another option could be for XR devices to broadcast signals that could provide bystanders with some transparency into what data is being collected and, ultimately, allow them to express preferences about being involved in XR experiences.[155]

Local processing and storage have emerged as a potential selling point for privacy-conscious individuals, but cloud computing may be essential to providing the raw processing power and graphics capabilities needed to drive intensive XR applications.[156] Some VR HMDs are currently tethered to expensive personal computers or game consoles, but 5G networks and other high-speed, low-latency broadband networks could permit cloud-based rendering and delivery of display content.[157] Edge computing, which relies on computing resources closer to the user, could provide a privacy-friendlier solution, and many AR wearables can leverage connections to mobile phones. As a policy matter, however, platforms may ultimately decide that some sensitive XR information like raw eye-tracking data or sensor image streams should only be stored or transmitted under limited circumstances.[158]

Moving forward, XR companies could consider processing their data streams in privacy or obscurity protective ways, including end-to-end encryption for sensitive information. Some of the privacy issues faced by Google Street View could prove illustrative. Launched in 2007, Street View is an ongoing effort by Google to map the world and create interactive panoramas of every street that was mapped. Early street photography revealed identifiable individuals in potentially embarrassing situations—picking their noses, sunbathing in bikinis, and entering adult book stores.[159] Google responded by developing tools to automatically blur faces and license plates and offering options for individuals to request additional blurring of houses and bodies.[160] In addition to this more visible data collection, Street View also captured network SSIDs, and the company let users opt out of this networking mapping by appending "_nomap" to the name of their network.[161] Similar technological solutions might be adapted to AR data streams.

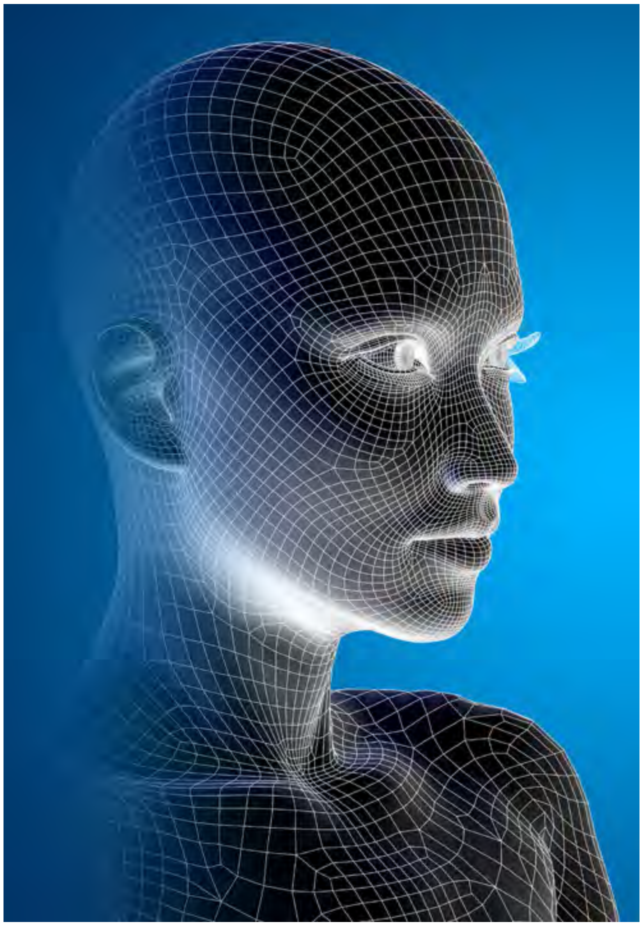
None of these technical choices address all privacy considerations posed by XR, and platforms and developers will need to be much more transparent about how they think about—and intend to protect—their users' privacy in XR.

B. Policy Solutions Include Transparency of Data, Establishing Privacy Commitments, Platform Accountability, and Equity in Avatar Creation

Policy solutions can supplement technical safeguards and provide an immediate path for establishing rules to govern XR technologies. Advocacy stakeholders, industry groups, and technical standards bodies are working on aspects of XR, leading to a proliferation of different privacy recommendations and best practices. These efforts are nascent, but hold promise. For instance, the XR Association has acknowledged the need for XR environments to be respectful, safe, and inclusive. Its second iteration of its XR Primer highlights emerging best practices that can be used by developers and platforms to establish foundational XR norms to build healthy digital communities and empowered users.[162] More recently, the Cyber-XR Coalition brought together digital organizations focused on diversity and inclusion to address ethics and safety in the development of XR and spatial technology.[163] Yet, privacy considerations are not the sole focus of these projects. It is timely for XR stakeholders to establish clear and forward-thinking privacy frameworks that guide the development of immersive technologies and build trust in XR experiences. Companies could be especially equipped to develop such frameworks and principles as internal developers have the best understanding of their own data practices and technological capabilities.

1. Providing Transparency and Establishing Privacy Commitments are Necessary to Promote Consumer Understanding and Trust

XR presents both challenges and a new opportunity to communicate notices about company data practices, specifically with regard to sensitive features like location mapping and eye-tracking technologies.



Unfortunately, the gap between what XR privacy policies disclose and the capabilities of current XR technologies and their accompanying sensors is confusing and unclear. Academic and security research, marketing materials, and traditional privacy disclosures present different impressions of what current HMDs and mobile AR are capable of. As a first step, XR companies should work with external stakeholders to more clearly convey their intentions with respect to XR data. Specific disclosures about location mapping and practices like eye tracking and other biometrically-derived data should be separately explained to users. Whether and how data is automatically recorded and shared should also be separately disclosed.[164]

Companies can go further by making commitments about their use of XR and their vision for how

immersive technology should develop moving forward. Mozilla has promoted ethical principles for an immersive web, attempting to balance privacy and security considerations with inclusive design and user safety.[165] These efforts have focused on areas where developers and platforms should proceed cautiously rather than producing prescriptive guidance.[166] Diane Hosfelt, a former Mozilla researcher, has gone further, echoing not just the transparency and accountability issues among XR stakeholders, but imploring the development of mechanisms to "level out asymmetries of knowledge and power" that can emerge in immersive environments.[167] Ms. Hosfelt has called for policies and tools to help users report and block harassment, empower individuals to define their immersive experiences, and generally minimize reliance on tracking and XR fingerprinting. Other recent efforts include Facebook Reality Labs' Responsible Innovation Principles for building products, including XR technology.[168] Principles include: 1. Never surprise people; 2. Provide controls that matter; 3. Consider everyone; and 4. Put people first.[169]

Corporate privacy and ethical principles also have lessons for privacy-protective XR, but further work is required to operationalize these directives. At minimum, companies deploying immersive technologies should:

- Establish clear policies regarding the collection, use, and sharing around sensitive XR data types, including user-provided location data and any biometrically-derived data.
- Limit third-party access to XR data and put in place procedures for responding to law enforcement or administrative demands for user information.
- Explore technical methods to automatically aggregate or pseudonymize XR data.
- Create accountability feedback loops so that external complaints, outside experts, and the non-expert community can be heard internally.
- Empower XR users through privacy-protective default settings and easily accessible user controls.
- Obtain prior user consent prior to conducting research *via* XR technologies.

- Consult with industry experts, advocates, policymakers, XR users, and a wider community of non-XR users and integrate stakeholder feedback into hardware and software design and data collection, use, sharing, and user control of their data.

Another idea suggested at the XR Privacy Summit is to adopt some form of institutional review board (IRB) model for XR applications. Similarly, companies could commit to a less formalized independent ethical review board to consider questions around data collection, use, sharing and other ethical concerns. This sort of independent review has been a recurring idea in ethical and privacy debates involving novel data processing. Ryan Calo, for instance, has called for the creation of "Consumer Subject Review Boards" to address ethical questions in corporate data research,[170] and both scholars and industry stakeholders have been debating the value of technical ethics committees that can provide guidance on the collection, sharing, and use of data and machine-learning applications.[171] A number of XR platforms already have developed ethical approaches to artificial intelligence,[172] and a commitment to some sort of ethical review of XR applications could be useful to highlight potential harms and identify mitigations. Review boards could also determine whether XR data could be used for research where obtaining prior user consent is impractical.

2. Platform Accountability is Necessary to Ensure Companies Adhere to Robust Developer Terms and Community Guidelines

While privacy issues will occur throughout the XR ecosystem, major platforms are well situated to ensure consumers are protected. Consumers typically acquire XR hardware and software through the major platforms. Some XR technologies are developed outside the major platform ecosystems, but those applications are primarily used by hobbyists, not the bulk of XR consumers. Apple and Google have sophisticated requirements and documentations in place to govern their mobile app stores, and Facebook and Twitter enforce rules for developers who build on their platforms. This platform governance model can also play an important role in setting expectations and driving conversations with XR developers and user communities.[173]

Magic Leap's Technical Requirements Checklist (TRC) includes privacy and safety requirements regarding many of the overarching concerns facing XR.[174] For instance, Magic Leap requires the applications that rely on user-generated content to have mechanisms for reporting and responding to objectionable content; its developer terms also forbid identification of non-users and require controls over how a user's personal information is displayed to other users or otherwise be publicly displayed outside an app experience. On-device recording of audio and video must be communicated to other users.

The TRCs also address more traditional data protection and privacy governance controls like the Fair Information Practices. While it's an open question how data minimization works in a persistent XR environment, several provisions encourage apps to limit the amount of information collected, stored, or transmitted. More importantly, HMD device data is prohibited from being appended to data sets unrelated to app functionally. Arguably any data set could be related to an app's purpose, but the TRCs prohibit (1) any use of device information to create a user profile based on either identifiable or pseudonymous data and (2) using any sort of techniques to fingerprint a user's device or engage in cross-device or cross-application tracking.

These types of strong protections and comprehensive developer guidelines can set a tone for developers and engender trust in privacy-conscious users. However, as XR platforms expand, effectively policing developers and apps will prove more difficult. The existing status quo places a tremendous amount of responsibility and authority on platforms, but automated app screening is an incomplete solution.

Feedback systems will be incredibly important. XR platforms and developers should prioritize inclusive development and provide responsive feedback mechanisms, and platforms have a basic responsibility to provide training to developers.[175]

3. Equitable Representation in Avatar Creation Will Empower Consumers and Increase Inclusion

Companies developing XR experiences should emphasize diverse, highly customizable, and inclusive avatars and avatar creation tools, fit to represent the breadth of the XR, and non-XR community based on widespread community feedback. The richness of presence felt by XR users is enhanced when adopting avatars of their choosing, allowing users to experience a virtual world on their own terms while representing themselves as they wish. Consumers adopting avatars in XR, and non-XR, digital spaces are calling for more customizable avatars reflecting a wider spectrum of gender identities, race, sexual preferences, religions, disabilities, age, and other attributes.

For example, Cyberpunk 2077—a popular video game—has been praised for its character creation tools providing diverse human representation for its avatars.[176] However, critics argue that the game is limited in its gender representation by only allowing deep-voiced avatars to identify as male, while higher-voiced characters identify as female.[177] Such limitations not only play into gender stereotypes, but prohibit some players from representing themselves in-game in a way that comports with their own identity and preferences, serving a less inviting and potentially less engaging experience. Additionally, highly customizable avatars can act as a sort of testing ground for users to present a new identity, such as a gender other than that assigned at birth, in a more anonymous, virtual space, before doing so in the physical world.[178]

The need to expand the diversity of avatars in XR only becomes more important as avatars become increasingly realistic and more accurately map to an individual's physical attributes and movements, leading to a greater sense of presence among users. To provide equitable and inclusive avatars, companies must not only offer avatar customization that maps to their current user demographics, but integrate feedback from the larger community on what features and attributes they would like to see integrated into avatars. Not only will more inclusive avatars serve the existing XR community's preferences, but could encourage non-XR users to more readily adopt a technology where they feel represented in the XR community.

Conclusion

The emergence of immersive XR experiences and technologies promises to be a new platform for communication, knowledge, and entertainment. The potential benefits of widespread XR adoption are considerable. While technical challenges, costs, and public acceptance are top-level concerns for XR stakeholders, risks to individuals' privacy, safety, and autonomy must be taken seriously. XR technologies are improving rapidly, but there is a disconnect between companies bullish on shaping digital reality and user communities skeptical of how sensitive information about themselves and their surroundings could be used in ways they don't expect or that could cause harm. Stakeholders must identify technical, policy, and legal solutions to build trust and address those concerns. Without doing so, societal benefits will be stunted as consumers will remain hesitant to adopt XR. Companies must deploy a mix of technical and policy solutions, while complying with the law, to earn widespread consumer trust and adoption.

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