Thematic Investing

Future Reality: Virtual, Augmented & Mixed Reality (VR, AR & MR) Primer

Thematic Investing

Bank of America Merrill Lynch

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A Transforming World: virtual, augmented & mixed reality

As part of our work on A Transforming World, we introduce a new Innovation-focused theme on virtual reality (VR), augmented reality (AR), and mixed reality (MR). This Primer sets out the challenges and opportunities offered by the theme.

The 4th computing revolution: one device to rule them all

VR/AR/MR is enabling a 4th wave of computing power via a spatial computing revolution that integrates disruptive technologies such as sensors, Big Data, the cloud, AI, and wearables. It has the potential to become the "form factor" for nextgen computing as a universal, smart, and intuitive interface for the internet of things (IoT) ecosystem. It could be the one device to disrupt and rule the world of technology – bridging the digital and physical worlds for the 3.5bn internet users, 3.6bn mobile broadband users, and 1.6bn with TVs globally. We believe near-term adoption will be driven by smartphone take-up (5bn installed base of gateway devices by 2018E); demographics (Gen Y and Z check their smartphones 150x per day); skyrocketing investment (record US$2bn from VCs in the past 12 months, 1,300 start-ups in recent years); M&A (AAPL/FB/GOOG acquiring 10+ relevant companies); and content roll-out (Pokémon Go, etc.).

Welcome to the Matrix: 2020E tipping point

VR/AR/MR could have 250-300mn users by the early 2020s, with the long-term potential to capture 2/3 of our leisure time, and 50% of our leisure dollars. Future reality could be transformative for the education, entertainment, financial services, gaming, healthcare, leisure, media, and retail industries. AR/MR will ultimately impact every sector and company by transforming how they communicate, design, manufacture, and sell products. Over 50% of organisations are testing AR given its potential to boost productivity (30% faster assembly), reduce costs (25-60% savings on installation & maintenance), and improve output (40-90% higher accuracy). Given the technical hurdles (processing speed, bandwidth, AI-analytics), we see the tipping point for exponential growth coming in 2019-20E. We also identify longer-term risks around the psychological and neurological impacts, social isolation, hindered vision, privacy and cybersecurity.

US$150bn market by 2022E: end-to-end entry points

VR/AR/MR is projected to be a US$150bn market by 2020-22E, with VR accounting for 1/4 (US$30-34bn) and AR/MR for 3/4 (US$90-117bn). We highlight end-to-end entry points for investors wishing to gain exposure to the Future Reality theme, and anticipate fast growth for the likes of head-mounted devices (HMDs), content, distribution, gaming, entertainment, enterprise applications, processors, sensors, cameras, batteries, displays, and cellular connectivity.

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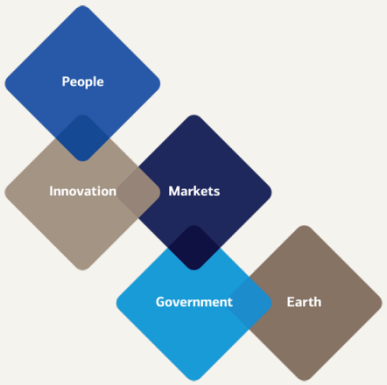
A Transforming World



Refer to important disclosures on page 40 to 41.

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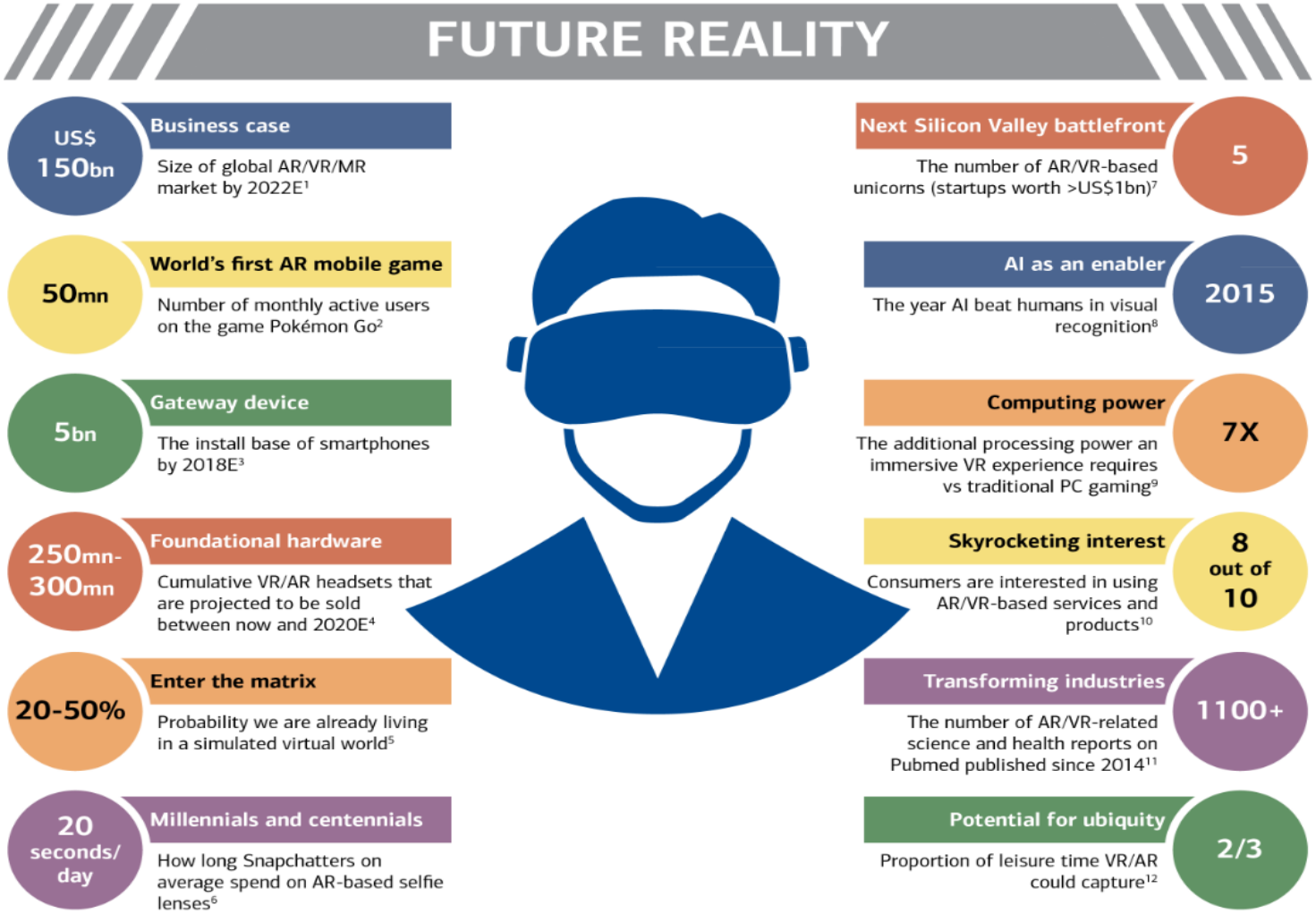
Future Reality: the 4th computing revolution

Virtual (VR), augmented (AR), and mixed reality (MR) is enabling a 4th wave of computing power via a spatial computing revolution that integrates disruptive technologies such as sensors, Big Data, the cloud, AI, and wearables. The eventual convergence of AR and VR devices could push the nascent market to become the "form factor" for nextgen computing as a universal, smart, and intuitive interface for the internet of things (IoT) ecosystem. It could be the one device to disrupt and rule the world of technology – bridging the digital and physical worlds for the 3.5bn internet users, 3.6bn mobile broadband users, and 1.6bn with TVs globally.

Despite breaking into the public consciousness through wildly popular consumer-focused technology such as Pokémon Go, it will ultimately impact every sector and company by transforming how they communicate, design, manufacture, and sell products. As with most transformative technologies, adoption will be a curved line, not straight. We see the inflection point occurring around 2019-20E, when the combination of a seamless form factor, smarter software, strong content, long battery life, and cellular capability creates the intersection to drive exponential growth.

Exhibit 1: Future Reality by the numbers



Source: BofA Merrill Lynch Global Research based on cited sources

Future reality 101: disruption is the name of the game

Augmented and virtual reality is breaking into the public consciousness through wildly popular consumer-focused technology such as Pokémon Go, while even more profound commercial opportunities evolve in the background. The eventual convergence of AR and VR devices could push the nascent market to become the next electronic platform, and replicate the volumes reached by TVs, PCs and smartphones.

Artificial reality encompasses a wide spectrum of technologies that bridge physical and digital experiences. This includes virtual reality (VR) – fully immersive digital reality; augmented reality (AR) – devices with superimposed text, sound, graphics or video onto the physical world; and mixed reality (MR) – real and virtual objects are combined. Much of the same technology and enablers underlie each platform, and we expect the lines to blur in the coming years and headsets' features and functions to transcend the boundaries of artificial reality.

Augmented reality (AR) and virtual reality (VR) are two of several technologies that are within the Internet of Things (IoT)-enabled disruption ecosystem. Together with other innovation accelerators – artificial intelligence (AI), robotics, Big Data, and wearables – AR/VR/MR can drive efficiencies, transform established sectors, and create new business opportunities. AI is a key technology that enables much of artificial reality, where computer vision, speech recognition, natural language processing (NLP), and machine learning facilitate AR/MR functionality. In turn, artificial reality can generate a plethora of contextual user data to serve as feedstock for AI. While the technologies leverage off one another, they share the same development challenges, such as processing speed, bandwidth, and analytics, in order to facilitate a seamless interconnected ecosystem.

The key word for virtual reality is presence – ultimately, trying to alter the experience that the brain is constructing and telling us we are having. The VR puzzle thus entails 1) driving the perceptual system, 2) changing our sensing and reconstruction of reality, and 3) enabling human-VR interaction. Of the six human perceptual inputs that must be hacked – vision, hearing, taste, smell, vestibular (balance), and haptics (touch) – we have gained much ground on vision and hearing. Vision is one of our most important senses, accounting for 70% of all sensory receptors and 50% of brain capacity (source: Merieb, E. N. & Hoehn, K. 2007). VR displays will reach 3D photorealistic 360˚ video in the coming years. For sound, many platforms are able to model 3D audio time series that employ accurate physics to generate true-to-life sound.

AR and MR, in contrast to VR, aim to blend digital objects with the user's existing reality. At the core, they are a delivery system that channels rich, contextual content to be superimposed on the view of the real world. The long-term aim is a device that unlocks information and augments senses – e.g. customers can scan a product in a grocery store to see price comparisons and the full nutritional information; see traffic directions superimposed directly into the street as the person is walking; gauge the reaction of the person they are conversing with. AR technologies can also be broken down into 1) geospatial – using GPS data, 2) 2D AR – ability to recognise predefined 2D objects (posters, landmarks, etc), and 3) 3D AR – full cognition of objects and surroundings.

Mobile AR is likely to be one of the fastest-moving platforms in the near term (3.5bn AR apps to be downloaded in 2017, 200mn mobile AR users by end of 2016), as evidenced by the success of the AR-enabled social mobile game Pokémon Go. Pokémon Go is the fastest app ever to reach 10mn downloads, achieving the milestone after just seven days. It amassed more than 50mn active users spending 44min / day in the first two weeks and earning over $35mn during that time. While this is only one hit game, it shows the potential of leveraging the ubiquity of smartphones.

Both virtual reality and augmented reality represent an evolution towards intuitive interactions. The human-machine interface has shifted from punch cards and paper in mainframes, to point-click-type computers, to touchscreens on mobile phones. Artificial reality takes it one step further, by removing any tangible interface at all, allowing people to communicate through natural modes of interaction such as gaze, gesture, voice, and eventually context. By shortening the chain of commands, attention is shifted from the device or machine to more real-world interactions.

Millennials (born 1981-1997) and Gen Z (born 1998-present), who together account for 4.4bn people or 59% of the world's population, will lead the charge in AR/VR adoption (source: UN). More than 2 out of 5 people between the ages of 16 and 34 say they are interested in a VR headset. Within gamers and branded video viewers this is as high as 1 in 2 (source: GlobalWebIndex). They are already consuming more TV, video, gaming (63% play games), and social media (55% connect with family) via their smartphone than any other generation; it seems only natural that integrating AR/VR will be the future.

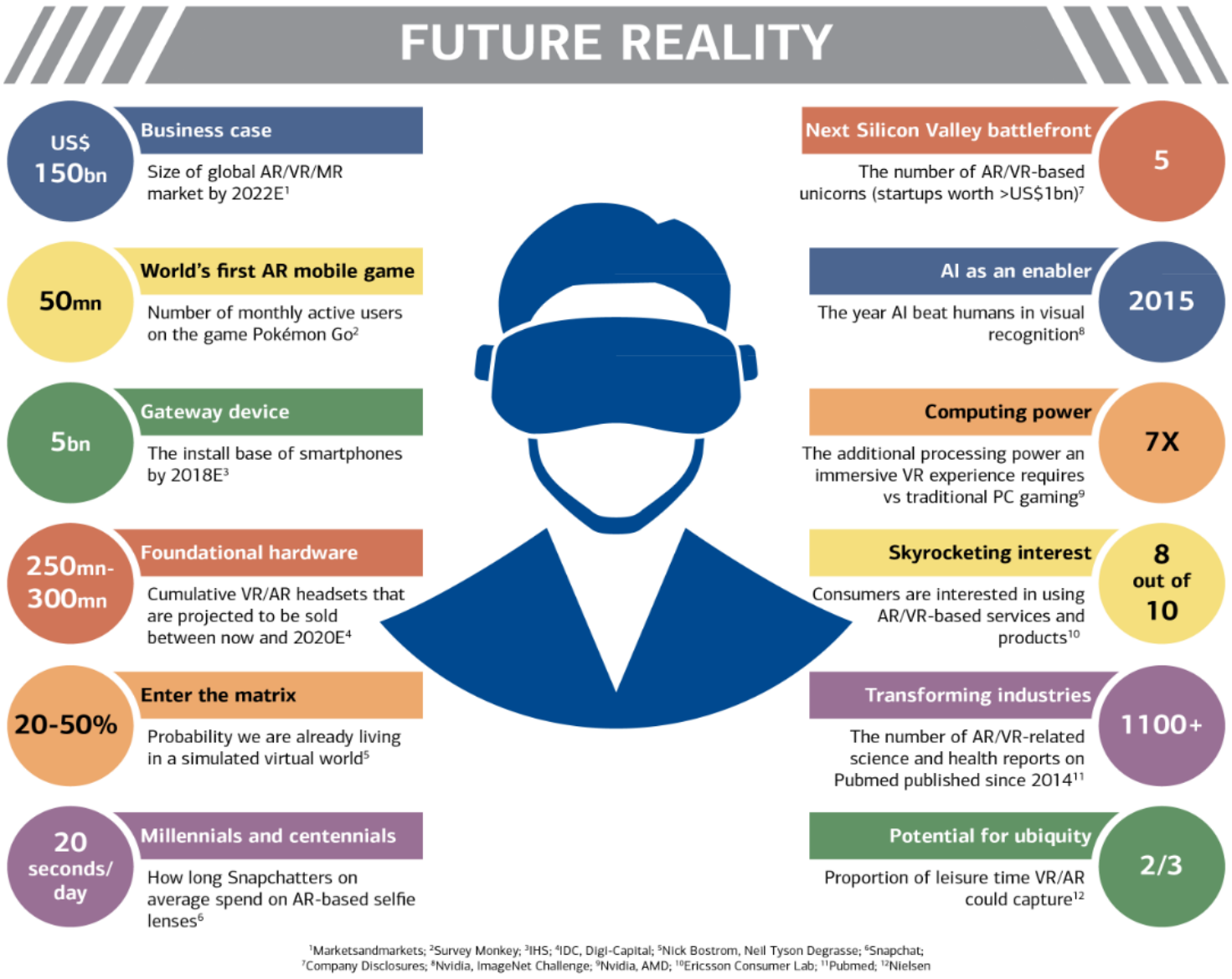
Artificial reality has potential to transform leisure time as well as the workplace. Virtual reality and augmented reality have potential to capture 2/3 of leisure time and 1/2 of all leisure dollars if the platform penetrates activities like video games, TV, movies, internet, music, and social networking (source: Nielsen). The long-term potential for the platform is its ability to disrupt enterprises by reducing time (30% faster assemblies) and cost (25-60% savings on installation and maintenance), while improving output (40-90% higher accuracy) (source: Richardson et al 2014, Honeywell, DHL). Having hands-free access to rich information, schematics, videos, pictures, instructions, etc., could improve the performance of more than 110mn deskless workers in the world (source: PwC, Atheer).

AR will disrupt the US$514bn global advertising market both in the near and long term. The single-largest driver of advertising spend will be native mobile ads, and augmented reality could be the next platform to interact with customers. Mobile digital ads will account for US$1 out of every US$3 spent on advertising, quadrupling in the US from US$19bn in 2014 to US$77.1bn by 2020 (source: eMarketer). 2/3 of that will be native ads, and AR could be a seamless integrator of advertising content since it would have context regarding where customers are, what they are looking at, and potentially what they are interested in (source: IHS 2016).

Artificial reality is becoming the next Silicon Valley battleground. Both private and corporate investment is ramping up, including $2bn in VC investment in the past 12 months and 353 completed deals between 2010 and 2015 (source: Digi-Capital, Pitchbook, company disclosures). There are 800+ VR start-ups, and 600+ AR start-ups in Angel List as of August 2016, which has already produced five unicorns – Oculus, Magic Leap, MindMaze, Blippar, and Razer (source: Angel List, Crunchbase, company disclosures). Many start-ups are competing with large-cap tech incumbents, which own 70% of US AR patents. Sony, Samsung, Microsoft, and Qualcomm lead in VR/AR IP, while Magic Leap dominates within start-ups (source: Envision IP, IPWatchdog). M&A activity has been robust, with Google, Facebook, and Apple each purchasing 10+ relevant companies since 2010 (source: company disclosures).

Despite the long-term opportunities, hype around AR and VR is likely understating the time horizon for widespread adoption and earnings impact. Challenges regarding bandwidth, content, design, processing power, and cost are still very real. John Riccitiello of game engine Unity warns against the "gap of disappointment", where VR/AR does not follow a linear trajectory, and misses lofty near-term expectations. As for most transformative technologies, there is likely to be a gestation period before the product enjoys exponential growth and widespread adoption. While end markets such as gaming will see the earliest adoption, the true inflection point may not occur until 2019 or 2020 (source: Gartner).

Exhibit 2: Future Reality by the numbers



Source: BofA Merrill Lynch Global Research based on cited sources

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Artificial reality: VR/AR/MR/ER

AR and VR are within a spectrum of artificial realities. The term artificial reality was first coined by computer scientist Myron Krueger in the 1960s to describe an interactive immersive environment. Today the term encompasses a wide range of technologies that bridge physical and digital experiences, including virtual reality, augmented reality, mixed reality, and extended reality.

- **Virtual reality (VR)**: users enter and interact with a fully immersive digital reality. This environment can be computer-generated or captured by video. In order to replace a user's existing reality with a digital one, VR must occlude the user's natural surroundings.
- **Augmented reality (AR)**: devices or wearable displays that superimpose text, sound, graphics or video on top of our view of the physical world around us. This digital information is tailored to the context and space in the real environment. AR lets you see both synthetic light and natural light bouncing off objects in the real world.
- **Mixed reality (MR)**: a system that combines real and virtual objects with information shown based on AR. Virtual objects are integrated into real space and can be made responsive to the natural world. Virtual objects are meant to look believable, while this is not a strict requirement for AR. Thus, MR aims to take the best combination of VR and AR.
- **Extended reality (ER)**: a less discussed platform where users can direct devices through separate physical spaces in real time. Common use cases could be the flying of drones, undersea exploration, or surgical robots (source: IDC, PWC).

Table 1: The key characteristics of the various emerging technologies that blend the physical and digital worlds

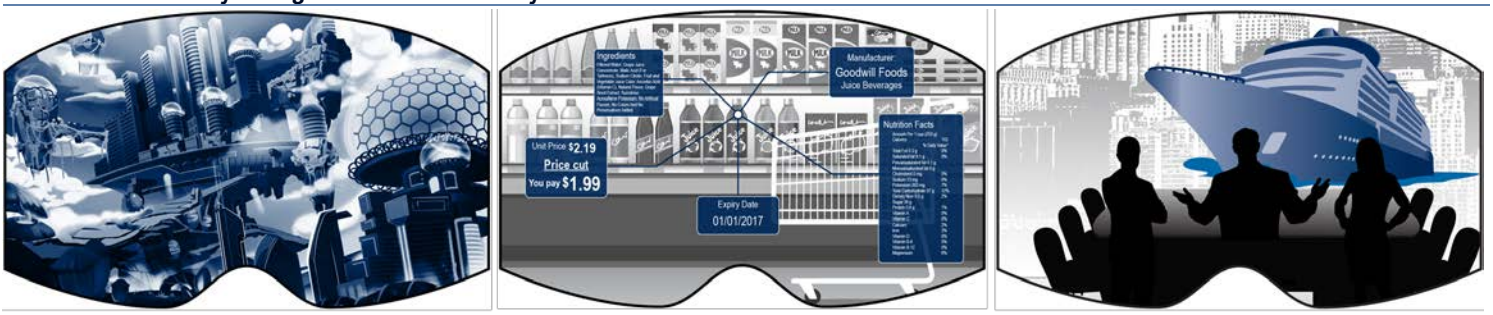
Feature	Augmented reality (AR)	Mixed reality (MR)	Virtual reality (VR)	Extended reality (ER)
Presence: The user is at the location of the experience	Yes	Yes	No	No
Real time: The user is interacting in real time with the environment	Yes	Yes	Yes and No	Yes
See-through capability	Yes	Yes	No	No
Movement: The user can physically move in the environment	Yes	Yes	No	No
Time horizon of enterprise adoption	2 to 4 years	3 to 7 years	2 to 4 years	Already in use

Source: PWC

Lines are blurring

Today's headset manufacturers fall into either the VR or AR/MR camps. Much of the technology and enablers are the same. Over the next few years we will likely see HMD features and functions that cross the lines of artificial reality.

Exhibit 3: Virtual Reality vs. Augmented vs. Mixed Reality

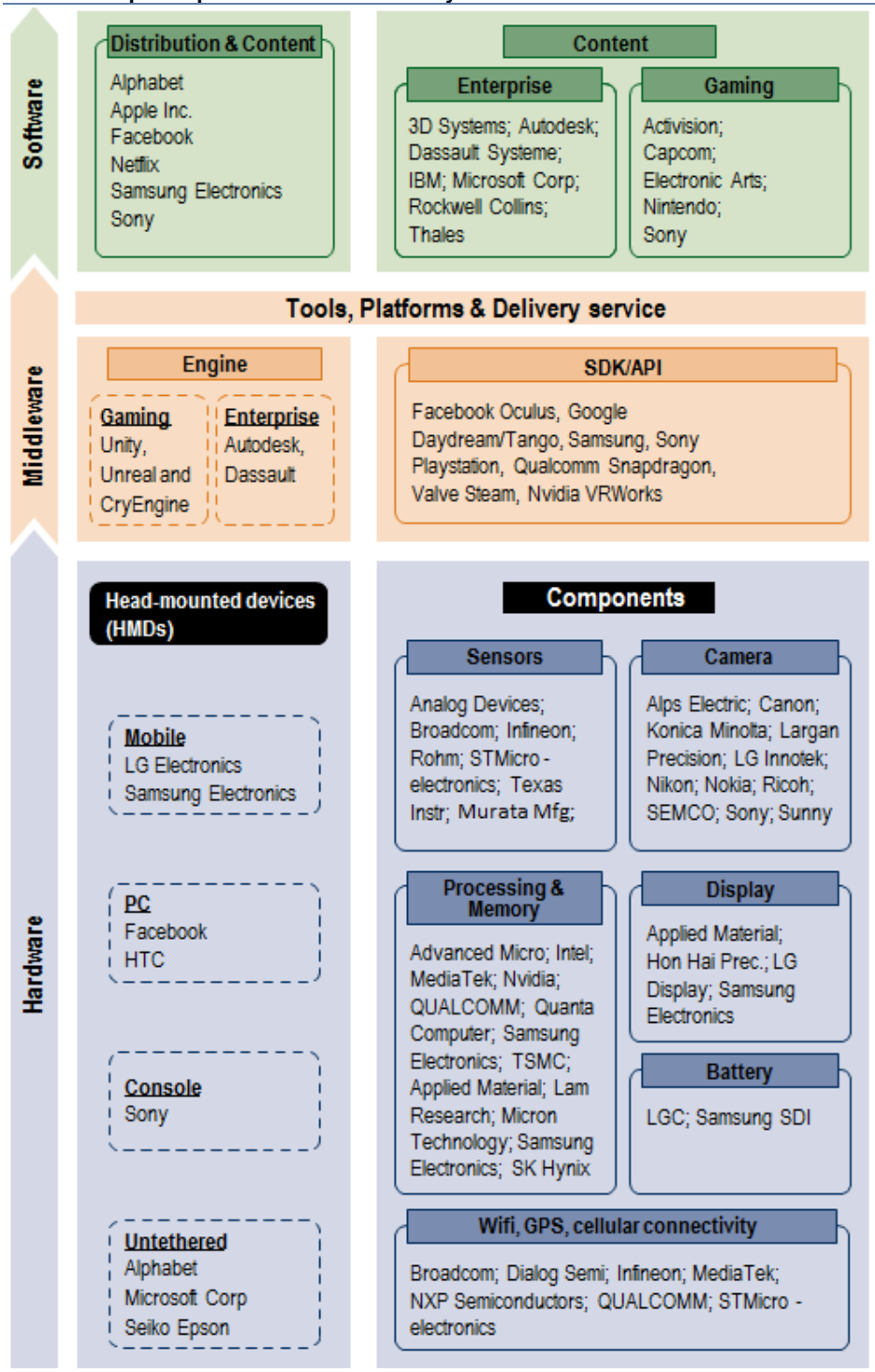


Virtual Reality | Augmented Reality | Mixed Reality

Source: BofA Merrill Lynch Global Research

Many of the major players and component suppliers span different ecosystems.

Exhibit 4: Sample companies within artificial reality



Source: BofA Merrill Lynch Global Research

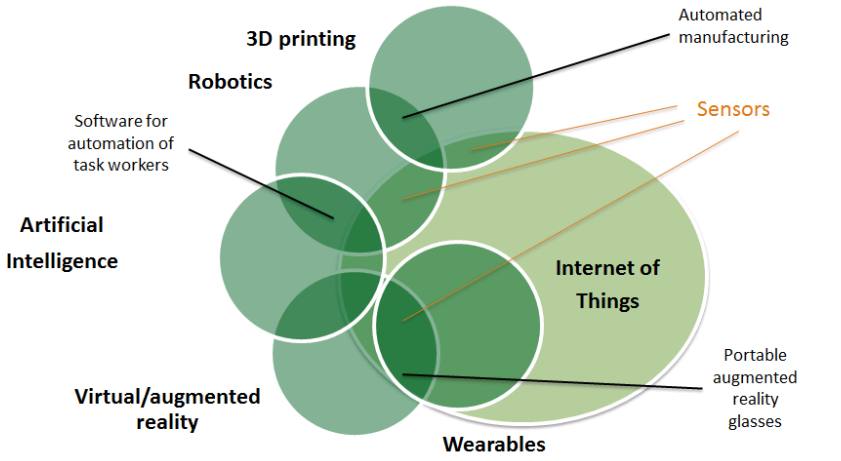
The disruption ecosystem

Augmented reality (AR) and virtual reality (VR) are two of several innovation accelerators, or technologies that have tremendous potential to drive innovation, bring disruption to established frameworks, and create new business opportunities (source: IDC). The rise in the internet of things (IoT) serves as the foundation of each of the technologies, providing them with universal connectivity and data communications. There are also strong intersections between them, putting them in symbiotic

relationships that enable them to leverage off one another. For instance, AR and VR provide context and software for wearables, while artificial intelligence (AI) enables a more context-driven AR experience. All would generate copious amounts of Big Data, which is the ultimate feedstock for AI.

The innovation accelerators also often share the same development challenges, such as processing speed, bandwidth, and analytics, in order to facilitate a seamless interconnected ecosystem.

Exhibit 5: Intersection of innovation accelerators



Source: IDC, BofA Merrill Lynch Global Research

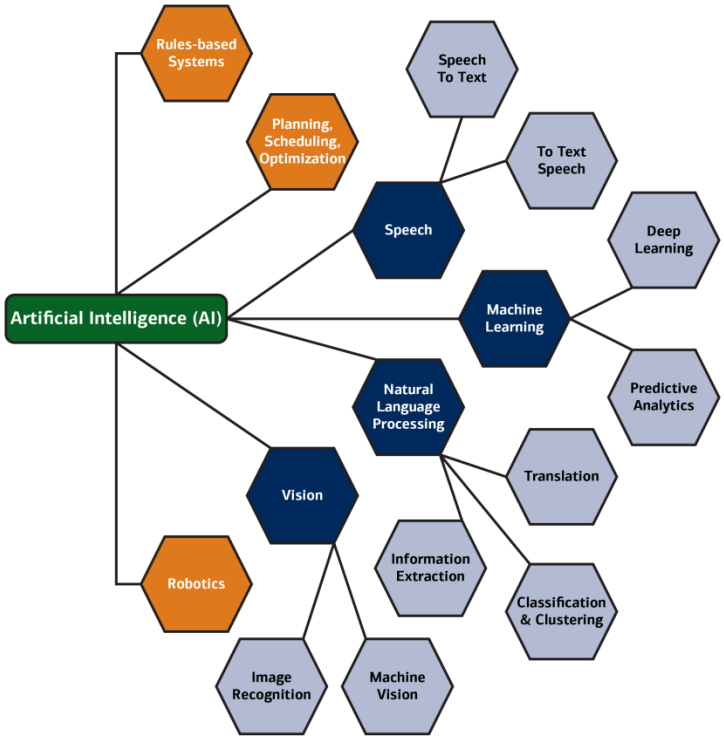
Extending IoT by removing barriers

The primary driver of IoT adoption has been increasing efficiencies and quality by connecting disparate assets, and artificial reality is a major extension of this by removing barriers to communication and experiences. Barriers between people can be erased if they can chat over virtual meetings. Barriers within businesses can be broken down if an engineer can design and interact with his model through a mixed reality headset before commencing production.

Artificial intelligence is a key enabler

Artificial intelligence underlies much of artificial reality, especially augmented and mixed reality. Branches of AI including vision, speech recognition, natural language processing (NLP), and machine learning facilitate the form factor that AR/MR is trying to become. For instance, imbedding virtual objects is at the core of AR/MR, requiring identification of real world surroundings enabled for AI machine vision. Speech recognition and NLP facilitate a seamless and intuitive interface with the computing platform.

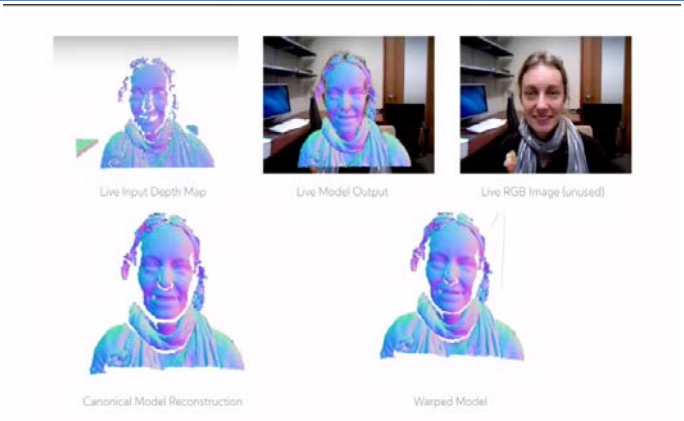
Exhibit 6: Branches of AI



Source: BofA Merrill Lynch Global Research

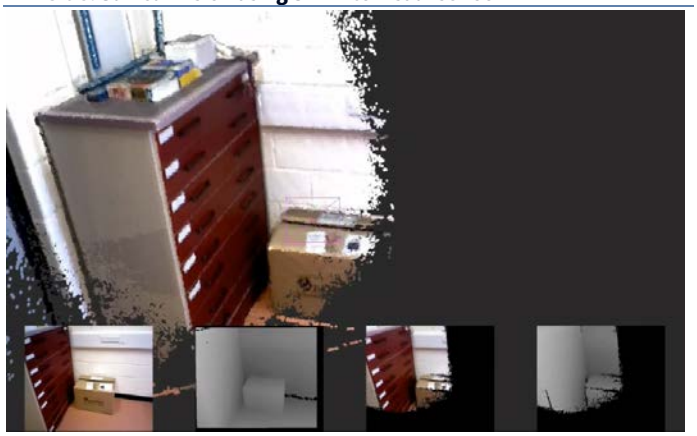
Machine vision acquires, analyses, and processes images and understands real world visual information. It constructs 3D information from 2D images based on structures at the scene, with the aim of replicating or exceeding human vision using AI software (source: Prabhu et al 2016). Facebook Oculus purchased Surreal Vision in 2015, a company that specialises in nextgen simultaneous location and mapping (SLAM). The software can match real-time data points in a database of known objects, adapt the model according to existing information, and extrapolate those properties to the current setting (source: Newcombe et al 2011). The machine can thus systematically see and understand objects and people as well as humans can.

Exhibit 7: Surreal Vision using SLAM to visualise person



Source: Oculus Connect 2

Exhibit 8: Surreal Vision using SLAM to visualise room

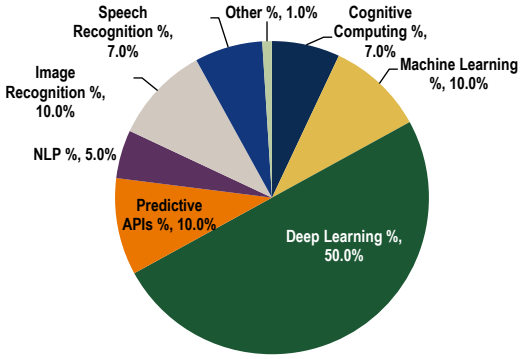


Source: Oculus Connect 2

US$127bn AI market by 2025E

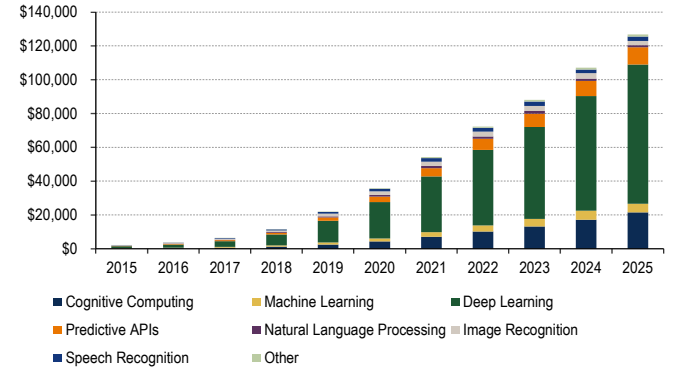
Our global technology team believes that AI can rise from US$2.1bn in 2015 to US$127bn by 2025E, implying a CAGR of 51%. It will be the single largest driver of tech spend over the course of the next decade.

Figure 1: Artificial Intelligence revenue technology by silo 2015



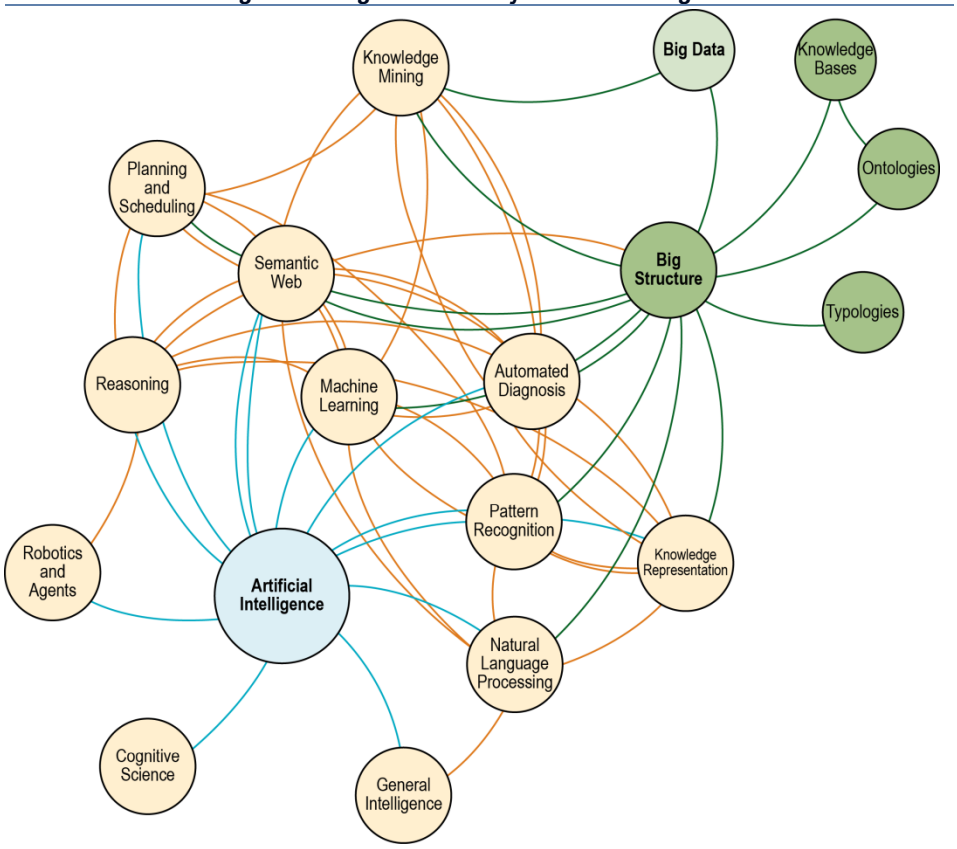
Source: Tractica

Figure 2: Artificial Intelligence revenue growth by technology silo 2015-2025



Source: BofA Merrill Lynch Global Research estimates

Exhibit 9: Artificial Intelligence and Big Data are two symbiotic technologies



Source: Mike Bergman

Enter *The Matrix*

20-50% probability we are already living in a simulated virtual world

Many scientists, philosophers, and business leaders believe that there is a 20-50% probability that humans are already living in a computer-simulated virtual world. In April 2016, researchers gathered at the American Museum of Natural History to debate this notion. The argument is that we are already approaching photorealistic 3D simulations that millions of people can simultaneously participate in. It is conceivable that with advancements in artificial intelligence, virtual reality, and computing power, members of future civilizations could have decided to run a simulation of their ancestors. Oxford University philosopher Nick Bostrom wrote a famous paper in 2003 setting this outcome as one of three, with no way of telling which is true. US astrophysicist and cosmologist Neil deGrasse Tyson pegs the probability that this is the case at 50-50 (source: Scientific American). Elon Musk, the investor, engineer and inventor, sees only a one in billions chance that we are living in a true base reality (source: Code Conference 2016).

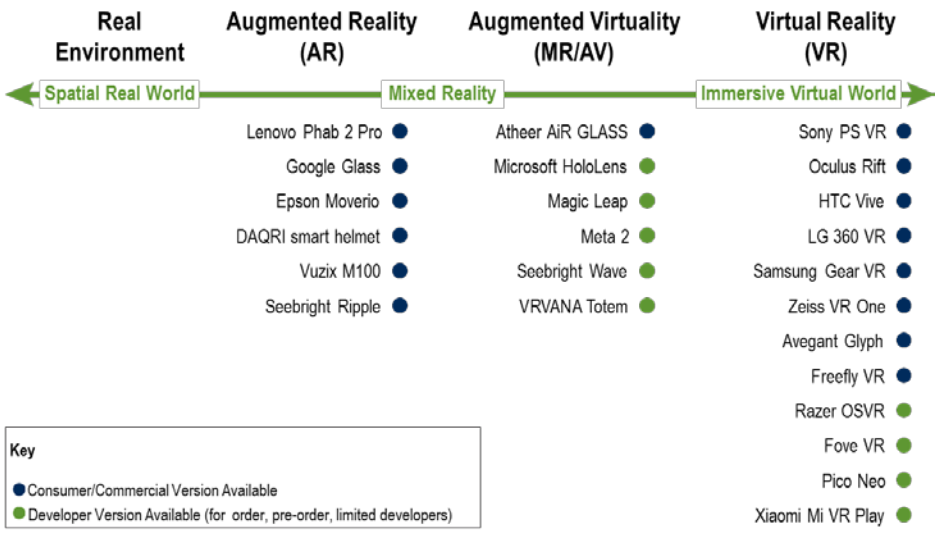
Nick Bostrom's three probable scenarios for humanity:

1) Human species reaches extinction before reaching "posthuman" stage
2) Posthuman civilization does not run simulation of their evolutionary history
3) We are living in a computer simulation

The VR/AR headset spectrum

A plethora of head-mounted devices (HMDs) for both VR and AR have hit the markets in the last 12-18 months. High-end MR systems, however, remain in the development stage.

Exhibit 10: Spectrum of AR/VR headsets



Source: BofA Merrill Lynch Global Research

VR: presence is the last true medium

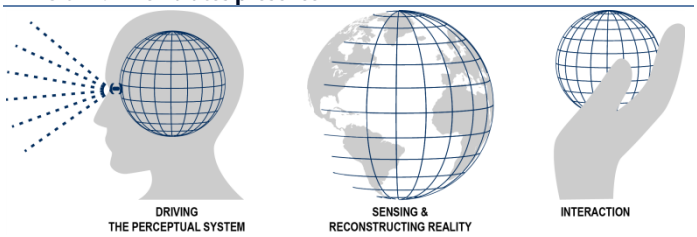
"By the 2030s, virtual reality will be totally realistic and compelling and we will spend most of our time in virtual environments." – Ray Kurzweil's prediction in 2003

The key word for virtual reality is presence. It is not supposed to simply emulate reality, but rather to be reality. This is ultimately a problem of perception and psychology: we

are trying to alter the experience that the brain is constructing and telling us we are having. The VR puzzle thus entails driving the perceptual system, sensing and reconstructing reality, and enabling interaction with the artificial reality.

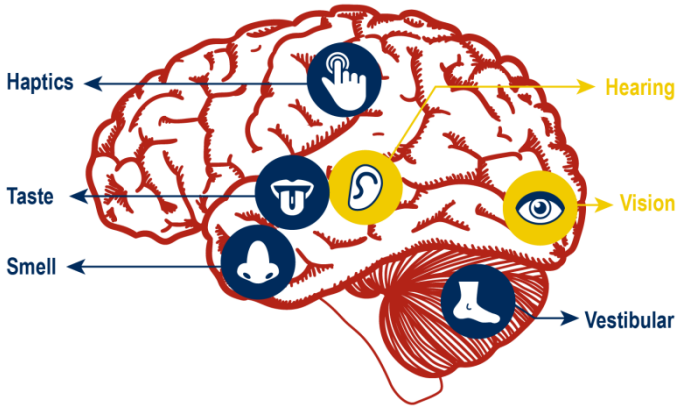
Out of the six perceptual inputs that must be hacked – vision, hearing, taste, smell, vestibular, and haptics – we have gained much ground on vision and hearing.

Exhibit 11: VR emulates presence



Source: Oculus 2015, BofA Merrill Lynch Global Research

Exhibit 12: Tricking the human senses



Source: Oculus 2015, BofA Merrill Lynch Global Research

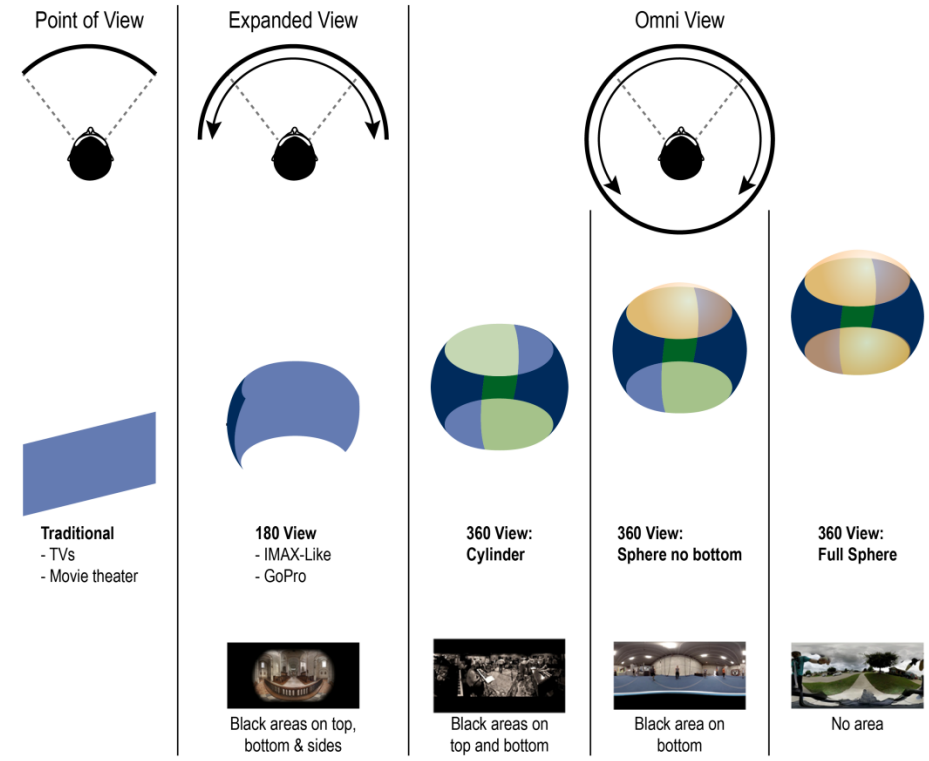
I think that immersive 3-D content is the obvious next thing after video – Mark Zuckerberg

Tricking the eye: 360° visual experiences

The first hurdle to immersive experience is vision. Large format cinemas such as IMAX make viewers feel surrounded by the imagery. 360˚ VR videos go a step further to give an omni-view – the ability to look in any direction – bringing viewers into the movie itself (source: Samsung).

70% of our sensory receptors are in our eyes, and 50% of the brain is involved in visual processing (source: Merieb, E. N. & Hoehn, K. 2007)

Exhibit 13: Trajectory to 360 vision



Source: Samsung Electronics, BofA Merrill Lynch Global Research

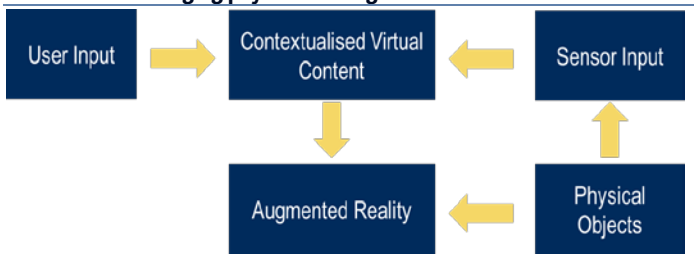
3D sound and the rest

Great strides have been made in modelling 3D audio using software. This has been technologically challenging as sound is a 3D time series, where the user needs to be able to discern the direction a sound is travelling from. Sound and physics must be used to model an acoustically accurate audio that is computed in real time. VR engines and standalone plugins are beginning to provide such offering. Haptics and vestibular have been even tougher given users do not want to purchase or use large cumbersome gloves or treadmills. Taste and smell sensory signals may even be years away, if possible at all.

AR/MR bridges physical and digital world

AR and MR, in contrast to VR, aim to blend digital objects with the user's existing reality. At the core, they are a delivery system that channels rich, contextual content to be superimposed on the view of the real world. A transparent display screen or camera conveys the outside environment, whereas VR blocks out the outside environment all together.

Exhibit 14: AR bridging physical and digital worlds



Source: Euromonitor, BofA Merrill Lynch Global Research

Table 2: Software, Middleware, Hardware within AR

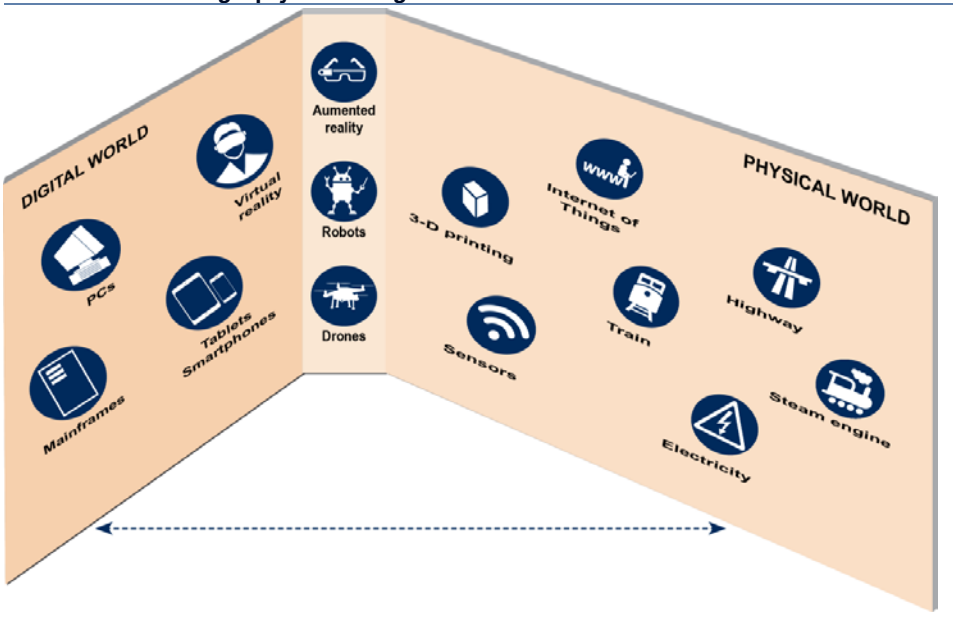
AR Engines	AR Software	AR Hardware
SDKs	Applications	Mobile devices
	Content management systems	Smart glasses
		HMDs

Source: BofA Merrill Lynch Global Research

The primary value proposition of AR and MR is the ability to bridge the physical and digital worlds. By combining the various sensor data, the software analytics can get a full context of the user's surrounding, and augment human senses with relevant information. Although high-end platforms such as Microsoft HoloLens or Daqri Smart

Helmet have already been made available, they are too expensive for the average consumer. As costs come down and the form factor becomes more practical, we can see it the technology becoming as ubiquitous as smartphones.

Exhibit 15: AR/MR bridges physical and digital world

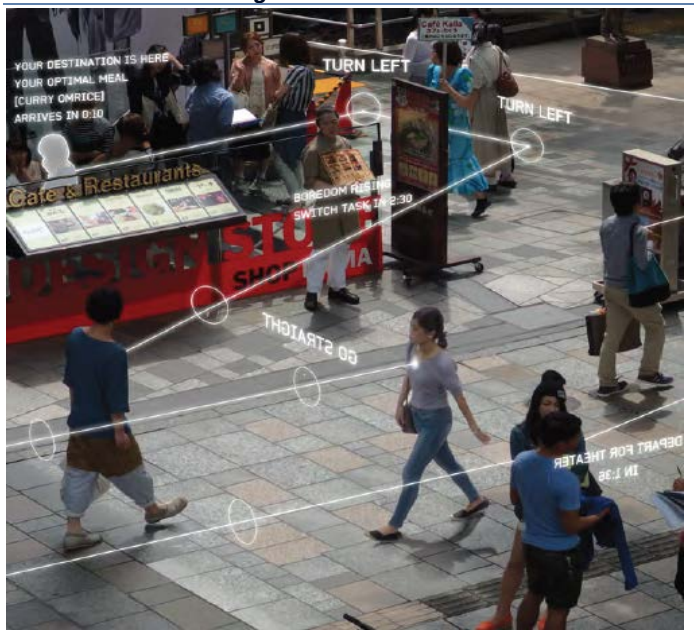


Source: PWC, BofA Merrill Lynch Global Research

Augments human senses

In the future, the aim is for everyone to be armed with a device that could unlock information and augment their senses. For instance, customers can scan a product in a grocery store to see price comparisons and the full nutritional information; scan a landmark and see relevant historical information; see traffic directions superimposed directly into the street as the person is walking; gauge the reaction of the person they are conversing with.

Exhibit 16: AR with walking directions



Source: Institute for the Future

Exhibit 17: AR with public speaking cues

Source: Institute for the Future

Promise of emotion-aware computing

Start-ups like the MIT spin-off Affectiva are already moving to incorporate emotion intelligence in wearables. The company has the world's largest emotion data repository with 40bn emotion data points, from 4mn faces, in 15k tested media types, in >75 countries, which allows it to detect human reactions and moods. The software can already be implemented in PCs, smartphones, and Google Glass through existing cameras (source: Affectiva). Tel Aviv-based Beyond Verbal can do the same using vocal cues. Tech giants are also moving into the space. IBM's Watson and start-up Emotient, acquired by Apple in early 2016, are examples of this. We believe it is probable that all devices, whether smartphone or AR/VR headsets, could be equipped with this software in the future.

Exhibit 18: Affectiva device-subject setup

Source: Affectiva

Exhibit 19: Affectiva – emotion reading it visualised within AR device

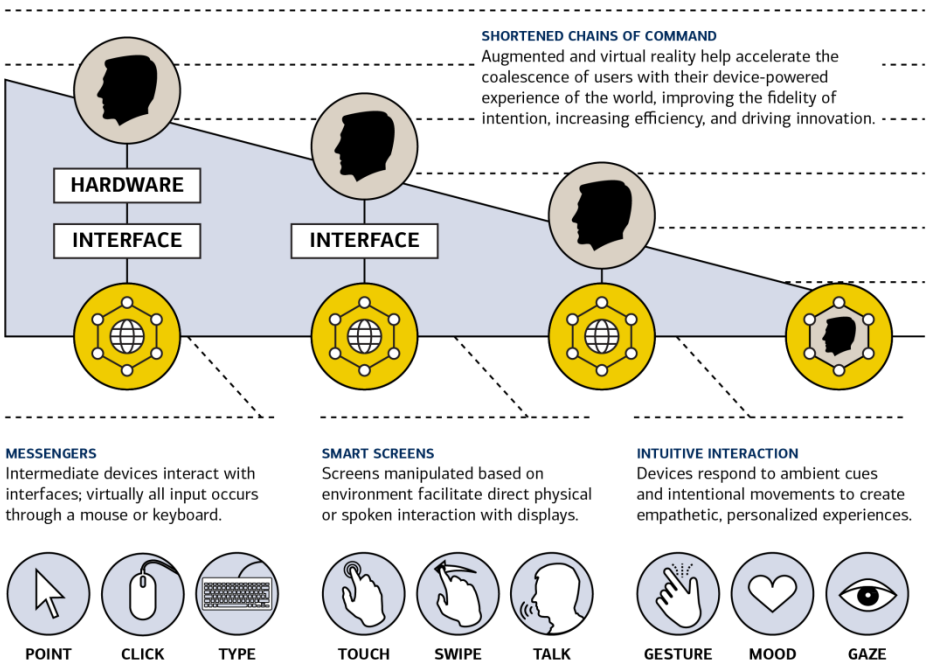
Source: Affectiva

Intuitive interaction propelling nextgen communications

Both virtual reality and augmented reality represent an evolution towards intuitive interactions. The human-machine interface has shifted from punch cards and paper in mainframes, to point-click-type computers, to touchscreens on mobile phones. Artificial reality takes it one step further, by removing any tangible interface at all, allowing

people to communicate through natural modes of interaction such as gaze, gesture, voice, and eventually context. By shortening the chain of commands, attention is shifted from the device or machine to more real world interactions.

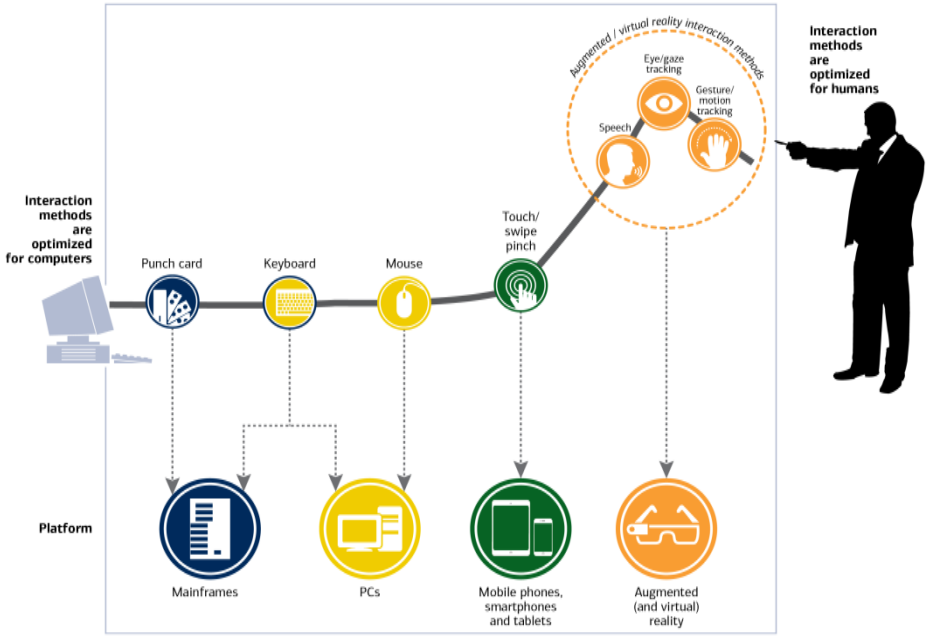
Exhibit 20: The evolution of interaction



Source: Deloitte

Humans communicate easily through speech, physical gestures, and eye contact. One of the main advantages of AR is that it can convey information and complete tasks while leaving the user's hands free to multi-task. Visual, speech, and gesture recognition technologies have made tremendous progress. In the future this can be combined, where the computer can have context and understand user intent.

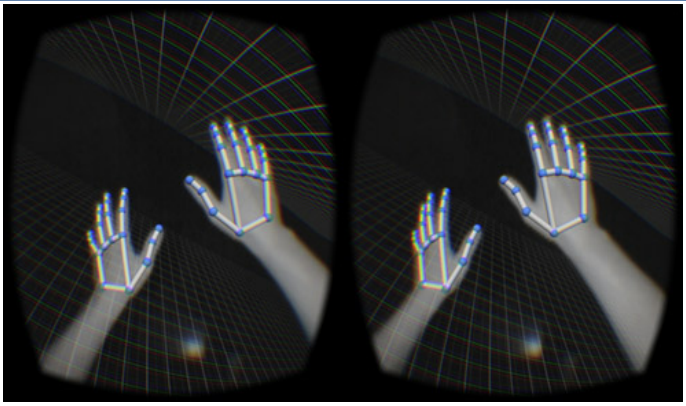
Exhibit 21: Each computing platform has evolved with a dominant interaction method. The methods that will dominate AR and VR applications are yet to be established.



Source: PwC

- **Gesture** – a core part of nextgen AR is using hands to interact with projected images in front of them. Microsoft HoloLens foresees users gesturing to open apps, select and size items, and drag and drop holograms. The same is true for VR users, who would be able to interact with the virtual environment that they are set in. Companies like Leap Motion use a combination of VGA cameras, LEDs, and software to model all 70,000 permutations of a hands potential motion (source: PWC).

Exhibit 22: Leap Motion tracking in augmented reality – tracking the 10 fingers and joints for a gesture interface



Source: Leap Motion

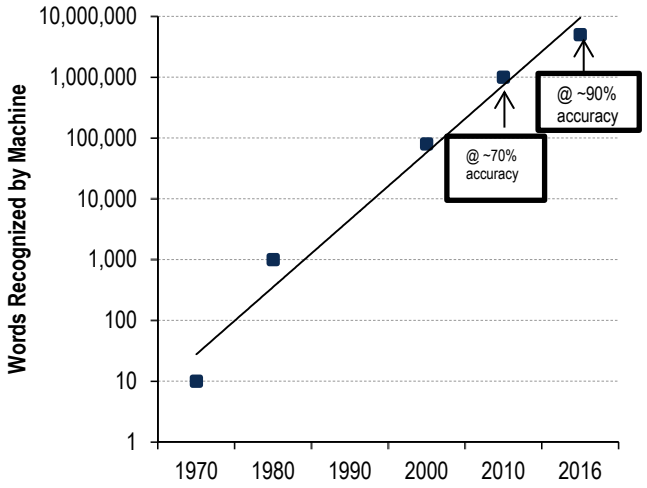
Exhibit 23: Microsoft Hololens gesture control of virtual screens

Source: Microsoft

- **Voice** – AI-enabled machine speech recognition has progressed from a 70% accuracy rate in 2010 to 90% in 2016 (source: KPCB). AR and VR platforms will allow for the use of voice commands to navigate, select, open, command, and control apps. The more interaction with the machine, the better the accuracy.

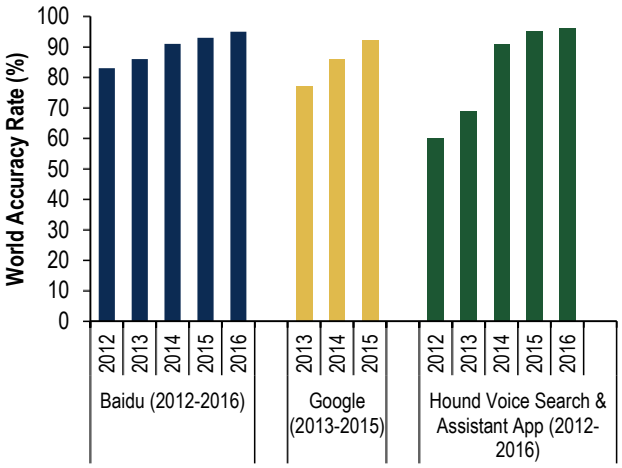
Humans can speak 150 vs type 40 words per minute on average (source: Kleiner Perkins Caufield Byers)

Chart 1: Words recognised by machine (per Google), 1970-2016



Source: KPCB

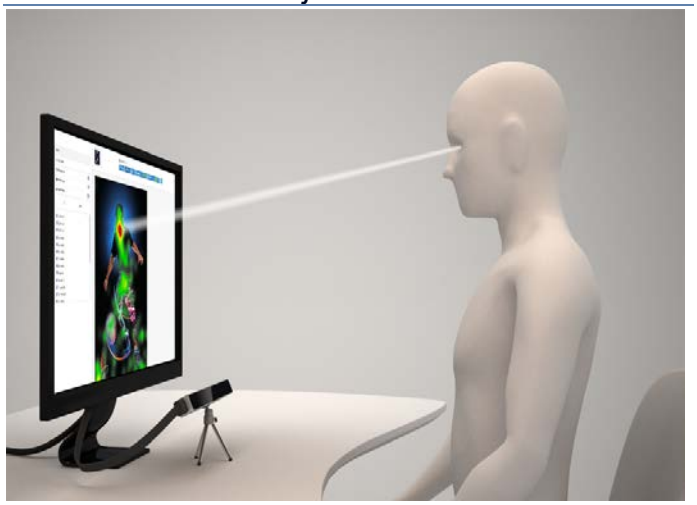
Chart 2: Word Accuracy Rates by Platform*, 2012–16



Source: KPCB
*Word accuracy rate definitions are unique to each company

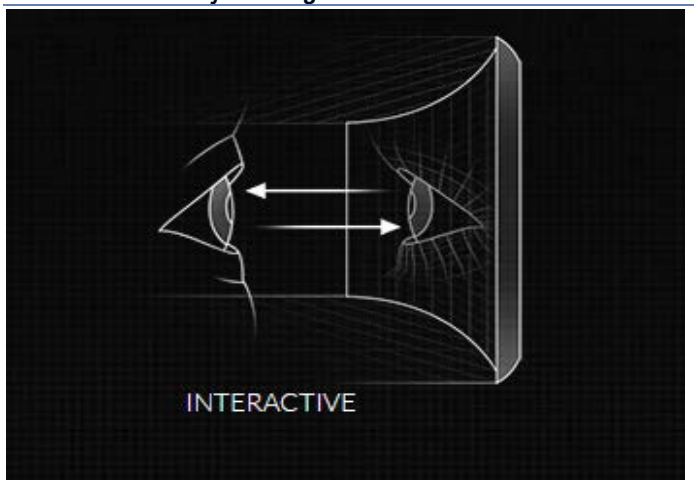
- **Gaze** – eye trackers use built-in sensors to track eye movement as a way of controlling a device, application, or game. This can act as a control interface and could help to detect user focus, interest, as well as emotion – the ultimate turnkey to simulate natural human-human interactions. The company The Eye Tribe uses a high-resolution, high-speed camera aimed at the eye. Even the smallest eye movements are detected and interpolated by the software to see what the user is looking at. You can have an instance where an e-book will know when to turn the page as you finish reading the last sentence (source: PWD, The Eye Tribe). The Epson Moverio AR HMD and FOVE VR HMD take it a step further, and use an infrared light.

Exhibit 24: User in front of an eye tracker



Source: The Eye Tribe

Exhibit 25: FOVE VR eye tracking



Source: Fove

Wide spectrum of AR delivery

Augmented reality technologies span a wide range, from free app-based solutions for your smartphone to integrated solutions like the Microsoft HoloLens that are sold at US$3000.

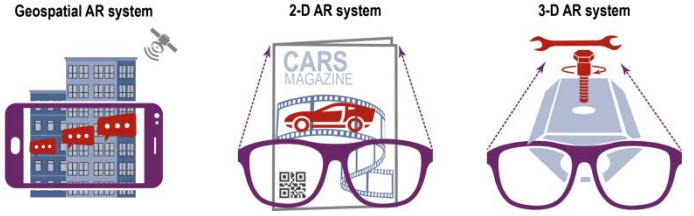
- **Geospatial** – the simplest form of AR, and has been around for several years. It involves digital overlays atop a real-time real-world view, primary driven by GPS data. Almost any mobile device with GPS is equipped to handle it. Yelp Monocle and ZipRealty StreetScan are examples where business establishments or real estate,

respectively, are rendered on top of the display. Software companies such as Blippar's Layar provide SDKs that let app developers add GPS-based AR features to mobile apps.

- **2D AR** – is able to recognise 2D objects within the frame, such as posters, books, magazines, landmarks, packaged goods, and to react in a predefined way – playing a video, opening a webpage, showing an interactive 3D model, etc. It often recognises objects through a distinct symbol or machine vision. The camera points at object X and causes the smartphone to undertake Y. Pokémon Go has the phone's GPS trigger Pokémon characters to appear on the screen, which then interact with the real environment that they recognise, such as sitting on a table surface or leaning against a tree. Blippar, Apple's Metaio, and Wikitude all offer SDKs with a large image library to aid 2D recognition.

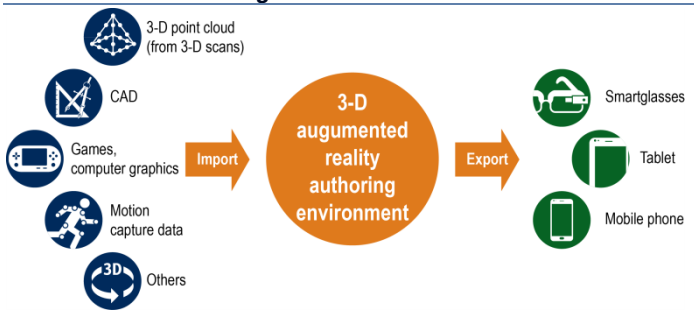
- **3D AR** – 3D tools are the most complex and require headsets and high-quality, accurate content for end uses such as computer-aided design (CAD) models or games. At the enterprise level, many companies already have CAD models of their own products or assets, and AR authoring tools then provide simple ways to augment 3D assets with images, charts, videos, real-time sensor information, etc. Objects outside of CAD libraries would require more sophisticated AI machine vision, processing power, and rendering capabilities. Most forms of high-end interactive 3D AR such as Microsoft HoloLens and Magic Leap are only in the development stages.

Exhibit 26: Geospatial AR system



Source: PWC, BofA Merrill Lynch Global Research

Exhibit 27: 3D AR authoring environment



Source: PWC, BofA Merrill Lynch Global Research

Exhibit 28: AR/MR platforms

	Google Tango Lenovo Phab 2 Pro	Epson Moverio BT-300	Google Glass	Meta 2 (Developer's edition)	Microsoft Hololens (Developer's edition)
					
Platform	Screenless viewer	Standalone	Standalone	Tethered - PC	Standalone
Price	$499	$699.99	$1500	$949	$3,000
Panel Resolution	2560 x 1440	1280 x 720	640 x 360	2560 x 1440	1268 x 720
Sensors	Gyroscope Accelerometer Fisheye motion tracking camera Depth sensor camera	GPS Compass Gyroscope Accelerometer Microphone 5MP camera	Gyroscope Accelerometer Magnetometer Ambient light sensor Proximity sensor	Gyroscope Accelerometer 720p front-facing HD camera Depth camera	Gyroscope Accelerometer Magnetometer 4 environment understanding cameras 1 depth camera 12MP photo / HD video camera Mixed reality capture 4 microphones 1 ambient light sensor
Processor	Inclusive: Qualcomm® Snapdragon™ 652 processor, optimized for Tango	Inclusive: Intel Atom X5 1.44Ghz Dual Core, Android 5.1, 1GB RAM, 8GB internal memory	Inclusive: Texas Instruments OMAP4430 processor	Separate requirement: Support for Windows 8 or 10 applications, NVIDIA GT 650M / AMD Radeon HD7970, Intel i7-3610QM equivalent or greater, 8 GB RAM, HDMI 1.4 video output, 1x USB 3.0 ports, 64 bit Unity 5+ on Windows, Intel HD compatible sound card, USB 3.0	Inclusive: Windows 10. Hardware: CPU - Intel Atom x5-Z8100 1.04GHz, Intel Airmont (14nm), 4 Logical Processors, 64-bit , 2 HD 16:9 light engines, Intel 32 bit architecture HPU 1.0, 64GB Flash memory, 2GB CPU and 1GB HPU RAM, Battery Life is 2-3 hours of active use. Up to 2 weeks of standby time
Release date	Sep-16	Late 2016	April-2012 & discontinued in Jan 2015	Q3 2016	March 30 2016 for developer edition
Misc				Sensor array for hand interactions and positional tracking, Tethered	Includes a clicker to select, scroll, hold, and double-click; first fully untethered holographic computer

Source: BofA Merrill Lynch Global Research based on company disclosures

Mobile AR: 3.5bn app downloads, 200mn users

3.5bn – number of AR apps could be downloaded in 2017
200mn – number of mobile AR users by end of 2016

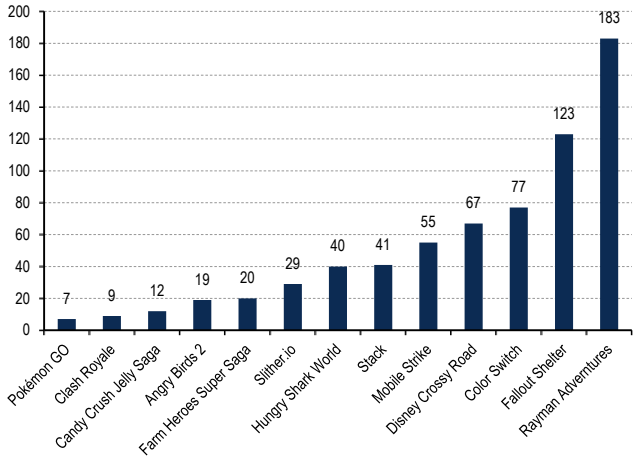
Despite the cost of integrated AR solutions, mobile AR has existed for several years and is on a swift upward trajectory. Some 118mn AR apps were downloaded in 2012, which could balloon to 3.5bn by 2017. Mobile AR users could also triple, from 60mn in 2013 to 200mn by the end of this year (source: Plastic Mobile).

Pokémon Go: the world's intro to AR social mobile gaming

Pokémon Go, an augmented reality game released 6 July 2016, has taken the mobile gaming world by storm, rising to the top-grossing position on the iOS and Android App stores in a single day. Pokémon Go is the fastest app ever to reach 10mn downloads, achieving the milestone after just seven days even with a limited geographic launch, topping the previous record held by Clash Royale (a Supercell game) of nine days. Pokémon Go was averaging $4mn per day in revenue just days after launch and earning

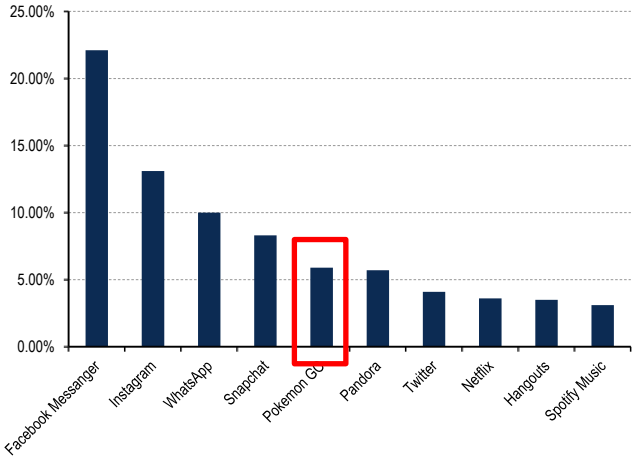
$35mn in the first two weeks (according to Superdata) and recent reports indicate it has over 50mn monthly active users (source: Survey Monkey).

Figure 3: # of days to reach 10 million downloads on Android



Source: SimilarWeb, BofA Merrill Lynch Global Research estimates

Figure 4: Daily active users as % of US Android users

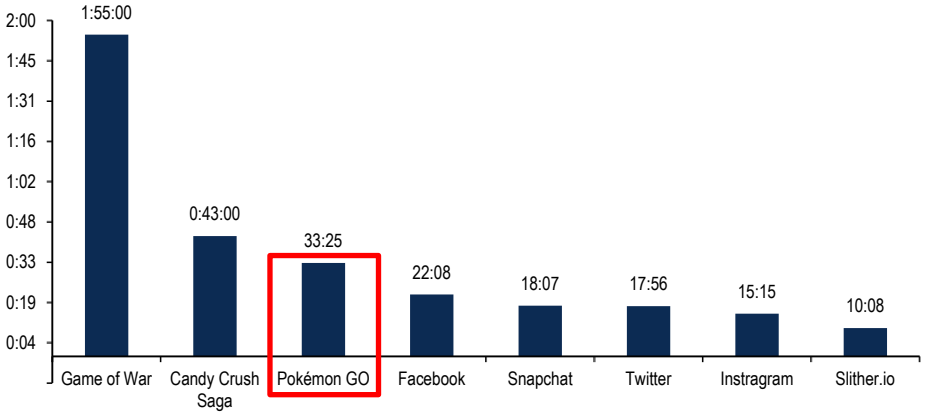


Source: SimilarWeb, BofA Merrill Lynch Global Research

Pokémon Go has high engagement with users (despite limited functionality indoors) with SurveyMonkey reporting average usage of 44 minutes per day, higher than many mainstream apps such as Facebook, Snapchat, and Twitter. However, some major mobile gaming titles such as Game of War and Candy Crush Saga still have higher usage. Time spent on Pokémon Go may take time away from online activities such as gaming, social media, and video viewing – a risk for the Internet media sector. We expect July Internet usage data to be closely watched to see if there are signs of a share shift.

Figure 5: Average minutes of usage per day on Android devices

Pokémon Go users average 33 minutes per day above most social media Apps



Source: Surveymonkey, BofA Merrill Lynch Global Research

Unique experience combined with a powerful IP and brand

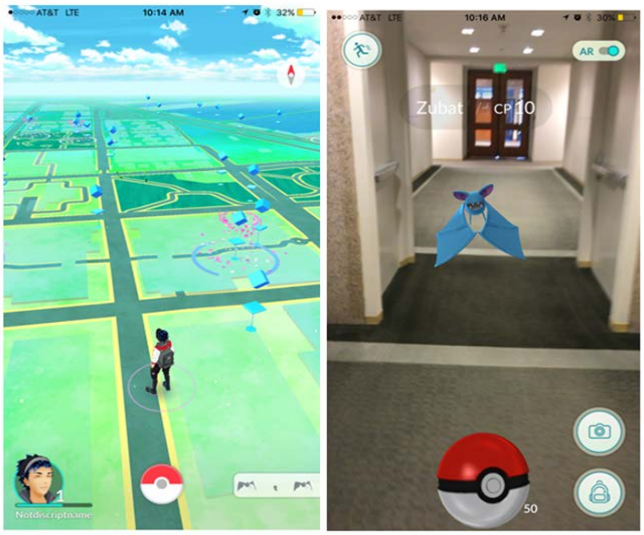
52% of Pokémon Go players made new friends while playing the game

58% got the app because the game encouraged them to go outside (source: MFour)

Pokémon Go, at its core, is a location-based augmented reality game that encourages users to move around real world locations to find and capture Pokémon (short for Pocket Monsters). Augmented reality gaming on mobile and portable devices is not a new concept, with Nintendo adding AR functionality in titles on the Nintendo DS, and several AR games released on mobile including Ingress (created by Niantic), Crayola Color Alive, Zombies everywhere, AR invaders, and Toywheel's Toy Car RC.

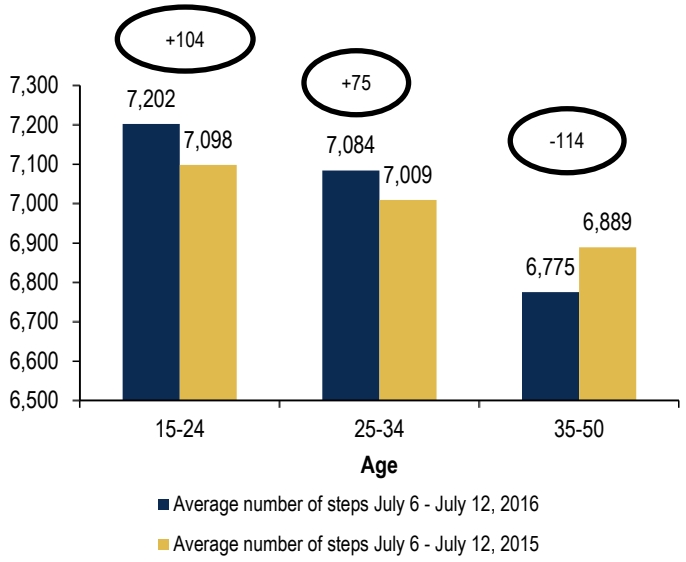
Pokémon Go has three key features driving its success, in our opinion, that future apps and games may try to replicate: 1) strong intellectual property (IP) that resonates across generations of adults and children; 2) a collection element that drives users to search for rare Pokémon; and 3) an innovative system of play that encourages users to interact with the real world. There are 151 Pokémon for users to capture but they only appear in certain locations, encouraging users to move around cities trying to catch them all. This has intriguing social elements, with people interacting in the real world rather than in online-only settings.

Figure 6: Pokémon Go utilises real world map data and augmented reality for experience



Source: BofA Merrill Lynch Global Research

Chart 3: Number of steps by age group



Source: Withings

Millennials are walking more to catch Pokémon

US Millennials have taken 107 more steps per week after Pokémon Go vs the previous year

The first UK person to find all Pokémon walked 225km (140mi), and lost 12.7kg (28lb) in the process

Players must travel in the real world to catch the virtual monsters, which is making users walk more. According to data from Withings, consumers aged 15-24 on average walked 104 more steps than during the same period in the prior year, while 25-34 walked 75

more steps. The first UK player to catch all Pokémon lost nearly 30lb in the process (source: BBC, The Telegraph).

Millennials and Gen Z are drivers of mindshare

83% of Pokémon Go players are aged 18-34 (source: MFour)

Younger demographics such as Millennials (born 1981-1997) and Gen Z (born 1998-present) have been leading the charge in AR/VR adoption. More than 2 out of 5 people between the ages of 16 and 34 say they are interested in a VR headset (source: Globalwebindex). This is particularly impactful given the combination of Millennials and Gen Z has emerged as the world's largest demographic with 4.4bn people, 59% of the total 7.3bn population. Millennials (75.4mn) overtook the Boomers in 2015 to become the largest living generation in US history – and their numbers are not projected to peak until 2036E (source: Pew Research Center, US Census Bureau).

Exhibit 29: Generations at a glance

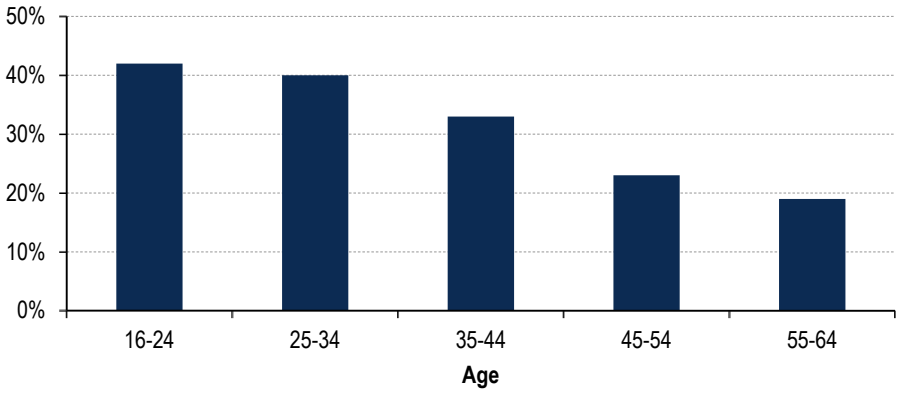
Gen Z will be a key driver of AR/VR technological adoption

Generation	Greatest /Silent	Baby Boomers	Gen X	Millennials	Gen Z
Years Born	1923 - 1945	1946-1964	1965-1980	1981-1997	1998-2016
Age in 2016	71-93Y	52-70Y	36-51Y	19-35Y	0-18Y
Population (Global)	0.3bn	1.1bn	1.5bn	2bn	2.4bn
% of Global Population	5%	15%	20%	27%	32%
Life-Defining Events	World War I and II Great Depression Electric Appliances	Cold War Moon Landing Transistor Invented	End of Cold War Live Aid First Personal Computer	9/11 Terrorist Attacks Iraq War Advent of Social Media	Post-Great Recession Arab Spring Rise of AI
Communication Style	Letter	Telephone	Email / SMS	Instant Message	Emojis
Key Technology	Car	TV	PC	Smartphone	AR/VR
Hobby	Reading	Watching TV	Surfing the Internet	Video Games	Music Streaming
Digital Proficiency	Pre-Digital	Digital Immigrants	Early Digital Adopters	Digital Natives	Digital Innates
Iconic Figure	Franklin D. Roosevelt	John F. Kennedy	Kurt Cobain	Mark Zuckerberg	Malala
Music	Jazz Swing	Elvis Beatles	Nirvana Madonna	Britney Spears Justin Timberlake	Justin Bieber Taylor Swift
How They Get Around	'55 Ford Thunderbird	SUV	Bicycle / Car	Uber / Lyft	Mom's Prius
Current Living Situation	Retirement Home	Semi Detached House	Own Small Apartment	Sharing an Apartment	Parents' House
Social network other than Facebook	The Rotary Club	Match.com	LinkedIn	Tinder	Snapchat
Deepest Fear	The world in 2016	No longer center of attention	What about my generation	Paying off student debt	Low batteries
Key Life Question	How did the country go so wrong?	Where's the Viagra?	What's the point?	What's a career?	What's a landline?
Defining Condition	Permanently Aggrieved	Erectile Dysfunction	ADHD	Gluten-Intolerant	Peanut Allergy
What They Spend On	Oklahoma Community Dinner Theater	VIP tickets to The Rolling Stones	Burning Man	Coachella	Minecraft

Source: iKinetic, McCrindle, Pew Research, Bruce Feirstein – Vanity Fair, various sources, BofA Merrill Lynch Global Research

Chart 4: Interest in Virtual Reality headsets - by age

% who are interested in using VR in the future



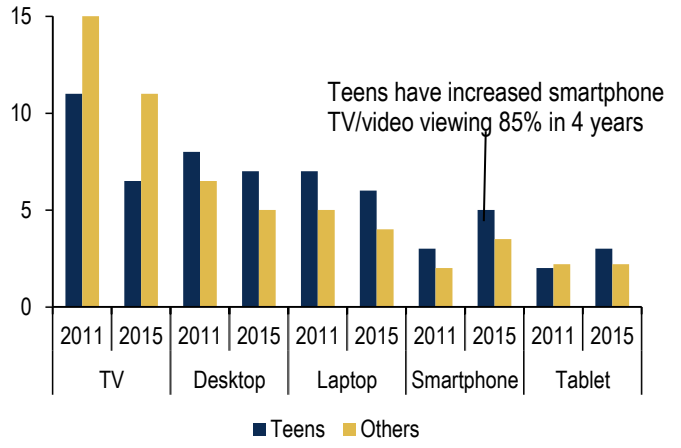
Source: Global Web Index

Tech natives are looking for new mediums

Younger demographics are interacting with their tech devices more than ever. On their smartphones:
-63% play games
-60% shop online
-50% read the news (source: Coupofy)

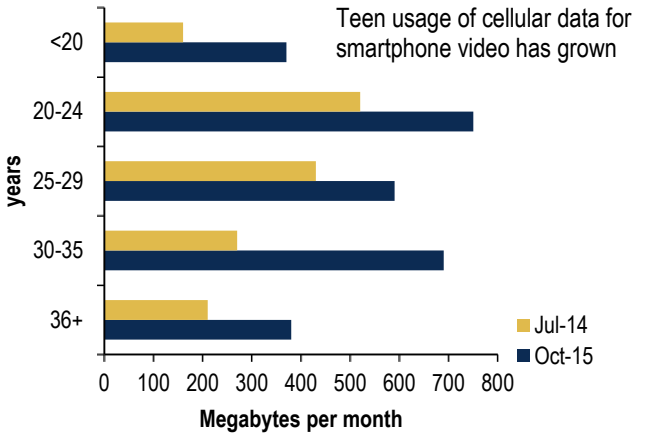
Millennials and Gen Z are already consuming more TV, video, gaming, and social media on their smartphones than any other generation, so it seems only logical that integrating AR/VR will be the future. It shows great promise, given that 1 in 2 gamers and branded video viewers would like to try out VR technology (source: GlobalWebIndex).

Chart 5: Total weekly hours of TV/video viewing at home



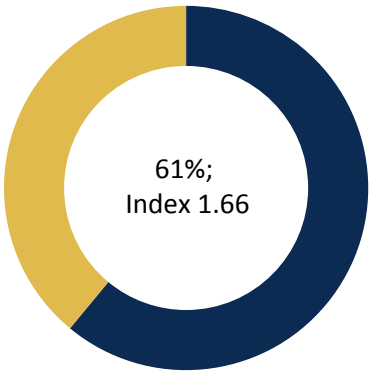
Source: Ericsson

Chart 6: Cellular video data use - teen vs others



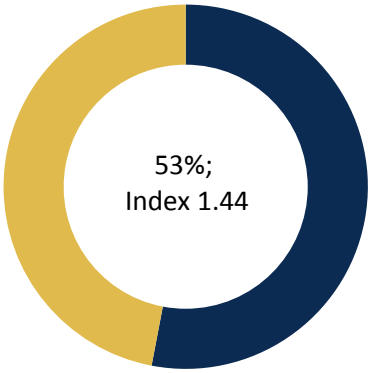
Source: Ericsson

Chart 7: Interest in Virtual Reality headsets – by Audience
Smartwatch Owners



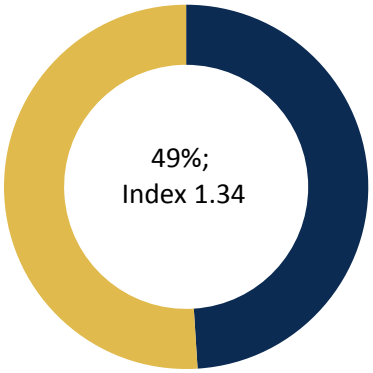
Source: Global web index

Chart 8: Interest in Virtual Reality headsets – by Audience
Gamers



Source: Global web index

Chart 9: Interest in Virtual Reality headsets – by Audience
Brand Video Viewers

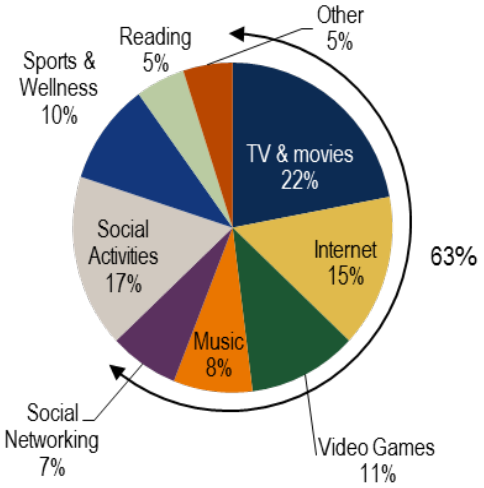


Source: Global web index

Leisure: potential to dominate 2/3 time, 1/2 dollars

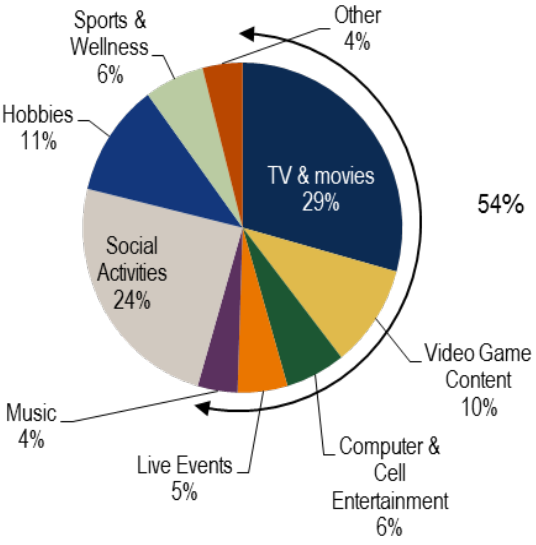
Pokémon Go may have captured the imagination of companies and marketers globally, but the true consumer potential of AR/VR could be much higher. Americans that play video games spent 2/3 (63%) of their leisure time on video games, TV, movies, internet, music, and social networking. They spent over half of their leisure budget (54%) on paying for it (source: Nielsen). Providers such as Netflix, Disney, IMAX, and Facebook are actively rolling out content for immersive entertainment, social VR, and music.

Exhibit 30: Claimed weekly leisure time
% of leisure hours: Gamers Aged 13+



Source: Nielsen

Exhibit 31: Claimed monthly leisure spend
% of leisure dollars: Households spending $1+ per month on gaming



Source: Nielsen

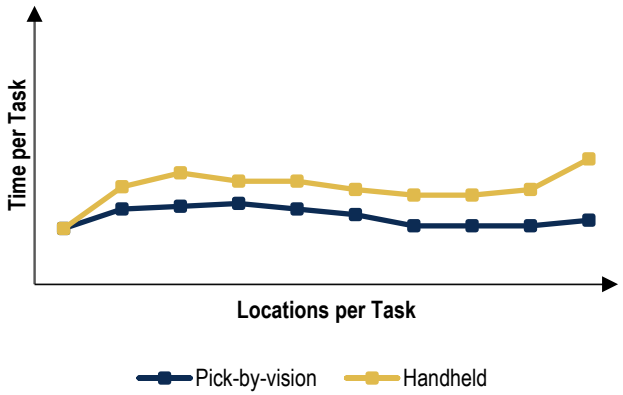
Enterprise: long-term efficiencies

50% of organizations are testing AR software or are planning to do so (source: IDC, TechTarget)

Although AR has entered the public consciousness through Pokémon Go, the long-term potential for the platform is its ability to disrupt enterprises. By presenting relevant information to workers in an intuitive interface, it can reduce time, errors, and cost, while improving output. In a recent pilot project, DHL found that warehouse workers equipped with AR smartglasses were able to pick objects with 25% higher efficiency and fewer errors (source: DHL). This is particularly impactful as logistics accounted for 8.3% of US GDP in 2014 (source: PWC). Similarly, Boeing factory trainees assembling a mock airplane wing were 30% faster and 90% more accurate using AR-animated instructions vs PDF documents (source: Richardson et al 2014).

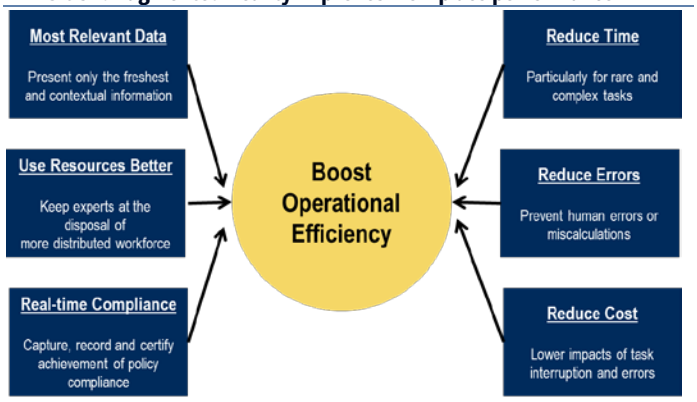
Chart 10: DHL Staff equipped with Google Glass/VuzixM100 with Ubimax xPick

>25% performance increase



Source: DHL

Exhibit 32: Augmented Reality improves workplace performance



Source: AREA

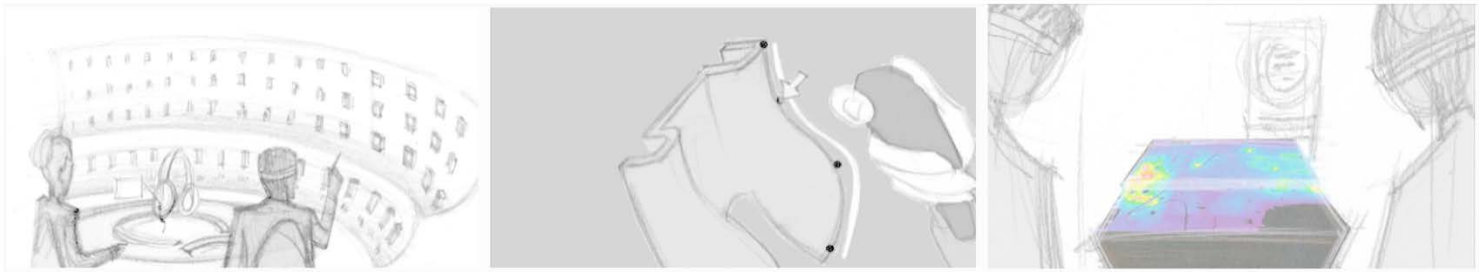
110mn deskless jobs could benefit from AR

Industrials and healthcare will be the first sectors to adopt AR and VR. According to AR HMD-maker Atheer, there are more than 110mn deskless workers in the world whose performance could be improved with the use of technologies like AR. These include anyone whose job is to be knowledgeable about physical equipment or the medical history of the person they are treating. Having hands-free access to rich information, schematics, videos, pictures, instructions, etc. on the job would be invaluable for them (source: PWC).

Transforming the office: Microsoft HoloLens and Autodesk Fusion case study

Platforms like mixed reality aim to transform how all workplaces function. Microsoft HoloLens kicked off a joint project called 'FreeForm' with Autodesk Fusion 360. The project went beyond 3D models on computer screens, and took the models into the real world. Designers and engineers could interact in real time with models in a shared workspace. Work areas could have infinite space by using walls and open areas overlaid with digital objects. The project changed how people worked with data, the environment, peers, and their customers (source: Autodesk).

Exhibit 33: Early concepts for Microsoft HoloLens + Fusion 360 integration



Source: Autodesk

The vision is for designers and engineers to be able to create and edit directly from a holographic model, and to use the same platform to pitch directly to the end client (source: Autodesk).

Exhibit 34: Autodesk's vision of 3D design using Microsoft HoloLens

Source: Autodesk

Exhibit 35: Autodesk's vision of 3D design using Microsoft HoloLens

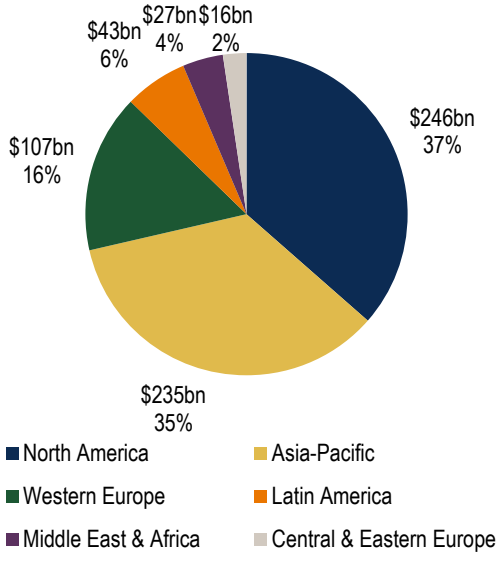
Source: Autodesk

Disrupting the US$674bn global advertising market

Mobile ads surpassed print ads for the first time in 2015 (source: eMarketer)

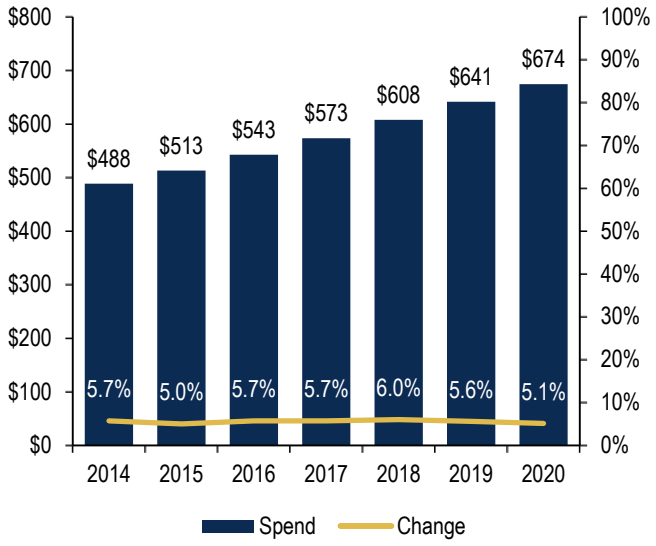
Augmented reality has great potential to tap into the global advertising market, which is expected to grow at a 5.6% CAGR from US$514bn in 2015 to US$674bn by 2020E. It can do so by enabling hyper-local native digital mobile advertising. The US is the world's largest ad market, comprising ~1/3 of the total. Close to half (45%) of all ads there will be digital by 2020E, of which 3/4 will be mobile digital ads. In terms of spend, mobile digital ads will quadruple from US$19bn in the US in 2014 to US$77.1bn by the end of the decade (source: eMarketer).

Chart 11: Total media ad spending worldwide, 2020



Source: eMarketer

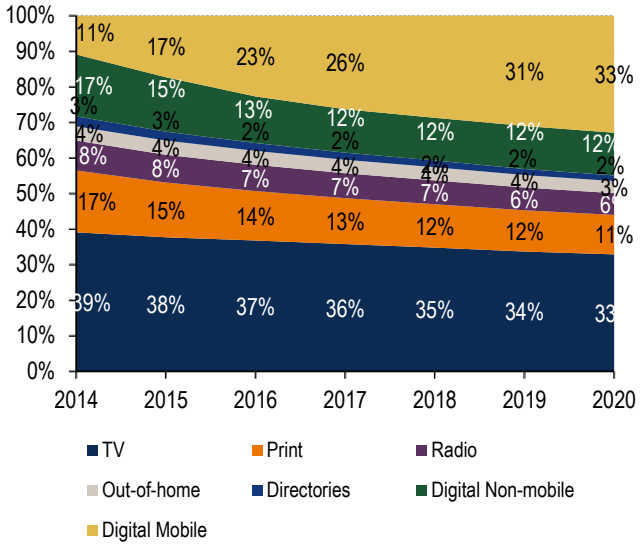
Chart 12: Total media ad spending worldwide, 2014-2020



Source: eMarketer

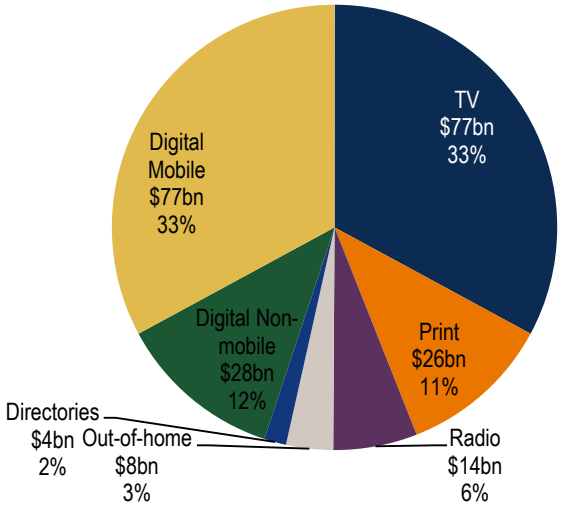
Every US$1 out of US$2 spent on advertising in the US by 2020E will be some form of digital, and 3/4 of that will be mobile (source: eMarketer)

Chart 13: US total media ad spending share, by media, 2014-20



Source: eMarketer

Chart 14: US TV vs Digital Ad Spending, by device, 2020



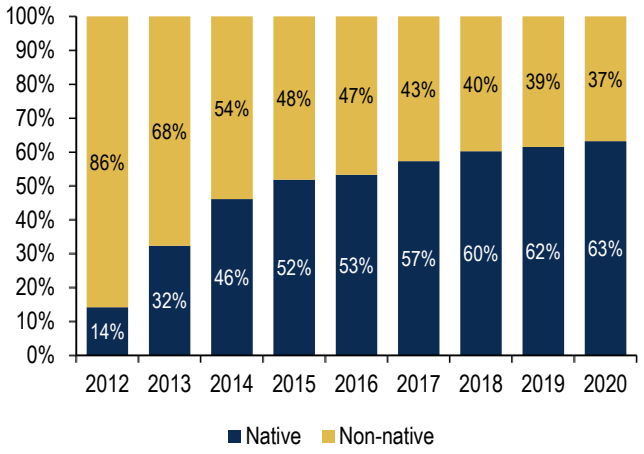
Source: eMarketer

US$53bn in mobile native ads by 2020E, 70% CAGR

US adults are spending 2 hours 51min / day on non-voice activities on mobile devices, 1 hour 31min of that is on mobile phones (source: eMarketer)

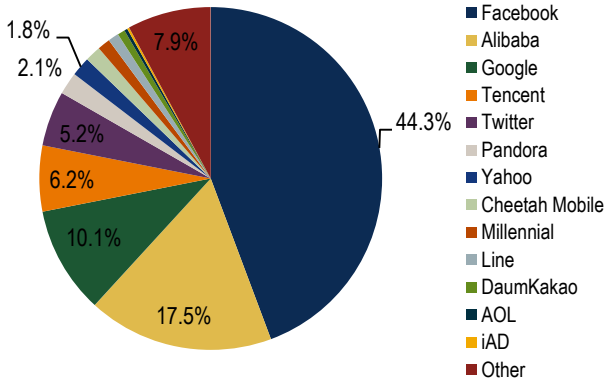
The single-largest driver of advertising spend will be native mobile ads, and augmented reality could be the next platform to interact with customers. By 2020E, 2/3 of mobile ads will be native, making up US$53.4bn in annual revenue. Many social media companies such as Facebook, Tencent, and Twitter are already using native ads, many of which take the form of in-stream ads (source: IHS 2016).

Chart 15: Global native share of total mobile display advertising (%)



Source: IHS

Chart 16: Global mobile display advertising share by company in 2015



Source: IHS

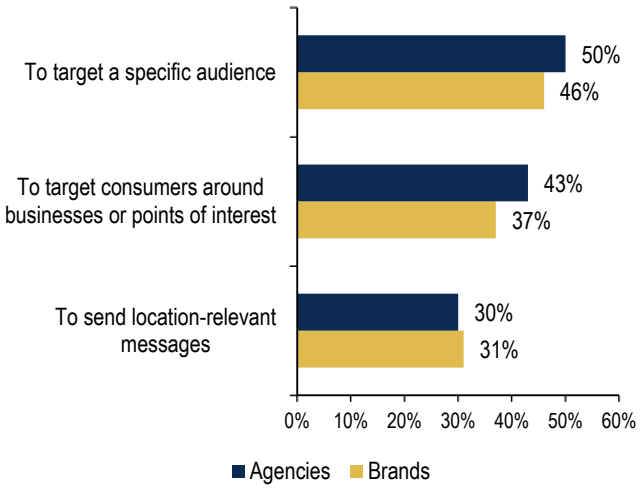
Hyper local-based advertising

8 in 10 marketers worldwide use location-targeting for mobile advertising, according to May 2015 polling by xAd

Augmented and mixed reality platforms are the ideal platform for location-based advertising. It knows where you are, can direct you into the store, knows what you are looking at, and can ultimately sell you the product. Around half of all marketers use the medium to target specific groups or consumers near a point of interest, and 2/3 do so through mobile coupons. Media-focused strategy consultant BIA/Kelsey forecasts that mobile location-targeted ads will continue to outpace national and international placements, and could hit US$18.2bn by 2019, rising at a 28% CAGR from US$6.7bn in 2015.

Chart 17: Ways in which agency vs. brand marketers worldwide use location targeting in mobile ad campaigns, May 2015

% of respondents



Source: eMarketer

Chart 18: Most effective methods for attributing in-store purchases to mobile ads according to US marketers, Oct 2015

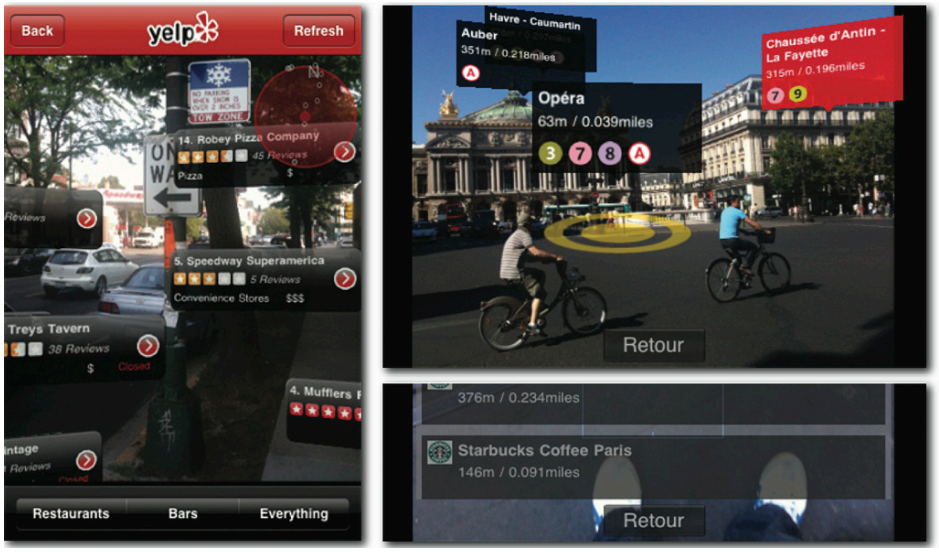
% of respondents

Source: eMarketer

Yelp Monocle is an AR-enabled social reviewing service launched in 2009, which uses the phone GPS and compass to display AR markets for nearby establishments.

Companies can use similar modes to advertise their restaurant, store, or other service, and help customers select products within the establishment.

Exhibit 36: Sample screenshot using Yelp Monocle



Source: Flickr

Heavy private and corporate investment

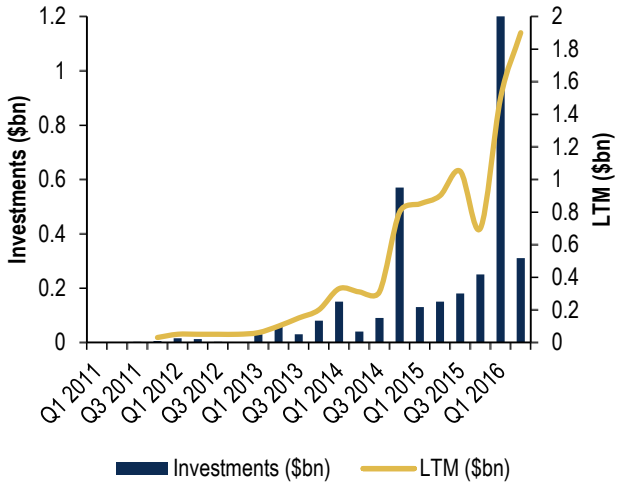
-$2bn in VC investment in last 12 months
-353 completed deals between 2010 and 2015
-5 VR/AR unicorns

Many of the technological advances in recent years underpin interest in VR/AR, with significant funding poured into the space by both venture funds and major corporations. Between 2010 and 2015, VCs deployed US$4bn in the VR/AR field across 353 completed deals, and another US$2bn in the last 12 months through June 2016 (source: Pitchbook, Digi-Capital). This is a significant ramp-up in investment. Areas of interest span a wide range including AR/VR hardware, services, games, advertising, consumer apps, machine vision, peripherals, and end-to-end solutions.

In addition to traditional VCs, a mix of corporations, private equity, and hedge funds have been investing in the burgeoning sector. In June 2016, over 30 VC firms and corporations, led by HTC, formed the VR Venture Capital Alliance to deploy capital in the space.

US$10bn – the amount of deployable capital of VR Venture Capital Alliance (source: VRVCA)

Chart 19: Digi-Capital AR/VR Investments ($bn)



Source: Digi-Capital

Table 3: Most capitalised VR companies

	Company	Total amount raised
	Oculus VR*	2.1bn
2	Magic Leap	1.39bn
3	LENSAR**	191.1mn
4	NextVR	115.5mn
5	Jaunt	101.3mn
6	Blippar	99mn
7	Vuforia	65mn
8	Matterport	57.7mn
9	Avegant	37mn
10	Playful	33mn

Source: PitchBook Data, Inc., Crunchbase
*Includes FB acquisition
**Agreed to $59mn acquisition on 16-Nov-2015

200k developers, 1,000+ start-ups, 5 unicorns

US$793.5mn – the amount Magic Leap raised in 2016, one of the largest C-rounds in history (source: Crunch Base)

Facebook's US$2bn acquisition of Oculus in 2014 was a turning point in the industry, marking when VR moved out of the gamers' basement and became a product sold by tech titans. By September 2015, there were more than 200k developers self-identifying as focusing on Oculus development alone. Angel List has 800+ VR start-ups, and 600+ AR start-ups in its catalogue as of August 2016. The burgeoning interest in AR/VR has already produced five unicorns thus far – Oculus, Magic Leap, MindMaze, Blippar, and Razer, with tremendous appetite for more development.

Table 4: Artificial Reality unicorns

	Magic Leap	MindMaze	Blippar	Razer
Type	AR/MR	AR/VR	AR	VR
Country	US	Switzerland	UK	US
Segment	Hardware, Software	Hardware, Software	Software	Hardware, Software
	AR platform that has raised US$1.4bn to date for a US$4.5bn valuation. Uses digital lightfields to send computer-generated images into the user's eyes. The company is expected to release a software development kit (SDK) in 2016 (source: Magic Leap, TechCrunch)	The company stands in the intersection of neuroscience and IoT, tapping into advances in computer vision, electroencephalographic scans, 3D motion capture cameras for gesture detection and object/user recognition. MindMaze makes a headset called MindLeap, which is a certified medical device in Europe. One application is for helping retrain the brain in stroke victims (source: MindMaze)	AR and machine learning software company. The Blippar app allows users to scan objects and unlock content. 1000+ brands are using Blippar in 170+ countries. After acquiring the Dutch AR firm, Layar in 2014, the formed one of the world's largest userbase for AR, now standing at 65mn+ (source: Blippar)	Producer of gaming equipment. Introduced the Razer OSVR, virtual reality device and open-source software ecosystem in 2015 (source: Razer)

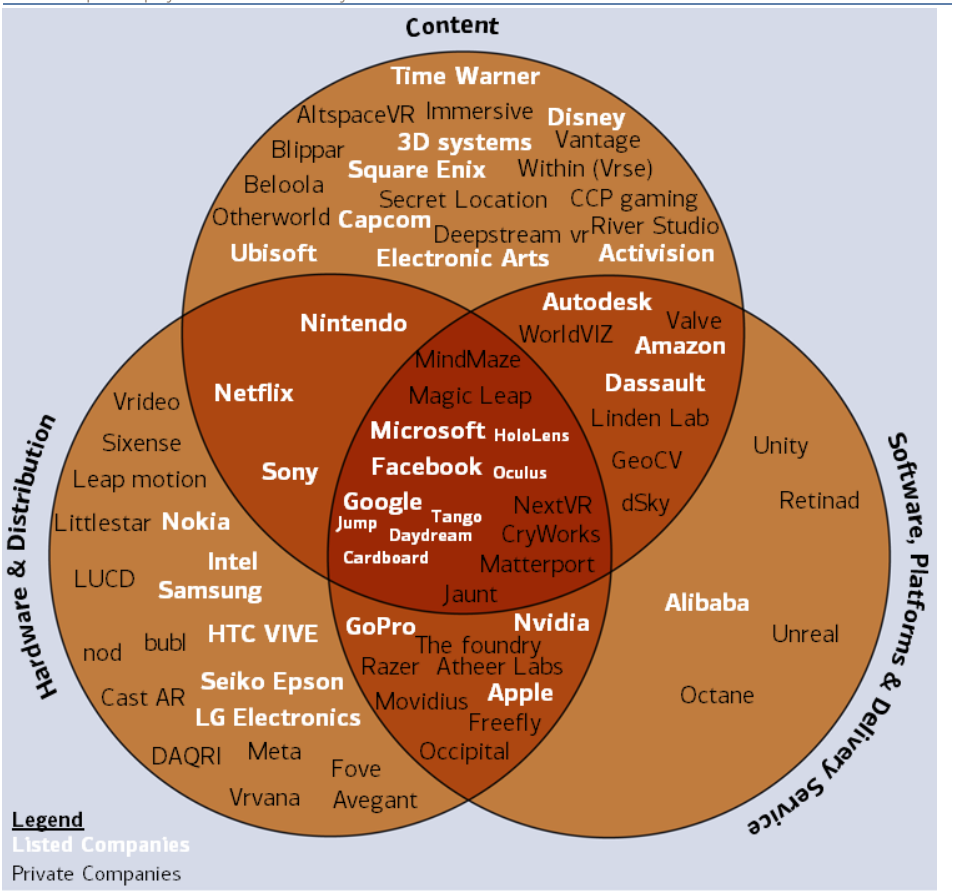
Source: BofA Merrill Lynch Global Research based on company disclosures

Start-ups competing with major players

Tech titans – Facebook, Google, and Microsoft – currently dominate end-to-end platform solutions, while listed incumbents and start-ups in consumer devices, entertainment, and industrial software are building strong niches within the space.

Exhibit 37: Start-ups playing major role

Public and private players in the AR/VR ecosystem

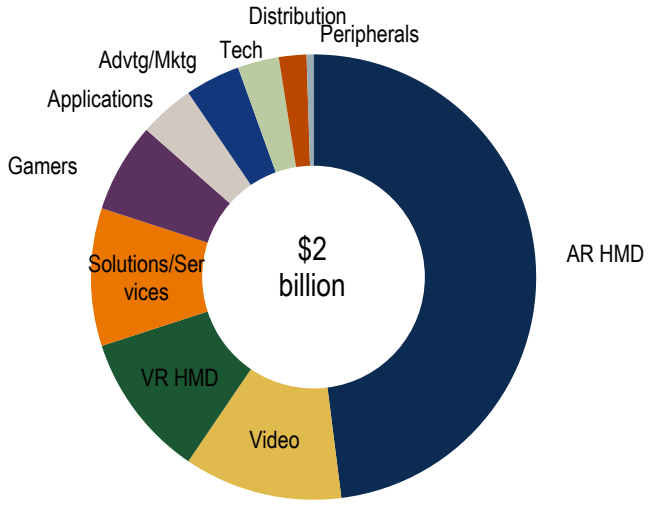


Source: BofA Merrill Lynch Global Research

The next Silicon Valley battlefront

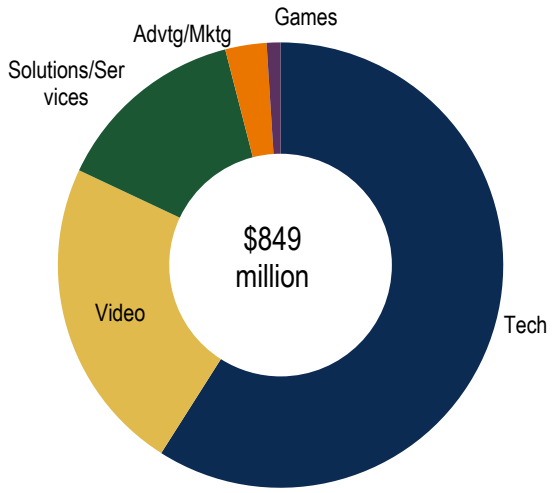
Public and private companies of various sizes have been heating up M&A activity in AR/VR. The last 12 months through June 2016 saw nearly a billion (US$849mn) in M&A activity, with the bulk focused on tech, video, and services (source: Digi-Capital). US tech companies Google, Facebook, and Apple have each purchased over 10 companies in the space since 2010 (source: company disclosures).

Chart 20: AR/VR Investments LTM to Q2 2016



Source: Digi-capital

Chart 21: AR/VR M&A LTM to Q2 2016



Source: Digi-capital

Table 5: Technology giants have been on a AR/VR buying spree in recent years

	Google	Apple	Facebook	Intel	Microsoft	Qualcomm	Amazon	Sony
	Moodstocks: Jul-16	FlyBy Media: Jan-16	Masquerade: Mar-16	Movidius: Sept-2016	Havok: Oct-15	Euvision: Sep-14	Evi Technologies: Apr-13, $26	Toshiba Image Sensor unit: Oct-15, $155mn
	NorthBit: Apr-16	Emotient: Jan-16	Two Big Ears: May-16	Nervana: Aug-16, $400mn	N-Trig: Apr-15, $30	Kooaba: Jan-14	Ivona: Jan-13	SoftKinetic Systems: Oct-15
	Molecular Imprints : Jun-15	Faceshift: Nov-15	Pebbles Interface: Jul-15, $60	Saffron: Oct-15	Perceptive Pixel: Jul-12	EPOS Development: Sep-12	Yap: Nov-11	
	Skillman & Hacket: Apr-15	Vocal IQ: Oct-15	Surreal Vision: May-15	Recon Jet: Jun-15, $175mn	Canesta: Oct-10	GestureTek: Jul-11		
	Thrive Audio: Apr-15	Metaio: May-15	Wit.ai: Jan-15	Lemoptix: Mar-15	3DV: Mar-09, $35			
	Tilt Brush: Apr-15	LinX: Apr-15, $20	Nimble VR: Dec-14	Composyt Labs: Jan-15				
	Dark Blue Labs: Oct-14	Privaris Patents: Dec-14	13th Lab: Dec-14	Indisys: Sep-13, $26mn				
	Vision Factory: Oct-14	Novauris: Jan-14	Oculus: Mar-14, $2,000	Omek Interactive: Jul-13, $50mn				
	Jetpac: Aug-14	PrimeSense: Nov-13, $345	Jibbigo (Mobile Technologies): Aug-13	TYZX: Jul-12				
	Quest Visual: May-14	AuthenTec: Jul-12, $356	Face.Com: Jun-12, $60					
	DeepMind Technologies: Jan-14, $400mn	Polar Rose: Sep-10, $29						
	Industrial Perception: Dec-13	Siri: Apr-10, $200						
	Flutter: Oct-13, $40mn							
	SR Tech Group, LLC - Patents: Jul-13							
	wavii: Apr-13, $30mn							
	Viewdle: Oct-12, $40mn							
	PittPatt: Jul-11, $38mn							
	SayNow: Jan-11							
	Phonetic Arts: Dec-10							
Count	**19**	**12**	**10**	**9**	**5**	**4**	**3**	**2**

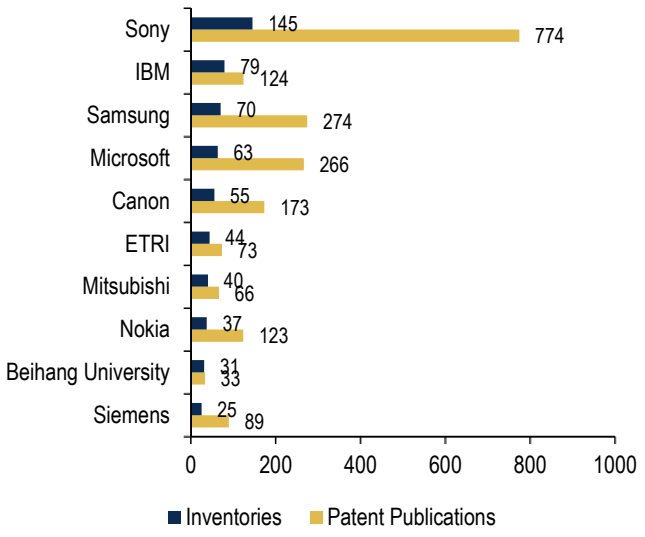
Source: BofA Merrill Lynch based on company disclosures, Pagemill, Capital IQ

IP led by Sony, Samsung, Microsoft, Qualcomm

As with many disruptive technologies, AR/VR intellectual property is led by a small number of tech titans. Around 70% of US AR patents (~5,500) are owned by large-cap corporations, leaving 2,400 to smaller companies and individuals (source: Envision IP). Sony takes the lead in both AR and VR, followed by Samsung, Microsoft, and Qualcomm. Of the private companies, Magic Leap dominates in both AR and VR (source: Envision IP, IPWatchdog). Several acquisitions are likely to be driven by IP, including Apple's buyout of Metaio, and Microsoft's acquisition of Osterhout's IP.

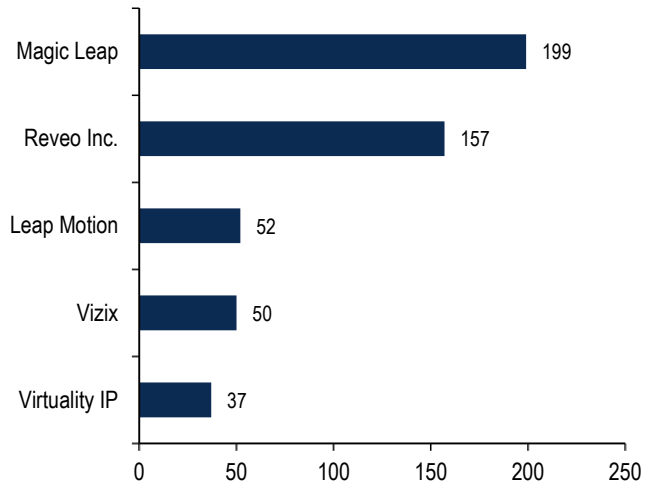
Chart 22: Top 10 patent holders of VR

Inventories vs Patent Publications



Source: IPWatchdog

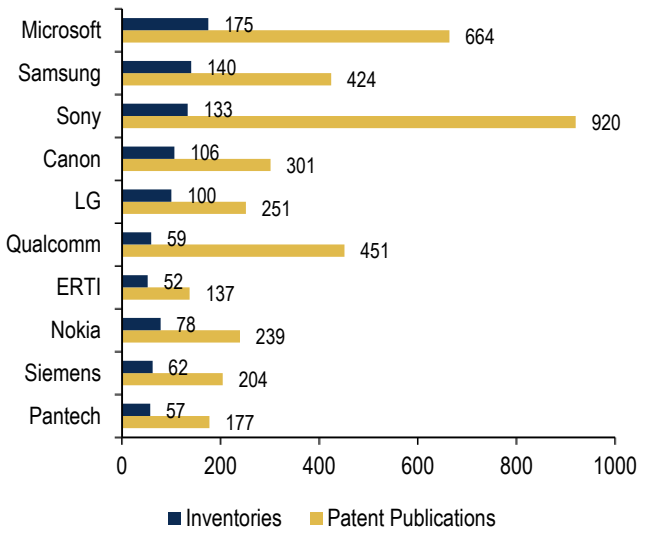
Chart 23: Top 5 players start-ups in VR with respect to patent publications



Source: IPWatchdog

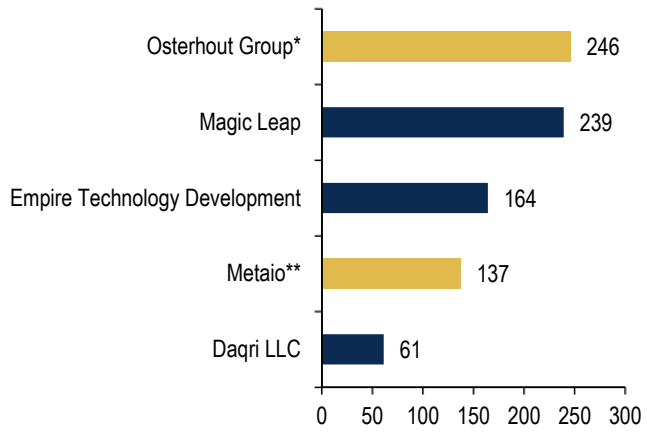
Chart 24: Top 10 patent holders of AR

Inventories vs Patent Publications



Source: IPWatchdog

Chart 25: Top 5 players start-ups in AR with respect to patent publications



Source: IPWatchdog
*IP acquired by Microsoft
**acquired by Apple

Content is king, but also the challenge

Although hardware costs and technology barriers will persist for several years, the long-term challenge will be compelling content generation so that consumers view the platform as a worthwhile investment. Likewise, AR/VR content providers are reluctant to develop without a large installed base given it may be capital-intensive, especially in the early stages (source: Euromonitor).

In an increasingly digital world, software and content are where the long-term value is given that hardware ASPs will likely decline. For instance, content is estimated to be worth 2/3 of the ~US$500bn global TV market (source: Liberty Global, BCG).

Tech titans encourage content creation

Platform providers such as Facebook, Google and Snapchat are experimenting with user-generated AR/VR content. Facebook is building its own VR camera called Facebook Surround 360 to capture 3D images, where the designs will be free and openly available. Google Daydream, Jump, and Tango provide end-to-end solutions that allow anyone to create their own content. Snapchat has been experimenting with AR-based facial filters for its 100mn+ daily active users who spend an average of 25-30min on the app each day (source: Company presentations). Greater public adoption will translate to more immersive footage or augmented video for people to consume on Oculus or Google headsets.

Beware of the hype cycle, for now

Media hype around AR and VR is likely understating the time horizon for widespread adoption and earnings impact. As for most transformative technologies, there is generally a gestation period before the growth phase, when the product enjoys exponential growth and widespread adoption. Challenges regarding bandwidth, content, design, processing power, and cost are still very real. While end markets such as gaming will see the earliest adoption and are expected to arrive this year, widespread AR personal computing and virtual social networks could take several years to reach fruition. The true inflection point could arrive around 2019 or 2020, when sensors, analytics, battery life, and cellular capability coincide to create an affordable ecosystem (source: Gartner).

> "This is a 30- to 60-minute experience. We will get to hours, but that's not necessarily the first generation." – Brendan Iribe, co-founder and CEO of Oculus, speaking on the Oculus Rift

Table 6: Priority Matrix for Emerging Technologies, 2015

Benefit	Years to mainstream adoption			
	less than 2 years	2 to 5 years	5 to 10 years	more than 10 years
transformational		Citizen Data Science Hybrid Cloud Computing Machine Learning	3D Bioprinting Systems for Organ Transplant Autonomous Vehicles Digital Dexterity Digital Security Internet of Things IoT Platform Micro Data Centers People-Literate Technology Smart Advisors Software-Defined Security Virtual Personal Assistants	Human Augmentation Smart Dust
high		Advanced Analytics With Self-Service Delivery Autonomous Field Vehicles Enterprise 3D Printing Gesture Control	Augmented Reality Biochips Connected Home Consumer 3D Printing	Bioacoustic Sensing Neurobusiness Quantum Computing

Table 6: Priority Matrix for Emerging Technologies, 2015

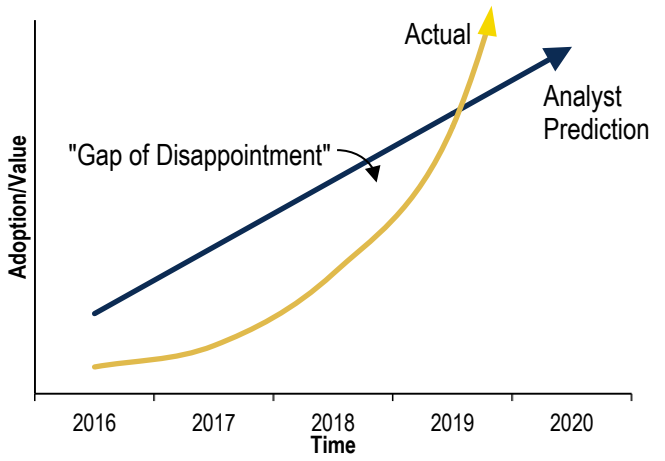
Benefit	Years to mainstream adoption			
	less than 2 years	2 to 5 years	5 to 10 years	more than 10 years
			Cryptocurrencies Natural-Language Question Answering Smart Robots Wearables	
moderate		Cryptocurrency Exchange Speech-to-Speech Translation	Affective Computing Virtual Reality	Brain-Computer Interface Volumetric Displays
low				

Source: Gartner 2015

John Riccitiello, CEO of one of the largest game engines, Unity Technologies, warns against the "gap of disappointment", the period when actual adoption undershoots street expectations. The technical complexity of artificial reality and the difficulty in user monetization could mean that VR and AR platforms do not follow a linear trajectory and miss lofty near-term expectations. Expectations are likely to reset lower when the limitations in hardware and ecosystem innovation become tangible. Nonetheless, with time the adoption and impact of an artificial reality ecosystem could be much more pervasive and transformative than expected.

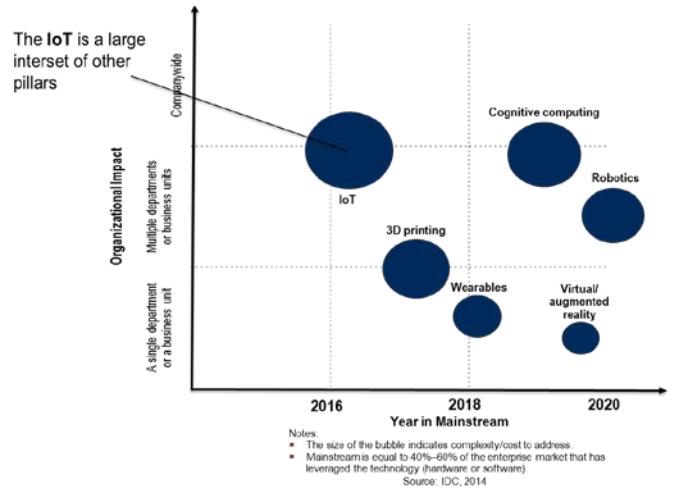
Chart 26: Gap of disappointment

Actual versus analyst predictions of AR/VR adoption rate



Source: John Riccitiello

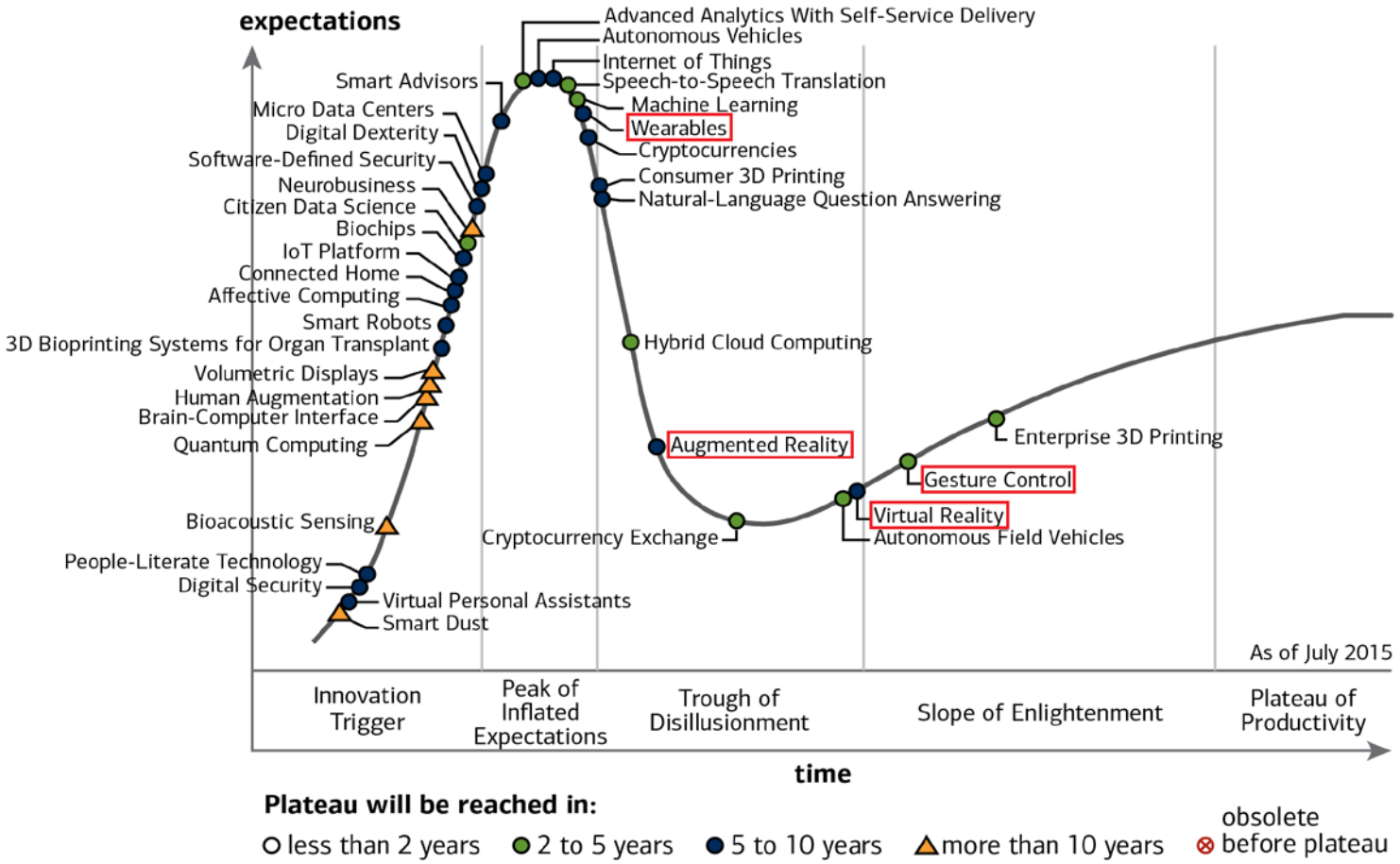
Exhibit 38: Time impact of innovation accelerators



Source: IDC

Augmented reality and virtual reality and imbedded technologies like gesture control maybe be completing the "trough of disillusionment," according to Gartner. They have passed a hurdle in development, where there is deep understanding and a plethora of applications, putting them on an upward trajectory towards commercial adoption.

Exhibit 39: Hype cycle for Emerging Technologies, 2015



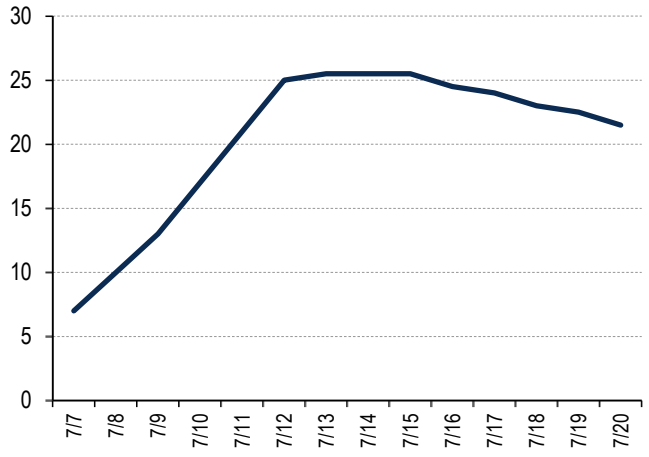
Source: Gartner

Already past "peak Pokémon"

1 out of 10 Americans played Pokémon Go at the height of the craze (source: SurveyMonkey)

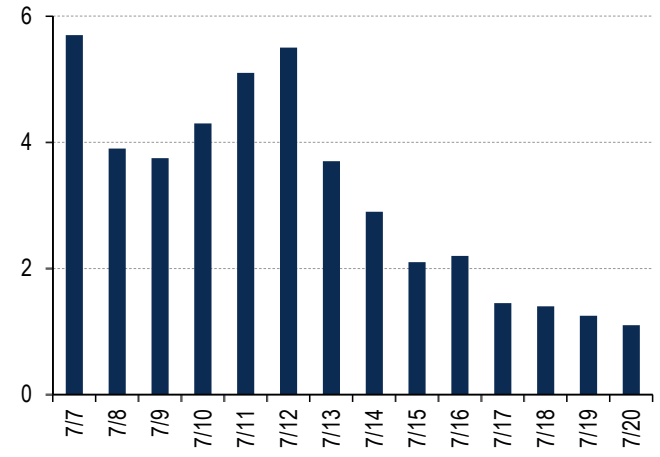
Pokémon Go, an augmented reality game that has taken the world by storm in 2016, has already shown marginal declines in interest. According to data from SurveyMonkey, the game registered its highest daily active users on 14 July, exactly one week after the game's debut, when 25mn US smartphone users were logging onto the game. Downloads of the game were highest at its debut, before declining slowly thereafter, along with usage levels (source: SurveyMonkey).

Chart 27: Pokemon Go usage peaked on 14 July 2016
Daily active users (iOS and Android)



Source: SurveyMonkey

Chart 28: Downloads peaked on the day of release
Total downloads (mn)



Source: SurveyMonkey

Impacting mind and body

In October 2014, a 31-year-old San Diego patient was diagnosed with "internet addition disorder" after experiencing withdrawal symptoms from Google Glass use (source: Yung et al 15).

In addition to technical hurdles, VR/AR has potential long-term risks that we are only in the early stages of investigating. Increasing screen-saturation has already negatively affected how humans satisfy their social and psychological needs. Psychological and neurological disorders, addiction, social isolation, false memories, obscured vision, and decline in performance must all be considered. For digital natives such as Millennials and Gen Z, this will have a profound impact on how people interact with one another and the world. Greater dominance of device time with VR/AR/MR is likely to exacerbate this impact in the coming years.

- **Neurological disorders** – a UCLA study showed that rats in virtual and real worlds exhibited different activities in their hippocampal neurons. The activity in the brains of those in the VR world was random and abnormal, including over half that simply shut down in the virtual environment (source: Aghajan et al 2015, UCLA).
- **Inability to distinguish between VR and real life** – a 2009 Stanford study showed that children immersed in a VR experience of playing with whales could not distinguish between false memory and reality one week later (source: Segovia et al 2009).
- **Social isolation** – role-play VR games can exacerbate social isolation. There are rising numbers of teens and young adults who stay at home and display depressive and obsessive-compulsive tendencies.

700k-1.5mn – the number of hikikomori, Japanese citizens who refuse to leave their homes. Their average age is 31 (source: The Japan Times)

- **Hindered vision** – certain AR users may experience reduced depth of focus, distance and speed perception, and reaction time. AR may exacerbate poor eyesight

by reducing peripheral vision and straining eyes by requiring people to quickly change focal distances (source: Institute of Electrical and Electronics).

80-95% of children and teenagers in China, South Korea, and Taiwan have myopia, which is believed to be linked to increased use of electronic devices (source: Ian Morgan, Australian National University).

- **Decline in performance** – a Siemens study shows that certain AR displays actually increased the time to completion for certain manual tasks, such as machine maintenance (source: Zheng et al 2015)

Privacy and cybersecurity risk growing with a larger (digital) footprint

AR/VR devices by their very nature are designed to capture more information about users than ever before. Information needs to be collected and analysed in real time. Sensors can record a user's activities and personal information such as heart rate, body temperature, conversations and information about their surroundings. Users may unwittingly leave digital footprints (information about users derived from sensors) that can threaten their privacy. As the number and variety of sensors grows, it will be cumbersome for users to specify fine-grained policies about who can access which footprints (source: Kapadia). A large proportion of one's entire stream of observations could be given to a company for analysis and storage (source: Rosner 2014). Key implications include:

- **Intellectual property** – there is greater scope to gather and potentially transform copyrighted or trademarked material that appears in the real world. For example, recording copyrighted material likely constitutes copying.

- **Discrimination** – AR can furnish users with truthful information they should not have, or at least that they cannot legally use to make decisions. For instance, a system could use facial recognition to pull up a job candidate's mug shot, social media profile, or relationship status in a jurisdiction that does not permit employers to discriminate based on arrest history, marital status, or other information that may be available through technological intervention. Thus, the use of AR could contribute to forms of illegal discrimination, raising possible legal liability for users and developers.

- **Bystander risk** – always-on cameras and other sensors will create a privacy risk for bystanders.

- **Ad attackers** – information could be used to integrate advertising and marketing initiatives. Tailoring of specific content for every user on the basis of their personal profile becomes possible and leads to privacy concerns. Ad attackers include third-party content such as syndicated ads. An "ad attacker" tricks a trusted channel into incorporating their malicious content, e.g., via ad brokers.

- **Network attackers** – either through man-in-the-middle attacks or by being on the same network as the victim, a network attacker can listen in on the communications between the AR browser and the AR provider, AR channel owners, and third-party servers.

- **Breaking out of the sandbox** – conventional webpages cannot access the camera or other native resources outside the browser unless explicitly authorised by the user. An AR browser's access rights could be hijacked by malicious webpages to gain this access without involving the user (source: Rosner; McPherson; Zarsky).

Disclosures

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Underperform	N/A	≥ 20%

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