

TV in VR

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Introduction

The evolution of storytelling has gone through various phases. Earliest known methods were through plain text. Plays and theatres were used to bring some of these stories to life but for the most part, artists relied on their audience to imagine the fictional worlds they were describing. Illustrations were a nice addition to help visualize an artist's perception. With the advent of cinema in the early 1900's starting with silent films to the current summer blockbusters with their CGI, 3D and surround sound – viewers are transported into these imaginary worlds – to experience these worlds just as the creators of this content envisioned it. Virtual reality, with its ability to provide an immersive medium with a sense of presence and depth is the next frontier of storytelling.

Seminal events in history - Moon landing in 1969

When Neil Armstrong and Buzz Aldrin took the first steps on the moon - it captured the imagination of the world. The culmination of a grand vision and the accompanying technological breakthroughs brought about an event that transfixed generations to come. As it happened in the 1969, the enabling technology for experiencing this event was the trusted radio or through grainy broadcasts of television anchors describing the events as they were described to them!

Super Bowl 49

As the Seattle Seahawks stood a yard away from winning the Super Bowl in 2015, 115 million people watched on NBC in the United States alone. In front of their big screen TVs and every possible option explained to them by the commentators, the casual and the rabid football fan alike watched as the Seahawks lost due to a confluence of events. The more rabid amongst them – possibly from Seattle and Boston, took to Twitter and Facebook to lament and rejoice respectively. The Super Bowl is one of the most watched events every year and lets millions of viewers experience its ups and downs and commercials in a variety of ways. All of which is enabled by the technology of our times.

Virtual reality is the next step in this frontier of technology that will drive our experiences. It will redefine our expectations of experiencing events, will add to our perspective and immerse us in visceral ways.

In the coming sections, we cover the evolution of VR, the VR technology ecosystem, applications which are ready for takeoff now vs future, the market opportunity and where the investments are happening. Finally we cover the potential challenges and social changes as a result of wider adoption.

VR Evolution

One can find evidence of virtual reality long before the word virtual reality was coined in late 1980's. Panoramic paintings can be viewed as the earliest attempts to show things in 360 degree. These paintings were aimed to provide to the viewer's entire field of vision to make them feel present at the scene.(see painting of Battle of Borodino from nineteenth century in figure below). Virtual reality experience in the earlier days was limited to providing a sense of depth. The guiding principle for all the devices invented upto the popular google cardboard is based on demonstration of Charles Wheatstone's research that the brain processes separate two-dimensional images from each eye into a single object of three dimensions. Below figure shows the evolution of VR over the years.

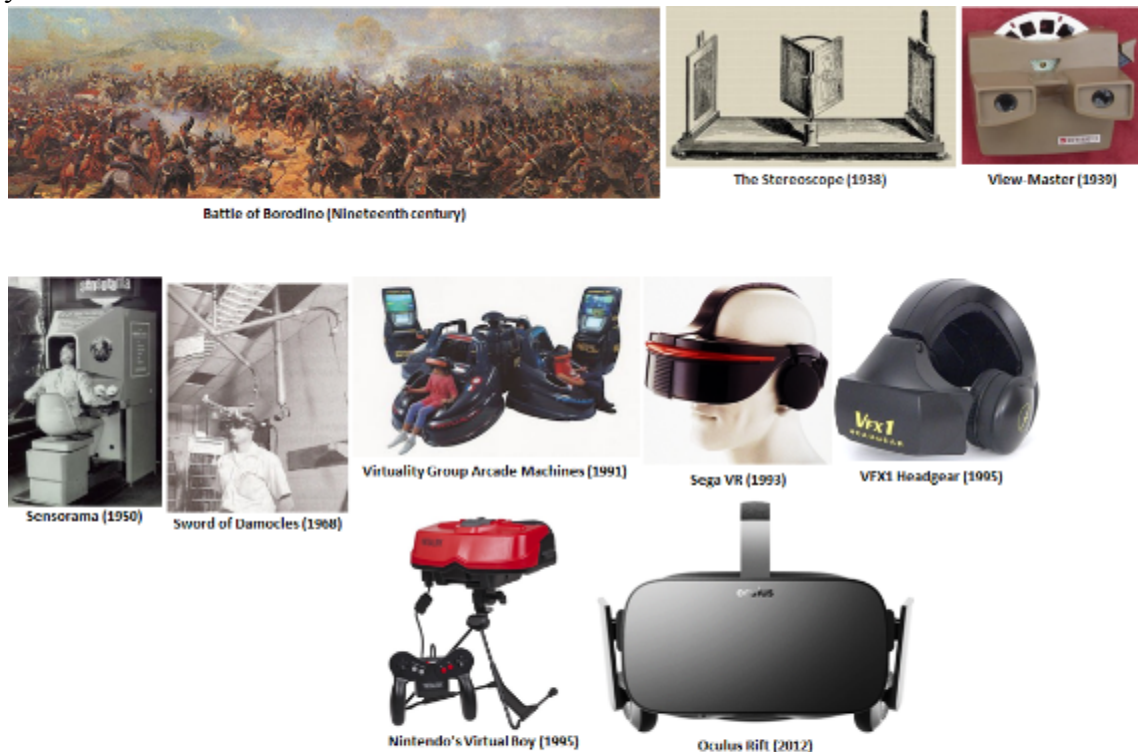


Figure 1: VR evolution in pictures

Earlier versions of virtual reality devices(before 1950):

In 1838 Charles Wheatstone created first stereoscope. It used a pair of mirrors at 45 degree angles to the user's eyes, each reflecting a picture located off to the side. In 1938 William Gruber developed a then popular device "The View-Master" which used a circular cardboard with colored transparencies and lenses to give a feel for depth and was cleverly used for viewing famous landmarks and touristic attractions.

1950s

Cinematographer Morton Heilig introduced the Sensorama which is like an arcade-style theatre cabinet that would stimulate senses in addition to vision. The Sensorama was designed to fully immerse the individual in the film by using not just sight and sound. It featured stereo speakers, a stereoscopic 3D display, fans, smell generators and a vibrating chair. Morton himself build 6 short films to give the virtual experience in sensorama. Morton also build first head mounted display (HMD). Unlike today's interactive HMD's, Morton's device was non interactive with no motion sensors. The headset provided stereoscopic 3D and wide vision with stereo sound.

1960s

In 1961 two engineer from Philco Corporation (Comeau & Bryan) developed an HMD with motion tracking capability. It was called Headsight (First motion tracking HMD), which was designed for training of military personnel. Headsight did not have the integration of computer and image generation. Later in 1965 Ivan Sutherland developed new HMD called "Ultimate display". This device is much closer to today's VR devices, it allowed user to get a feel of virtual reality through HMD and it appeared realistic through augmented 3D sound and tactile feedback. Computer hardware was used to create virtual reality and user had the ability to interact with objects (like augmented reality). In 1968 Ivan Sutherland and his student Bob Sproull developed a device called "Sword of Damocles" this device had VR and AR features, but was huge scary looking with its heavy head mount and straps. Head mounted display was so heavy that it has to be suspended from ceiling.

Virtual reality term was coined in 1987 by visual programing lab; this was the first company to sell Virtual Reality goggles (EyePhone 1 \$9400; EyePhone HRX \$49,000) and gloves (\$9000).

In 1990

By 1991 virtual reality was made available to public by Virtuality Group Arcade Machines and games. These machines allowed players to wear a set of VR goggles and play on gaming machines with realtime immersive stereoscopic 3D visuals. Some units were also networked together for a multi-player gaming experience.

Sega announced launch of headset in 1991 and displayed it in 1993, this prototype has a LCD display screen, motion tracking system and sound system. Although five games were developed for this device, it never hit the market due to immense technical

challenges and common health issues that accompanied VR technology, headaches and motion sickness.

Year 1995 saw launch of two virtual reality devices, Nintendo's Virtual Boy and Forte Technologies' VFX1 Headgear. Virtual boy's life was short lived due to its no head tracking option, poor quality images and red LCD graphics. Users soon started complaining of dizziness, nausea and headaches. Virtual boy was sold only on North America with couple of games. Even with prices discounts this device could not stay in market beyond 1996.

VFX1 Headgear kit was sold for around \$600 dollars which included a solid VR helmet with dual LCD displays, three degrees of motion tracking and built-in stereo speakers, plus a handheld controller called a Cyberpuck with its own motion sensors. It only had a 45 degree field of view and 263x230 pixel per eye display with only 256 colors – a refresh rate of 60Hz and a library of great games including Doom, Descent and Quake helped it survive in market for reasonable period.

Virtual reality in the 21st century

Beginning of 21st century has brought significant improvement in technology that not only enhanced Virtual reality experience but also made them smaller (comfortable), powerful (faster) and cheaper. A surge in virtual reality devices and technological development can be seen in 2012-2015 due to . Big brand companies like Google (cardboard), Samsung(Gear VR) and HTC (VIVE) have surfaced in the market. Among these Oculus Rift (announced in 2012) has been the most popular VR headset in the market with Facebook purchasing it for 2B dollars.

VR Technology and EcoSystem

A true *360 degree 3D stereoscopic* VR experience should give you a sense of *presence*, with wide field of view (*fov*), minimal *latency*, high resolution with true positional head tracking.

There are three main segments of technology, which come together to provide an end to end immersive 3D virtual reality experience namely:

- Hardware and Distribution
- Content Creation
- Software Platforms and Delivery

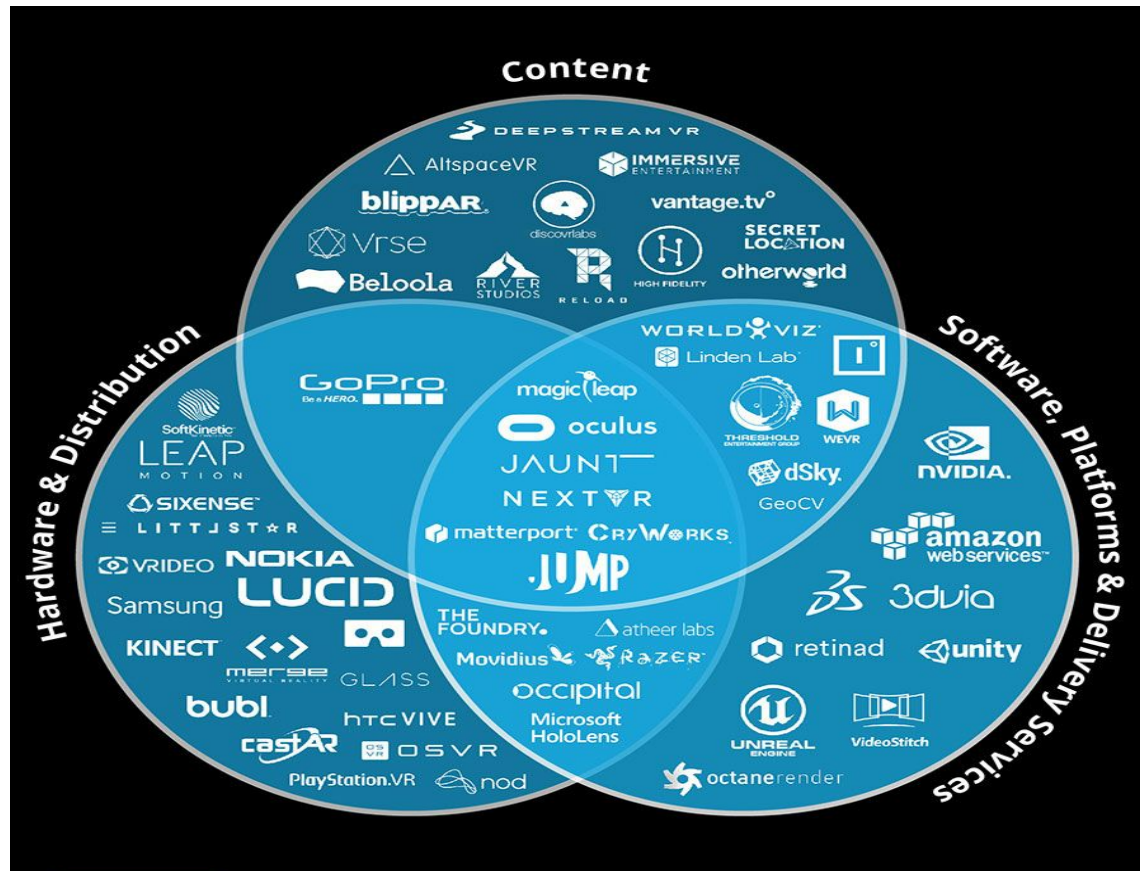
In the following sections we first explain some of the VR concepts and then cover each of the three segments from a technology and company perspective.

VR Concepts

Before we go deep into each VR segment, it's important to understand some of the key concepts related to VR. Below is a brief explanation of each of these terms:

- **Presence** - is point where you are truly convinced you are in the environment presented to you. you are on virtual Ledge, your mind knows its virtual and says "it's okay to move forward" but your body doesn't listen.
- **FOV** - A human can naturally see 170 degrees of viewable area (field of view). most consumer grade HMD(s) now display 90 degrees to 120 degrees of fov.
- **Latency** - is time between when viewers moves his/her head, and when you see physical updates on the screen. An acceptable latency is anywhere from 11 ms(for games) to 20 ms (for watching 360 3D VR videos)
- **Resolution** - is the number of pixels shows on the screen both in width and height. For example: most new VR devices like Oculus Rift DK2 has a resolution of 1920x1080 (also referred as 1080p) for each eye.
- **Head Tracking** - two forms
 - traditional head tracking - tracks head movement left, right, up, down, roll like clock rotation
 - positional tracking - movements and related translations of your body. sway side to side.

- Oculus rift uses infrared camera combined with magnetometers and gyroscopes. Camera picks up reflectors on the hmd and extrapolates positional data from how they are positioned
 - Sixense developed experimental addon that uses magnetic fields to detect position of a device, used in Samsung gear VR
 - HTC Valve uses Lighthouse technology for providing true positional movement
- **360 degree video** - is a flat equirectangular video projection that is morphed into a sphere for playback on VR headset. A standard world map is an example of equirectangular projection, which maps the surface of the world (sphere) onto orthogonal coordinates.
- **Stereoscopic 3D videos** - is really two videos, one mapped to each eye providing depth and 3D. so there are 2 cameras per field of view. Challenges in producing 3D videos
 - stitch camera footage for each eye separately.
 - create SBS(side by side) 3D video mapping the left and right video to each eye
 - the stereoscopic 3D reduces the video resolution because 2 side by side videos split the resolution of screen
 - max resolution on Gear VR is 1920×960 (half of the 3480×1920 for monoscopic video)
 - when viewing 4K 360 video (4096 x 2048) on Samsung Gear, which has a FOV of 120 degrees, you are only seeing $4096/3 = 1365$ i.e 1.3K.



Source: Fast Company¹

Hardware and Distribution

There are mainly two kinds of hardware component which enable end to end VR

¹

http://b.fastcompany.net/multisite_files/fastcompany/imagecache/slideshow_large/slideshow/2015/10/3052209-slide-s-3-vr-and-augmented-reality-will-soon-be-worth-150-billion-heres-who-the-players-are-manatt-infograp.png

experience.

Head Mounted Display (HMD) Devices

First is the head mounted display (HMD) devices which people strap onto their heads to enjoy immersive 3D VR experiences. In the HMD segment, here are the key players:

- Oculus Rift - is one of the first serious VR headset product which started the most recent wave of serious investments in VR. It's priced at 600 USD currently as of April 2016, in addition needs a PC with high end specs priced at 1100 USD, as of April 2016.
- Samsung Gear VR headset - relies on Samsung Galaxy phones for the processing power and display and core VR tech provided by Oculus Rift. The gear itself is priced at 100 USD, which is pretty compelling if you already own a compatible Samsung Galaxy edge phone.
- HTC Vive - is very similar to Oculus Rift in feature spec and pricing. One big extra thing which Vive has is the trackable controllers which let you see your hands in front of you as you move around in VR. It has big game store HTC Steam offering numerous games.
- Playstation VR - from Sony is priced at 300 USD (as of April 2016) and has similar features and capabilities to HTC Vive and Oculus Rift. The big difference is that it does not require a separate high end PC, although it does require you to own Playstation console.
- Google Cardboard - is the cheapest headset (literally made of cardboard for under 10 USD) which provides viewers with a glimpse of immersive experience possibilities without paying any money.

3D VR Cameras

The other major piece of hardware is the cameras which produce 360 videos

- [Richo Theta](#) - 1080p HD, 30 fps - handy camera for taking 360 videos, cheapest - 360 USD
- [Freedom 360](#) - 6 GoPro cameras on a rig.
- [Nokia OZO](#) - one of the most expensive professional grade cameras, costs around

- 60,000 USD, has eight lenses each with 195 degrees FOV.
- [Vuze Camera](#) - has 8 HD cameras with realtime seamless stitching to make a equirectangular video.
- [Google Jump](#) - 16 camera rig in circular array, stitching together stereoscopic VR video
- [Lytro Immerge](#) - breakthrough technology providing 6 degrees of freedom in live action environment.
- [NextVR](#) - Have professional broadcast setup for live sports and entertainment.
- [JauntVR](#) - professional broadcaster

Content Creation

While the initial focus has been around fixing the rough edges in the hardware (both headsets and camera) in the long run, it's the content which will be the key differentiator. VR is a completely new medium for consuming content, which requires a reset in the thinking of the way the producers have traditionally produced video content. Some of the interesting companies in this space are

- [WeVR](#)
- [VRSE](#)
- [MilkVR](#)

All these companies are producing short form 360 degree 3D VR content experiences which are either passive or interactive.

Software Platforms and Delivery Services

For delivering the VR content from the 360 cameras to the user's donning the HMD headsets, several software platforms and delivery services are involved. Some of the areas in which these platforms are playing are:

- Gaming Engines - Unity 3D with their gaming engine SDKs for iOS, Android, Oculus Rift is a big player for helping produce 3D VR games.
- Video Stitching Software - The raw 360 degree video images taken from different cameras need to be stitched together by a stitching software. This process involves whole lot of image processing including image correction to remove lens

distortion, composing final image pixels for both left and right eye.

- **Delivery of video bits over the network** - For the users to eventually see the VR content, companies like Amazon AWS provide capability to transfer bits over the network via traditional CDNs. Other companies like Facebook and Youtube have their own CDN for delivering 360 videos to the consumers over the web.

As you can see from the diagram, there are several companies like NextVR, Oculus, GoPro and WeVR which have a presence in all three segments to provide an end to end immersive VR experience.

VR Applications & timelines

While every aspect of our lives can be touched by VR applications, we see significant activity in following application areas:

- **Games:** This is the first application where there are many products being released in 2016 and expect market adoption to accelerate. Led primarily by Oculus, Samsung, Sony, and HTC, the platform has caught the attention of gamers and tech enthusiasts alike. IDC estimates that VR headset makers will ship 9.6 million units and generate \$2.3 billion in 2016. With this push on hardware headsets we expect to see the beginning of a reasonable install base for content creators to target.
- **Training:** This is another application where we see adoption taking off in 2016. As VR provides an immersive experience and enables to accelerate the learning curve, it is being used by Military, NASA and other enterprises to innovate and disrupt the training industry as we know it. Strivrlabs² has been a pioneer in the Sports training in Virtual Reality. Since incorporating in January 2015, STRIVR has quickly gained momentum with elite teams, signing 6 NFL teams in addition to 12 collegiate teams. STRIVR has also expanded into basketball and hockey, with one NCAA basketball team, one NBA team, one WNBA team, and one NHL team using the company's training platform. Strivrlabs is trying to break into this market by employing former Super Bowl Champions and NCAA D1 All-Americans, and advisers include a Head Coach and NFL team President.

² www.strivrlabs.com

- **Entertainment/Theme parks:** This is another application where VR is pushing the boundaries of theme park experience. Six flags³ has introduced a ground-breaking new ride experience – the New Revolution Virtual Reality Coaster. Wearing wireless Gear VR headsets, riders become “co-pilots” on their own virtual fighter jets and be transported into a futuristic battle to save planet Earth from an alien invasion. - See more at:
- **Advertisement:** is an interesting application area which has the potential to disrupt or accelerate a number of businesses that are reliant on commercial advertising revenue streams. With the launch of YouTube’s 360 degree video ads, almost every business with a web presence will need to embrace 360 video commercial production. They cannot afford to sit out the wave of successful VR video ads⁴. When Coca Cola marked the 100th anniversary of their first ever Coke bottle – their engaging 360 degree videos and aced out standard streaming ads by a whopping 36%.
- **Tourism:** The travel and tourism⁵ industry is all about selling an experience; a feeling, a landscape, the history of a particular destination. Traditionally, this has been accomplished through shared experiences and pictures from friends and other traditional marketing channels. With VR, it can open up a new channel to reach many more potential customers effectively.
- **Entertainment/Sports** - In this sector, NextVR⁶ has pioneered and developed a custom lens-to-lens system for capturing and delivering live and on-demand virtual reality experiences in true broadcast quality. With its patented technology, NextVR is the only company capable of transmitting *live* high definition, three-dimensional virtual reality content over the Internet delivering a completely immersive and life-like experience for the viewer. It’s producing VR content for Daytona⁷ Car Racing, NBA Basketball games.
- **Healthcare:** There are many areas in healthcare where VR is starting to take off, like surgery simulation, phobia treatment, robotic surgery and skills training. Healthcare involves a lot more regulation and hence will adopt VR over a longer time frame as the technology matures.

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<https://www.sixflags.com/overgeorgia/attractions/vr/news-release#sthash.EAPeHYSG.dpuf> <https://www.sixflags.com/overgeorgia/attractions/vr/overview>

⁴ <http://www.konceptvr.com/youtubes-360-video-ads-launch-changes-ad-game/>

⁵ <https://www.tnooz.com/article/virtual-reality-tourism-marketing/>

⁶ <http://fortune.com/2016/03/07/fox-sports-to-stream-march-madness-in-virtual-reality/>

⁷

<http://variety.com/2016/digital/news/fox-sports-virtual-reality-nextvr-daytona-500-1201708198/>

Market Opportunity

The overall market opportunity for VR is dominated by VR games⁸ in the short run. The entertainment industry is looking at this new medium closely and the predictions over the next few years show that this industry is looking to exploit this medium in order to grow revenues

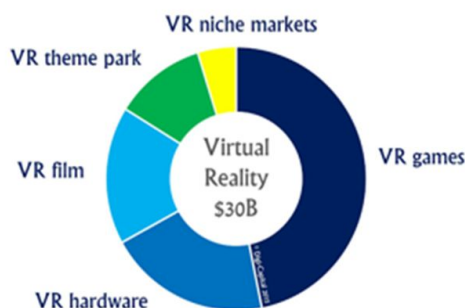
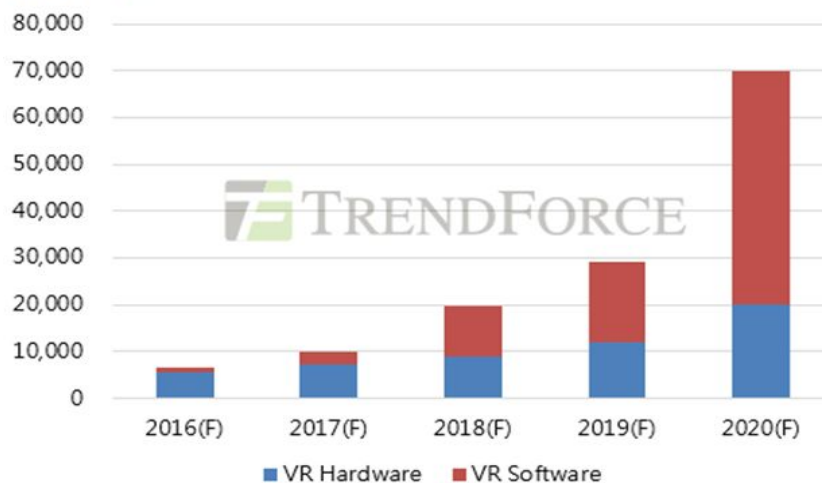


Figure: Global VR Market Value, 2016~2020

Unit: US\$ Million



Source: TrendForce, Dec., 2015

The opportunity for the VR headsets, haptics and camera manufacturers are predicted to be a significant portion of the revenue generated by the industry. As the devices mature

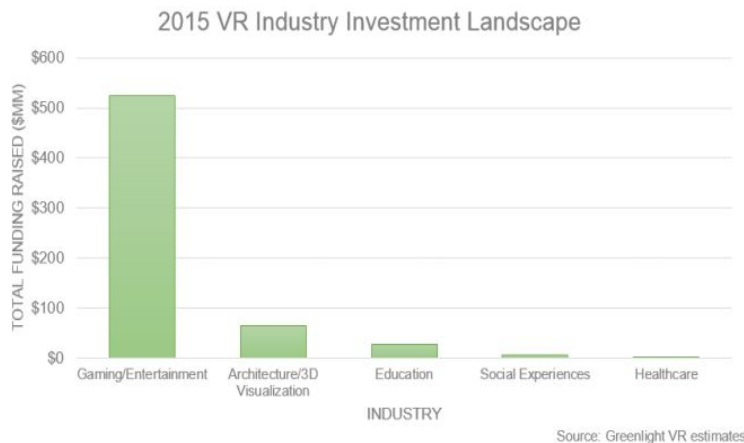
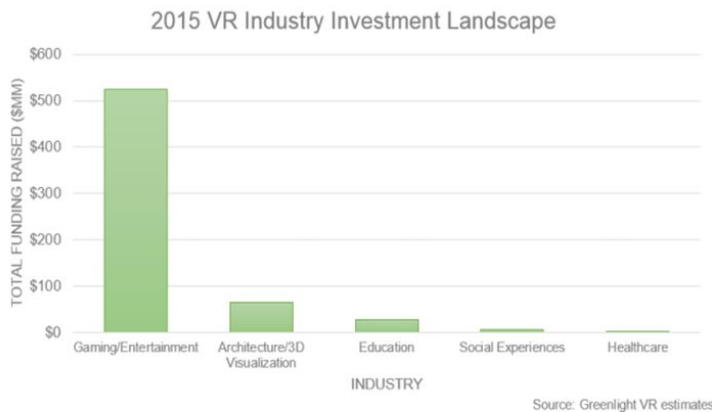
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<http://www.digi-capital.com/news/2015/04/augmentedvirtual-reality-to-hit-150-billion-disrupting-mobile-by-2020/#.Vx2cfvkrLmE>

and there is more adoption of the platforms, the content providers / software creators for VR are expected to dominate the overall market⁹.

Where is the investment going?

By now we all understand that the market opportunity for VR is huge and technology is becoming mature enough to deliver. The key question is whether there is enough venture capital funding some of these VR applications and if yes, which areas are seeing critical mass of funding. Based on estimates from Greenlight VR¹⁰, gaming and entertainment sectors have seen the majority of the funding, followed by Architecture/3D visualization and education. This can also be observed by the VR products.



⁹ <http://press.trendforce.com/press/20151204-2210.html>

¹⁰

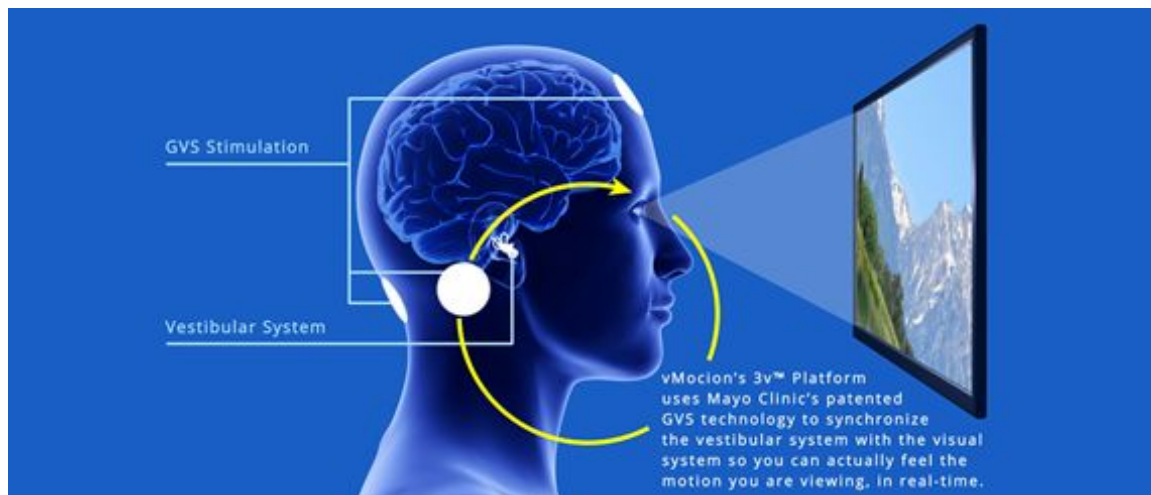
<http://frenchtechhub.com/blog/2015/09/whats-actually-happening-in-the-virtual-reality-vr-industry/>

Challenges & Changes

While VR is being adopted in in several application areas, here are some of hte challenges and changes in people's behavior we expect to see in near future:

Motion sickness - The main reason for motion sickness is latency, the tiny but perceptible delay between when you move your head in VR and when the image in front of your eyes changes—creating a mismatch between the motion we feel (with our inner ears) and the image we see (with our eyes). In real life, the delay is essentially zero. "Our sensory system and motor systems are very tightly coupled," says Beau Cronin, who earned his PhD in computational neuroscience at MIT and is writing a book on the neuroscience of VR. To improve Motion sickness or latency issues many approaches are proposed which involve improving display technology (decrease pixel switching time, refresh rate), head tracker and predicting head movement.

vMocion is using the Mayo Clinic's Galvanic Vestibular Stimulation technology to create a more immersive VR experience by stimulating the inner ear to perceive motion. See below figure¹¹.



Wearable head-gear: In the past several years, significant progress has been made to make the head gears lighter so that they can sit comfortably on wearer's head. Latest Oculus Rift and HTC Vive are relatively lighter at ~470 grams, and can be easily donned with a single hand like a baseball cap, there are still areas to improve in reducing heat

¹¹ <http://www.vmocion.com/technology.html>

generated from display screens and providing wider field of view. We believe in the next 5 years, the size of headgear will be a lot smaller and simpler to handle almost similar to eyeglasses.

Social interaction: As Virtual reality experiences gain wider adoption, analysts believe it will bring changes in social interactions that were not seen with TV or internet. Researchers believe new immersive technology could lead to isolation and when social needs are met online, in-person interaction may not be needed as much. If VR technology is truly immersive, it could lead to addiction behavior and confusion between reality and virtual reality from serious gamers. Privacy will be at greater risk as all virtual reality experience can be tracked and manipulated.

In Spite of the perceived challenges in social interactions, these interactions could actually be much more immersive and powerful with virtual reality as one can virtually interact with friends and relatives all over the world without travelling overseas. News media like New York Times and nonprofit organizations are already building 360 degree VR experiences in form of short movie clips, that generate powerful feelings of empathy amongst the rich and powerful donors.

Summary

In summary, virtual reality is the next frontier in terms of providing a complete new medium for interaction that has visceral sense of presence and immersiveness that connects humans in ways that's never been possible with any other medium. We believe the conditions are ripe for VR to takeoff in a big way, causing disruption to incumbents across the industry segments starting with gaming and short story telling.

For adoption beyond gaming, the real innovations will happen in content space, where producers would use this medium's capabilities to provide an authentic storytelling experience in sectors like education, movies and beyond. Eventually, the confluence of virtual reality with augmented reality will lead users to truly achieve the holy grail of 'teleportation' (being in multiple places at the same time) experience.

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8. [Google Cardboard Jump Camera Spec](#)
9. [VR Concepts](#)
10. [VR meets AR to enable teleporting](#)



National rankings consistently place UC Berkeley's undergraduate and graduate programs among the world's best. Berkeley is home to top scholars in every discipline, accomplished writers and musicians, star athletes, and stellar scientists—all drawn to this public university by its rich opportunities for groundbreaking research, innovative thinking and creativity, and service to society.