What If ***Reality*** + ***Digital Reality*** Becomes ***Reality***

An IEEE Digital Reality White Paper

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Introduction

An industry panel held at IEEE Globecom in December 2019 titled Roadmapping Communications Technologies discussed a few aspects of the IEEE Digital Reality Initiative in IEEE Future Directions.

As I was preparing for the talk I started to feel uneasy on the very name of the initiative: Digital Reality. The more I considered it the more misleading it seemed. This white paper presents a perspective on Digital Reality and its technical roadmap, possibly convincing you too that a different name would be better.

Figure 1 The IEEE Future Directions Digital Reality Initiative is looking at the impact of a growing digital world interacting with the physical one. Image credit: IEEE Digital Reality Initiative

The area of "Digital Reality" is a mélange of technology that is influenced by psychology, economics, society and even a bit of philosophy. It is an interesting field due to its broad-reaching nature, and the IEEE Digital Reality Initiative solicits involvement of people of varied backgrounds.

The evolution of modern computers allowed for a progressive capability to process numbers on the one hand and to convert a growing variety of manifestation of the physical world in numbers. As an example sounds, music, voice can be converted into digits, transported via telecommunications networks, and then translated back into sounds, music, voice. As technology improved the fidelity of the transformation, that is, the conversion from the physical reality to the digital one and back to the physical one, has become so good that we no longer appreciate the conversion going on.

Of course, music and voice is just an example (chosen because it was actually the first "conversion" that took root). Landscapes are transformed into digital images that can be displayed on big screens providing immersive sensations to the point you perceive it is real. Virtual reality technology is developing and improving to provide a seamless immersive world indistinguishable from the real one, integrating visual and haptic sensations. The experience is not seamless yet but improving every year.

Bits are now used to mimic sensations; sentiment analyses of crowds have progressed significantly. This is significantly different, however. When an image is converted into a digital representation, the original image is a physical thing. Not so when sensations, emotions, feelings or crowd sentiments are being translated. Here, the translation is based on some wild estimation of a physical world that cannot be pinpointed in a mechanical way. Data (digital entities) to create other data.

Yet, these emerging meanings can be quite accurate and can be used in simulation to a good degree of fidelity. Take as an example the design of security exits in a mall. Engineers together with psychologists and experts in human behavior use software to simulate what could happen if a dangerous situation (true or just perceived) materializes in a crowd inside the mall. Will there be a stampede? Will the designed security exits and exit pathways be adequate to manage the stampede? This software creates a digital reality of a sort that coexists with the physical reality of the (future) mall and is taken very seriously as reality.

Our technology has progressed to the point that the everyday physical reality becomes expanded, and that virtual digital reality becomes as real as the physical one.

Virtual Life versus Real Life

As previously mentioned, there may be situations where the digital world can represent a reality that is not to be found in specific physical objects. There is much more.

Figure 2 Second Life made the headlines of magazines and newspapers several years ago. It has now faded from the everyday perception of most people although it is still being used by several people and even companies. Image credit: Second Life

Consider Second Life, a platform for developing 3D content and experiences. In a few years it created a worldwide mania where everybody wanted to develop a "second life" in cyberspace, and several companies created offices and shops in cyberspace. Those representations were clearly virtual, and no one could mistake them for real life. Yet, from a psychological point of view a few people felt they were living a second life in cyberspace. That is another way of looking at Digital Reality, creating something in the cyberspace that can be psychologically and emotionally perceived as reality. People met in Second Life; spent time sitting on a bench looking at (the avatar of) other people walking along; and so on.

The peak of interest faded away (in a very few years) partly because the visual representation was too "cartoonish" to support a feeling of reality. It is interesting to note that some people fled from the physical reality to find a cocoon in the digital reality.

There are many other examples. Actually, there is a lot of concern about youngsters preferring to retreat into cyberspace, finding their reality there, rather than facing and living in the physical world interacting with real people. As technology progresses and becomes able to deliver real-life experiences in cyberspace, some feel this problem will become worse. Communications has already, to a certain extent, shifted to cyberspace: people meet in the cyberspace, develop an attraction, and quite often the breakup of a relationship is done through cyberspace. This loss of the human touch is clearly disturbing. Others prefer to see the glass half full and say that cyberspace provides an "additional" reality where people who have problems expressing themselves in the physical space can find support, possibly training themselves to live a better life in the real world.

Second Life has faded from the spotlight, but the need for people to have a second life in cyberspace is still very much a reality. Facebook, Tinder, and many others, have in a way taken up the needs fulfilled by Second Life, getting rid of the "cartoonish" part and letting people create their second life, or second personality, using images, voice and text. Facebook is not underestimating the role that VR can play and has acquired Oculus Rift, investing significant money in the hope that VR could eventually provide a stronger feeling of community and more sophisticated and natural sharing. Tinder and other apps facilitating the connection of people have the ultimate goal of bringing people together in "real life," but it is likely they will extend their business model to facilitate virtual encounters, as soon as digital reality becomes more real.

In this view Digital Reality is opposing physical reality:

- Shouldn't efforts be focused to create a better true reality, rather than wasting resources

on creating a fake Digital Reality?

- Are we pursuing Digital Reality because it is easier to create a pleasing and sellable digital reality than to improve the real physical reality?
- Isn't Digital Reality a parallel to the LSD movement of the 1960s in societal terms, where technology replaces chemistry to provide an alternative world (it is not surprising, in this view, that there is a call for detox from cyberspace. For example, Apple developed features on the iPhone to provide awareness on the time spent online)?

These are tricky questions, but, in some ways, they are moot questions since this is happening, and some people are starting to wonder who will be the winner in this fight.
Overall, these issues are often providing a bad halo on the idea of pursuing a Digital Reality. The very fact that it is called Digital Reality highlights that it is not the "real thing". This is the first reason Digital Reality may be a misnomer.

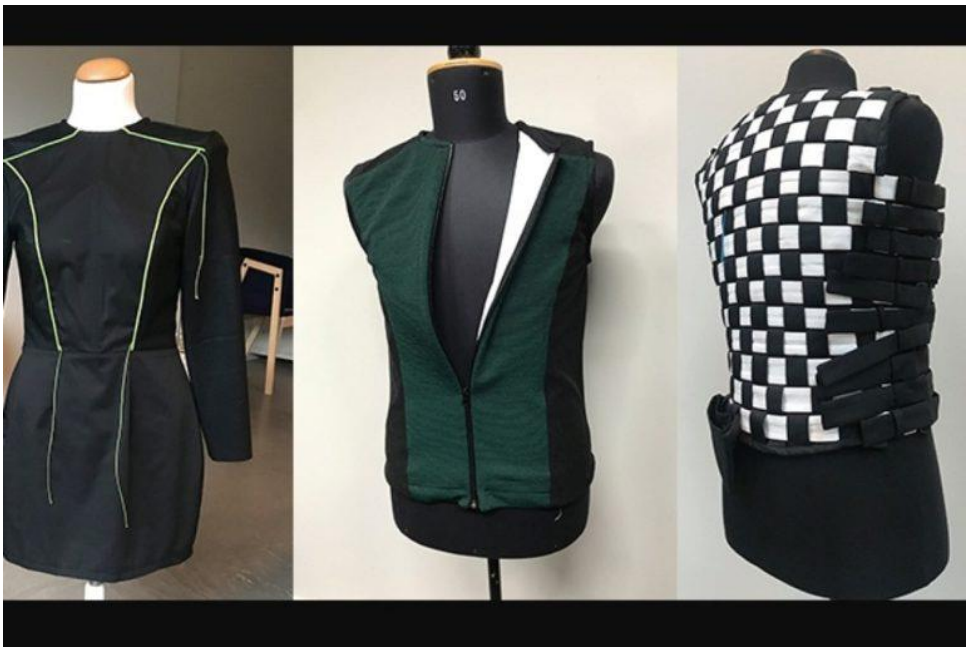

Figure 3 Haptic clothes can provide the sensation of being touched, The photo depicts haptic clothes designed to provide an interaction channel to guide the deafblind. Similar haptic dress concepts might be used in a future for more effective and immersive digital reality. Image credit: University of Boras

The Brain and its Response to Virtual Senses

Our visual sense steers our perceptions, however vision is only part of the picture. Unless the brain receives inputs from the other senses that confirm what the eyes are saying, it will detect that something is weird, and the sensation of reality will get skewed. This is the case when a video is viewed at an IMAX theatre. Yes, you experience the immersive sensation, you feel tricked in somehow falling along with the rollercoaster on the screen because your field of vision is completely embedded in the video, but at the same time your proprioceptors which respond to position and movement of the body are sending the brain a discordant message that your body is not moving at all. Hence the feeling of nausea that many people experience.

Even in situations where movement is not involved, the brain is quick to detect that something is wrong, sometimes just because it does not receive confirmation signals from the other senses.

Technology is progressing to recreate sensations involving all our senses. Visual and aural sensations can now be created at a fidelity level that matches the sensitivity of our senses. Technology is available that tricks the brain into believing it is getting real signals, for example, 4k video when filling our extended field of vision does and high fidelity (hifi) sound surround for our hearing.

Tricking our sense of smell, taste, touch and movement is more difficult. These four senses, however, are needed only in specific situations. if virtually eating is not required, then the mimicking the sense of taste is not necessary. Similarly, if there is no movement in a virtual space, the perception of movement is not required. Smell is often a complementary sensation, so the brain (differently from the one of a dog) does not raise a red flag if there is no sensation of smell. If you are immersed into a visual perception of a beach and waves breaking on the rocky shore, visual and aural fidelity are essential to feel like being there. The salty smell that you would perceive if you were actually there be a nice addition to the perception but if it is not there your brain is not going to scream "fake, fake…".

The sense of touch, likewise, is not always needed but whenever there is a situation where in the real world touch is part of the experience, the lack of touch sensation would immediately result in an artificial perception. The brain would immediately become aware that something is wrong and it is not the real thing. Providing tactile sensations that can be accurate enough to fool our brain is quite difficult but progress is being made.

There are haptic devices that can recreate the exact sensation of using a tool, like in surgery training. Haptic scalpels have been used for several years providing the future surgeon the exact sensations she will experience when performing surgery on a patient. In flight simulators haptic controls are in widespread use, recreating the sensation of the real cloche. Actually, the digital stick on the fly-by-wire Airbus is haptic; it provides the pilot the feeling of being directly connected to the moving parts of the wing through a controlled force-feedback mechanism.

Consider recreating the sensation of reaching out during a conference call and touching an object that is being shown to us remotely or touching the hand of our children as we talk to them from thousands of miles away. There are haptic gloves that can provide an almost accurate sensation but they are bulky and cannot provide the full spectrum of sensations. For sure they don't feel like the real thing. Besides, touching something when that something is a living thing is two way communications; you touch your child and both people feel the touch. This is not possible, yet. If on your side there is a need to recreate the touch sensation on your hand (that is where a haptic glove comes in), on your child, there would be a need for having actuators all over his body, or a robot that can impersonate you and your actions actually touching (with your touch) your kid. This is currently nowhere near availability.

There are a number of prototypes that can create the sensation of being touched using a haptic surface overlaid on the skin of a person. The problem is that these prototypes are bulky, even when they are in form of a plastic fabric placed on the skin. The sensation of being touched can be created, but it is both limited to the area where the haptic skin is layered and the person's brain will perceive that there is an object on the skin which will destroy the feeling of reality.

Using a robot, or a robotic arm to touch as a proxy presents similar perception problems. The person will feel touch, via the robotic proxy, but will also perceive the robot, hence destroying the feeling of proximity.

Perhaps by the end of the next decade there will be artificial skin that could be layered on our skin without being perceived as an external object to provide tactile sensations from far away although this may be a stretch goal. What may happen is a scaled down version of a wearable haptic skin, which is being pursued by the pornography industry to complement virtual reality goggles.

Regarding technical aspects, communicating a touch sensation requires establishing a feedback loop, you –the toucher- needs to feel that you are touching and he –the touched- needs to feel the touch. These two are related and require very low latency communications, in the order of a millisecond. As the latency increases both people start realizing there is something funny going on, and once the hundred millisecond latency (delay) is reached, the sensation no longer feels at all real. Hence the communications infrastructure is playing a crucial role. 5G may provide a better support in this area, but it is not enough.
This is, obviously, another area where the concept of "digital reality" may be incorrect, stressing that the more you attempt to provide a real-life experience the more you are messing up with reality. Again, a negative perception of Digital Reality.

Digital Reality and Industry

Digital Reality is raising debate when discussing people becoming part of virtual worlds, however the use of Digital Reality in manufacturing, education, healthcare and more is showing mostly upsides and no critical downsides.

Previously it was noted that one of the key aspects of Digital Reality is the possibility of translating the physical world into a virtual world. Today this possibility exists through the use of Internet of Things (IoT) and Digital Twins.

Industry began to create digital models of products as part of the design phase many years ago, basically as soon as mini-computers (e.g., DEC) had their way into the production environment. The software supporting the creation of these models have become more and more sophisticated, flexible and performant, supporting simulation and linking various suppliers in the value chain. By the 1980s Boeing was able to design the 777 airplane completely in cyberspace, up to the last rivet. No mockup was developed; everything took place in the cyberspace creating a digital plane. All suppliers in the value chain had to use this cyberspace platform to design, test and simulate the integration of their components for the digital plane. Customers were made to experience the look and feel of the plane by looking at its digital version and decided on the furbishing based on its digital representation. The Boeing 777 was probably the first large, complex, manufacturing endeavor that shifted processes to cyberspace by making use of Digital Reality.

Today more and more companies are following in the footsteps of Boeing and working in cyberspace throughout the value chain. This is also starting to transform the user experience. Ikea provides an app letting its clients look at a virtual version of the products overlaid in their home through augmented reality. Using a tablet or a smartphone camera, an image of your living room can be displayed, and the app provides the ability choose an Ikea product such as a vase, a lamp, a chair, or a couch and see how it would look in that room. Of course, there are options to change the color of the fabric, try different sizes and move it around to get a feeling of the possibilities.

In a way, the Ikea app is very basic. There is so much more that could be done to deliver a much better experience:

- The capability to rearrange the real objects in room to make space for the product (notice how in this situation the physical reality is distorted through the digital one…);
- The ability to customize the product and send the customization request to Ikea to get an on-demand product. This goes beyond augmented reality but it is an integral part of Industry 4.0, and although Ikea at the moment does not support customization, things will change in the next decade. Notice that this means using Digital Reality to create a new Physical Reality;

- The ability to simulate, and experience what it means having such a product, e.g., by placing the couch in that corner, how is the view to the television? This implies using Digital Reality to mockup a future Physical Reality)

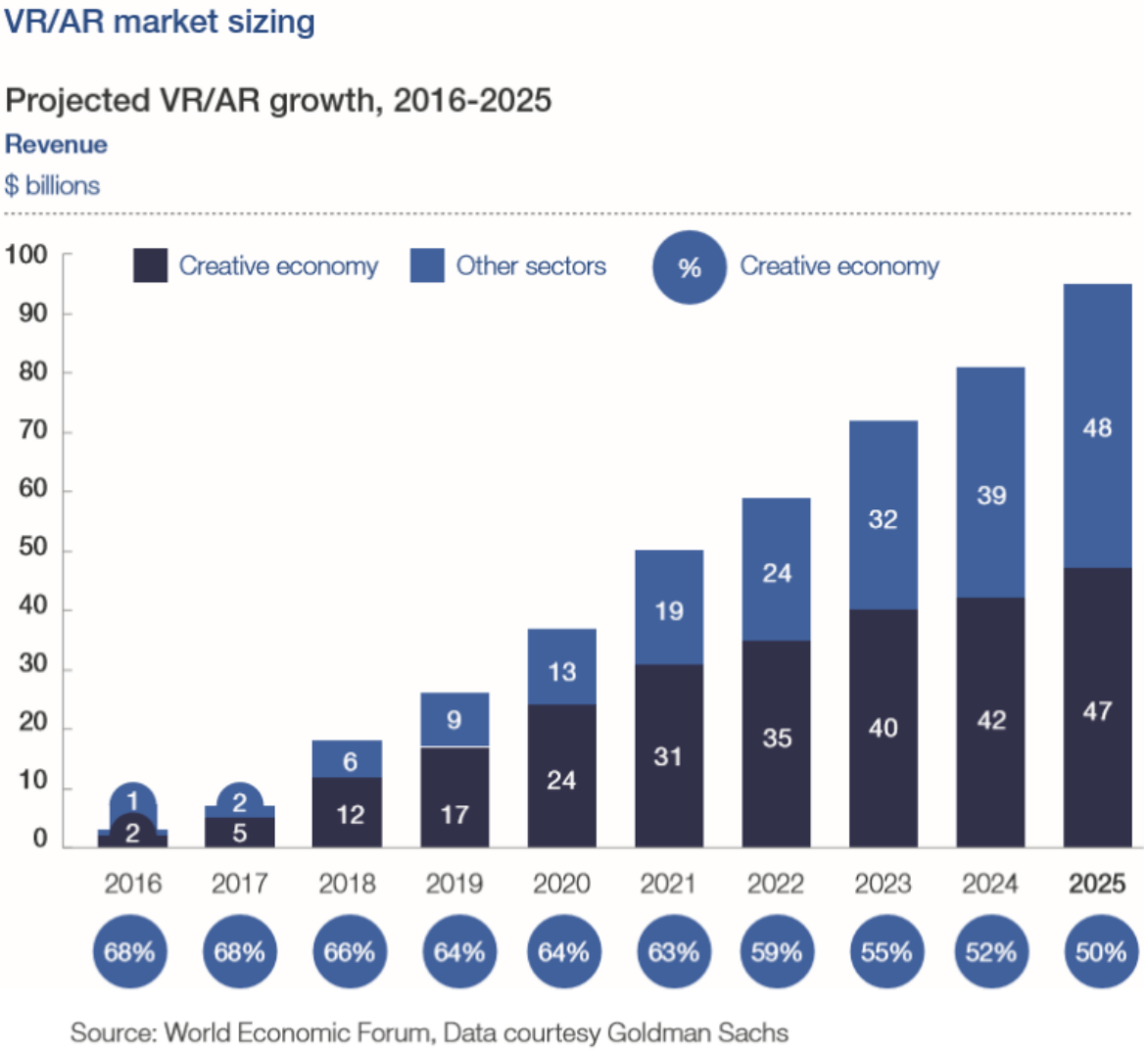

Figure 4 The expected growth of Digital Reality, seen through the adoption of Augmented and Virtual Reality. Notice that the expectation is to reach close to $100B in 2025, up from the $26B expected in 2019. That is four times more in just six years. Also of interest the expectation of the adoption of Digital Reality outside of the creative economy. By 2025 the expectation is to see an adoption by many sectors outside the creative ones, an indication that Digital Reality will start percolating the whole business landscape. Image Source: World Economic Forum on data from Goldman Sachs

In the case of Ikea, we are looking at the representation in bits, in cyberspace, of real physical products that we can order right away. The boundaries between a physical and a digital reality are not so well defined; there are tools and interfaces that are not just allowing movement seamlessly from one to the other, they are also blurring, from a perceptual point of view, those boundaries.

Looking at philosophical domain, humans are the measure of all things, and we as single persons are experiencing unique realities. As the boundaries between physical reality and digital reality blurs, so it blurs our measuring stick.

Digital Reality and Consumer Electronics

Figure 5 Alexa has found its way into our homes; there were 100 million devices embedding Alexa as of January 2019 which means tens of million homes have Alexa bringing in some sort of Digital Reality into the home, changing the way the home is and feels and thus changing its physical reality. Image credit: Amazon

Consider the existence of services like movies and music on demand. These are present in cyberspace, in some cloud from a service provider, yet, once we subscribe, they are becoming part of our ambient, our home. Alexa is a bridge to access this Digital Reality made of music and more. Interestingly, Alexa is doing more than playing the role of a browser or interface. It learns about our taste and habits. In doing so it is creating a digital reality adapted to our environment and mood.

My home, as I experience it, as well as how you experience it when visiting me, is becoming a physical place finely tuned by a digital reality (music, images, lighting) that is coming from cyberspace and orchestrated by software.

It is not just my home. When there are over 100 million devices embedding Alexa it means that a new way of living is emerging, one where you just voice your questions on weather or on what music should play. In a way it is like having an Aladdin lamp at home, supporting perhaps a little less magic but at the same time it is becoming so entrenched in our everyday life, it has an even bigger impact on our behavior than that magical lamp.

On second thought, it's not clear that Alexa delivers second-tier magic when compared to Aladdin's lamp. Think about it: the Genie asks Aladdin the wishes to grant, and that seems quite reasonable to children. How could the Genie know in advance what was on Aladdin's mind?

Figure 6 The Aladdin Genie can do magic; Alexa, to a certain extent, can do magic as well, sometimes going even further than the Genie. Image credit: Disney

Yet, sometimes Alexa seems to know what's on our mind, what our tastes are, or what music should play. The concept of digital twin is along these lines. A digital twin is mirroring a physical reality but is also a history of the evolution of that reality (its digital thread). It provides ways for software applications to use the physical reality mirrored in cyberspace to transform it, creating a new Digital Reality that is no longer mirroring the original physical reality but has the power of affecting our perception of reality by overlaying it on our perceived reality.

The point is that not only the boundaries between the physical and digital realities are getting fuzzier, the digital reality may transform the physical reality, or in other words a new reality is emerging, the one where physical and digital are coalescing.

Digital Reality and Simulation

Alexa is mentioned as an example of a Digital Reality that is often overlooked as a mere, although smarter, interface. As pointed out it is actually much more. Digital Reality is becoming pervasive to the point that we won't even realize we are moving into a fuzzy space and through the fading boundaries separating physical from digital reality. Digital Twins were described as mirrors and bridges across what used to be the chasm between physical and virtual. Simulations provides another area where the physical and digital come together.

Figure 7 Flight Simulators have become so close to reality that pilots are using them to hone their skills and to prepare for a flight. Image credit: Microsoft

Simulation, in a way, means using digital reality to mirror the physical one, sometimes a not yet existing physical reality, some other times an attempt to stretch an existing physical reality into the future under a certain set of conditions to see what would happen. Until a few years ago the boundary between reality and simulation of reality was clear cut. No longer so.

Take the advance made in flight simulators, advances that have led airlines to use expensive flight simulators to train pilots as well as to "certify" pilots! This is important because it means that what a pilot does on a flight simulator is "exactly" the same as what he will be doing in the real plane, should conditions be the same. If you are good on the flight simulator you are good for the reality. There is no more separation between the two. In a way it looks like Einstein's thought experiments: you won't be able to tell the difference between the two realities. A corollary is: if you are not able to tell the difference how can you distinguish between the two? In Einstein's case it was the distinction between moving in an accelerated field or being subject to gravity. His conclusion? Since there is no possibility to distinguish one from the other then they are one and the same.

Flight simulators used by airlines for their pilots are very complex machines, involving all senses, not just vision, also aural and proprioceptors—position, orientation, and acceleration. They are not affecting most of us so they do not lead to an emerging culture of a new reality.
Now there are advanced flight simulators coming to the mass market. X-plane 11 and the coming MS FS 2020 have achieved a level of accuracy, and more importantly, can deliver a sense of reality that is getting close to the one of professional simulators.

It is interesting how these mass market simulators are being used. There are a few flight aficionados using them as a substitute of the real thing (second best thing to being a real pilot), but a growing number of people are using them to look around. The reviews of the MSFS 2020 indicate that people are flying over their homes and were amazed to see the familiar landscape viewed from above.

Virtual tourism is a growing reality, and in the next decade is going to see a tremendous growth and the emergence of new services particularly as emerging AR/VR technologies delivers seamless immersion capability. For example, climbing to the most famous peaks via virtual reality is already emerging.

As this grows, there will be mounting concerns with objections to a world (and culture) that shifts towards the substitution of the real with the virtual (VR) or that more and more people need

virtual to complement the real (Augmented Reality). Others will point out the beauty of virtual tourism, enabling anybody everywhere in the world to visit any place in the world.

I can imagine AR based services that would place me in a different city, on my end exploring it in real time VR and on the other hand having some people in that city seeing me through AR and interacting with me. Am I going to become a real presence for them, through AR? I guess so. Where is the dividing line between digital and real? Isn't the voice of my friend over a telephone line completely real? Why shouldn't my image on a faraway city be as real as that?

Digital Reality and Adult Entertainment

Even though this subject may be a bit contentious, it is included here for three reasons:

- VR in pornography is a rapidly growing "reality"
- VR in pornography is facing technological challenges that are so far keeping it quite separate from reality
- It is fueling the adoption of new technologies that will overflow into other sectors.

It is a fact that VR represents a very small niche in the pornography landscape. In 2018, PornHub website statistics indicated 4.7 million clips uploaded, for a total of over a million hours of video content (corresponding to 115 years of continuous watching), 4.4 Exabytes of data transferred (12 PB per day) and 33.5 billion visits. And there are many more similar websites. Of all of this, VR pornography represents less than 0.2%.

The reasons it is not available are in the complexity of filming in a way that is supporting VR as well as in the relative scarcity of VR goggles. As a matter of fact, it is interesting to notice that on Christmas there is a spike in VR pornography views, most likely because people are receiving VR goggles as Christmas present and decide to use them right away. So, VR is a small fraction of the overall content and a small fraction of the access, however it is also growing very rapidly (for example, when VR pornography was first included in PornoHub in 2016 there were 90 clips, by the end of the year the clips grew to 2,600). The general feeling is that once better and less expensive VR devices become available VR will increase significantly.

However, and this relates to the second point of why this topic is included, VR in pornography is quite difficult to create and experience from a technical and perceptual point of view and this is what keeps VR (Digital Reality) well separated from reality.

When you are experiencing Digital Reality in the context of virtual tourism, you can get the sensation of being part of that Digital Reality; you can feel like you are really there since you can move your head and your eyes will capture a changing landscape. In VR pornography, however, you could play the role of a spectator and with VR googles you can move your eyes to look, as an example, not at the actors but at the ceiling or around the room. However, it is most unlikely that you would do that. The focus is on the action and looking around does not add anything, actually, it detracts from it. There are, however, a few that are experimenting with this form of immersion claiming it may be appreciated.

In virtual tourism the viewer focuses on a scene, like a stall selling local crafts. In VR pornography in order to focus and let's say impersonate one of the actors to get the feeling of being there you would need to assume the position of the actor, otherwise the visual image you get will not be in sync with what your brain is getting from the proprioceptors. This creates a sensation that something is quite wrong. Rather than having the digital reality seamlessly overlapping with the physical one you get dissonant feedback.

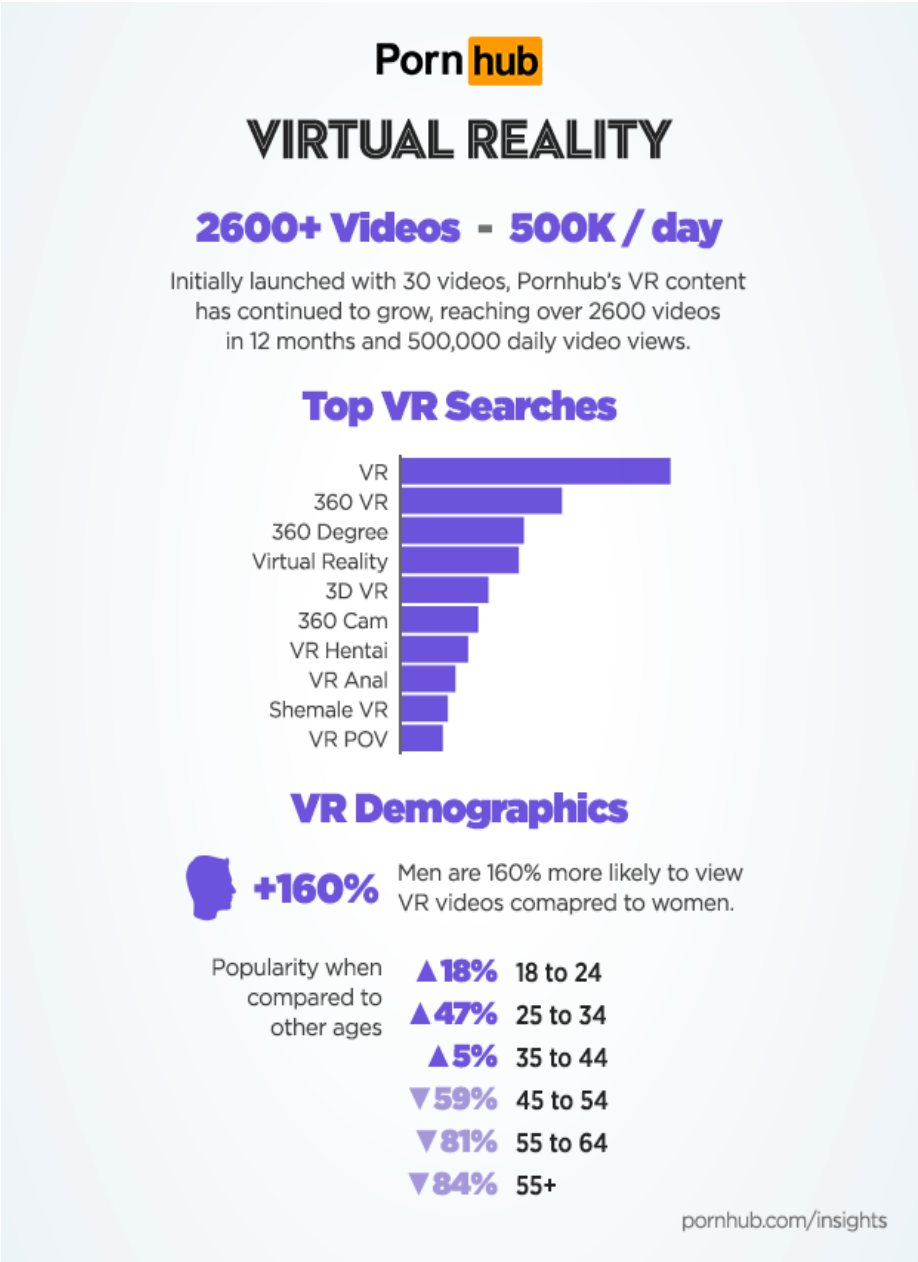

Figure 8 VR is still a fraction of the porno content online but it is rapidly growing. Image credit: PornHub.com/Insights

Contrary to VR in tourism, where the experience is more real as the VR improves, in VR pornography, the better the VR, the more disjointed the experience becomes from reality. In other words, the technology is not currently available that would allow impersonation of an actor (and even if such a technology would be available it would not feel it as real unless the actor position and movements are perfectly mimicked).

It is different if the VR is not applied to a video but it is used as an enhanced video conference, providing a one on one experience. A variation of this scenario, leveraging 3D imaging and artificial intelligence, is the interaction with avatars. In this case the availability of effective haptic interfaces may add significantly to the video conference video stream. This is touching upon the third point, the steering of VR pornography to the evolution of some technologies.

This is an area where the concerns already expressed on the fading boundaries between Digital and Physical Reality become even deeper, involving ethical and societal aspects.

Digital Reality and the Trend Towards Softwarization

In industry, more and more products are a mixture of hardware and software. While in the past software was totally embedded, and in the end just a different sort of "material", nowadays, more and more, software is decoupled from the hardware. It might still reside in the product but it is connected to the web, to the manufacturer, to one or more service providers, and this connection affects its behavior. In some cases, part of the software is not even residing in the product but somewhere in the cloud. Digital Reality can no longer be separated from the physical one; our perception of the physical reality requires the co-presence of the digital reality.

Figure 9 A graphic from several years ago used to explain the trend towards product softwarization. In this case a digital camera operates using embedded software that can be updated and extended both by the camera producer as well as by third parties. This software is both the engine of the digital camera and a platform delivering features and services. The end user seldom perceives what feature is hardware based and what feature is software based.

The reasons for this decoupling of hardware and software are several:

- to decrease the cost in manufacturing by moving features to software which is easier to replicate (the software is written once and then installed at a minimal cost on all instances of the product);
- to increase flexibility, making it easier to change/upgrade features;
- to open up the product to third parties, allowing them to increase the value of the product by making more features available
- to shift the business model from selling a product to selling a service or to use the product as a platform to deliver services

- to obtain feedback from the product use through the Internet and be able to provide remote maintenance and proactive maintenance

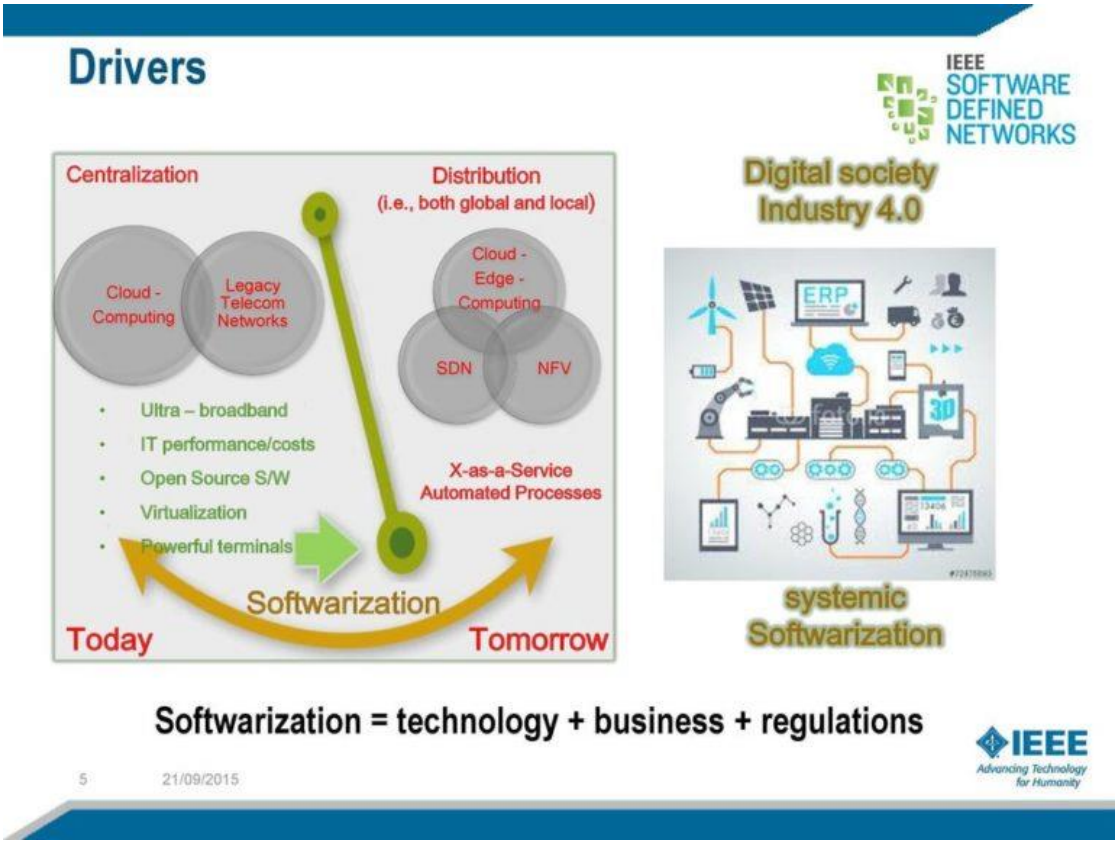

Figure 10 The global trend towards softwarization. Image credit: IEEE Future Directions

Today more and more products are software "based" to the point that it becomes a moot exercise trying to separate the perception of the product in terms of hardware and software. Most of the time the end user does not even know if a feature is implemented in hardware or software, locally or somewhere in the cloud.

Consider the example of the smart phone (a typical product where software and hardware are one and the same from the user perspective in terms of features) for real time translation. The user doesn't know if the translation is taking place locally or in the cloud. Consider the editing of photos on your smartphone - is the rendering done locally or in the cloud? More computationally intensive functionalities are taking place in the cloud but these are completely transparent to the user (unless, of course, no connection is available in which case the user realizes that something is wrong).

Figure 1 shows the multiple relationships that may exist among a digital camera and the digital space. Some of these relationships are established to download or update the software on the camera from the camera manufacturer or third parties' providers. Other relationships are taking the digital photos from the camera to the cloud where they can be further processed and sometimes mixed with digital photos taken by other photographers to create an image that is an interpretation of reality (like one where people have been removed from the image, the image has been expanded to include more surrounding space, and so on).

Computational photography is an area where Digital and Physical Realities merge.

Digital Reality and Systems

Interestingly digitalization and softwarization is happening not just at products or equipment level but also at system and network level.

An airplane engine has its digital twin, a digital model in cyberspace that can be used in many ways, including the provisioning of information via virtual and augmented reality to designers, maintenance crew, pilots (for training as well as operation purposes) and of course for simulation. At the same time, the "digital" engine is a component of the "digital" airplane and it interacts in cyberspace with the other airplane digital components. Today pilots are seeing data segmented by components through their glass cockpit; military pilots and planes interface with the various components through the use of augmented reality (head up displays). In the future, more sophisticated interfaces connecting the pilots with the digital airplane providing a view at a global level, rather than simply seeing a small view of the plane's operation will be available. This approach will make Digital Reality the primary interface to the Physical Reality.

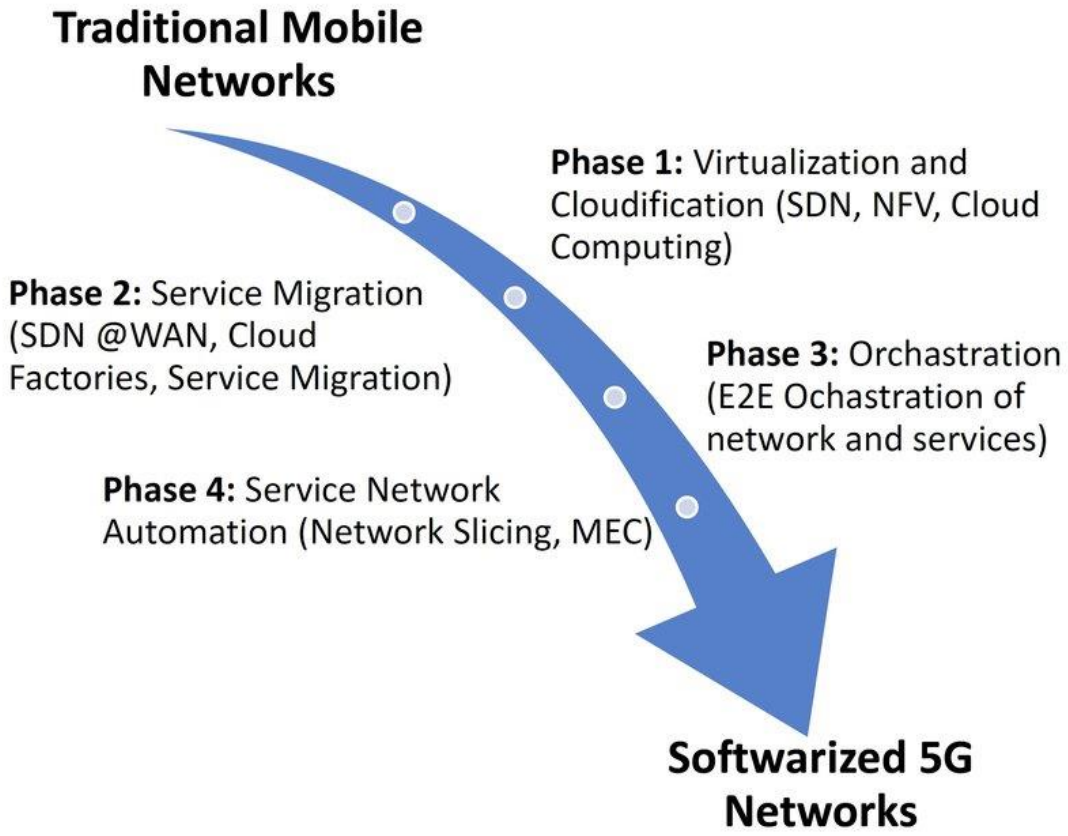

Figure 11 The softwarization trend extends to systems. The graphic indicates the evolution towards the provisioning of 5G using network softwarization. Image credit: Rabia Khan et al. Tomsk Polytechnic University

Telecommunications networks have been evolving to become more and more flexible, both to be more efficient in the use of resources and in the delivery of services. The Signaling System #7 (SS7) was probably the first step towards the use of a digital image of the whole network in order to become aware of the current use of resources network-wide and make decisions to maximize their use. Intelligent Networks followed suit and then there was the Cloud, the Service Features Interaction, Service Virtualization, and it continues.

In this last decade there has been a global paradigm shift bringing any network component and any network process into cyberspace, enabling the operation, management and exploitation of the network resources in cyberspace, through Software Defined Networking (SDN) and Network Function Virtualization (NFV). In a way these technologies and overall paradigm move the network to cyberspace, and services or service providers can custom tailor the digital network. This customized digital network then creates a physical network mirroring it.

Figure 12 Hiroshi Ishii has been leading research on Tangible Interfaces. One of the applications is the design of internet networks using digital modelling and SandScape, a broad surface covered with sand. By moving the sand and placing objects on the sand representing network equipment, one could experiment the effect of different architectures. It was a mixture of digital and physical reality used to grasp the effect on a "different" physical reality. Image credit: Media Lab

This is a completely new implementation strategy. Rather than creating a digital model of a physical entity (or conceptual entity like a plane composed of its physical entities), a digital entity is developed that, through various interactions, will mirror its image into the physical space.

5G is probably the first network that can take full advantage of this top down, digital to physical, approach. It is unlikely to see a full-fledged softwarized 5G network in the coming years. 6G may be needed to see that kind of network, hence 10 more years at least. However, softwarization is in the 5G genes, and once softwarization takes place to create 6G (which likely will be the only way to create that network) a progressive –retrograde- softwarization of 5G will occur as well. By the way, according to the Chinese "vision" 6G will be the network that blurs the lines between the Digital and the Physical Reality.

Digital Reality and Processes

Digital Reality is becoming reality not just for products but also for systems, including complex systems like telecommunications networks. Digital Reality is also becoming reality for processes. This is of particular interest, and significance, for the manufacturing industry and its value chain.

Figure 13 Factory Chief Engineer Wearing VR Headset Designs Engine Turbine on the Holographic Projection Table. Image credit: Futuristic Design of Virtual Mixed Reality Application.

Digitalization starts at the design phase and keeps evolving through the whole value chain. Co-design is performed on the digital model; simulation is performed on the digital model of single components and of their resulting assemblage. Most importantly, the tool design and the simulation of their deployment and operation is done at the digital level. The impact of failure in any component on the assembly line is simulated and evaluated at the digital level.
Furthermore, along the value chain some software components become part of the digital space and are seen both as a digital representation and as real components.

The whole process results in the development of the final product's digital twin, and each step is recorded in the digital twin's thread. At the delivery point (where the product is packaged and shipped) the digital twin is instantiated and becomes the mirror of that specific product instance.

The connection between the digital space and the workspace is supported by virtual reality and augmented reality technologies. Virtual reality comes into play in the design phase, where only a digital model exists and in the subsequent phases where no connection to the physical reality exists (e.g., looking at ways to organize the work of several robots over an assembly line, showing an end customer the intended product and the possible result of its customization, engaging the user in the operation of a product in a virtual space). Augmented reality comes into play when additional, digital information can enhance the understanding of a physical reality overlaying the former on the latter.

Industry 4.0, by making digital reality a fundamental part of its paradigm, will both benefit and stimulate the evolution of Virtual and Augmented Reality technologies, as well as all technologies that can leverage data, like data analytics, data rendering, artificial intelligence in all its forms, and, of course all data transmission technologies. In a way, it will lead the digital transformation of the industry and society. Healthcare will follow suit, providing the digital processing on human bodies: predictive medicine and social medicine will be based on Digital Reality, on the creation and leveraging of Digital Twins mirroring people.

The industrial adoption of Digital Reality will include workers' skills and knowledge (Cognitive Digital Twins). These will be seen as resources mirrored in the digital space, to be managed and leveraged by the industrial processes. The mirroring of people's behaviors in the digital space will become important in the modelling, planning and operation of smart cities. Fintech is already largely based on Digital Reality, and the inclusion of people's moods and investment trends is already subject to study giving rise to ever more sophisticated analytics.

Digital modelling of skills and knowledge will change the approach and delivery of education, particularly of continuous education. Modelling of moods and perceptions will drive the impact of Digital Reality on government and the reshaping of democracy. All of this means profound changes in society and along with it the rise of new ethical questions and societal challenges.

The shift to a new reality resulting from the merging of Physical and Digital is taking place today, through the process of the Digital Transformation. It will probably take two decades to reach

maturity and consolidation. The ongoing activities of the IEEE Digital Reality Initiative will be focusing on this transformation process, on the enabling technologies and on the market trends resulting in a forthcoming white paper.

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