Advancing Technology for Humanity and Earth (+Water+Air)

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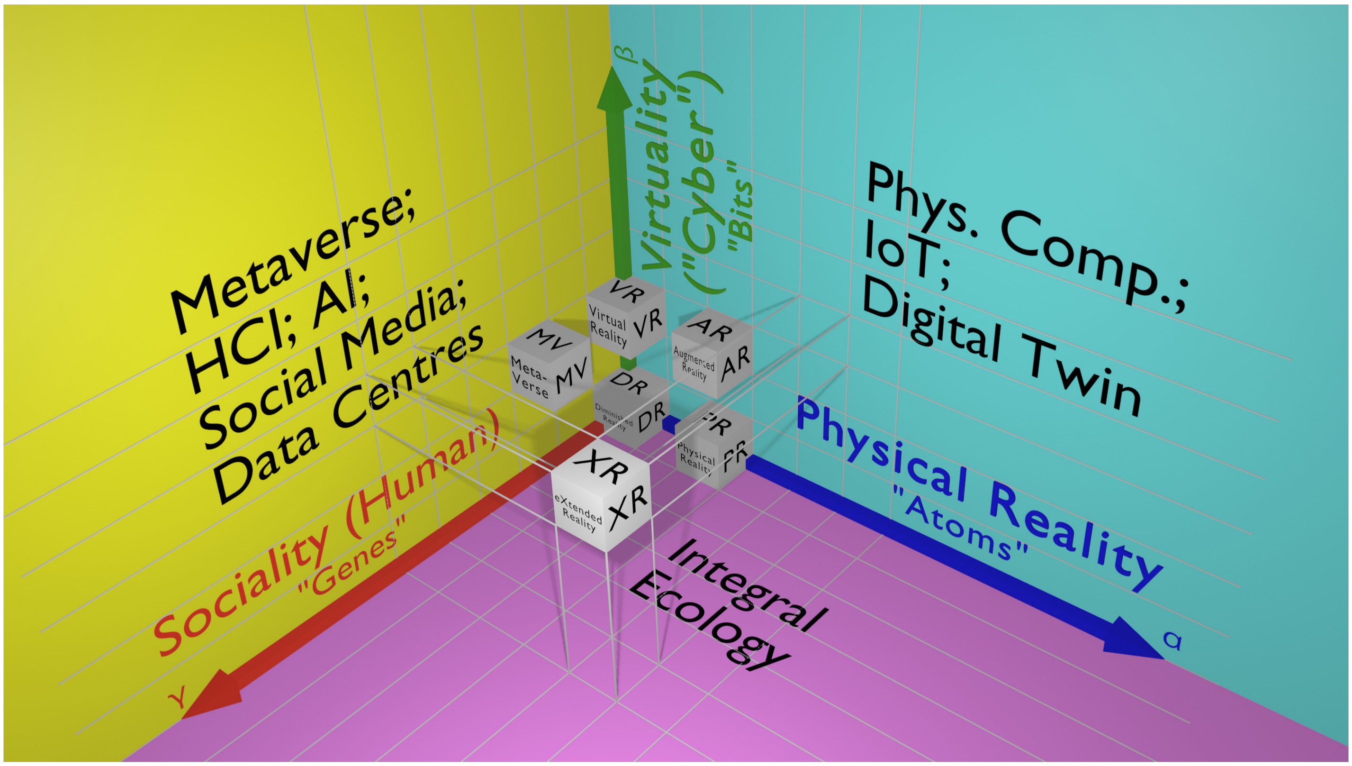

Figure 1: The Socio-Cyber-Physical Taxonomy: Virtual Reality (VR) exists along the Virtuality (Cyber) axis ("Bits"). Physical Reality (PR), exists along the Physical Reality axis ("Atoms"). AR (Augmented Reality) combines the world of "Atoms" and the world of "Bits" and exists in the Reality+Virtuality plane of Physical Computing and Internet of Things (IoT). XR (eXtended Reality) spans the entire Socio-Cyber-Physical Space, interpolating between the various Realities and extrapolating beyond them [8, 15, 19, 27, 40, 56].

Abstract

As technology advances, the integration of physical, virtual, and social worlds has led to a complex landscape of "Realities" such as Virtual Reality (VR), Augmented Reality (AR), metaverse, spatial computing, and other emerging paradigms. This paper builds upon and refines the concept of eXtended Reality (XR) as the unifying framework that not only interpolates across these diverse realities but also extrapolates (extends) to create entirely new possibilities. XR is the "physical spatial metaverse," bridging the physical world, the virtual world of artificial intelligence, and the social world of human interaction. These three worlds define the Socio-Cyber-Physical Taxonomy of XR that allows us to identify underexplored research areas such as Diminished Reality (DR), and chart future directions to **advance technology for people and planet**. We highlight the six core properties of XR for applications in sustainability, healthcare, frontline work, and daily life. Central to this vision is the development of AI-driven wearable technologies, such as the smart eyeglass, that sustainably extend human capabilities.

Keywords

XR (eXtended Reality), VR (Virtual Reality), AR (Augmented Reality), MR (Mediated Reality), PR (Physical Reality), DR (Diminished Reality), SR (Spatial Reality), IR (Intelligent Reality), Metaverse, Mersivity

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1 XR and (Im)mersivity

Traditionally computers were large and cumbersome and were mainly associated with large indoor installations. Eyewear such as Virtual Reality (VR) systems were also large and cumbersome, confined to labs, living rooms, or other indoor locations, where the user is isolated from the natural physical world. As we bring these technologies into the real world, we have Augmented Reality (AR) overlays combining the real world and the virtual world (Fig. 1).

XR (eXtended Reality) brings together the physical world, virtual world, and social world (Fig. 1) to connect us to each other and our surroundings. XR is technology for humanity and Earth. Tech for people and planet!

We begin with a brief look at the Socio-Cyber-Physical Space upon which XR is founded (Fig. 1), then motivate it through the example and use-case of wearable AI, and then revisit the concept of Socio-Cyber-Physical space in detail in Section 5.

1.1 XR is social, technological, and physical

XR is, by its very nature, technology that connects us to each other and to the physical world around us, as outlined in the Socio-Cyber-Physical Space of Fig. 1 which forms a convenient taxonomy/ontology of the 'R's ("Realities"). VR (Virtual Reality) exists entirely along the Virtuality axis. PR (Physical Reality), i.e. the real world, exists along the Reality axis of the physical world made of atoms (earth, water, air, etc.). AR (Augmented Reality) combines the world of "atoms" and the world of "bits" and exists in the Reality+Virtuality plane. Technologies that attenuate or diminish our senses (e.g. ear plugs, dark sunglasses, welding helmets, baseball caps) are examples of DR (Diminished Reality) which exists near the origin of the space (where the axes meet). HCI (Human-Computer Interaction) and the Metaverse (shared social VR) exist in the Virtuality+Sociality plane. XR (eXtended Reality) spans the entire Socio-Cyber-Physical space, interpolating between the various Realities and extrapolating beyond them [8, 15, 19, 27, 40, 56]. Fig. 1 is a simplified version of much of the work outlined in a previous IEEE Special Issue (see the introductory text [13]), and associated preprint [41].

2 Wearable AI: Introduction and motivation

A good example of XR is Wearable AI [34, 40] (Wearable Artificial Intelligence) which can take the form of a smart eyeglass. The combination of XR and AI is also known as XI (eXtended Intelligence) [40, 48].

Wearable AI [34] in the form of an AI-Driven eyeglass ("A-Eyeglass") offers capabilities that no other form factor can support. For example, XR takes the form of contextual information displayed directly upon the user's field of view. AI insights using machine learning algorithms provide predictive analysis and recommendations. Hands-free operation now enables seamless multitasking, especially in critical or high-stress environments. Integration with Internet of Things (IoT) and other cyber-physical systems (Fig. 1) enables real-time updates and remote access. Moreover XR allows us to see beyond mere overlays, e.g. so that we can see in the ultravoilet, infrared, electromagnetic, and acoustic spectrum and share these visions with others since XR is shared and collaborative by its very nature [24, 40].

The AI-driven smart eyeglass represent a pivotal advancement in wearable technology, as it embodies XR by combining Augmented Reality (AR), Artificial Intelligence (AI), connectivity, Human-Computer Interaction, Metaverse, and Internet of Things, to extend human interaction within the physical, virtual, and social worlds. These devices provide tailored solutions for sustainable healthcare, support for frontline workers, and optimized day-to-day activities such as sports and personal health. By focusing on sustainability, the smart eyeglass aligns with global efforts to improve health outcomes, reduce resource consumption, and foster a connected, data-driven lifestyle. All this while allowing people to get their heads out of their phones and back into the real world with the rest of humanity and earth.

A smart eyeglass powered by AI can extend human capabilities (XI = eXtended Intelligence) by integrating real-time data processing, contextual insights, and advanced user interfaces into wearable technology. The ability to extend physical reality with computational intelligence and social intelligence positions these devices as indispensable tools across industries and everyday life. Wearable AI such as embodied by the smart eyeglass is one very effective way to create a link connecting the virtual (artificial), real (physical), and social worlds especially as they are driven by AI. In a world increasingly focused on sustainability, the smart eyeglass offers scalable efficient solutions for healthcare, frontline workers, and individual users. Healthcare is at the forefront of leveraging the AI-eyeglass for sustainable and impactful solutions. For the patient directly, remote patient monitoring using an AI driven eyeglass enables healthcare professionals to monitor patients remotely through XR-based dashboards, reducing travel needs and resource consumption. Sensors in the eyeglass measure what's happening around the patient (environment) as well as what's happening inside the patient's body ("invironment") and, most importantly, the relationship between these (e.g. correlating electrocardiogram irregularities with environmental factors as captured by outward-facing cameras in the eyeglass).

AI algorithms analyze patient (invironment) data, together with surroundings (environment) providing early warnings for critical health events. This approach can minimize hospital admissions, cuts costs, and improve patient outcomes. In operating rooms, the smart eyeglass is currently providing surgeons with XR-guided visuals of critical anatomy, AI-powered diagnostics, and procedural checklists, enhancing precision and reducing errors. The reduction of surgical errors also results in better resource utilization. Medical students and professionals use the smart eyeglass for XR training from remote support to a first person perspective allowing students or experts to select between a bird's-eye-view or a "Point-of-Eye" view of live procedures. These applications reduce the need for physical resources like cadavers or expensive training setups.

Empowering frontline workers in industries such as construction, logistics, and emergency response are increasingly relying on the AI/XR-eyeglass for safety, efficien-cy, and sustainability. AI algorithms integrated into an eyeglass can identify workplace hazards, such as structural instability or hazardous materials, alerting workers in real-time and preventing accidents. Frontline workers can receive XR overlays and XR sensory extension with step-by-step instructions, reducing errors and training time. This is particularly useful in scenarios where manuals or printed materials are impractical. A smart eyeglass equipped with environmental sensors and AI analytics supports emergency responders in assessing dangerous situations, tracking personnel, and coordinating rescue efforts more efficiently.

AI insights help optimize material usage, equipment operation, and energy consumption, promoting environmentally conscious practices in industries that rely on frontline labor.

The smart eyeglass is revolutionizing the way individuals approach personal health, fitness, and daily activities.

Athletes use the smart eyeglass for real-time performance metrics, such as speed, distance, and biofeedback. AI-powered coaching delivers personalized insights, helping users optimize training while preventing injuries. Casual fitness enthusiasts benefit from wearable AI [34] that monitors activity levels, heart rate, calorie consumption, and environmental factors, providing actionable recommendations for a healthier lifestyle.

The smart eyeglass tracks vital signs such as oxygen levels, heart rate variability (HRV), and sleep patterns, helping users maintain optimal health. AI integration ensures early detection of anomalies, promoting preventative care. For users in urban environments, the smart eyeglass facilitates navigation, communication, and extended reality overlays, together with extended senses, for improved situational awareness. Whether finding a bike path or checking air quality, or seeing in complete darkness, or seeing a safeyfield (path of safest travel), the AI-eyelgass provides practical solutions to everyday challenges.

The adoption of the AI-eyeglass is not just about convenience, it also aligns with broader sustainability goals, by enabling remote healthcare, minimizing travel for remote support and work, and streamlining industrial processes. The smart eyeglass contributes to significant reductions in carbon emissions. For example, the ability to see in complete darkness reduces the need for electric lighting.

The smart eyeglass improves efficiency in material and energy use, particularly in industries like manufacturing and logistics, promoting a circular economy. Affordable smart eyeglasses powered by AI can bring advanced capabilities to underserved populations, bridge the digital divide, and foster equitable access to technology.

Wearability and fashion-forward design are critical for the success of smart eyeglasses.

However, to be successful a key performance metric for smart eyeglasses is wearability and fashion. For many years, manufacturers have only been offering bulky, heavy, power-hungry and strange-looking devices. Only recently the technology is finally becoming available to deliver the lightweight all-day wearable fashion forward solutions that are critical to the industry's success. Wearability and fashion are critical factors for the success of smart eyeglasses, as they directly influence user adoption, satisfaction, and sustained use. A Smart eyeglass must be comfortable, stylish, and versatile to succeed in the marketplace. Consumers view such a product as both a functional tool and a personal accessory, so design must reflect a careful balance of functionality, comfort, and aesthetics.

AI eyeglasses are on the verge of completely changing the socio-cyber-physical relationship, connecting people, planet, and technology.

AI-eyeglasses represent a transformative shift in how humans interact with technology and the world around them. From revolutionizing healthcare to empowering frontline workers and enhancing daily life, these devices foster a profound connection between people, technology, and the environment. By focusing on sustainable and scalable applications, the smart eyeglass stands as a beacon of hope for a future where technology serves both humanity and the planet.

XR in the form of wearable AI-glass will:

- enhance sustainability through reduced resource use and improved efficiency.
- have applications in healthcare and frontline work and showcase their transformative potential;
- work for everyday use cases that bridge the gap between advanced technology and accessible, meaningful benefits for individuals;
- not only deliver innovative features but also integrate seamlessly into users' lives and wardrobes.

We envision a future where smart glasses not only improve lives but also contribute to a healthier planet.

3 Historical and philosophical background

To fully appreciate the benefit of XR above and beyond AR, we need to look at the historical background leading up to XR and Metavision/Metaveillance (and metaverse).

3.1 Technology that truly connects us to each other and our surroundings

While much has been done with social media and collaborative computing in an effort to connect us, an important goal of XR has always been to connect us in a profound way. This connection can (and often should) go beyond merely collaborating in the virtual world, to include the social and physical worlds. Consider some historical examples of XR.

Firstly, consider the S.W.I.M., an early spatial computing system developed in Canada in the early 1970s [1, 2, 24, 29–31, 35]. This system comprised arrays of computer-controlled light sources set in motion in a darkened room, and arranged in such a way as to allow viewers to see electromagnetic radio waves, sound waves, and other physical phenomena. SWIM is based on very broad-band hardware, so it updates in less than 100 nanoseconds, thus having an effective "frame rate" of many megahertz.

What was unique about SWIM was that it facilitated direct human interaction among large groups (e.g. hundreds or thousands) of people, able to see and understand things happening beyond the normal range of human perception [40]. See Fig. 2.

As a second example of XR, consider Sicherheitsglaeser, a live performance presented at Ars Electronica Sept. 1997, based on concepts presented the conference [25], followed by an art exhibit at List Visual Arts Centre Oct-Dec 1997 [26]. It comprised of a wearable computer supporting a large remote audience of more than 30,000 people, engaged in an XR (eXtended Reality) metavision experience, while at the same time featuring both an inwards-facing display for the wearer, and an outwards-facing display for a local audience. In this way Sicherheitsglaeser facilitated direct interaction between remote and local participants. See Fig. 3.

Figure 2: S.W.I.M. (Sequential Wave Imprinting Machine) is a spatial computing system invented in Canada in the early 1970s that allows large numbers of people to see, understand, grasp, touch, and feel electromagnetic radio waves, sound waves, and other phenomena at exact 1:1 scale with perfect alignment between the physical and virtual content, updated at effectively millions of frames per second (instantaneously) [40]. It may be used with the XR eyewear, but it can also be seen by thousands of people in the surrounding space without the need for any special eyewear, as shown to an extremely large audience at this recent tradeshow.

Figure 3: Sicherheitsglaeser presented at Ars Electronica 1997 used a wearable computer with both an inwards-facing eyeglass display for the wearer to see, as well as an outwards-facing eyeglass display (on the same eyeglass) for local participants to see. It facilitated a direct and meaningful connection between the virtual, physical, and social worlds of more than 30,000 remote participants and hundreds of local participants as a form of performance art.

As a third example of XR, consider the use of wearable computing during an icewater swim that allows a group of swimmers to remain in contact with each other and with remote members of the swim group for safety and situational awareness, as illustrated in Fig. 4. Wearable computers, such as Vuzix SmartSwim, allow the partipants to each their own, as well as each-others' vital signs, heart, respiration, and brain activity (e.g. blood-oxygen levels in the brain by way of fNIRS which is more reliable than EEG underwater). Additionally swimmers see their own and each other's kolympographic [39] information including map, location, heading, direction, etc., as well as water temperature, wave-height data, and water quality data.

As a fourth example, consider the possibility for XR to connect us to each other and to the wilderness, nature, etc., such as at a campfire (Fig. 5).

It should be emphasized here that XR as a wearable immersive technology has the capacity to bring about a deeply profound connection between humans by connecting them to each other and their surroundings/environment/world.

We are all part of each others' surroundings, e.g. any one of us could truthfully say: "You are part of my environment and I am part of your environment.". Thus we cannot over-stress the importance of the full and complete Socio-Cyber-Physical connection afforded by XR.

4 Mersivity

The examples of XR provided in the previous section highlight examples of Mersivity. Mersivity regards technology as a generalized vessel that connects us to each other and to our surroundings.

We can consider these connections more formally as follows. Referring to Fig. 6

This set of connections define Mersivity, i.e. the way in which we can regard technology as a generalized vessel (eyeglass, shoes, clothes, boat, car, building, etc.) denoted here as a smart paddleboard that connects us to each other and to our surroundings. Such technologies are im**mersive** and can encapsulate or enclose us to some degree. We believe that technology should also be exmersive, e.g. durable enough as to not encumber us, We like technologies that can suit our lifestyle, e.g. allow us to go hiking in the wilderness, go for a swim, or paddle in the water. Othewrise we run the risk that technologies could imprison us and keep us away from our surroundings/environment. In this way technology must serve not only humanity but also nature/surroundings/environmnent/earth/water/air....

5 The XR (Socio-Cyber-Physical) Space

Wearable technologies that can merge, mix, mediate, modify, and remix the physical, virtual, and social worlds were created fifty years ago, in Canada, with the invention of Metavision and Metaveillance (1974) and SWIM (1974), an early form of wearable spatial computer [1, 2, 24, 29–31, 35].

VR (Virtual Reality), a term coined by Artaud in 1958 [6], and exemplified by the stereoscopic viewing apparatus of Sir Charles Wheatstone in 1838, Morton Heilig's Sensorama, of 1956 (the first VR machine), and Ivan Sutherland's machine of 1968 [58], was characterized by an apparatus within a fixed setting, typically an indoor setting, while seated.

What sets wearable technologies apart from this tradition is the emphasis on connecting people to their surroundings, and to each other, e.g. being able to walk, run, swim, etc., while wearing and using the technology. Along with these wearable technologies has come a dizzying and confusing collection of often conflicting terminology. Along with VR (Virtual Reality), we now have many other 'R's such as: AR (Augmented Reality); MR (Mediated Reality); IR (Intelligent Reality), SR (Spatial Reality) or spatial computing; and Metaverse.

Figure 4: Example of XR for situational awareness during icewater swimming. A wearable computer with XR eyeglass connects each participant to the others and to their surroundings. XR is about connecting us to each other and our surroundings, without imposing limits on what we can do or experience.

We seek to clarify this confusion through revisiting the concept of eXtended Reality (XR). We begin by discussing how the concept of the XRspace (Fig. 1) can be represented as a taxonomy or ontology of “Realities” along three axes: Physical, Virtual, and Social. For simplicity the axes are color-coded, using blue to represent the Physicality (“Earth”) axis, green to represent the Virtuality ("Cyber" / "Tech") axis, and red to represent the Humanity axis. The color scheme for these three axes follows the illustration of Fig. 7.

Let us begin with “Atoms” and “Bits”, the cyan-colored (blue and green) Physical Computing plane of Fig. 1.

5.1 Atoms and Bits

Consider two axes: the physical world of “atoms” (earth, water, air, etc.) and the virtual/cyber world of “bits”. Together these axes illustrate “Physical Computing”, i.e. a “Cyber-Physical” System (CPS), defined by Physicality (“atoms”) and Virtuality (“bits”) axes in Fig. 1.

This is a simplified version of the figure previously outlined in a preprint [41] to a past IEEE Special Issue [13]. Together, the Physical axis (denoted in blue) and the Virtual axis (denoted in green) define the Cyber-Physical Plane (denoted in Fig. 1 in cyan, which is a color that contains equal parts blue and green).

For simplicity, the Cyber-Physical Plane alone, in two-dimensions, is shown in Fig. 8

As we trace a path such as a line or arc from VR (Virtuality) to PR (Physicality), we can seamlessly move along a continuum, as suggested by Milgram [45] and others [57]. Milgram’s Mixed Reality continuum provides a provides a one-dimensional transition between Physical Reality (PR) and Virtual Reality (VR). However, a significant drawback of this one-dimensional continuum is the lack of origin or zero-point. A zero-point helps us address important technologies of attenuation, such as dark sunglasses, welding helmets, light shields such as baseball caps, and the like. More generally, diminished reality is as important as augmented reality [11, 12, 18, 21, 33, 36, 42, 47, 55]. Thus having an axis with an

Figure 5: CampfireVR/XR: Technology should connect us to our environment, and should work everwhere, not just in the home or factory. The MannLab Mersivity underwater VR glass as well as the Vuzix SmartSwim are examples of technology that works well in nearly any environment.

origin is quite a bit more useful than having an axis that has no origin [41].

Other axis-based taxonomies include the three-dimensional taxonomy (3 axes) of Skarbez [57] which suffers from a similar problem, lacking a clearly defined zero-point origin for the three axes.

Taxonomies and ontologies often help identify underexplored areas of research. Referring to Fig. 8 we see the lower-left quadrant, i.e. the zero-point, missing in the Milgram and Skarbez taxonomies, is an underexplored area in the literature on "the Realities". Technologies like dark sunglasses, welding glass, earplugs, etc., are important, and indeed we can innovate with adaptive noise cancellation, smart sunglasses, smart welding helmets, etc., to create a whole new area of research called "Diminished Reality" ("DR") [11, 12, 18, 21, 33, 36, 42, 47, 55], as suggested in Fig. 9.

An example of DR is a sensory-deprivation float-tank where stimulus from reality and virtuality is greatly attenuated. This doesn't mean the brain does nothing. In fact we hallucinate strongly in a float tank. But the input to the senses is close to zero physically (no sound or light, etc.) and virtually (no distracting emails or texts).

The history of Cyber-Physical Systems (CPS) is very nicely summarized by Lee[22]:

> The term "cyber-physical systems" emerged around 2006, when it was coined by Helen Gill at the National Science Foundation in the United States. The related term "cyberspace" is attributed to William Gibson, who used the term in the novel Neuromancer, but the roots of the term CPS are older and deeper. It would be more accurate to view the terms "cyberspace" and "cyber-physical systems" as stemming from the same root, "cybernetics," which was coined by Norbert Wiener[64], an American mathematician. Wiener's control logic was effectively a computation, albeit one carried out with analog circuits and mechanical parts, and therefore, cybernetics is the conjunction of physical processes, computation and communication. Wiener derived the term from the Greek κυβερνήτης (kybernetes), meaning helmsman, governor, pilot or rudder.[22]

5.2 HCI and Metaverse ("Bits" and "Genes")

Human-Computer Interaction (HCI) concerns itself with the interplay between the virtual/cyber world of computing technology (the green "bits" axis of Fig. 1) and the human/social world, which is a third axis denoted in red, as "Sociality". These axes (red and green) define the yellow plane (yellow is a color comprised of equal parts red and green) of Fig. 1.

The concept of "cyborg" (a word coined by Manfred Clynes in the 1960s meaning "cybernetic organism") also exists in the yellow Socio-Cyber plane denoted "Metaverse" (i.e. collaborative social VR).

The IEEE's tagline, "Advancing Techology for Humanity", could be construed as also existing in the yellow Metaverse plane.

The cellphone is an example of a technology that can truly connect humans on a social level. The first handheld wireless telephone, a prototype DynaTAC model (weighting about 2 kg), was invented and used in New York City, 1973 April 3rd, by Martin Cooper of Motorola [59].

Indeed, social media, often associated with handheld devices like cellphones, also exists in the yellow Cyber-Social plane.

Increasingly, smartphones now support 3D graphics applications as well, giving us shared virtual reality experiences.

5.3 Integral Ecology ("Atoms" and "Genes")

Discussion of the Socio-Cyber-Physical space would not be complete without also considering the magenta-colored plane at the bottom of Fig 1. Magenta is a colour comprised of red and blue, as this plane is spanned by the blue Physical Reality ("Atoms") and the red Sociality ("Genes") axes.

This plane is best described as the plane of "Integral Ecology". Integral Ecology is the study of the relationships between living organisms and their environment [44]. The concept was adopted by Pope Francis (born Jorge Mario Bergoglio) in his encyclical Laudato si' (2015) [54] which emphasizes the interdependence between people and their natural environment, with emphasis on how soil quality, water purification, and air quality affect and are affected by human life.

Integral Ecology seeks to protect both the environment and the well-being of society. This approach combines environmental sustainability and socio-economic issues.

Francis writes: "[t]he global economic crises have made painfully obvious the detrimental effects of disregarding our common destiny, which cannot exclude those who come after us."

Others such as Thomas Berry emphasize harmony between humans adn earth [44].

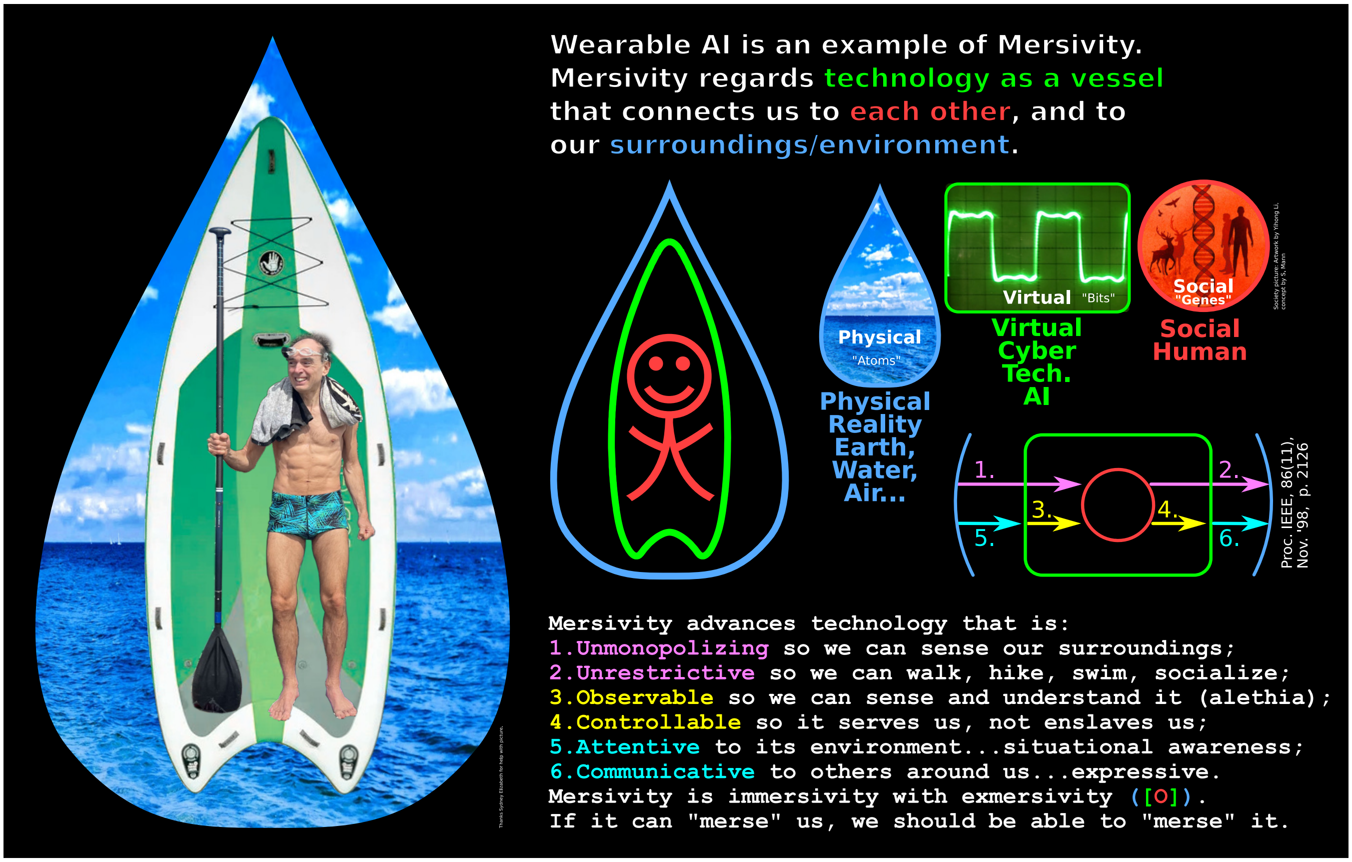

Figure 6: Technology as a generalized vessel that has a symmetry of connectivity (i.e. both immersive and exmersive). The resulting signal-flow symmetry to/from and through the technology gives us six signal flow paths and therefore six desirable properties for Mersivity.

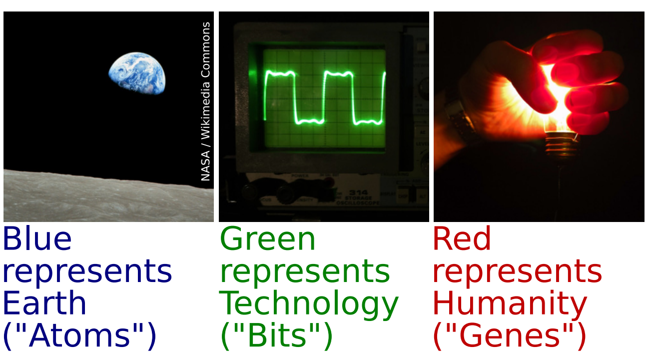

Figure 7: NASA Earthrise photo showing the blue planet Earth. Photograph of an oscilloscope showing the green trace, representing "Bits". Photograph of a human hand holding a white light bulb in the dark, showing the red glow through the blood under the flesh.

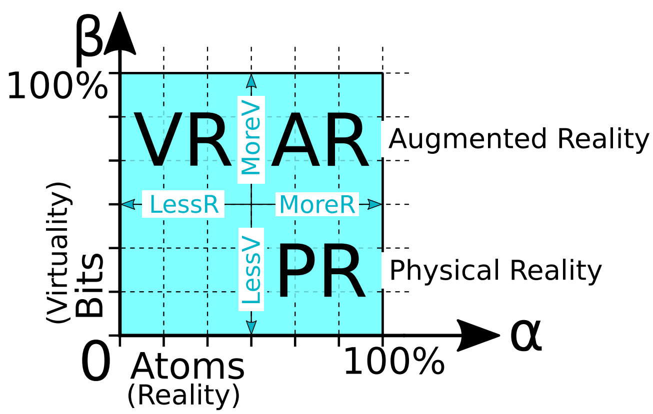

Figure 8: The Cyber-Physical (Atoms-Bits) Plane has Physical Reality (PR) on the Physicality ("Atoms") axis and Virtual Reality (VR) on the Virtuality ("Bits") axis. Here the plane is shown segmented into four quadrants.

5.4 Atoms, Bits, and Genes

The commonly used "Bits and Atoms" metaphor (e.g. MIT's Center for Bits and Atoms) is a simplification that takes quite a bit of poetic license (there exist sub-atomic particles, and also computation

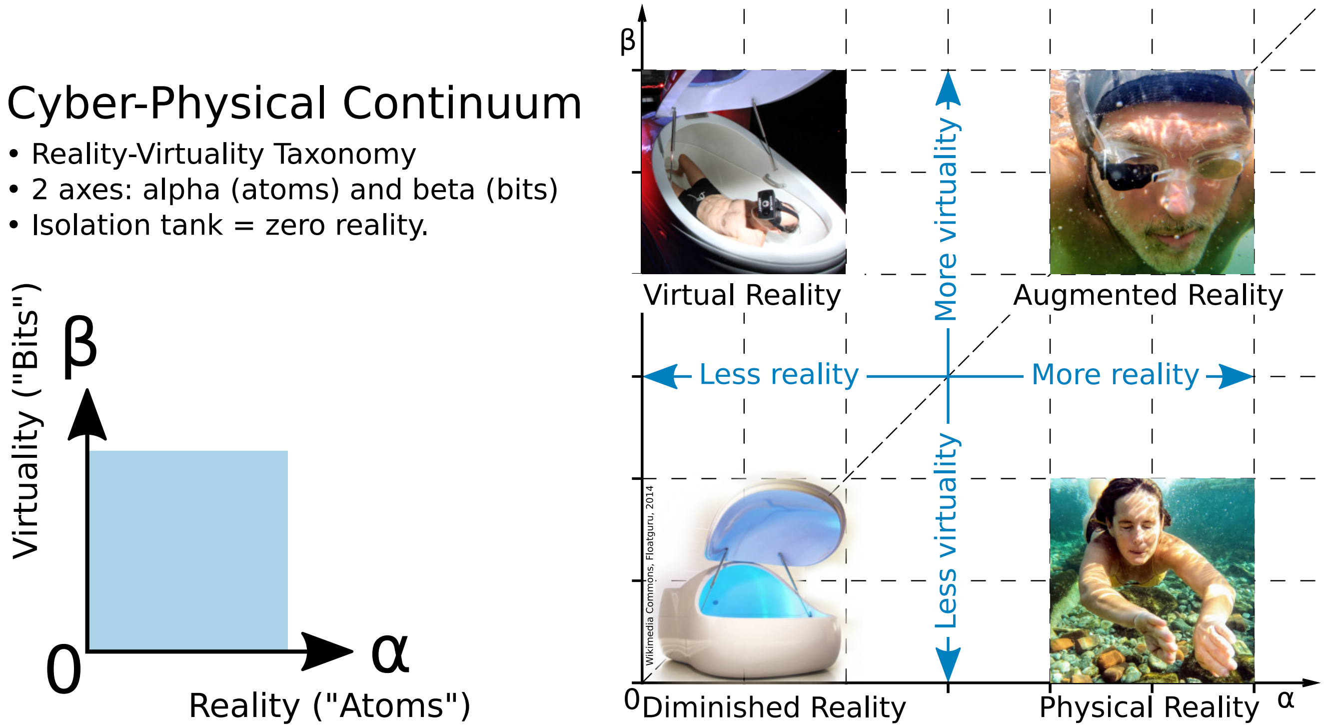

Figure 9: The Cyber-Physical Continuum with four examples: Icewater swimming gives a strong connection to physical reality (PR). A sensory-deprivation float tank diminishes stimulus from physical and virtual sources. A VR float tank cuts out the physical world so that the only stimulus is the virtual content. Icewater swimming with a Vuzix SmartSwim provides some physical and some virtual reality content.

cannot exist without physical hardware): "Bits" can't exist without "Atoms". Likewise, humans are also made of atoms, but we apply the same poetic license in considering Humanity/Sociality as a separate axis, giving us Atoms, Bits, and Genes. We call this space the Socio-Cyber-Physical Space, or simply XR-space.

XR-space is the space fully spanned by XR (eXtended Reality), which is the generalized reality that interpolates between the various Realities and eXtrapolates beyond them [8, 15, 19, 27, 40, 56], through technologies that deeply connect to both the physical and social worlds, with such concepts as Immersive XR (e.g. WaterHCI = Water-Human-Computer Interaction) [39, 49, 51].

6 XR

Summarizing Fig. 1. The XR Space is a taxonomy or ontology of the 'R's ("Realities"), the Metaverse, HCI, and the like. VR (Virtual Reality) exists entirely along the Virtuality axis. PR (Physical Reality), i.e. the real world, exists along the Reality axis. AR (Augmented Reality) exists in the Reality+Virtuality plane.

Technologies like ear plugs, dark sunglasses, welding helmets, baseball caps, etc., are examples of DR (Diminished Reality) which exists near the origin of the space (where the axes meet). Perhaps the best example of a technology at the origin of XRspace is the sensor deprivation "float tank" that provides us with zero stimulus.

HCI (Human-Computer Interaction) and the Metaverse (shared social VR) exist in the Cyber-Social (Sociality and Virtuality) plane.

XR (eXtended Reality) spans the entire Socio-Cyber-Physical space, interpolating between the various Realities and extrapolating beyond them. What is described here is a simplified version of much of the work outlined in a previous IEEE Special Issue [13].

7 XRscalespace

The XRspace of Fig. 1 as an organizational taxonomy considers the amount of Physicality, Virtuality, and Sociality, whereas we wish to also consider the scale, and thus introduce XRscalespace in which the three axes are the scale of Physicality, $s(\alpha)$, the scale of Virtuality, $s(\beta)$, and the scale of Sociality, $s(\gamma)$, as in [38] or reciprocal scale as in [27]. If we use logarithmic axes, XRscalespace divides the three-dimensional $s(\alpha), s(\beta), s(\gamma)$ space into 8 octants, as: small v. large physical scale (e.g. clothes versus car versus smart building, smart city, etc.); "little data" (distributed e.g. blockchain) v. "big data" (centralized), and sousveillance [3–5, 7, 9, 10, 14, 16, 17, 20, 23, 28, 32, 37, 43, 46, 50, 52, 53, 60–63] (sensing at small social scale as with personal technologies and self-recording) v. surveillance (sensing at large social scale). It has been observed that most technologies exist along the diagonal of this space, e.g. wearable technolgies (technologies at a small physical scale) tend to be distributed ("little data") and sousveillant, whereas city-scale technologies (e.g. technology at a large physical cale) tend to be centralized ("big data") and surveillant [27].

8 Future research directions

The Socio-Cyber-Physical Space/Taxonomy (the "Atoms-Bits-Genes" framework) lends itself to a family of taxonomies and ontologies that allow us to organize and understand a wide range of technologies and identify new underexplored areas of possible research, such as city-scale sousveillance, which exist in the "corners" and "edge-cases" of the taxonomy (e.g. off the main diagonal). Additionally, much needs to be done to explore areas close to the origin of the space, i.e. Diminished Reality (DR). For example, how can an AI-eyeglass help us simplify the world and help a visually impaired person find their way, or help someone suffering from excess stimulus (e.g. someone on the autism spectrum) get a simplified understanding of an otherwise overwhelming world.

Moreover, how can we combine sparse areas of the taxonomy space? For example, how might we extend our senses way out onto the extremes (like more than 100% of what we can normally sense) while at the same time diminishing other aspects of our senses to make "space" for the extra-senses. How might we use synthetic synesthesia to endow ourselves with additional senses that we can make space for through the power of Diminshed Reality (DR)?

Finally, how can we use all of this to advance technology for humanity and earth (+water + air), e.g. can we tame the monster of technology with a piece of itself, using DR to connect us to our natural world? Can we create a new reality in which we feel the pain of our actions upon the planet before we take these actions or at least before it is too late?

9 Conclusion

This paper highlights the importance of, and key features of, XR = eXtended Reality, as embodied by technologies like the AI-eyeglass.

XR exists within the Socio-Cyber-Physical Space (XR-Space) taxonomy/ontology, which leads us naturally to the concept of Mersivity and six desiderata for technology in service of people and planet. Technology should be:

(1) Unmonopolizing so we can continue to sense our surroundings;
(2) Unrestrictive so we can continue to affect our surroundings;
(3) Observable so we can sense and understand the technology;
(4) Controllable so it senses us in a way that serves us and our environment;
(5) Attentive to its environment, e.g. to help us understand our surroundings;
(6) Communicative to our surroundings. We are part of each others' environment, so in this way the technology serves as a form of communication that truly connects us to each other.

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