

# Embodied Information Behavior, Mixed Reality and Big Data

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## ABSTRACT

A renaissance in the development of virtual (VR), augmented (AR), and mixed reality (MR) technologies with a focus on consumer and industrial applications is underway. As data becomes ubiquitous in our lives, a need arises to revisit the role of our bodies, explicitly in relation to data or information. Our observation is that VR/AR/MR technology development is a vision of the future framed in terms of promissory narratives. These narratives develop alongside the underlying enabling technologies and create new use contexts for virtual experiences. It is a vision rooted in the combination of responsive, interactive, dynamic, sharable data streams, and augmentation of the physical senses for capabilities beyond those normally humanly possible. In parallel to the varied definitions of information and approaches to elucidating information behavior, a myriad of definitions and methods of measuring and understanding presence in virtual experiences exist. These and other ideas will be tested by designers, developers and technology adopters as the broader ecology of head-worn devices for virtual experiences evolves in order to reap the full potential and benefits of these emerging technologies.

**Keywords:** Embodiment, information behavior, presence, big data, virtual, augmented or mixed reality, head-worn display, HMD, promissory narrative.

## 1. MERGING DIGITAL DATA AND THE PHYSICAL WORLD: DATA-DRIVEN EXPERIENCES

A resurgence in the development of virtual (VR), augmented (AR), and mixed reality (MR) technologies with a focus on consumer and industrial applications is underway. Recent or upcoming releases of head-worn displays run the gamut from see-through monoscopic to 3D stereoscopic displays in form factors that include glasses, clip-ons, wrap-arounds, helmets, and smartphone holders. Devices promoted for consumer or industrial use include Oculus Rift Development Kit 2 [1], Samsung Gear VR Innovator Edition [2], Google Cardboard [3], Microsoft HoloLens [4], Daqri Smart Helmet [5], Razer OSVR [6], Google Glass [7] and both Sony's SmartEyeglass Attach [8] and Project Morpheus [9], plus emerging visions for virtual experiences such as the Magic Leap [10]. Along with many similar systems (e.g. Epson Moverio [11], Vuzix [12], VRVANA [13], Meta1 [14], Avegant [15], Sensics [16], FOVE [17], Sulon Cortex [18], etc.) these technologies form part of a computational ecology interconnected at multiple levels of scale: high performance distributed computing (cloud), workstation, laptop, or tablet/mobile computing and ubiquitous computing embedded in everyday objects and wearables. Combined with connectivity and access to data in the cloud, these 25 billion (and growing) myriad handheld devices, tools, wearables, and appliances are interconnected via the internet and capable of sending and receiving data from what is termed, the "Internet of Things" or "IoT" [19]. The result: a "Digital Universe" estimated to reach 44 trillion gigabytes by 2020, 10% of which is anticipated to come from the Internet of Things [20].

This complex ecosystem of interrelationships between (cloud) computing, connectivity, mobility and data reflects a persistent and ongoing digitization of nature and culture. Data streams woven into the fabric of our lives have far-reaching impact, and they exist along a continuum from massive heterogeneous cloud-based data stores subjected to algorithmic analyses to personal data streams (e.g. generated by health or fitness wearables and consumed by us daily in pre-formatted analytic doses via their accompanying mobile apps). The ways in which we characterize and reap the benefits of big data or small (e.g. personal data streams [21] or the Quantified Self movement - <http://quantifiedself.com>) is evolving in parallel with these trends. Our attention is shifting from sheer size and heterogeneity to considerations of our ability to access, search, aggregate, and cross-reference data across platforms [22]. The IoT is predicted to expand from 25 billion to an estimated 50 billion interconnected devices in 2020 [19] and

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encompass use scenarios in medicine, smart energy grids, home appliances, transportation, entertainment and beyond – a vision of the future in which material reality and digital data blend seamlessly.

As data becomes as ubiquitous in our lives as the architecture we exist within or the air we breathe, a need arises to revisit the role of our bodies, our physical embodiment and senses, explicitly in relation to data or information [23]. This need is readily apparent when we consider specific sensory or other physiological limitations. For instance, perceivers can experience color blindness, change blindness, or inattentional blindness – or we can simply be in the wrong position or height to perceive information readily available in our environment [24]. Immersion in 3D/4D data in order to obtain insights not possible with a 2D data display is a primary use of virtual reality in multiple application domains. Embodiment is fundamental to our experiences with data or information. In VR, embodiment pertains to our experience of our biological body as well as a potential sense of embodiment (SoE) within a virtual body [25]. Embodiment also plays a role in our definitions of presence [26] – a sense of ‘being there’ [27] is another key aspect of our experience within virtual environments (see [28], [29], [30], [31]).

Our observation is that today’s renaissance in consumer and industrial VR/MR technology is framed by a vision of the future in promissory narratives [32] that bring new considerations to the role of both embodiment and presence in virtual experiences. These narratives develop alongside the underlying enabling technologies and create new use contexts for virtual experiences, a vision rooted in the combination of responsive, interactive, dynamic, sharable data streams, augmentation of the physical senses for capabilities beyond those normally humanly possible (e.g. DAQRI Smart Helmet with rear-view cameras [5] that enable you to see what is in front of you and behind you simultaneously), and mobility via untethered head-worn devices connected to the internet (wirelessly or via smartphones).

## 2. A NEW LANDSCAPE OF VIRTUAL EXPERIENCES

To capture a “snapshot” of the fluctuating landscape of consumer VR/MR devices and the promissory space within which they are evolving, we reviewed (approximately) 40 recently released and upcoming head-worn device (HWD) technologies. Research into the “sociology of expectations has demonstrated how visions of the future, articulated in relation to novel technologies, are not ‘mere hype,’ but are fundamentally generative of technoscientific projects” [32, p.4]. The communication of expectation, a form of promissory communication, is designed by technology creators and the specialized community of analysts and other communications professionals interacting with a given technological domain to present a vision of the future that is stable and linear enough to encourage buy-in by investors and eventual technology adopters at multiple levels [32]. Expectations and promises are set high to “stimulate agenda-setting processes (both technical and political) and to build ‘protected spaces,’” environments that allow a combination of innovation and accountability [34] throughout the course of technological development.

Given that technological expectations have been demonstrated to influence the development of new artifacts and knowledge [34,35] we looked at these technologies and devices from the point of view of their vision of the future. Overall, the emerging landscape presents a vision for human interaction with data streams mediated by head-worn technology that seeks to create a seamless virtual experience blending both physical and virtual worlds. The ways in which this proposed blending is accomplished and the new use contexts it provides vary according to differences in devices and technologies, yet our review has yielded a set of shared characteristics.

From publicly accessible sources (e.g. websites, brochures, images, text and multimedia) we collected a set of features, specifications and descriptive information about the proposed use contexts and virtual experiences. We considered the uses and benefits of each technology, as presented to its intended audience, in relation to two layers of underlying enabling technologies [36]: those required to produce the devices directly (e.g. display type and resolution, field of view, latency, registration capabilities, position/orientation tracking etc.) and those which generate the proposed use contexts (e.g. mobility, computation, connectivity, access to and interaction with data, etc.). We then clustered devices by underlying technologies to enable us to focus our discussion on several representative device types. Table 1 summarizes the set of enabling technologies most commonly found among representative device types.

Table 1. Trends in enabling technologies: a sample of the information we collected for approximately 40 devices/technologies.

VE - Type	HWD - Type	Released	Status	Device	Display	Mobility	Connectivity	2D/3D	CPU	FOV	Tracking (t Camera)	Audio	Location Tracking
VR	HMD	2012: Launch / 2013: DK1 / 2014: DK2 Developer Model	In development	Oculus Rift	Wrap-around	Stationary	Computer	3D	Computer	Wide	Head/Posit	Y	Spatial no
	HMD	Announced: 2014 GDC	In development	Sony Morpheus	Wrap-around	Mobile	Wireless	3D	Integrated	Wide	H	Y	Stereo GPS-phone
	HMD	12/8/14	Consumer	Samsung Gear VR	Wrap-around/Phone	Mobile	Wireless	3D	Integrated	Wide	H	Y	Spatial GPS-phone
	HMD	Release Date: June 2015	Developer Model	Razer OSVR	Wrap-around	Stationary	Computer	3D	Computer	Wide	H	Y	User defin no
MR	HMD	Release Date: October 2015	Consumer	VR/ARNA Totem	Wrap-around	Stationary	Computer	3D	Computer	Wide	H	Y	Spatial no
	HMD	-	In development	FOVE	Wrap-around	-	-	3D	-	-	-	-	-
	HMD	-	-	Cardboard, DIY 3D print etc.)	Phone	-	-	3D	Integrated	-	-	-	-
	Glasses-based/Circular Band	Demo: February 2015	In development	Microsoft HoloLens	See-through	Mobile	Wireless	3D	Integrated	Wide	H	Y	?
AR	Glasses-based/Helmet	N/A	In development	Dagri SmartHelmet	See-through	Mobile	Wireless	3D	UNK	Wide	H	Y (F/B)	No Inertial
	HMD	Developer Kit: February 2015	In development	Sulon Cortex	Wrap-around / TBD	Mobile	-	-	-	-	-	-	-
	Glasses-based/HUD	Developer: February 2013	Dev/Canceled - Release UNK?	Google Glass	See-through	Mobile	Wireless	2D	Phone	Narrow	n	Y	Mono GPS-phone
	Glasses-based/HUD	In development	-	Athwer Labs	See-through	Mobile	Wireless	2D	Phone	Narrow	n	Y	Mono
Unknown	Clip-on/Glasses-Based/HUD	Announced: CES 2015	In development	Sony Eyeglasses Attach	See-through	Mobile	Wireless	2D	UNK	Narrow	n	Y	no
	Glasses-based or Clip-on/HUD	2014	Released - Enterprise	Vuzix M100 Smart Glasses	See-through	Mobile	Wireless	2D	H	H	H	Y	mono no
	Glasses-based/HUD	2014	Developer Model	Epson Moverio BT-200	See-through	Mobile	Wireless	3D	-	H	H	Y	Stereo GPS-phone
	HMD	N/A	In development	Meta1	See-through	Mobile	Wireless	3D	-	narrow	H	Y	Spatial
Unknown	N/A	Unknown	Released - status UNK	Microvision	Retinal Scanning	Mobile	N/A	-	-	-	-	-	-
Unknown	Unknown	Unknown	Unknown	Magic Leap	UNK	-	-	-	-	-	-	-	-

Categories of information we were able to obtain from publicly accessible sources include: virtual experience type (VR/AR/MR), form factor, mobility, CPU, tracking (position/orientation), field of view, display type and resolution, weight, sensors (accelerometer, gyroscope, magnetometer, camera, location), diatropic adjustment, and inter-pupillary distance (IPD) adjustment. The emergence of a new landscape of VR/MR/AR (collectively, virtual experiences (VE) is evident from the release dates. The majority of the devices/technologies have been released since 2012 as developer kits, SDKs (software development kits), and APIs (application programming interfaces), and/or early adopter/enthusiast models. Others have yet to be released even as developer models as of early 2015.

To elucidate the relationships between technology characteristics and proposed use contexts, in addition to this information we reviewed publicly accessible 2D images, multimedia content, and accompanying text for each device. In the two paragraphs below and in the subsequent figures 1 - 6 we present several examples of this image/multimedia content and accompanying text that frames the proposed use contexts. These are not all inclusive. They are selected to demonstrate the range of technologies and proposed use contexts and are organized along a continuum according to their release status, which we have classified as one of three categories: released (consumer, enterprise, industrial), developer model, or announced/in development. *Released (Consumer/enterprise/industrial)* indicates the device is available for retail purchase and use by consumers or enterprise/industry. *Developer model* indicates the device is available for purchase as a developer kit/SDK for advanced users such as developers or enthusiasts. *Announced/in development* indicates the device has been announced, and the publicly accessible information indicates it is in development.

For example, a head worn device recently released for consumer use is the Samsung Gear VR Innovator Edition [2]. Along with a single image of the head worn display that holds a Samsung Galaxy Note 4, the text on the Design section [37] of the product website reads: “Beyond Imagination,” followed by “Immersive experience anywhere, anytime just for me.” The second page scroll down from the top view of the Features section [37] of the same site shows a drawing of a user immersed in the viewing experience. The image of the user viewing multiple media sources on a curved virtual screen is accompanied by the information that the HWD has a 96-degree field of view and the heading “Ultimate fascinating viewing experience.” The accompanying paragraph includes the wording “...lets you feel the world beyond your peripheral vision.” The Gear VR Innovator Edition proposes multiple use contexts for mobile virtual reality HMDs.

Within this type of virtual experience in which mobility plays a key role, the Sulon Cortex [18] is an example of a head-worn display (HWD) that is in development. Highlighting its mobility and integration with computation, the technology is presented as a “spatially aware computing platform” that will “transform the world,” “unleash your imagination,” and “revolutionize the way we live our lives” [18]. The head-worn device is described as containing sensors and scanners that enable it to integrate the physical environment around the user within the context of the virtual environment. For example, the proposed use contexts for the Sulon Cortex include the potential to capture spatial data from the physical environment and render this information in real-time, spatially co-registered within the virtual environment the user is experiencing dynamically.

The figures below present additional examples of HWD technologies along the continuum of release stages.

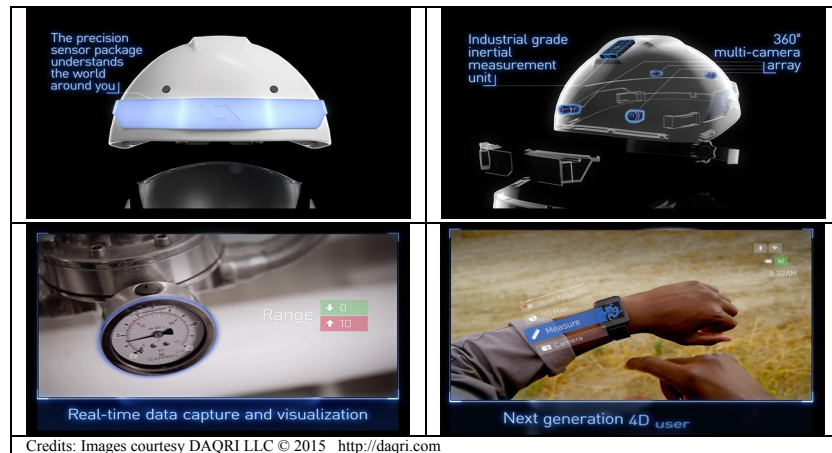


Figure 1: Released (Industrial): DAQRI 4D Studio and DAQRI Smart Helmet

**Description:** The DAQRI Smart Helmet is an AR helmet that uses forward- and backward-facing cameras, an industrial grade inertial movement sensor, and a see-through, glasses-based display, enabling information to be overlaid on pertinent artifacts in the environment. **Use contexts:** industrial/workplace (helmet); 4D SDK (enterprise, educational) **Quotes:** “*Make the world your screen.*” “*Precision sensor package understands the world around you.*” “*Next generation: 4D User*” “*Real-time data...*” “*Seamlessly integrate into any workflow.*”



Figure 2: Released (Enterprise): Vuzix | View the Future

**Description:** The Vuzix M100 is an AR device that allows the display of digital information on a monocular see-through display and communication through a forward facing camera and built-in microphone and headphone. **Use contexts:** Virtual glass flight cockpit, HUD pilot display, healthcare, industrial, field-work, customer service. **Quotes:** “*...serve up the digital world “hands free,” offering unprecedented access to information, data collection and more.*” “*Real-time team communications and patient data access.*” “*Real-time diagnostics for remote operations.*”



Figure 3: Developer Model: Oculus Rift Development Kit 2

**Description:** The Oculus Rift DK2 is an immersive VR HMD that sends data about head position (using a built-in accelerometer, gyroscope, and magnetometer) and orientation (using the combination of built-in IR LEDs and an externally mounted IR camera) to an external device for computational processing, which then translates and updates the visual information on the display. **Use contexts:** entertainment, gaming, education, industrial/workplace. **Quotes:** “Next Generation Virtual Reality” “I’m comfortable in this environment, I know it’s not real, but I think it is.” “Take the experience to a whole other level.” “Something everyone thought couldn’t exist.”

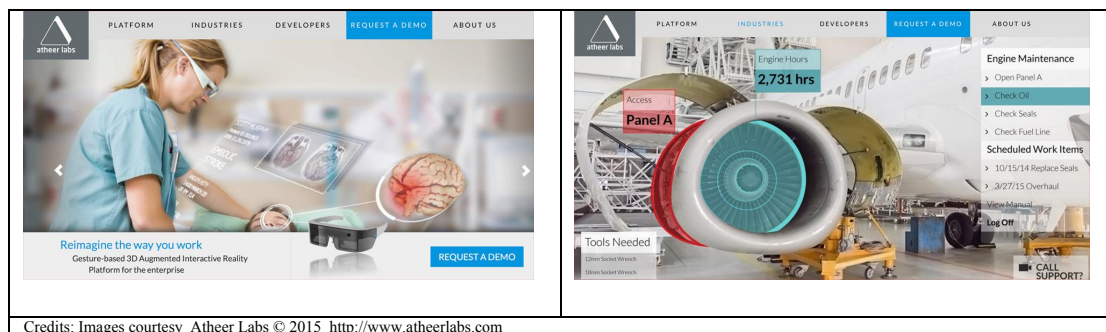


Figure 4: Developer model: Atheer Labs Air DK2 and Air OS

**Description:** The Atheer Labs DK2 proposes a contextually aware 3D augmented reality experience with gesture-based interaction with the digital information displayed. **Use contexts:** Enterprise/industrial (Field services, healthcare, oil and gas, and warehousing markets). **Quotes:** “Atheer Labs, Air™ DK2 and AirOS, Augmented interactive Reality (AiR™), presents stereoscopic digital content overlaid on physical environments combined with gesture based interaction,” “...a future where the physical and the digital converge to create a better, safer and more open world.” “Contextualized 3D Augmented Reality. Displaying the right information at the right place and at the right time ... unmatched rich, contextual, and actionable data on the go.” “... empowers workers to interact with the digital world with the same ease as they do in the physical world....”

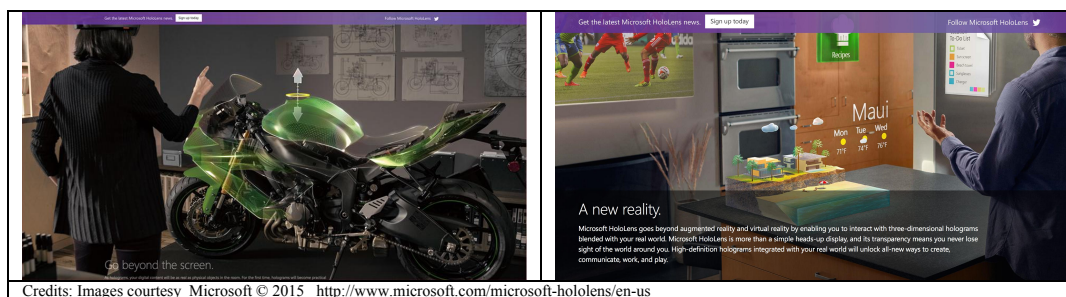


Figure 5: Announced/In Development: Microsoft Hololens

**Description:** The Microsoft Hololens is an MR device that includes gestural control, spatial sound, and voice input using built-in processors and a see-through display that enables the display of and interaction with spatially aware 2D and 3D content in the environment. **Use contexts:** Work, leisure, education, entertainment. **Quotes:** “A new reality.” “...interact with 3D holograms blended with your real world...unlock all-new ways to create, communicate, work and play.” “Our digital lives seamlessly connect with real life.” “You’re at the center of a world that blends digital with reality.” “Your digital content and creations become more relevant when they come to life in the world around you.” “Go Beyond the Screen.” “As holograms, your digital content will be as real as physical objects in the room. For the first time, holograms will become practical tools of daily life.”





Figure 6: Announced/In Development: Magic Leap

**Description:** The Magic Leap is either a VR, MR, or AR technology. Information regarding its specifications, form factors or underlying technologies has not been released as of early 2015. **Use contexts:** To be determined - possibly entertainment, gaming, education, industrial, workplace. **Quotes:** “It’s time to bring magic back into the world.” “The human brain is still the best display ever made.”

Within each of the examples above, the text and images convey use contexts and future visions for individual HWD technologies. We now explore the possibilities for a collective set of use contexts and future visions through removing text from its original context and placing the text content in a combined list view. What emerges (table 2 below) is a common promissory space of communication about use contexts and future visions for interactions among material reality and digital data, irrespective of HWD device type or technology. Table 2 contains the text quotes from each of the technologies described in Figures 1 - 6 above.

Table 2. An emergent communication space: resonance among proposed use contexts.

“Beyond Imagination” [37]
“Immersive experience anywhere, anytime just for me.” [37]
“Ultimate fascinating viewing experience.” [37]
“...Lets you feel the world beyond your peripheral vision.” [37]
“Spatially aware computing platform.” [18]
“Transform the world,” [18]
“Unleash your imagination.” [18]
“Revolutionize the way we live our lives.” [18]
“Make the world your screen.” [Fig.1]
“Precisions sensor package understands the world around you.” [Fig.1]
“Next generation: 4D User” [Fig.1]
“Real-time data...” [Fig.1]
“Seamlessly integrate into any workflow” [Fig.1]
“...serve up the digital world ‘hands free,’ offering unprecedented access to information, data collection and more.” [Fig.2]
“Real-time team communications and patient data access” [Fig.2]
“Real-time diagnostics for remote operations” [Fig.2]
“Next Generation Virtual Reality” [Fig.3]
“...a future where the physical and the digital converge to create a better, safer and more open world.” [Fig.4]
“ Contextualized 3D Augmented Reality. Displaying the right information at the right place and at the right time gives your mobile workforce unmatched rich, contextual, and actionable data on the go.” [Fig.4]
“...empowers workers to interact with the digital world with the same ease as they do in the physical world, by putting natural, gesture-based interaction at the center of the computing experience.” [Fig.4]
“A new reality.” [Fig.5]
“...interact with 3D holograms blended with your real world.“...unlock all-new ways to create, communicate, work and play.” [Fig.5]

“Our digital lives seamlessly connect with real life.” [Fig.5]  
 “You’re at the center of a world that blends digital with reality.” [Fig.5]  
 “Your digital content and creations become more relevant when they come to life in the world around you.” [Fig.5]  
 “Go Beyond the Screen” [Fig.5]  
 “As holograms, your digital content will be as real as physical objects in the room. For the first time, holograms will become practical tools of daily life.” [Fig.5]  
 “It’s time to bring magic back into the world.” [Fig.6]  
 “The human brain is still the best display ever made.<sup>TM</sup>” [Fig.6]

The juxtaposition of virtual experiences, enabling technologies, proposed use contexts and text and image information reveals resonance among the multiple technologies. This yields a promissory space that communicates a shared expectation of VR/MR as having the potential to transform everyday activities for how we work, live and play through data-driven experiences. It envisions transformation of human potential via the interactions between two sets of enabling technologies - those that make up the devices themselves, and those that make up the emerging Internet of Things, its computational and telecommunications backbone, and access to data in a variety of forms.

While our work represents only an initial foray into elucidating promissory narratives as constellated in the current VR/MR technological landscape, several common threads emerge. We observe that the proposed seamless interaction of material reality and digital data envisions: 1) *immersion on-demand (ubiquity)*, 2) *immersion on-the-go (mobility)*, 3) *sensorial augmentation beyond that which is humanly possible (multi-scale, real-time feedback between sensors, input and data-driven content)*, and 4) *hybrid virtual experiences consisting of ‘being there’ and ‘being here.’* While not all technologies exhibit these characteristics equally, many of them envision a dualistic, hybrid experience in which the seamless merger of digital/virtual and material realities simultaneously transport a user to ‘being there’ in a virtual context while at the same time ‘being here’ in a manner that is congruent with their physical reality/environment. While the notion of ubiquitous and mobile virtual reality is not new, now that both layers of enabling technology are maturing such that ubiquity is part of the promissory narrative of these technologies, our inquiry turns to not *if* or *when* but rather *what does the potential for ‘being there’ while ‘being here’ mean with regard to information behavior and presence in virtual experiences?*

### 3. BEING THERE AND BEING HERE: INFORMATION, EMBODIMENT, AND PRESENCE

Multiple definitions of information exist, each with different utility. Distinct from quantitative definitions (a legacy of Shannon’s mathematical theory of communication [61,62] and Weiner’s cybernetics [63]), a broad definition relevant to the promissory communication space of data-driven virtual experiences is that offered by Marcia Bates in which information is considered as “all instances where people interact with their environment in any such way that leaves some impression on them—that is, adds or changes their knowledge store” [38]. Similarly, in prior work by one of the authors of this paper, information is considered as “a matter of perception that requires a human subject for the information to be perceived [23].” These definitions consider information as existing in the context of our cognitive and perceptual systems and processes and emerging through interaction with our environment.

The body itself is widely regarded as shaping and mediating thought processes [39 - 46] and in turn, our physical interactions with the environment are seen as providing a basis for cognitive processes (e.g. as in the symbolic off-loading of tasks onto our environment [47]. Lueg’s model [23] for grounding information in human perception, and developing concepts for embodied information behavior, consists of four layers: “1) information ‘perceived’ but not actually ‘sensed’ (e.g. illusions, false memories); 2) information consciously perceived (‘information to work with’); 3) information ‘sensed but not perceived’ (e.g. inattention blindness); and 4) information not ‘sensed’ (because of impaired vision, body orientation, etc.)” These are subsequently bounded by the contexts of “Information humans are not able to ‘sense’” and “information subconsciously perceived” [23]. As discussed by Lueg [23], a wealth of information behavior research exists regarding use of information sources during information seeking, as well as situational factors that influence information behavior, yet understanding regarding the failure to notice relevant information, which is to be expected, is sparse. Given the importance of perception to our engagement with the real-world, Lueg presents a call to action to develop methods to characterize how what we perceive will change in response to our physical movement and orientation, and emphasizes a need to identify not only what information we can detect/report that we do perceive, but

specifically that which we fail to perceive and which we cannot readily articulate that we have missed. Yet perception and embodiment are not the sole determinants of information behavior. Psychological factors such as “anxiety, desire, leisure, pleasure, boredom, frustration, uncertainty, curiosity, serendipity, surprise, anticipation, immersion, sense-making or cognition, habits, and memory, among others” [48] also influence information behavior. Contextualized within this complex and evolving understanding of human information behavior, the promissory narratives for ubiquitous data-driven experiences facilitated by mobile head-worn VR/MR technologies lead to several interconnected questions: *How does embodiment function in relation to information in the above proposed use contexts where the base environment is physical and digital objects are not only overlaid upon physical artifacts with increasingly accurate spatial registration, but in which the interaction itself becomes a dualistic physical-digital hybrid? How will embodiment be affected by sensorial augmentation beyond what is humanly possible? Is information behavior in these proposed use contexts the same as it is currently in physical environments?*

In parallel to the varied definitions of information and approaches to elucidating information behavior, a myriad of definitions and methods for measuring and understanding presence in virtual experiences exist. Perception, cognition and emotion come together in establishing our sense of presence in virtual experiences [49]. Holistic definitions include: Rheingold’s “out-of-the-body experience” [50]; Steuer’s sense of being in a mediated environment rather than the immediate physical environment [51]; Slater’s extent to which a virtual experience becomes the dominant reality [56]; Biocca & Delaney’s “degree to which a virtual environment submerges the perceptual system of the user” [52]; McLellan’s feeling of being in a location other than where you actually are [53]; Lombard and Ditton’s perceptual illusion of non-mediation [30]; Witmer and Singer’s sense of “being there” [27]; Riva and Waterworth’s cognitive neuroscience approach to proto/core/extended presence related to perception-action, selective attention on perception and verification of significance (respectively)[55]; Lee’s psychological state of “virtuality of experience goes unnoticed” [31]; Waterworth & Waterworth’s psychological focus on perceptual processing [29]; Kiltner, Groten & Slater’s sense of embodiment, sense of self-location, agency and body ownership [25]; and Benyon’s presence in blended spaces [60].

Along with these definitions are measurement techniques that span over 50 subjective measures (questionnaires, continuous assessment, qualitative measures, psychophysical measures, subjective corroborative measures) and more than 15 objective corroborative measures (psychophysiological measures, neural correlates, behavioral measures, and task performance measures [57]. Here again promissory narratives for ubiquitous data-driven experiences facilitated by mobile head-worn VR/MR technologies lead to additional interconnected questions: *How will the definition and measures of psychological presence change in use contexts that are designed to foster dualistic experiences of ‘being there’ and ‘being here?’ How will this dualistic experience affect our information behaviors in virtual experiences?* This is particularly interesting in light of the fact that virtual environments tend to be designed (artificial) whereas the real world isn’t. Rather the real world is “constantly changing, intrinsically unpredictable and infinitely rich” which means that we have evolved to perceptually and cognitively manage these inherent characteristics of real-world settings [58].

#### 4. FUTURE DIRECTIONS: EMBODIMENT & ENGAGING MULTIPLE VIEWPOINTS

From this initial review, our observation is that these proposed hybrid virtual experiences of ‘being there’ and ‘being here’ motivate a need for research to validate and/or extend our understanding of both embodiment in relation to information behavior and in relation to our sense of presence in virtual/mixed reality. *What would we need to do to begin to answer this and the prior questions, and the many more that will arise, as virtual experiences shift from hand-held screen-based devices (smartphones/tablets etc.) to head-worn devices encompassing the majority of our senses and integrated as part of our daily lives?*

Recent work by Tönnis, Plecher and Klinker [59] provides a classification for representations of information in augmented reality, and work by David Benyon [60] establishes the concept of blended spaces, presence in these spaces, and design of user experiences for them as well. The five-dimensional classification schema established by Tönnis, et al. includes: “Temporality: continuous versus discrete representation of virtual objects; Dimensionality: the number of features (dimensions) that virtual and physical objects possess as well as methods to visualize and render them; Viewpoint reference frame: ego-centric versus exo-centric and ego-motion-based control of viewpoints; Mounting/registration: spatial relationships between objects; Type of reference: concepts regarding the visibility of referred-to physical objects” [59, p.997]. Benyon’s definition of blended spaces incorporates work in blended theory to develop user experiences within blended digital-physical spaces [60]. This ties back to both the trajectory of linking information behavior to embodiment and cognition, and work in how the body shapes mind and thought. “Blending theory (BT), or conceptual integration, is a theory of cognition that builds upon and further develops the idea that we



think and reason through a complex network of mental spaces (domains) and conceptual projections from one domain to another. Most importantly BT ties in with the ideas of metaphor, which is a “mapping from one domain to another and hence to the ideas of Lakoff and Johnson (1980) and Lakoff and Johnson (1999) and their philosophy of ‘experientialism’ or cognitive semantics” [60, p.222]. Benyon advocates design with awareness on the ontology, topology, volatility and agents of both physical and digital/virtual spaces to create correspondences and adequate transitions to/from physical/virtual content [60]. From this he goes on to discuss effects on presence in blended virtual experiences. He defines presence as “the experience, that [designers] are trying to create for people” [60 p. 223] and envisions a sense of presence that is multidimensional and distributed and a world that “allows us to engage with those ideas physically through our bodies” [60 p. 224]. The work by Benyon and Tönnis et al. represents the diversity of viewpoints and the kinds of explorations required to achieve the visions of the future proposed throughout the emerging landscape of data-driven virtual experiences. These and other ideas will be tested, by designers, developers, technology adopters and the marketplace, as the broader ecology of head-worn devices for virtual experiences evolves. While only two of many possibilities, they highlight the value of engaging a broad community in addressing these questions and raising their own viewpoints in order to reap the full potential and benefits of these emerging technologies.

## REFERENCES

- [1] Oculus Rift Development Kit 2 : <https://www.oculus.com/dk2/> (Last accessed: 6 February 2015)
- [2] Samsung Gear VR Innovator Edition: <http://www.samsung.com/global/microsite/gearvr/index.html> (Last accessed: 6 February 2015)
- [3] Google Cardboard: <https://www.google.com/get/cardboard/>
- [4] Microsoft Hololens: <http://www.microsoft.com/microsoft-hololens/en-us> (Last accessed: 6 February 2015)
- [5] Daqri Smart Helmet: <http://hardware.daqri.com/smarthelmet> (Last accessed: 6 February 2015)
- [6] Razer OSVR: <http://www.razerzone.com/osvr> (Last accessed: 6 February 2015)
- [7] Google Glass: <http://www.google.com/glass/start/> (Last accessed: 6 February 2015)
- [8] Sony Smarteyeglass Attach: <http://www.sony.net/SonyInfo/News/Press/201412/14-118E/> (Last accessed: 6 February 2015)
- [9] Project Morpheus: <http://www.sony.com/SCA/company-news/press-releases/sony-computer-entertainment-america-inc/2014/sony-computer-entertainment-announces-project-morp.shtml> (Last accessed: 6 February 2015)
- [10] Magic Leap: <http://www.magicleap.com/> (Last accessed: 6 February 2015)
- [11] Epson Moverio: <http://www.epson.com/cgi-bin/Store/jsp/Product.do?sku=V11H560020> (Last accessed: 6 February 2015)
- [12] Vuzix: [http://www.vuzix.com/consumer/products\\_m100/](http://www.vuzix.com/consumer/products_m100/) (Last accessed: 6 February 2015)
- [13] VRVANA: <http://www.vrvana.com/> (Last accessed: 6 February 2015)
- [14] Meta1: <https://www.getameta.com/products> (Last accessed: 6 February 2015)
- [15] Avegant: <http://avegant.com/> (Last accessed: 6 February 2015)
- [16] Sensics: <http://sensics.com/> (Last accessed: 6 February 2015)
- [17] FOVE: <http://fove-inc.com/#topcontent> (Last accessed: 6 February 2015)
- [18] Sulon Cortex: <http://sulontechnologies.com> (Last accessed: 6 February 2015)
- [19] US Federal Trade Commission Report: “Internet of Things: Privacy and Security in a connected world” (2015). <http://www.ftc.gov/system/files/documents/reports/federal-trade-commission-staff-report-november-2013-workshop-entitled-internet-things-privacy/150127iotrpt.pdf> (Last accessed: 6 February 2015)
- [20] IDC Report: EMC Digital Universe (2014). <http://www.emc.com/leadership/digital-universe/index.htm> (Last accessed: 6 February 2015)
- [21] Estrin, D., “Small data, where n = me,” *Commun. ACM* 57(4), 32–34 (2014).
- [22] danah boyd & Kate Crawford, “Critical questions for big data,” *Information, Communication & Society*, 15(5), 662-679 (2012).

- [23] danah boyd & Kate Crawford, "Critical questions for big data," *Information, Communication & Society*, 15(5), 662-679 (2012).
- [24] Lueg, C. (In Press). "The Missing Link: Information behavior research and its estranged relationship with embodiment." *Journal of the Association for Information Science and Technology*, Wiley, to appear.
- [25] Kiltner, K., Groten, R. and Slater, M., "The sense of embodiment in virtual reality," *Presence Teleoperators Virtual Environ.* 21(4), 373–387 (2012).
- [26] Biocca, F. "The cyborg's dilemma: Embodiment in virtual environments." Presented at the 2nd International Conference on Cognitive Technology, (1997).
- [27] Witmer, B. G. and Singer, M. J., "Measuring presence in virtual environments: A presence questionnaire," *Presence Teleoperators. Virtual Environ.* 7, 225–240 (1998).
- [28] Riva, G., "From technology to communication: Psycho-social issues in developing virtual environments," *Journal of Visual Languages and Computing*, 10, 87-97 (1999).
- [29] Waterworth, E. L. and Waterworth, J. A., "Focus, locus, and sensus: The three dimensions of virtual experience.," *Cyberpsychol. Behav.* 4(2), 203–213 (2001).
- [30] Lombard, M. and Ditton, T. "At the heart of it all: The concept of presence." *Journal of Computer-Mediated Communication* 3(2), (1997).
- [31] Lee, K.M. "Presence, explicated," *Communication Theory* 14(1), 27-50 (2004).
- [32] Morrison, M. and Cornips, L., "Exploring the role of dedicated online biotechnology news providers in the innovation economy," *Sci. Technol. Human Values* 37, 262–285 (2012).
- [33] Geels, F. W., and W. A. Smit. "Failed technology futures: Pitfalls and lessons from a historical survey." *Futures* 32, 867–85 (2000).
- [34] Pollock, N. and Williams, R., "The business of expectations: How promissory organisations shape technology & innovation," 40(4), 525-548, (2010).
- [35] Carroll, J. M., Kellogg, W. A. and Rosson, M.B., "The Task-Artifact Cycle" In: Carroll, John M. (ed.). [Designing Interaction: Psychology at the Human-Computer Interface]. Cambridge, UK: Cambridge University Press (1991).
- [36] Azuma, R., Baillet, Y., Behringer, R., Feiner, S., Julier, S., and MacIntyre, B., "Recent advances in augmented reality," *IEEE Comput. Graph. Appl.* 21 (December) (2001).
- [37] Gear VR:  
[http://www.samsung.com/global/microsite/gearvr/gearvr\\_design.html](http://www.samsung.com/global/microsite/gearvr/gearvr_design.html),  
[http://www.samsung.com/global/microsite/gearvr/gearvr\\_features.html](http://www.samsung.com/global/microsite/gearvr/gearvr_features.html) (Last accessed: 6 February 2015)
- [38] Bates, Marcia J., "Information Behavior" In *Encyclopedia of Library and Information Sciences*, 3rd Ed. Marcia J. Bates and Mary Niles Maack, Eds. New York: CRC Press, vol. 3, pp. 2381-2391(2010).
- [39] Clark, A., [Being There: Putting Brain, Body and World Together Again], MIT Press, Cambridge, MA (1997).
- [40] Clark, A., [Supersizing the Mind], Oxford University Press, Oxford (2008).
- [41] Clark, A. and D. Chalmers, "The Extended Mind." *Analysis*, 58(1), 10-23 (1998).
- [42] Varela, F. J., Thompson, E., and Rosch, E., [The Embodied Mind: Cognitive Science and Human Experience], MIT Press, Cambridge MA (1991).
- [43] Hendriks-Jansen, H., [Catching Ourselves in the Act: Situated Activity, Interactive Emergence, Evolution, and Human Thought], MIT Press, Cambridge MA (1996).
- [44] Johnson, M., [The Body in the Mind], University of Chicago Press, Chicago (1987).
- [45] Lakoff, G. and Johnson, M., [Philosophy In The Flesh: the Embodied Mind and its Challenge to Western Thought], Basic Books (1999).
- [46] Damasio, A., [The Feeling of What Happens: Body and Emotion in the Making of Consciousness], Houghton Mifflin Harcourt, New York (1999).
- [47] Wilson, M., "Six views of embodied cognition." *Psychonomic Bulletin and Review*, 9, 625-636 (2004).
- [48] Keilty, P. Embodiment and desire in browsing online pornography. *Proc. i-Conference*, Toronto, Canada, 41–47 (2012).

- [49] Ijsselstein, W., and Riva, G., "Being there: The experience of presence in mediated environments," *Being There Concepts, Eff. Meas. user presence Synth. Environ.*, 14 (2003).
- [50] Rheingold, H., [Virtual Reality], Simon & Schuster, New York (1991).
- [51] J. Steuer, "Defining virtual reality: Dimensions determining telepresence," *J. Commun.* 42, 73–93 (1992).
- [52] Biocca, F. and Delaney, B., "Immersive Virtual Reality Technology," Chap. 4 in [Communication in the Age of Virtual Reality], F. Biocca and M. R. Levy, Eds., 57-124, Routledge, Hillsdale, NJ (1995).
- [53] McLellan, H. "Virtual Realities" in [Handbook of Research for Educational Communications and Technology], J. M. Spector, M. D. Merrill, J. Merrienboer, and M. P. Driscoll, Eds., pp. 461-498, Routledge, Hillsdale, NJ (1996).
- [54] Witmer, B. G., Singer, M. J., "Measuring Presence in Virtual Environments: A Presence Questionnaire," *Presence Teleoperators Virtual Environ.* 7, 225–240 (1998).
- [55] Riva, G. and Waterworth, J., "Presence and the self: a cognitive neuroscience approach," *Presence Connect* 3, 1–14 (2003).
- [56] Slater, M., Usoh, M., "Representations Systems , Perceptual Position and Presence in Immersive Virtual Environments" (1992).
- [57] van Baren, J. and Ijsselstein, W., "Deliverable 5 Measuring Presence : A guide to current measurement approaches," *Measurement*, 0, (2004).
- [58] Lueg, C. and Pfeifer, R., "Cognition, Situatedness, and Situated Design." *Proc Second International Conference on Cognitive Technology*, 25–28 August 1997, Aizu, Japan, 124–135. IEEE. (1997).
- [59] Tönnis, M., Plecher, D. A., and Klinker, G., "Representing information – Classifying the Augmented Reality presentation space," *Comput. Graph.* 37(8), 997–1011 (2013).
- [60] Benyon, D., "Presence in blended spaces," *Interacting with Computers*, 24, 219-226 (2012).
- [61] Shannon, C.E. A mathematical theory of communication. *Bell System Technical Journal* 27(3), 379-423 (1948).
- [62] Shannon, C.E. and Weaver, W. *The Mathematical Theory of Communication*; University of Illinois Press: Urbana, IL, (1975).
- [63] Wiener, N. *Cybernetics: Or Control and Communication in the Animal and the Machine*, 2nd Ed.: MIT Press: Cambridge, MA, (1961).