Definition, Background and Research Perspectives Behind 'Cognitive Aspects of Virtual Reality' (cVR)

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Abstract—**In this paper, a definition outlining the scope and goals of the field of Cognitive Aspects of Virtual Reality (cVR) is provided. Leading up to and alongside the definition, the paper includes a discussion on the background behind cVR – with a special focus on new human-AI capablities driven by cognitive, psychological, social and technological factors. Finally, the paper provides an outline of related research fields that can act as synergies in relation to cVR, while at the same time formulates questions and hypotheses that may drive future research in cVR.**

Index Terms—**virtual reality; mixed reality, augmented reality, cognitive infocommunications; metaverse, cognitive aspects of virtual reality**

I. Introduction

Technological development in the past decade has led to the emergence of a variety of new applications in computer graphics that increasingly merge physical reality with the digital realm in the context of interactive 3D spaces. Such applications are often referred to as virtual reality (VR), augmented reality (AR), mixed reality (MR) or – in an overarching sense – as extended reality (XR) applications. In this paper, we often use 'virtual reality' (VR) as a general term for all of the above, for reasons explained in [1].

In a VR application, the user's digital environment is often considerably enhanced and may also be augmented with digital representations of users (avatars), objects, events and processes (digital twins and simulations). Recently, with increased interest in the "*Web 3.0*" concept, a new kind of *Metaverse* is also envisaged which can naturally complement VR frameworks to create seamless interactions between the physical and digital world in a way that is not only spatial but also de-centralized and can also have strong social implications [2]. As the border between real and virtual becomes increasingly fuzzy, and as platforms emerge that are perhaps more de-centralized / participatory, a new level of human-ICT collaboration will become possible which of course integrates the existing digital 2D world, but also supersedes it in important ways. All of this in turn extends the capabilities of humans and ICT for further co-evolution.

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Even without Web 3.0 and the Metaverse, VR technologies are in and of themselves drivers of key changes in human-ICT co-evolution. Big Tech companies like Apple, Google, Microsoft, Facebook, Samsung and others have invested large amounts into these technologies, as a result of which VR has become a 12 Bn USD industry in 2020, a number that is projected to grow to over 72 Bn USD by 2024 [3]. There are in fact compelling reasons behind this growth. In much the same way that character-based user interfaces (e.g. MS DOS) were superseded in the late 1980s - early 1990s by graphical user interfaces (e.g. Lisa, developed by Apple in 1983, and later the Windows and Mac OS platforms), so too can it be expected that spatial content will become increasingly more prevalent and eventually supersede (but nevertheless integrate) 2D layouts. In parallel, as the relative benefits in terms of user effectiveness became clear following the transition from character-based to 2D GUI-based interactions, it can be expected that even greater relative benefits will be identified as a result the transition from 2D to 3D, as highlighted by a number of studies in recent years [4]–[7].

Although the pioneers of VR immediately recognized the technology as a foundation for a new infocommunications platform [8], it is still often considered as primarily being suited to applications in gaming and entertainment, and in the professional domains to simulation and training. During the past decade, we have seen gradual changes in this regard as well, as VR has become poised to enter the areas of basic and higher education [9]–[11], healthcare [12]–[15], engineering and many other professional industries [16]–[20]. With further increased support by AI methods, VR now emerges as a platform in which human capabilities are not only extended but also qualitatively augmented. In parallel, developments in miniaturized sensor and actuator technologies are leading to a further merging between VR and the digital twin concept, as well as more generally with portable and location-aware informatics devices. Humans, AI and digital twins, then, are emerging as a new 'cognitive triad' (see later) in VR; and as a platform that can integrate all of these trends, VR is changing the way in which information is accessed and understood by humans, leading to an increase in the effectiveness, productivity and safety of digital processes and knowledge transfer.

The field of "***Cognitive Aspects of VR***" is strongly motivated by a holistic perspective on "reality plus capability"

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technologies which can be expected to take the cognitive triad to the next level of the "spatial cognitive cloud". The increased data hunger of VR systems, the ability to process and interpret large amounts of data via AI solutions, the need to be able to monitor and control physical processes as well as the need for effective mitigation of information overload on the human side all point to this transition, which in turn can be expected to have an effect on human pyschological, social and economic structures.

II. Virtual Reality from a CogInfoCom Perspective

In this section, the background and possible future of VR is considered from the perspective of cognitive infocommunications – a nascent scientific field that focuses on synergies between modern infocommunications (which is itself a result of a convergence process between media, communications and informatics) and the cognitive sciences [21], [22].

A. VR as an infocommunications system

One key aspect of VR is that it expands both spatial and temporal perspectives, as well as enhances the way in which humans share, understand and organize information.

1) Spatial and temporal perspective: From this perspective, the role of VR as a radically new medium of communication that transcends space and time has been acknowledged for a long time. According to Jaron Lanier, who is widely credited for coining the term 'virtual reality', VR is especially unique in that it can lead to a way of thinking that supersedes even the conceptual level [8], given that an object represented in such a framework has the capacity to become an object in and of itself, rather than a representation of something else – in other words, the need for a mental transformation from reference to referent is removed. Further, from Lanier's perspective, VR is an environment where users can achieve new forms of self-expression in a collaborative way regardless of space and in a temporally asynchronous way.

Regardless of whether or not this vision eventually becomes actualized, VR holds the capacity to enable users to jump between past and future (imagined or prognosticated) spatial configurations regardless of their current physical location. Further, it can enable different scales of space and time to be interacted with simultaneously, in a spatio-temporal setting with its own somewhat modified logic (which nevertheless reflects the logic of physical reality). As a result, it can pave the way to the emergence of a new spatial way of thinking (spatial cognition) that is no longer tethered to the purely physical.

2) Information organization perspective: At the same time, with the emergence of specific VR platforms for the organization and sharing of web-based documents in a spatial context, perhaps a more recent realization is that the potential behind VR to radically improve the way humans organize information is no less groundbreaking. From this perspective, higher-level considerations both from informatics and psychology become strongly relevant, including, among others, how information can best be represented via spatial relationships, or how human capabilities for comprehension, retention etc. can be modeled in a spatial framework.

Specifically, it has been shown in numerous studies that more information can be shared and acted on in collaborative ways at a lower cognitive cost when 3D spaces are used as opposed to 2D representations, such that the semantic, spatial and / or temporal relationships among the content are reflected in their relative size and position in 3D [4], [5], [23]–[25].

As a result, VR represents a major step forward in the transition from command-based interactions to dyanamic interfaces based on affordances in keeping with human intuitions highlighted in [26]. In a strong sense, VR can be considered as an infocommunication tool that brings users an improved effectiveness, efficiency in parallel with an improved overall experience. It incorporates the capacity to share and collaboratively utilize large amounts of information, organized based on their relative importance, relative position within a workflow or in terms of other inter-dependencies in a way that transcends both space and time. At the same time, spatial interfaces in general can be more 'life-like' and hence more comfortable to users, who can now use their digital tools to understand and manipulate reality at multiple levels of space and time.

B. VR as a CogInfoCom platform

In the mid-term to long-term, VR can be expected to further merge together with sensor technologies and artificial intelligence, thereby becoming not only an infocommunication platform, but a platform that is more aptly described as a cognitive infocommunication (CogInfoCom) platform.

As described in [5], VR already incorporates the capacity to communicate with users along several new dimensions compared to more traditional platforms, thereby making better use of and in turn supporting human mental models that are grounded in space and time. However, complemented by sensor technologies (IoT) and AI, extended reality technologies in general are poised to integrate all corners of our daily lives, including more 'traditional' IT tools (documents, media, 2D interfaces), the physical 3D world (whether real, imagined or simulated), the user's mental reality (i.e. how information is organized, what content is relevant to which location at what time in the user's mind), and the influence of the user's decisions (real or hypothetical) on all of the above. With AI, such platforms can also become increasingly autonomous, thereby making decisions such as:

- what content to present to users in what location and at what time
- what concepts to use to help users search the content relevant to them, even at a higher, content-group level that addresses complete spatial layouts
- what paths to provide (in terms of sequences of locations and viewpoint orientations) to enable users to traverse through the displayed information in a sequential manner
- how to support higher-level human cognitive capabilities, e.g. memory, assocation, learning, recall, problem solving, collaborative effectiveness

It is important to emphasize that decisions made by such an autonomous system will likely be made based on the user's

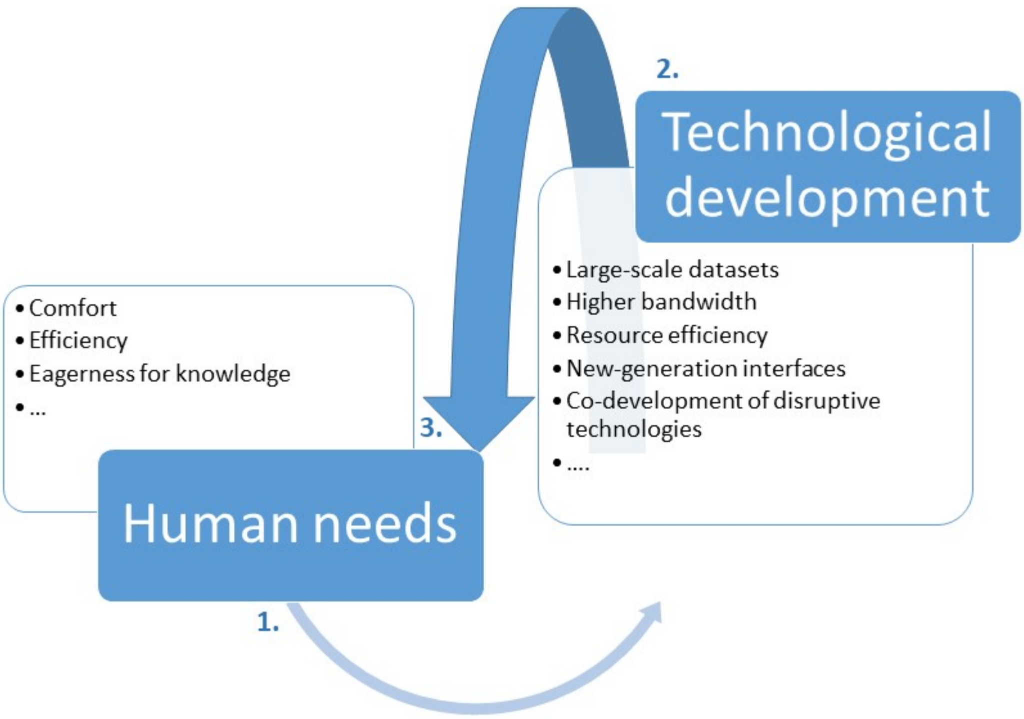

Fig. 1. Closed-loop cycle of evolving human needs that simultaneously drive and are shaped by technological development.

own behaviors (movement in the space, content consumption patterns, knowledge and capability metrics – which can be obtained through gamified situations [27], [28] – and more). As a result, a kind of symbiotic relationship can emerge between the human user and the AI supported ICT platform, with emergent behaviors that would be inconceivable without the involvement of both.

At the same time, the development of such autonomous AI-supported systems has a flip side in the sense that in order to perform well, such systems have the implicit goal of learning to "categorize" (predict) human thinking and behavior as closely as possible. One way to achieve this is to influence users' thinking patterns such that they fall into only a few well-defined categories. Some researchers argue that this is just the mechanism behind e.g. tribalism on social media platforms, or the emergence of just a few product categories that sell the best on e-commerce platforms – a result created by effective learning systems that usually have the goal of maximizing a single metric such as user engagement in terms of time spent on a given platform [29], [30]. Developing methods and solutions that turn the huge promise behind AI-supported spatial ICT into a reality while also credibly addressing such concerns is a key point of motivation behind cVR.

III. Definition of Cognitive Aspects of Virtual Reality and Synergies With Related Fields

Based on the above considerations, we propose the following definition for Cognitive Aspects of Virtual Reality (cVR):

Cognitive Aspects of Virtual Reality (cVR) *investigates the next phases of IT evolution characterized by a transition from digital environments based on 2D graphical user interfaces (e.g. windows, images, 2D widgets) to 3D spaces which represent a higher-level integration of VR/AR/MR systems, human spatial cognition, the 2D digital world (i.e. Web 2.0, Web 3.0) and artificial intelligence (AI). A primary focus of cVR is how this transition simultaneously makes use of and augments human capabilities, including psychological, cognitive and social capabilities – especially capabilities linked to a deeper understanding of geometric, temporal and semantic relationships. By extension, cVR further investigates the effects of these changes in human and AI capabilities with respect to a variety of sectors including education, commerce, healthcare, industrial production and others.*

In the context of prior research and other fields, cVR can both gain inspiration from and contribute results to the following partially overlapping / partially unique fields:

A. cVR and Cognitive Infocommunications

Cognitive infocommunications (CogInfoCom) is an interdisciplinary research field that facilitates new syngergies between infocommunications and the cognitive sciences. One of the primary goals of CogInfoCom is to help the effective interaction between humans and computers and expand human cognitive capabilities with the help of infocommunications devices. Furthermore, it aims to provide a systematic view on the co-evolution of infocommunication devices, and cognitive processes [21], [22].

According to McLellan, virtual reality is a cognitive tool, as this technology was devised to enable people to deal with information more easily [31]. As outlined in section II-A, several recent results confirm and expand on this view. Importantly, it is a view that coincides with the aims of CogInfoCom – to extend and enhance the human cognitive capabilities – but does so in a specific framework of spatial technologies. In this sense, cVR and CogInfoCom are closely related.

B. cVR and Artificial Intelligence

Since around 2010, the field of Artificial Intelligence (AI) has seen a major breakthrough with the emergence of (deep) neural networks (DNNs) as an efficient and highly effective solution to many difficult problems. In the past decade, many classical approaches, including reinforcement learning [32] and even symbolic reasoning [33] have been cross-pollinated by advances in DNNs, leading to a true renaissance in AI research.

New approaches in cVR clearly have much inspiration to draw from modern AI methods, as many of the key problems behind cVR can be traced back to the challenge of modeling human cognitive capabilities using the only source of information available: the patterns based on which users interact with the given virtual reality. Examples of capabilities that may be relevant, in particular, within a spatial environment include:

- Capabilities for mentally organizing and navigating a large variety of information sources which may appear simultaneously in a single digital 3D environment (in much the same way as someone may have 50 tabs open in their web browser, a VR space could display 50 'in-game' browser windows at the click of a button [5]) – a challenge which evokes the term ***big big data***, which has to do with the analysis of simultaneous user interactions with an exponentially growing number of information sources
- Capabilities for influencing users' attention to, as well as retention and recall of information within VR – all of which are connected to the intelligent generation of environments, content layouts and also to the semi-supervised semantic modeling of content that users engage with [5]
- Capabilities for spatial navigation and for controlling avatar behaviors – which brings to the forefront the question of how humans can connect with an already deployed AI that transforms in puts to these modalities (a possibility that may emerge from the homuncular flexibility hypothesis, see e.g. [34], [35])

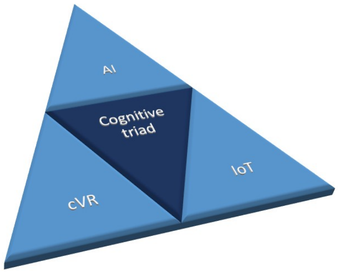

Fig. 2. Graphic depiction of the cognitive triad which represents a meeting point between humans, digital twins and AI.

- Capabilities for thinking based on spatial movements and spatial metaphors – a capability that is a core foundation behind human thinking [36]–[38]. Here, we posit the existence of what we refer to as an ***invisible VR*** – a virtual reality that already exists embedded in human mental models. The goal is to be able to map this invisible VR onto the visible VR that users interact with.

C. cVR and Internet of Things

As described in [1], the field of Internet of Things (IoT) represents a vision that integrates distributed computation (based on sensors, actuators, wearables and even digital twins) with intelligent connections. This vision brings the (dynamic) state of the physical world into direct connection with the digital world, and has quickly led to the emergence of further "Internet-of-X" fields including Internet of Everything, Internet of Nano Things, Internet of Mobile Things and more [39]–[41].

From the cVR perspective, it is important to note that the above fields are mostly technology (network) oriented, and therefore none of them address questions that have to do with the presentation / representation layer of the relevant applications. Further cognitive aspects, including users' capabilities towards understanding and acting upon the relevant data are also largely disregarded, as such questions lie outside of the technological aspects of efficiently connecting a large number of devices and routing data between them. Nevertheless, these are important aspects that can often be well addressed in the context of 3D spatial interfaces. At the meeting point of cVR, IoT and AI, a new kind of co-evolution involving humans, digital twins (IoT) and AI can emerge, which we refer to as the ***cognitive triad***.

D. cVR and Digital Reality / Internet of Digital Reality

According to Baranyi, Wersényi, Csapó and Budai [1], [42], humanity has reached an inflection point in its social and technological evolution, characterized by a human-ICT co-evolution and entanglement that could lead to a qualitatively new kind of reality. This is referred to as the digital reality:

"A Digital Reality (DR) is a high-level integration of virtual reality (including augmented reality, virtual and digital simulations, and twins), artificial intelligence, and 2D digital environments which creates a highly contextual reality for humans in which previously disparate realms of human experience are brought together. DR encompasses not only industrial applications but also helps increase productivity in all corners of life (both physical and digital), thereby enabling the development of new social entities and structures, such as 3D digital universities, 3D businesses, 3D governance, 3D web-based digital entertainment, 3D collaborative sites, and marketplaces."

The authors highlighted that digital reality is not equal to "all digital solutions", but is instead an integration of the different digital solutions such that human immersion and contextuality are key [1], [42].

cVR has a lot to offer when it comes to implementing Digital Reality, as spatial interactions are a key component of digital reality, and also because spatial and temporal contextualization are common to many cVR applications. At the same time, these fields have partially separate concerns as cVR places more emphasis on understanding the cognitive capabilities of users and ICT platforms in the context of a 3D interface, whereas Digital Reality has a more technical outlook on bringing together disparate realms of human reality.

IV. Conclusions

At the heart of the field of Cognitive Aspects of Virtual Reality (cVR) is how human cognitive capabilities can be both extended and augmented using a combination of technologies in a 3D spatial context. In this paper, a definition of cVR was proposed and its motivation and background was discussed from numerous perspectives. Based on this discussion, our hypothesis is that virtual realities tailored based on human-ICT cognitive aspects can result in simulated environments that are life-like to the point where physical and online activities can evolve into a blended experience.

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Péter Baranyi established the Cognitive Infocommunications concept around 2010. It is a scientific discipline today focusing on the new cognitive capabilities of the blended combination of human and informatics. It has an annual IEEE International Conference and a number of scientific journal special issues. He invented the TP model transformation which is a higher-order singular value decomposition of continuous functions. It has a crucial role in nonlinear control design theories and opens new ways for optimization. He is the inventor of MaxWhere which is the first 3D platform including 3D web, 3D browser, 3D store, and 3D Cloud. His research group published a number of journal papers firstly reporting that users get 40-50% better effectiveness in 3D digital environments. These results got a very high international impact within a few years.