Concepts of Cognitive Infocommunications

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***Abstract*—Cognitive Infocommunications (CogInfoCom) is an interdisciplinary field that explores the interplay between the cognitive sciences and infocommunication technologies (ICT). This paper presents recent transformative changes in Cognitive Infocommunications, emerging both on the technological and the human side. Concepts such as Digital Reality and Cognitive Entities are also presented, which have emerged as a result recent technological convergence and further entanglement of ICT with human cognition. In addition, the current focal points of CogInfoCom research are presented to emphasize the entangled nature of human-technology interactions and human-technology co-evolution.**

***Index Terms*—CogInfoCom, cognitive infocommunications, cognitive entity, digital reality, Generation of Cognitive Entities (Gen CE).**

I. Introduction

In the current era of rapid technological advancements and increasing reliance on digital systems, the field of cognitive infocommunications (CogInfoCom) [1], [2] has emerged as a key area of study. CogInfoCom is an interdisciplinary field that explores the interplay of cognitive sciences and information and communication technologies (ICT), aiming to understand and enhance both short-term interactions and long-term co-evolution between humans and digital systems. In order to support researchers and practitioners in orienting this landscape, in this paper, we take stock of the fundamental concepts behind the fields and organize them into a novel system by highlighting emergent relationships between them. This is important both in terms of establishing a common vocabulary that can prevent the fragmentation of the field and also in terms of increasing the comprehensibility of these key concepts for those who are new to the field or have experience in other, closely related fields such as AI.

Over the past decade, digital technologies, infocommunication devices, as well as the psychological, cognitive and social context in which users encounter them have undergone several changes and developments. The co-evolution of infocommunication technologies and humans seems to have reached the point where a unified perspective focusing on cognitive entities as a whole seems to be a more viable research approach in many cases compared to existing approaches focusing on separate human and techical measures.

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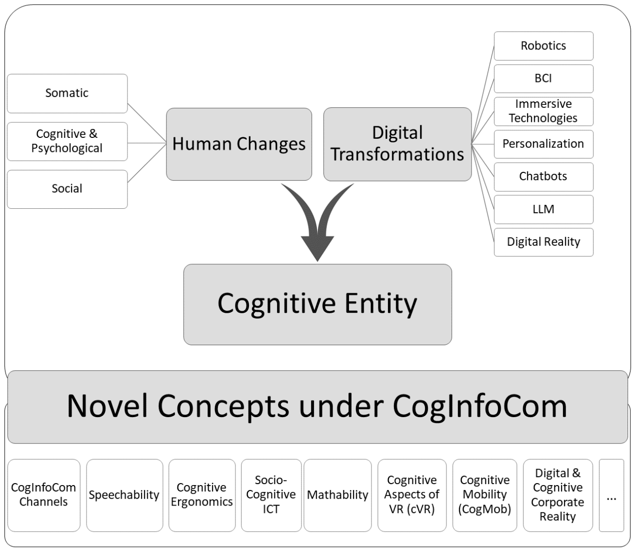

Fig. 1. A graphical overview of the structure of the paper and the key concepts discussed in the paper.

The paper is structured as follows. Section II presents some of the recent changes that we have identified in human users as a result of the widespread adoption of ICT technologies. This is followed by a presentation of recent changes in technology which are relevant to CogInfoCom in Section III. We make the case that these changes are so entangled, not just on the technological level, but also involving the human users that the following part it is worth highlighting the concept of Cognitive Entities, which is the subject of Section IV. This novel focus on the notion of cognitive entities in turn underlines the need to revisit other key concepts of CogInfoCom; therefore, Section V presents some of the more recent focal points of CogInfoCom in light of these developments. The paper concludes with a brief summary of its key points in Section VI. The structure of the paper is presented visually on Fig. 1.

II. Changes in Human Physical and Cognitive Systems

In recent decades, human behavior and lifestyles have undergone significant changes due to the widespread adoption of various infocommunication technologies. These changes have brought about irreversible transformations, particularly concerning the accessibility of the Internet, even from early childhood and in increasingly remote locations, leading to distinct developmental patterns compared to previous generations.

Although individual usage patterns, ergonomic practices, and personal habits vary, there has been a general increase

DOI: 10.36244/ICJ.2024.5.5

in average daily screen time. Since 2013, this has risen by nearly fifty minutes. As of 2021, the average daily screen time across all devices is 6 hours and 58 minutes [3]. The pervasive use of mobile devices for activities such as voice/e-mail communication, social media, multimedia consumption, and gaming has significantly impacted body posture; an effect that is noticeable both in terms of ergonomics and over the long term. Furthermore, these novel usage patterns of ICT devices also have broader implications for users' mental and physical health.

Below, we summarize some of the somatic, cognitive / psychological and sociel changes that are most relevant to the topic at hand.

A. Somatic effects

1) Tech Neck: Pain symptoms in the neck and neighboring regions are commonly experienced during or after prolonged looking down, such as when engaging in text messaging on handheld devices [4]–[6]. Research suggests that the use of smartphones while standing results in a more rigid posture compared to sitting [7]. These neck and shoulder pain symptoms are not limited to adults; they also affect teenagers [8]. In addition to phone usage, other factors such as prolonged sitting, obesity, and sedentary lifestyle have been identified as contributors to the increased prevalence of musculoskeletal pain [5].

2) Texting Thumb: The so-called "texting thumb", "PlayStation thumb", or more precisely, De Quervain's syndrome, is a common repetitive use injury that is frequently observed. Studies have found a higher prevalence of this syndrome among individuals with problematic smartphone use [9].

3) Vision Problems: Excessive screen time and prolonged staring at screens can lead to various vision problems, including eye strain, dryness, blurred vision, and headaches. These symptoms are often associated with conditions such as computer vision syndrome and digital eye strain. Additionally, the blue light emitted by screens can disrupt sleep patterns and potentially contribute to long-term eye problems [5], [10].

4) Sleep Disruptions: Previous research on screen time [11] has already emphasized the importance of minimizing screen usage, especially in the hours leading up to bedtime. However, the widespread use of smartphones has made it common for individuals to use them directly before sleep, which can further disrupt sleep patterns. One contributing factor is exposure to blue light, which can suppress the production of melatonin, a hormone that regulates sleep-wake cycles. The constant connectivity and notifications from smartphones can also disrupt sleep by inducing anxiety and promoting a state of alertness rather than relaxation. In a recent experiment, it was found that reducing blue light exposure during the night resulted in improved subjective sleep quality [12]. Additionally, other results indicated that using smartphones in bed led to increased sleep latency, higher average heart rate, lower heart rate variability, and a decrease in total sleep time. These findings suggest a poorer quality of rest, with a higher proportion of wake periods during the night [13].

B. Cognitive and Psychological Changes

The constant use of technology has been found to have both positive and negative effects on brain function and behavior [14]. The key contributing factors are information overload, screen time, and media multitasking. Interestingly, information overload has been a long-standing issue throughout history, but in the 21st century, its consequences are more pronounced due to society's heavy reliance on information [15]. Media multitasking, characterized by simultaneous processing or, according to the neurocognitive literature, rapid task-switching, has become a prominent feature of modern technology [16]. In the following, we consider different aspects of the impacts these changes have on human cognition.

1) Cognitive Development: Emerging research on the impact of technology on children reveals intriguing and slightly contradictory findings.

In general, children's screen time has become a concern, as even children under the age of 2 are now spending over an hour every day engaged with screens, leading to reduced reading time. This pattern has been associated with negative outcomes such as impaired language development, executive functioning, and decreased connectivity between brain regions involved in word recognition, language, and cognitive control. Additionally, screen time has been found to predict behavioral problems and poorer theory of mind [14], [17].

At the same time, studies have also uncovered several factors that can mitigate or sometimes reverse these tendencies. For example, studies have suggested that high-quality television programs without commercials can even be positively associated with attention and executive control measures. Conversely, commercial breaks disrupt children's engagement, indicating the importance of uninterrupted content [18], [19]. Educational cartoons and programs have also been linked to positive learning outcomes and improved executive function [20]. Moreover, touch screen devices, with their interactive nature, facilitate active engagement and control over information flow, enhancing children's ability to learn from video content [21].

These insights underscore the significance of content quality and interactivity in shaping the effects of technology on children's attention, learning, and cognitive development [16].

Furthermore, technology can offer cognitive exercise for the aging brain. Engaging in mentally challenging tasks such as searching online has been shown to potentially delay cognitive decline [22]; as a result, serious gaming can play a key role in mitigating the effects of aging, both physical and cognitive [23]–[25].

2) Attention: Reduced attention span, originally noted by Carr [26] on the basis of self-observation, is a widely discussed topic, as some users have perceived a decline in their attention, both in terms of span and intensity. Although the direct link with the technology remains to be conclusively demonstrated, experts generally agree that a causality exists. The constant flow of information could interfere with sustained concentration and promote multi-tasking between various information sources [27]. It is also possible that repetitive attentional shifts and multitasking directly impair human executive functions [28], and can also be linked to changes in the locality versus globality of attention [17]. Another factor of influence on attention span relates to the limited opportunities for offline interaction due to the constant use of technological devices. This lack of offline engagement may hinder the brain's ability to rest in its default mode, leading to attentional problems [29].

In addition to the above, structural changes have observed in individuals with Internet Use Disorders in the brain regions associated with attentional control, compared to the healthy control group [30]. These individuals have a threefold increased likelihood of Attention Deficit Hyperactivity Disorder (ADHD) [31]. Reduced gray matter in the anterior cingulate cortex and other prefrontal regions that are related to sustained concentration and the ability to ignore distractor stimuli has been observed in connection with excessive Internet usage [32] and media multitasking [33].

On the other hand, improved visual and spatial attention has also been observed in users after playing action video games for more than 4 days per week for 6 months [34]. In a similar vein, surgeons who played video games made 37% fewer surgical errors, and their response time was 27% faster than surgeons who did not play video games in one study [35].

3) Memory & Information Retrieval: There is a growing concern regarding the overreliance on online information as it serves as an always available external memory storage [31], [36]. However, certain patterns of brain activation that are crucial for the long-term storage of registered information are found to be missing [37], [38]. This raises questions about the potential impact of these phenomena on memory and cognition. One concept that has been explored is the "Google effect", where individuals tend to remember less factual information but instead remember where to access that information [37]. This suggests a shift in cognitive processes as individuals rely on the availability and accessibility of online information rather than their own memory.

4) Digital Skills: A study with a sample of 191 school-aged children categorized as either high-digital users or low-digital users, assessed these children in terms of verbal and visuoperceptual cognitive performance through standardized tests and a self-report questionnaire [39]. The results demonstrated a positive impact of digital exposure on cognitive development, as the high-digital users outperformed low-digital users in naming, semantic, visual memory, and logical reasoning tasks. These findings align with existing literature, highlighting the significant role of technology in enhancing cognitive abilities and promoting smart learning among children.

5) Multitasking Skills: Despite the negative impact multitasking can have on human cognition, it has become a skill valued in today's fast-paced world. However, it is important to note that multitasking abilities tend to decline linearly across the lifespan. Interestingly, experimental research has indicated that certain computer games have the potential to enhance multitasking skills [14], [40], [41].

6) Emotional & Social Intelligence: Increased screen time is often associated with reduced face-to-face communication [14]. Furthermore, a study conducted on preteens demonstrated that after five days without screens, they exhibited improved recognition of nonverbal emotional and social cues [42]. Another review by Bochicchio et al. [43] revealed the complexity of the role of digital games in children's cognitive and socio-emotional development, including both positive effects such as pro-social behaviors and negative effects such as anti-social behaviors and isolation. These findings highlight the potential impact of technology addiction on social interaction and the importance of exploring mental health apps as potential interventions [14].

C. Social Changes

Besides the technological and cognitive changes outlined in previous sections, it is also important to consider the social context in which users spend their everyday life. Many of the previously mentioned changes imply a change on the societal level. Connectivity without geographical limits among people has increased with the widespread access to smartphones and the Internet. Instant communication creates the feeling of connectedness. Digital communities have arisen as a result of these new means of communication and interaction.

The overall effects of these socio-technological changes are greatly under-researched at this time. As our social interactions intertwined with cognitive and technological changes reach an increasingly high level of complexity, not much data is available that could help uncover causal phenomena, leaving room for most researchers and practitioners to merely speculate. However, building on Heidegger, philosophers have raised the question as to whether technology is or can be regarded as neutral. For instance, the South-Korean philosopher Byung-Chul Han argues that the socia-technical situation today is responsible for burnout, for a significant increase in narcissism, for the disappearance of rituals, and for a general alienation. He argues that our societies followed not the Orwellian but rather the Huxleyan path towards a negative utopia, such that we have created a panopticon in which we are our own prison guards [44].

III. Digital Transformations

In addition to the human changes described in the previous section, digital technologies have undergone significant advancements in recent years. The digital transformations of the past decade have enhanced the cognitive capabilities of information and infocommunication systems. These systems, often referred to as "smart", have become increasingly complex, exhibiting advanced functionalities.

Furthermore, with the rapid pace of technological innovation, the issue of technology adoption has become increasingly relevant. The initial phase of technological acceptance is characterized by high expectations placed on new technologies, which may initially be exaggerated but eventually settle into a more realistic level. Criticisms during this phase play a vital role in guiding future developments by addressing shortcomings and shaping the trajectory of improvement. These evaluations serve as valuable feedback that help refine and optimize emerging technologies toward their full potential.

A. Robotics

Recent advances in robotics have been transformative, expanding the capabilities of robots. Notably, autonomous navigation in complex and dynamic environments has seen remarkable progress, thanks to the integration of sensor technologies and AI algorithms [45]. Learning-based methods are employed for ground vehicles navigating unstructured environments, utilizing perception to achieve context-aware navigation [46]. The emergence of collaborative robots, or cobots, has facilitated physical interaction between humans and robots in shared environments, opening up new possibilities in manufacturing, logistics, and healthcare [47]. Surgical and rehabilitation robots have made a significant contribution to the field of medicine, enhancing precision and patient outcomes [48]. Additionally, the development of soft robotic systems, that can interact with delicate objects more effectively can lead to further clinical applications [49]. By leveraging perception, navigation, and cognitive science [50], robotics continues to advance, pushing the boundaries of what robots can achieve in various domains.

B. Brain-computer Interfaces

Brain-computer interfaces (BCIs) facilitate direct communication between the brain and external devices, benefiting individuals with disabilities and there are further applications in diverse fields. BCIs receive and interpret brain signals, (and in the case of paralyzed patients it bypasses impaired neuromuscular pathways), to accomplish tasks and interact with the environment. Thanks to rapid advancements in neurotechnology and AI, brain signals used for brain-computer communication have progressed beyond sensory levels to encompass higher-level cognitive functions like goal-directed intentions [51], [52]. Advancements in flexible electronics have made BCIs compatible with the brain's mechanical properties [53]. The I3 evolutionary model [51] for BCIs includes stages of interface, interaction, and intelligence. Brain-computer interaction enables bidirectional communication and co-adaptation between the brain and computer. The integration of AI technology could augment human intelligence with BCIs [51].

C. Immersive and Non-Immserive Spatial Technologies

Over the past decade, Virtual Reality (VR), Augmented Reality (AR), and Extended Reality (XR) have witnessed remarkable advancements, revolutionizing the way we perceive and interact with digital content. VR and AR devices improved significantly in terms of display resolution, tracking accuracy, ergonomics, and wearable sensors [54], [55]. These improvements led to the application of these technologies in various industries such as healthcare [56], [57], education [58], [59], architecture [60], tourism [61] and entertainment. In an industrial setting, digital twins coexist with physical entities: the virtual model is connected to the physical one by sensors, to generate real-time data [62]. Digital twins allow the implementation of virtual safety training too [63]. Another current topic in this field is collaboration [64] and user-friendliness of content creation tools, that could allow the users to more easily create or edit the virtual environments [65], [66]. Similarly, the personalization of virtual spaces has become a topic of interest [67].

D. Personalization

Personalized recommendation systems have gained widespread usage across various domains, aiming to enhance user experiences by offering relevant and customized suggestions. These systems leverage user preferences and behavior to provide tailored recommendations. By analyzing user interactions with the system, such as past choices, browsing history, and feedback, these recommendation systems offer suggestions that align with individual interests [68]. As the demand for increasingly personalized experiences grows, certain systems go beyond conventional approaches, towards hyperpersonalization which involves real-time matching to provide customized experiences [69]. However, it should be noted, that hyperpersonalization can also trigger negative reactions [70]. These systems have the power to influence which information is easily accessible to users, effectively serving as digital nudges. Personalized recommendations impact our decision-making processes, as they guide and shape our choices based on the information presented [71]. This is often seen as beneficial, however, it has also been mentioned by several authors that optimizing a cost function in such a way can also have unexpected effects: by modifying the data (e.g., changing and leading to a uniformization of human behaviors) rather than predicting the data (e.g., understanding human preferences) more precisely [72]. As a result, Dörfler [73] emphasizes that although pattern recognition and its use in personalization can be hugely effective from a business standpoint, in a broader sense it does not work nearly as well as it is showcased by vendors: offten, instead of offering people what they want, they tell them what they *should* want.

E. Chatbots

Interest in chatbots has grown rapidly since 2016, with advancements in NLP allowing them to provide more interactive experiences [74]. Chatbots and virtual assistants are computer programs that simulate human-like conversations and understand human languages. They have found applications in diverse fields such as marketing, education, healthcare, cultural heritage, and entertainment. By combining NLP with cognitive computing, chatbots can offer intelligent functionalities across different categories, contextualizing data, personalizing information, and abstracting it e.g. for decision-making [75]. Acceptability and effectiveness of chatbots varies depending on the context, with factors like empathy in healthcare and pleasure in entertainment playing important roles [76]. Overall, chatbots with NLP capabilities enhance interactions and provide tailored experiences in various domains.

F. Large Language Models

Recent breakthroughs in AI research have been driven by the development of large language models (LLMs) based on the Transformer architecture [77]. Trained on massive amounts of web-text data, LLMs excel in natural language processing tasks. GPT-4 represents progress toward artificial general intelligence (AGI), as it can seemingly understand

and connect any topic, and perform diverse tasks. However, it is important to note that current capabilities still fall short of human-level abilities [78], especially when it comes to reasoning across multiple domains.

In the recent past, a new approach to studying LLMs has emerged, drawing inspiration from and being based on traditional psychology rather than solely relying on machine learning techniques [78]. An example of such an approach is the investigation of Theory of Mind (ToM) in LLMs [79]–[81], which refers to the ability to understand and attribute mental states to others. Current results showed that current LLMs seem to rely on shallow heuristics rather than robust ToM abilities [80]. A similar approach was applied with the creation of the "Baby Intuitions Benchmark (BIB)" tasks which probe commonsense psychology in LLMs. Results revealed that current neural-network models failed to capture infants' knowledge in many ways [82].

G. Digital Reality

Besides the novel advances in different technologies, an equally important aspect is their entanglement and convergence. Various information technologies, once seen as separate domains, are now becoming increasingly interconnected. Virtual Reality, Augmented Reality, Mixed Reality, Digital Twins, Artificial Intelligence, 5G networks, and the omnipresent 2D Web are experiencing widespread adoption, and their integration has the potential to shape a fundamentally new reality. This integration blurs the boundaries between the physical and digital world, as well as digital representations and simulations, leading to the emergence of a concept known as Digital Reality [83], [84]. This 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*". [83].

From the user's perspective, the convergence of these technologies feels seamless, as they complement one another and give rise to a digital reality. The boundaries between different technologies are becoming increasingly blurred, enabling easier connection and alignment, thereby facilitating more intuitive usage. The advent of Language and Learning Models (LLMs) further enhances this experience, as language serves as a universal interface, akin to a meta-dimension (metaD), enabling natural communication for human users.

IV. Cognitive Entity

Based on previously presented changes and developments both on the human and technological side, it is not surprising that the relationship between humans and technology has also become more engangled in recent years [2], [85]. As both human capabilities and technological advancements continue to evolve, their collaboration has the potential to yield a new level of entangled cognition, characterized by a qualitatively different experience. The concept of cognitive entities was introduced as a "*synergetic combination of humans, devices, infrastructure, and environment that is identifiable from the perspective of some (high-level) cognitive capability*" [2]. This term captures the entangled sets of humans and information and communication technology (ICT) capabilities that have evolved together [86]. While humans can be cognitive entities in themselves, many theoreticians and philosophers view machines as being incapable of cognitition without humans. For example, John Searle makes the distinction between *observer-independent* and *observer-relative* intelligence such that, for example, one chess grandmaster overcoming another chess grandmaster is a display of intelligence in an observer-independent sense, whereas Deep Blue overcoming Kasparov is a display of intelligence in an observer-relative sense: it is the human user of the computer who interprets its outputs as moves while the computer does not even "know" that it is playing chess [87], [88]. Building on the work of Hubert Dreyfus and John Searle, Dörfler [73] explores in which areas AI can replicate human performance or even outperform humans and what the areas are that are uniquely human.

The collaboration between humans and infocommunication technology facilitates joint operations that lead to increased efficiency. One illustrative example of this collaboration is when mathematicians work alongside current programs, resulting in a synergistic brainstorming process. In such instances, if the machine does not provide a counterexample, it signifies the potential value of exploring the idea further. Conversely, if the machine quickly identifies an existing counterexample, it indicates that pursuing the idea may not be worthwhile. This collaborative approach harnesses the strengths of both human intuition and machine processing power.

The concept of "generation CE" (generation of cognitive entities) was introduced in 2015 in [2] and later extended in [86]. Since then, the entanglement between humans and ICT has grown tighter and become inseparable as presented in the previous section. New, digital skills have emerged, such as learning and communicating through generative AI. Also in cognitive tasks such as naming, semantic and visual memory, and logical reasoning, high-digital users have been shown to outperform low-digital users [39]. This generation has grown up in close relation with information and communication technology from early childhood, leading to a genuine co-evolution with technology. Unlike older generations that had to adapt to emerging technologies, members of Generation CE have a more inherent relationship with ICT due to their early exposure.

Generation CE includes those born after 2010. This generation experiences a seamless integration of cognitive ICT into their everyday lives, with extended cognitive capabilities and easy access to information through devices at their fingertips. Their social lives are also partially conducted online, with online communities holding comparable significance to real-life communities.

A. Levels of Entanglement

From the perspective of interaction modes, the convergence of humans and information and communication technology can be observed across three distinct levels [86].

The first level of entanglement pertains to direct relationships at a low level, involving invasive and non-invasive interfaces such as brain-computer interfaces. This level enables direct sensing and control, however in most cases it is cumbersome due to the need for implanted or worn sensors, making it challenging to operate. Nevertheless, current technological advances allow us to go beyond sensory levels to encompass higher-level cognitive functions (as presented in Section III-B). The I3 model shows further directions in the direct linking of artificial and natural intelligence. Augmenting human intelligence by using BCI technology would allow the improvement of human perceptual abilities, information processing, and decision-making. The co-adaptation between brain and computer is a fundamental issue in the development of BCIs [51].

At the level of personal informatics devices, a different form of entanglement arises, where communication and interaction occur through various sensory modalities, including human and non-human components. Determining the appropriate "communication language" for message encoding, considering the semantics of the information, modalities used, application environment, and users' cognitive capabilities, becomes crucial at this level. Accommodating the transfer of a wide range of semantic concepts within the limitations of human sensory modalities presents a significant challenge. The trends in personalizing and providing relevant and customized suggestions allow an even higher reliance on these devices.

Lastly, a third level of entanglement manifests at the collective level of multi-user interactions. Applications at this layer leverage collective behaviors to support individual user interactions or analyze past behaviors (both individual and collective) to predict or analyze collective events. These applications often involve data-mining and analyzing diverse data sources, including social communication platforms and various activities.

B. Joint Measurement

If we take a more distant perspective, the close cooperation between humans and information and communication technology (ICT) allows for the possibility of joint measurement of the human-ICT combination. As humans and ICT co-evolve, new methodological considerations have emerged due to their interconnectedness becoming an integral aspect of our daily lives. Traditionally, human cognitive abilities and artificial cognitive abilities were assessed separately using diverse methods, although in some cases, the methods have converged, as presented in Subsection III-F. Given the potential for joint operations between humans and ICT to enhance efficiency, it is pertinent to measure the combined cognitive capability of this human-ICT combination rather than focusing solely on either component. The emphasis should shift toward measuring the cognitive entity as a whole. The Google effect [37] described earlier also shows the need for this shift in perspective, as it is so natural that the Internet is available at any time that people remember where they can access information rather than the factual information itself. Measuring cognitive entities instead of only natural cognitive capabilities would make it possible to measure general, everyday cognitive abilities since people are now almost only separated from their various smart devices in laboratory conditions.

C. Balanced Entanglement

The advantages of close entanglement and collaborative operation are easy to understand, as this allows a more efficient way to resolve related tasks. However, in some cases, there could be drawbacks to this close relationship. For example, turn-by-turn navigational aids that are commonly found in GPS devices have a negative effect on human spatial abilities. This detrimental effect can be lowered, by raising awareness and being more mindful when deciding whether to rely on navigational aids or not. Additionally, optimizing the interaction design of these devices to facilitate active information processing and integrating landmarks as reference points in GPS aids can promote greater environmental awareness [89]. Thus, it is important to find the right balance and to use these advantages of interconnectedness wisely.

V. Novel Concepts under CogInfoCom

Given the significant changes occurring on multiple levels, it becomes necessary to reassess the concept of CogInfoCom and its subtracks, placing greater emphasis on the role of cognitive entities. Cognitive infocommunications (CogInfoCom) [1], [2] investigates the "*link between the research areas of infocommunications and cognitive sciences, as well as the various engineering applications which have emerged as a synergic combination of these sciences*". Its primary focus is on the synergistic integration of these disciplines and their practical applications. The overarching goal of CogInfoCom is to explore the co-evolution of cognitive processes with infocommunications devices, enabling the extension of human cognitive capabilities beyond geographical constraints and fostering collaboration between natural and artificial cognitive systems. By facilitating this integration and expansion, CogInfoCom aims to enhance the effectiveness of engineering applications that involve cognitive collaboration.

It is important to emphasize that all presented concepts are intricately intertwined and entangled, influencing each other. They do not exist as isolated entities; rather, they coexist while maintaining their individual significance and impact. The current focal points of CogInfoCom, are presented in Fig. 2. The outer circle illustrates the three recent novel directions, which have seen significant advancements in the last few years. This progression is attributed to a substantial technological breakthrough, enabling their quicker integration into applied environments. Notably, these directions offer a more tangible manifestation and, in these cases, a rapid convergence with business and industrial demands aligning seamlessly with the ongoing research trajectory.

A. CogInfoCom Channels

CogInfoCom channels [90] tackle the communication challenges among cognitive entities when conveying new information. The framework integrates structural and semantic elements to define sensory messages linked to high-level concepts, utilizing icon-like and message-like design elements across modalities [91]–[96]. It incorporates a concept algebra-based toolset and the spiral discovery method [97] for mapping semantic meaning.

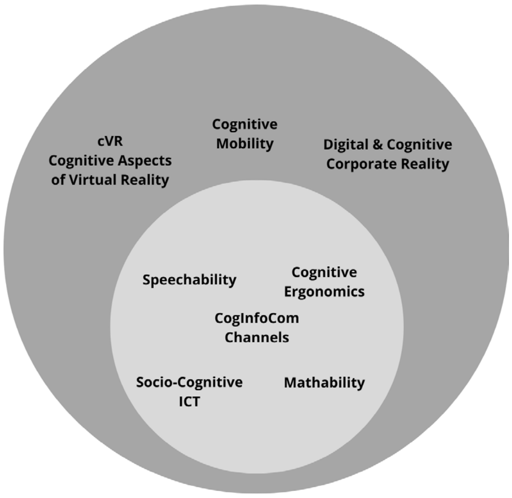

Fig. 2. Graphical representation of the current focus point under CogInfoCom. Note that the representation is not meant to be exhaustive; in addition to these concepts there exist others within the field of CogInfoCom that are still relevant and worth exploring.

B. Speechability

Speech and language are a fundamental part of human interaction. Speech is a complex modality, it has verbal components and also other components such as prosody, gestures, facial expressions, and so on. Furthermore, in human communication, speech not only serves for information sharing but also the emotional foundations and building of trust. The term *speechability* refers to the perspective of artificial devices, which are capable of generating speech (as presented in Subsection III-F about LLMs), but it is not the way humans are capable of doing it [98]. Several CogInfoCom researchers, including Anna Esposito, Carl Vogel, Gennaro Cordasco, Maria Koutsombogera, Stanislav Ondas, Klára Vicsi, and Costanza Navarretta, focused on the different aspects of speechability, such as speech recognition, multimodal cues, conversational fillers, phonological and spectral analysis and also corpus-based techniques [99]–[111].

C. Cognitive Ergonomics

Cognitive ergonomics, a field closely related to Human-Computer Interaction (HCI), encompasses the study of multi-sensory usability challenges arising from the increasing use of augmentative reality mediation. Noteworthy research has been conducted by Karoly Hercegfi, Anita Komlodi, and their research groups, exploring the opportunities and requirements in the field of ergonomics and human factors. Their work has highlighted the adaptation of ergonomic approaches, leading to synergies with CogInfoCom [112]–[116]. Furthermore, Ágoston Török [117] discussed the shift from HCI towards cognitive infocommunications, emphasizing understanding human behavior, limits, needs, and cognition in interface design. Additionally, Molnár and colleagues [118], [119] investigated the connection and communication between entities in infocommunication. Many researchers have also contributed to the diverse fields of user interface design, several researchers have also contributed, such as Atsushi Ito, Mihoko Niitsuma, Miroslav Macik and Zdenek Mikovec [120]–[123].

D. Socio-Cognitive ICT

Socio-Cognitive ICT, proposed by Hassan Charaf and his research group, refers to the intersection of social and cognitive aspects within computer networks. It emphasizes the cognitive properties that emerge through user interactions and explores how analyzing and managing information flow can enhance social capabilities. This concept enables applications like understanding crowd-generated phenomena and optimizing information flow in critical situations, bridging the gap between the social and cognitive aspects of ICT.

The term “socio-cognitive ICT” has gained prominence in describing these applications, which leverage the ongoing evolution towards the Internet of Digital & Cognitive Realities (IoD) and Smart Ecosystems [124], [125]. As Sallai [126] underlined, the convergence of communications [127], [128], information technology, media, Internet of Things (IoT), AR, VR, and artificial intelligence plays a significant role in creating smarter environments, including Smart Cities and Smart Factories.

E. Mathability

Mathability is a research direction that explores artificial and natural cognitive capabilities relevant to mathematics. It was introduced by Baranyi and Gilányi in 2013 [129], and through the years it evolved and broadened its meaning thanks to the work of Katarzyna Chmielewska [130]. It encompasses various aspects, ranging from basic arithmetic operations to high-level symbolic reasoning [129]. In addition to computing quantitative answers, mathability also emphasizes the ability to reason about the processes behind reaching those answers and incorporates estimated quantities and simplifying assumptions. This interdisciplinary field draws foundations from both human-related cognitive sciences and technology [131]–[136].

F. cVR – Cognitive Aspects of Virtual Reality

Cognitive Aspects of Virtual Reality (cVR) [137] is a field that explores the integration of 3D virtual environments, human spatial cognition, AI, and the digital world to enhance and augment human capabilities [138]–[144], particularly in understanding geometric, temporal, and semantic relationships, with implications across sectors such as education [145]–[154], commerce [155], [156], healthcare [57], [157], [158], and industrial production [159]–[161].

Recent advancements in virtual reality have shown promising applications in psychotherapy, including increasing empathy in individuals with Personality Disorders through shared emotional experiences [162] and improving the treatment of Social Anxiety Disorder through cost-effective and efficient virtual reality exposure therapy [163], highlighting the expanding potential of cVR in mental health.

cVR is a great example of how a branch of CogInfoCom is starting to grow and become a field in its own right: there is now a conference on the topic and more and more research institutes and universities are exploring the field.

G. Cognitive Mobility – CogMob

Cognitive Mobility (CogMob) integrates mobility, transportation, AI, and social sciences, aiming to understand and optimize mobility as a blend of artificial and human cognitive systems [164], [165]. Its primary objective is to present a comprehensive perspective on comprehending, modeling, and enhancing mobility on a broader scale, which provides a new holistic viewpoint of mobility. Notably, CogMob places emphasis on engineering applications within the mobility domain, aligning with its inherent nature.

H. Digital & Cognitive Corporate Reality

Digital & Cognitive Corporate Reality (DCR) is an interdisciplinary field that combines corporate management, business science, Internet of Digital & Cognitive Reality (IoD), and cognitive infocommunications to achieve a holistic understanding [166]. It explores the interactions among digital corporate ecosystems, IoD approaches, and hybrid human, organizational, and artificial cognitive capabilities. It aims to develop theoretical frameworks and practical solutions for various applications in this domain [167]–[171].

VI. Conclusion

The field of cognitive infocommunications has undergone significant changes in the last decade. Both human capabilities and digital/infocommunication technologies have seen remarkable transformations and advancements. As a result, not only has human psychology, cognition and the human social context changed, but a novel concept of Cognitive Entities has also emerged, in which human and digital capabilities are no longer clearly separable. The convergence of technologies has given rise to the concepts of Digital Reality, Cognitive Aspects of Virtual Reality and Cognitive Mobility. These developments call for a reevaluation of the field of cognitive infocommunications, and have motivated our presentation of its current focal points and branches.

Acknowledgment

The authors would like to express their gratitude to the entire CogInfoCom community for their invaluable contributions, support, and unwavering dedication to advancing the field of cognitive infocommunications over the years.

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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 non-linear 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.

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