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Special Issue on Internet of Digital and Cognitive Realities

Péter Baranyi, Ádám B. Csapó, Anna Esposito, and Atsushi Ito

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 has applications in various industries and enhances productivity in both physical and digital domains, leading to the emergence of new social entities and structures such as 3D digital universities, businesses, governance, web-based entertainment, collaborative sites, and marketplaces. The Internet of Digital Reality (IoD) comprises technologies that enable the management, transmission, and harmonization of digital realities in networked environments, prioritizing user accessibility, immersion, and experience through virtual reality and artificial intelligence. Considering the broad societal impact of IoD, papers addressing social and legal aspects of IoD are also encouraged.

The rapid advancements in information and communication technologies, coupled with the increasing capabilities of artificial intelligence, are leading to significant changes in various fields, including corporate management and business. This transformative shift is giving rise to new cognitive capabilities, both natural and artificial, which require a paradigm shift in our understanding and approaches to corporate management and business science. This paper introduces the concept of Digital and Cognitive Corporate Reality (DCR) as a comprehensive framework for discussing these changes, taking into account various scientific disciplines. The paper also provides use case examples to illustrate the advantages of adopting a holistic perspective in DCR.

The second paper turns to self-driving technology. The rapid development of self-driving technology has not yet led to widespread adoption of self-driving cars. As a result, with an aging population, accidents related to road rage and acceleration and brake errors are expected to persist. Stress is a major contributing factor to such dangerous driving behaviors. Therefore, it is crucial to develop technologies that can provide mental support to drivers when needed. In this study, we focused on the initial step of estimating driver emotions. To achieve this, we developed a technology that collects data on biological signals such as brain waves, heart rate, body movement, and driver operating status while driving, in order to estimate emotions. The authors also introduces the Positive and Negative Affect Schedule (PANAS) to assess the psychological states experienced by drivers. Furthermore, the paper presents the results of analyzing emotions using PANAS data and data obtained from electroencephalogram (EEG) readings and other biological signals from a car. Additionally, the authors discusses the relationship between this experimental environment and the Internet of Digital Reality (IoD).

This third paper introduces the Spinning Aufheben (SA) method, a novel idea generation approach that utilizes dialectic elements. The method enables infinite idea generation by rotating three elements. The paper discusses the application, model, validity, and social impact of the SA method, along with pilot project results involving 51 university students. The results show that the SA method effectively helped students determine their future career plans, with 46 students identifying their career goals and expressing appreciation for the method's results.

The fourth paper propeses the 'Aegis', an innovative elderly caretaking system. The ageing population presents challenges for countries, including Thailand, in providing quality care for the elderly. Mobile-based applications have potential in aged care, but few cater to the needs of the elderly and caregivers in Thailand. Using design thinking, the authors developed 'Aegis', an innovative elderly caretaking system. 'Aegis' enables effective communication between the elderly and caregivers, improving their quality of life. Usability evaluation with three elderly-caregiver pairs in Thailand showed positive results, emphasizing the importance of user-friendly design. The study provides usability recommendations for intergenerational digital technologies in HCI research.

The fifth paper proposes the Doing-When-Seeing (DWS) paradigm for interface design. The introduction of 2D graphical user interfaces in the 1980s revolutionized user interactions, enabling portable access to digital services with smartphones in the 2010s. These advancements have transformed our understanding of digital information systems, with immeasurable impacts. The current advancements in VR/AR, IoT, and AI are poised to bring about the next leap in cognitive expansion through portable and contextual spatial interfaces, known as Digital Realities (DRs). Users now expect personalized and context-aware engagement with digital content. This paper provides an overview of cognitive aspects relevant to content integration and management in DR environments, proposing the Doing-When-Seeing (DWS) paradigm for interface design. The paper demonstrates the applicability of this paradigm in creating, organizing, and retrieving content within 3D DR environments.

The guest editors of the Special Issue.

Digital & Cognitive Corporate Reality

Andrea Kő*, Ildikó Szabó*, Ádám B. Csapó‡, Tibor Kovács*, László Lőrincz*†, Péter Baranyi*†

***Abstract*—As part of the most recent developments in human co-evolution with information and communication technologies, the increasing complexity of our digital realities, as well as the expanding capabilities of omni-present artificial intelligence, are having profound implications. This transformative shift leads to a new era in many fields, including corporate management and business. Newly co-evolved cognitive capabilities, both natural and artificial, are emerging, necessitating a paradigm shift in our understanding and approaches to corporate management and business science. This paper introduces the concept of Digital and Cognitive Corporate Reality (DCR) to establish a new broader view for higher-level conceptual discussion, adopting a holistic perspective that encompasses related scientific fields. Following this definition, the paper briefly explores how different scientific disciplines can be expected to contribute to the development of DCR. Use case examples are also provided to demonstrate the benefits of the holistic perspective adopted in DCR.**

***Index Terms*—corporate management; business science; digital and cognitive corporate reality; internet of digital & cognitive reality; cognitive infocommunications**

I. Introduction

The European Union is committed to driving growth digitally; hence the Digital Agenda was developed by the European Parliament. A Digital Compass was created in 2021 to suggest actions in four fields (skills, businesses, infrastructure, and public services) [1]. The Digital Compass 2030 highlights the role of digital transformation (DT) in Europe's resilience, while President von der Leyen emphasizes some key areas of digitization, a European Cloud, leadership in ethical artificial intelligence, secure digital identity for all, and vastly improved data, supercomputer, and connectivity infrastructures [2].

The Digital Compass identifies four key fields; two are focused on digital capacities in infrastructures and education and skills, and the other two are concentrated on the digital transformation of business and public services [2]. Whilst action programs and tenders are created to enhance the national strategies derived from the EU's digital strategy, many companies hesitate to embrace the technologies and lag in the competition in the new digital reality [3]. Researchers elaborated several digital maturity assessment or readiness models to facilitate the transition of companies with practical insights about their digital status. The framework of Digital Maturity Technical Architecture built based on 28 digital maturity models encompasses the pillars of ICT, organization, and people [4]. Nevertheless, digital transformation literature in business and management also emphasizes that education has a significant role in DT. Education and training can benefit from the topics investigated in this field in an evidence-based way. The literature revolves around alternative or new forms of value creation; structural changes in companies, sectors, and industries; technological viewpoints in B2B or customer perspective in the B2C sector; digital capabilities, big data and their role in strategy development [5]. The human factor is also unquestionable in digital transformation [6]. Disruptive or ICT technologies have effects on not just the companies, but also the cognitive system of people. Both people and companies as a collaborative network are part of the digital transformation journey towards digital reality, supported by infocommunications and other disruptive technologies. This fact provided us with a new perspective based on which the concept of Digital & Cognitive Corporate Reality was derived.

This paper proposes the following definition for Digital & Cognitive Corporate Reality (DCR):

Definition 1. *Digital & Cognitive Corporate Reality is a scientific discipline integrating Corporate Management and Business Science, Internet of Digital & Cognitive Reality and Cognitive Infocommunications leading to a higher conceptual level, adopting a holistic view. DCR includes all corners of co-evolved natural and artificial cognitive capabilities, spanning the entire range of individual and social levels as well as network aspects. DCR research aims to explore interactions among the areas of digital corporate ecosystems (including processes, infrastructure, digital assets, organizational & human competencies, governance, regulatory and information security), and various approaches to the Internet of Digital & Cognitive Reality (including ICT, AI & data science, 2D / 3D digital environments and network science), all within a conceptual framework of hybrid human, organizational and artificial cognitive capabilities. Within these areas, DCR targets the development of both theoretical frameworks and practical solutions towards applications.*

The paper is structured as follows. Sections II-V introduce the contributions of and potential synergies with various fields from the perspective of DCR. Thus, section II presents digital corporate ecosystems that emerged from the intersection of corporate management and business science; section III focuses on the field of Cognitive Infocommunications with special focus on artificial and natural cognitive capabilities of cognitive entities, whereas section IV approaches DCR from viewpoint of the holistic systems forming an Internet of Digital & Cognitive Reality surrounding cognitive entities. Section V focuses on the breakthrough and disruptive technological enablers of artificial intelligence (AI) and spatial computing (VR/AR/MR). Finally, Section VI describes some use cases to better highlight the systemic, holistic viewpoint enabled by DCR.

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II. Digital Corporate Ecosystems

A. Corporate Management and Business Science in the Digital Age

Corporate Management and Business Science is concerned with the economics, strategy, management, and decision-making of corporations of various sizes, operating in diverse fields. The recent developments in information technology are fundamentally transforming how these corporations operate, enabling new artificial and natural cognitive capabilities towards working, competing, and collaborating. Business ecosystems are emerging that are characterized by groups of interacting firms, leading to vertical specialization and tight networked collaborations [7], forming Digital & Cognitive Realities [8], [9] of corporations. Organizational boundaries will blur both horizontally and vertically as a result of this turbulent business environment [10]. Digital technologies can enhance existing and create new cognitive infocommunications [11] capabilities (involving both an artificial and human side) of digital realities (DRs), which will play a key role in this business transformation:

- Connective capabilities: Network technologies and the Internet have laid the foundation for connecting sensors, equipment, customers, and suppliers, enabling the sharing of data and information. These technologies have not stopped evolving: RFID enables the automated identification of objects, location technologies make it possible to obtain accurate geospatial-temporal information about customers or transportation, while 5G infrastructure will enable low latency, high speed, real-time connectivity. Smart sensors, the Internet of Things (IoT) will provide data about the environment, the business processes and the products taking information availability to the next level. This will result in a new level of connectivity and an immense volume of data that could be used to build new analytical and intelligence capabilities.
- Analytical capabilities: the volume of data that is generated through the interaction with customers, suppliers as well as collected from IoT, RFID or location technologies, will enable us to understand better the behavior of the business environment, the stakeholders and the equipment. New analytical methods and technologies, utilizing Big Data can support data-driven decision-making to increase organizational efficiency and effectiveness.
- Intelligence capabilities: artificial intelligence as a scientific discipline has experienced enormous growth in the last decades. Current AI methods already provide endless business application possibilities for decision support: image recognition, process optimization, route planning, recommendation systems, or content creation generative AI techniques to name but a few. The capabilities of these AI methods are often superior to what humans can do. In addition, 3D spatial technologies like virtual and augmented reality (VR / AR) also enable humans to communicate with and interface to digital realities at a structurally higher level.

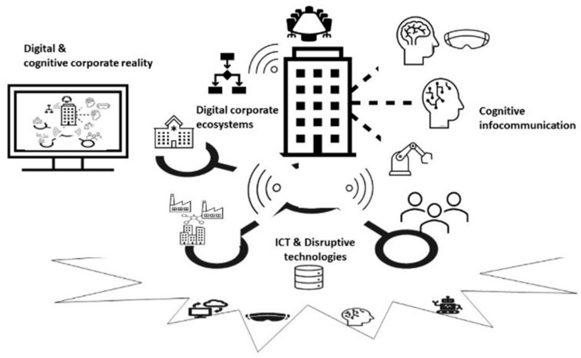

Fig. 1. Digital & Cognitive Corporate Reality

AI could play an especially pivotal role in helping users and digital systems to “brainstorm” new solutions together in a corporate and management environment, thereby transforming business processes and decision making. AI could enable building business applications that have either brand new or superior capabilities to existing ones. AI can help perform routine tasks, monitor processes within the environment, detect anomalies and defects, forecast demand for the planning of activities, and optimizing processes to enhance their efficiency and effectiveness [12].

There could be numerous applications to perform routine tasks of monitoring processes or the environment. Data generated as business activities are performed could be pre-screened through digital capabilities, and therefore more efficiently monitored by humans to identify deviations from what is desired. This information can be based on, inter alia geospatial-temporal data in logistics and transportation, network traffic from the computing infrastructure, IoT sensor data from manufacturing or transaction data from sales. Machine vision is one of the emerging artificial monitoring capabilities supporting routine applications, where machine learning algorithms are used to recognize pre-trained images or patterns and to perform business rules-based actions. Such methods can screen through millions of images, something that circumvents the limitations of human capabilities, while maintaining the quality of performance. However, based on this digital capability, humans can analyse the pre-screened and clustered images, to gain insights and to use them for building new applications – a synergy which demonstrates well the viability of hybrid cognitive capabilities.

The routine monitoring of processes or the environment is often used to detect anomalies, defects, and deviations from normal operation. Various AI models are capable of and can be trained to generate alerts if the data is different from what is deemed to be normal. Such models can use multiple sources of information simultaneously to increase detection capabilities, again augmenting human capabilities.

Forecasting is an important capability in running a business, enabling the future to be predicted, and thereby supporting preparation with resources, and optimized plans. AI can bring forecasting to a higher level [13] by using tailored models for each application field. Both the accuracy of the forecasts and their ability to cater to differences in patterns can be enhanced by using AI capabilities. Thus, AI has the capability of optimizing business processes [14] and creating plans for situations with many dimensions, constraints, and changes. The results of these optimizations are not only the most efficient ones but robust too. There are various exact and heuristic optimization methods available, whose performance could be significantly improved using AI methods, evolutionary computing algorithms being one of them.

Meanwhile DCR also entails companies embracing new technologies where several legal, ethical, cybersecurity issues emerge, especially in the case of AI. Robots driven by AI, autonomous vehicles can make decisions without external control. Questions arise about responsibilities, how to characterize new norms, apply human regulations on machines or modify them [15]. These issues need to be handled not just at governmental or international, but at an enterprise level as well. Corporate Digital Responsibility, as an analogy to Corporate Social Responsibility [16], is defined as "The set of shared values and norms guiding an organization's operations with respect to four main processes related to digital technology and data. These processes are the creation of technology and data capture, operation and decision-making, inspection and impact assessment, and refinement of technology and data" [16].

B. Digital Corporate Ecosystems

Under the DCR concept, Corporate Ecosystems, as a prominent organizational structure, focus on emerging capabilities of a dynamic group of largely independent economic players that create products or services that together constitute a coherent solution [16]. A Corporate Ecosystem can be defined as a "loose network of corporate actors; customers, suppliers, distributors, outsourcing partners, makers of related products and services, technology providers, and a host of other organizations that affect and are affected by the creation and delivery of a company's offering". Based on Moore (Moore, 1996, 2006), a Corporate Ecosystem is "an economic community supported by a foundation of interacting organizational units and individuals - the 'organisms of the company'. This economic community produces goods and services of value to customers, who are members of the ecosystem" [17]. In this context, the term 'ecosystem' is used as a biological metaphor that highlights the interdependence of all actors in the business environment, who "coevolve their capabilities and roles" [17]. Control capabilities of Corporate Ecosystems are not fully hierarchical, but there is some coordination mechanism.

The Digital Corporate Ecosystem (DCE) is a digital representation of the Corporate Ecosystem. DCE is a socio-technical environment of individuals, organizational units and digital technologies with collaborative and competitive cognitive capabilities to co-create value through shared digital platforms [17]. In digital platforms, coordination is generally achieved through access and interaction, that is generally regulated by a set of application programming interfaces (APIs) in the related Digital Corporate Reality. DCE includes collective intelligence achieved through tools for the formalization of knowledge built on top of a distributed persistent storage layer hosting digital organisms: business models, training modules, skill descriptions, digital contracts, software services, ontologies, dynamic semantic networks and taxonomies, folksonomies, tag clouds [18]. Nachira et al. [18] describe an isomorphic model between biological behavior and the behavior of the software, based on theoretical computer science implications and leading to a DCR having the capabilities of evolutionary self-organization and self-optimization (Evolutionary Environment or EvE). In our approach, connective, analytical and intelligence capabilities are core enablers of DCE. These can contribute to DCE boosting productivity and improving competitiveness, in the case of SMEs for the foreseeable future of at least 20 years [19]. Instead of a full business view, we put the focus on the corporate view, so we use Digital Corporate Ecosystems as an umbrella term.

III. Cognitive Infocommunications

Cognitive Infocommunications (CogInfoCom) is a research initiative proposed in 2010, which focuses on the analysis and synthesis of new cognitive capabilities – that are neither purely human, nor purely artificial – arising in co-evolved human-digital ICT environments. Since it was first proposed, an IEEE conference has been held focusing on relevant topics on a yearly basis, as a result of which CogInfoCom is widely regarded as a scientific discipline today.

The definition of the CogInfoCom is as follows [20]:

Definition 2. *"Cognitive Infocommunications investigates the link between the research areas of infocommunications and cognitive sciences, as well as the various engineering applications which have emerged as the synergic combination of these sciences. The primary goal of CogInfoCom is to provide a systematic view of how cognitive processes can co-evolve with infocommunications devices so that the capabilities of the human brain may not only be extended through these devices, irrespective of geographical distance but may also be blended with the capabilities of any artificially cognitive system. This merging and extension of cognitive capabilities are targeted towards engineering applications in which artificial and/or natural cognitive systems are enabled to work together more effectively."*

One of the key motivations behind DCR, from the perspective of CogInfoCom, is to develop a holistic view of how digital realities and humans can co-evolve, both at an individual and a social level, and how this co-evolution can provide new, entangled combinations of artificial and natural/social cognitive systems leading to newly integrated cognitive capabilities which cannot be explained at separate cognitive levels.

From a CogInfoCom perspective, the border between the natural and artificial cognitive capabilities of the present and the coming generations are becoming fuzzy or even disappearing. The CogInfoCom scientific discipline considers this "Human & ICT" combo as one Cognitive Entity (CE) with new cognitive capabilities instead of viewing it as a set of features emerging from human–ICT interactions [11].

Taking the view of CEs and their social level as a higher-order conceptual component, the development of scientific theories in Corporate Management and Business Science can based on new paradigms leading to a higher conceptual level, adopting a holistic view. For instance, in a corporate management environment, considering the CEs instead of sets of features and capabilities built on human–ICT interactions can allow researchers to focus on formalizing the cognitive capabilities of the management itself without investigating the structure of the interaction elements that may present a lower-level layer of abstraction ill-suited to describing high-level management issues.

IV. Internet of Digital & Cognitive Reality

The concepts of Digital Reality (DR) and Internet of Digital Reality (IoD) have recently been proposed to describe, analyse and synthesize 2D / 3D and augmented digital environments with digital content management and artificial intelligence in networked settings, enabling domain-driven digital environments centred around some coherent aspect.

The definition of IoD is as follows [8]:

Definition 3. *"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. Beyond the concepts of the Internet of Things and Internet of Everything, the Internet of Digital & Cognitive Realities (IoD) already encompasses the networking of the widest range of digital & cognitive entities to be managed, transmitted and harmonized, focusing on a higher level of user accessibility, immersiveness and experience with the help of virtual reality and artificial intelligence."*

A definition of "digital reality" has first been proposed by Deloitte Consulting LLP and the Consumer Technology Association as a trademarked term to refer to "technologies and capabilities that inhere in AR, VR, MR, 360deg video, and the immersive experience, enabling the simulation of reality in various ways" as described in [11]. In [9], this definition was extended through the addition of more context and a wider perspective focusing not only on the "3D visualization" but also highlighting the presence of "2D digital environments" and artificial intelligence-related, capability-oriented and social cognition aspects. The paper (Baranyi et al., 2021) also considered the Digital Reality concept in the emergence of a new kind of interconnectedness, referred to as the Internet of Digital Reality [8], based on a strong analogy with the Internet of Things (IoT). The paper [8] discusses the combination of VR / AR / XR and 2D windows like human environments in which virtual simulations, virtual twins and digital twins are integrated.

In the concept of IoD, the meaning of Reality plays a crucial role. Different definitions and understandings exist to explain the meaning of Reality. In [8], the authors characterize the meaning of this concept as a set of highly entangled natural and artificial cognitive capabilities that serve a common goal. In the case of corporate and business management, even existing solutions rely to a large extent on digital environments and personalized (human) digital capabilities, i.e., on cognitive entities (CEs) [11] being mapped onto corporate divisions. However, all of the general and specialized capabilities reflected in the systems being used ultimately serve the goals of - for instance - management. That is, all capabilities of the entire cognitive network of capabilities that have the purpose of serving management goals, can be considered as a part of the emergent Management Reality.

As an analogy, consider a garage and a car service. Both contain cars, repair tools, and human resources, but the integrated set of capabilities and the varying quality of those capabilities within the set highlight the different overall purposes of a garage versus a car service. It is the combination of these capabilities that creates a distinction. In a similar fashion, when artificial cognitive capabilities such as those provided by AR, VR, XR, 2D, Digital Twin, and AI are intertwined with natural cognitive capabilities to serve a shared objective, they create a Digital & Cognitive Reality. This is the connection between Digital Reality and the reality of management or corporate operations.

V. Breakthrough and Disruptive Technological Enablers

In this section, we provide a brief overview of the evolution of artificial intelligence (AI) and 3D spatial technologies, with special focus on how such technologies can be expected to influence DCRs.

A. Artificial intelligence (AI)

Founded in the 1950s, AI is a field focusing on the implementation of human-like intelligent behaviors in computer systems. In a document written by the pioneers of the field, McCarthy et. al. in 1955, the authors envision a "2 month, 10 man study", in an attempt "to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves" [21].

In retrospect, it is evident that the expectations set within the given timeframe were overly optimistic. However, it's also clear that they were perhaps broadly defined. As a result, the field of AI has been characterized by the emergence of a myriad of sub-fields, including knowledge-based systems, machine learning, soft computing, natural language processing, evolutionary computing and others. Also, the field has been characterized by an alternating sequence of booms and busts, with each boom precipitated by the maturation of different approaches, such as logical inference, statistical machine learning, training of artificial neural networks using backpropagation, or reinforcement learning.

1) Evolving conceptualizations of intelligence: Additionally, one can observe that the definition of what it means for a digital reality to be intelligent has also evolved – both in public perception, and among researchers.

Within the realm of public perception, when asked whether spell checking and grammar checking in word processing software, or human face recognition in digital camera software should be regarded as AI, no doubt users would have answered differently depending on whether they were asked in the 1980s, 1990s or early 2010s. This can only be expected, as the emergence and maturation of all technologies leads to a continuous re-evaluation of how they can best be put to use.

At the same time, AI is also somewhat unique in that there is no real consensus even among researchers as to what a truly intelligent system should look like. Not only public intellectuals and philosophers, but also researchers in AI as well as in various fields focusing on the relationship between humans and computers have adopted different, sometimes conflicting views on what it means for a machine to be intelligent and how best to support human intelligence via digital realities.

For example, some have criticized current widespread generative AI solutions as being purely statistical in nature, thereby not having a “real” understanding [22], [23]. Others have argued that to do statistical inference well, a real understanding has to implicitly emerge. For example, Hinton has argued that to translate the sentence “*the trophy doesn’t fit into the suitcase because it is too small*” to French, a large language model has to understand that it must generate the subject pronoun “elle (la valise)” instead of “il (le trophée)” because it is the suitcase that is too small, not the trophy; in contrast, if the sentence read “*the trophy doesn’t fit into the suitcase because it is too big*”, this would be the other way around.

Within the field of Human-Computer Interactions (HCI) in particular, Winograd and others have noted that a deep divide runs across the AI and HCI communities as to whether computers should behave like and be talked to as humans, or if making a clear distinction between artificial and human intelligence has practical and philosophical benefits [24] - an observation that was also one of the motivating factors behind CogInfoCom. These tensions have led to new definitions and conceptualizations of what is expected of intelligent digital realities, focusing on a broader perspective than the goal of optimizing some cost functions. In [25], a definition of “interactive human-centered AI” is presented, which focuses not only on interactivity and explainability, but also on levels of abstraction and granularity of control. In CogInfoCom, a hybrid viewpoint has been adopted that focuses on longer-term co-evolution and hybrid, or merged cognitive capabilities, thereby leaving the question of purely artificial intelligence aside [11].

2) An alternative view of implied deliberative intelligence: In this paper, we adopt an alternative perspective from those described above, with individual elements combined from different existing perspectives.

First, we propose to view the artificial cognitive capabilities extending human capabilities – as a component of new cognitive entities (CEs) [11] – towards vision and speech, whether in the direction of input (image recognition, speech recognition) or in the direction of output (image generation, text generation) as a kind of reflexive process as opposed to a deliberative one in AI systems. In much the same way as perception in humans is a more direct, lower-level process than high-level thinking, current generative AI solutions operate by passing an input through a feed-forward network in order to generate the next token, or the next iteration of noise to be removed (as in the case of diffusion-based image generation). Of course, such operation is far removed from the kind of iterative, deliberative reasoning-based process in which we as humans refine our work through self-critique, through the critique of others, or through other impulses that can be explained at a different level such as human psychology and neuroscience. The key point here is that a large language model like GPT-4 cannot go back and refine output that it has already generated.

Of course, in a sense such reflexive AI is an essential component of general intelligence, without which further progress would be difficult to imagine. For example, without the ability to generate grammatically correct text, or text that “makes sense” in view of earlier parts of a dialogue, it would be difficult both to interact with users at a high level, and to generate content in the first place that can later be refined. In this sense, basic visual and linguistic skills can be seen as prerequisite cognitive capabilities to high-level reasoning.

The task now, in our view, is to organize and embed these capabilities into a broader networked environment, consisting of individuals using them, of organizations with constituent individuals using them, and of other artificial capabilities that can be put to use in semi-automated workflows. This leads to a kind of implied deliberative intelligence embedded in DCR, as depicted on Figure 2.

B. *Spatial technologies*

We refer to all digital technologies that utilize spatial properties and relationships to present content to users as spatial technologies. Spatial technologies derive their significance from their ability to employ spatial metaphors that human cognition has become accustomed to in the physical environment through millions of years of evolution. Thus, instead of adopting file-folder hierarchies to structure information, a spatial technology might present documents in a way that reflects their topic, relative importance and context of use, thereby boosting the effectiveness of the human brain at various cognitive levels [26]–[30].

1) The benefits of realistic visualization: Visualization, simulation, and 3D graphical rendering are somewhat overlapping yet distinct concepts that can be used to enhance the efficiency of corporate realities at various levels. Central to these approaches is the notion that the more spatially and geometrically accurate the digital reality in which users receive feedback, the faster and more effective the interventions that they can make. For instance, in industrial settings, it may be the case that all of the pertinent feedback – including status messages, and alerts – can be provided to users as a text-based digital capability; still, a growing number of companies now use digital twins,

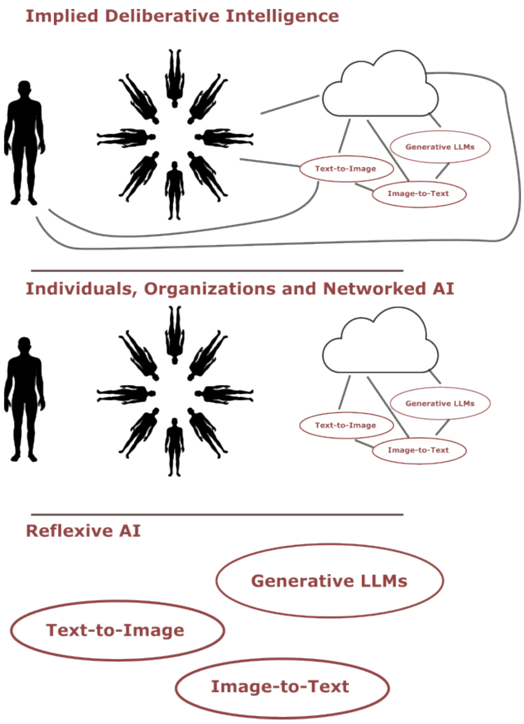

Fig. 2. Implied deliberative intelligence arising from reflexive AI, networked AI, individuals, and organizations.

which mirror the physical environment and its events on a digital interface that shows a similar geometry and a similar spatial structure to the physical environment. While sometimes counter intuitive, such high-fidelity feedback methods can be highly effective since users implicitly know where to look for what kind of information and are less likely to experience cognitive overload resulting from feedback messages that have no semantically relevant distinguishing features [31].

More recently, in part based on such successes, researchers have turned towards the use of 3D virtual environments, as opposed to 2D simulations with spatial aspects. Several authors have highlighted that virtual worlds have a unique potential to foster creativity in a way that the traditional Web cannot (see e.g., [32]). For example, it has been shown that the ability to explore spatial locations as users are able to have discussions with teammates, while in the meantime accessing supplementary information enable users to create associations between experiences that would normally belong to separate realms [30], [32]. Creativity improvements have also been observed by others in multimodal avatar scenarios [30].

Besides creativity, VR has also been observed to have a positive influence on cognitive capabilities in many respects. Thus, it has been shown that even a desktop VR platform is capable of generating more salient memories [27], to enable a higher degree of context awareness [26] and generate new cognitive capabilities towards obtaining a holistic overview of multimodal content [26]–[28].

2) 3D spatial technologies from a DCR perspective: VR and AR are core technologies contributing to both Digital Reality and Internet of Digital Reality; hence, they are also closely linked to DCR.

A key notion behind the corporate use of these technologies is that users are able to organize and access their digital content more effectively and at a lower cognitive load if their semantic relationships are encapsulated in 3D spatial metaphors. In practice, this means that documents that are related appear closer together in space, documents that contain key insights as opposed to supplementary materials appear relatively larger, and often documents are placed in the proximity of objects whose identity conveys some kind of meaning. For example, in a factory, management type documents would more likely be placed in the office spaces above the shop floor, whereas documents pertaining to the operation of individual machines would be accessible in the area where the machines are located.

From the holistic perspective of DCR, 3D spatial technologies together with AI solutions can provide solutions where the necessary information is available to users in a context-sensitive way and through an interface that enables them to achieve more with less effort.

C. AI and VR enablers from the perspective of Gartner Emerging Technologies in 2023

The 2023 Gartner Emerging Technologies and Trends Impact Radar emphasizes four key areas [33]: neuromorphic computing; self-supervised learning, metaverse, and human-centered AI (HCAI). Neuromorphic computing offers a new approach to modeling the operation of a biological brain using digital or analog processing techniques more accurately. Its use cases cover event detection, pattern recognition, and small dataset training. Self-supervised learning provides an automated approach to annotating and labeling data. It has special importance in the field of computer vision and NLP. Metaverse adds an immersive digital environment to Digital Reality. It contributes to the physical world real-time through decentralized, collaborative, interoperable, and spatially organized digital content. Human-centered AI suggests a model, where people and AI work together enriching cognitive performance, like learning and decision-making. HCAI deals with transparency and privacy and manages AI risks. It focuses on ethical, responsible behavior, and adds to AI a human touch [33].

VI. The Central Role of DCR in Practical Use Cases

A. CogInfoCom capabilities in cognitive entities and DCR

The field of CogInfoCom considers cognitive entities (CEs) as emergent human-digital systems with complex hybrid capabilities that are both natural and artificial but cannot be separated into natural and artificial components in a clear-cut way.

Depending on the context, both CEs and DCR can have natural cognitive capabilities and CogInfoCom capabilities in this hybrid sense. Conceptually, this results in a matrix, the rows of which distinguish between natural and CogInfoCom capabilities, and the columns of which distinguish between CE and DCR capabilities. Of course, such distinctions are not always crisp, but can have overlaps in a fuzzy sense. Nevertheless, it is often possible to associate a given example with one specific quadrant of this matrix. For example:

- When the focus is on a CE having CogInfoCom capabilities in a general environment not necessarily in corporate or management settings – such as using everyday AI and infocommunication devices, or collaborative or social knowledge sharing – the resulting capabilities can be seen as CogInfoCom capabilities of CE.
- When the focus is on a DCR having CogInfoCom capabilities specifically in a corporate or management environment, the resulting system can be seen as a CogInfoCom capability of DCR, where the human is extended as a component of newly emergent CEs.

B. Advanced collaborative capabilities of DCR

In the most general, abstract sense, collaborative capabilities can be seen as advanced CEs that can lead to the loosening of temporal, spatial and other contextual constraints that would be hard constraints without the formation of such CEs. Therefore, collaborative capabilities of DCR are supported by the enhanced CogInfoCom capabilities of such new CEs.

For example, new CEs involving human teamwork within computer networks loosen the constraint of having to work in the same physical location at the same time. Thus, online collaborative networks such as GitHub and Clickup and many others enable the collaboration of larger teams due to the loosening of physical and temporal constraints.

In a more radical sense, not only physical location and temporal requirements, but also contextual requirements such as whom to work with can be loosened in the context of new DCR CEs, as suggested by terms such as the ‘platform economy’ or the ‘gig economy’ [34]. A unifying feature of these platforms is that they apply new organizational methods in value creation, made available by a new kind of CE comprised of a flexible and dynamic workforce and computer networks. These either usurp existing markets or services or create entirely new ones that were not available previously [34].

From a DCR perspective, key differentials on the platform of work arise according to two dimensions. First, some of these operate on local markets that offer works that have to be provided on site, e.g., cleaning or delivering, while others on a global scale, such as online labor market platforms. Second, the autonomy of workers, is different, ranging from relatively high for creative projects present at online labor market platforms to very low in the case of drivers that are routed by the applications [35]. While online platforms promise the freedom of choice to workers in terms of time and amount of work that promises increasing inclusion (e.g., of workers from developing countries or ones doing family care work that excludes from traditional markets), structural constraints, such as worker dependence on the work and cultural constraints seriously limit this [36].

C. Emerging corporate roles in a DCR context

From a DCR perspective, many new opportunities are available to corporations to solve tasks that previously required countless hours of human labor, or which were simply impossible to achieve. However, an understanding of how these opportunities can best be brought to bear is still incomplete.

On the one hand, given the data sensitivity constraints, as well as the growing availability of open-source, self-hosted AI solutions, we envision that many companies will employ their own AI models in the coming years. This implies upfront costs and some degree of iteration in developing new infrastructures. However, it also implies that it will become necessary to train individuals to better understand the scope and limits of current AI solutions, given that the emergence of new, previously non-existent lines of work can be expected.

In addition, companies can be expected to leverage 3D spatial digital capabilities more and more, making areas of digital computing that had previously been reserved to gaming enthusiasts a central part of corporate infrastructure.

Based on the above, some possible newly created roles might include:

- Data curation: the collection of relevant data based on which AI models can be further refined, with a preference towards one-shot learning episodes for increased flexibility.
- Prompt engineering: the formulation of useful inputs to AI systems for specific use cases
- AI operator tasks: the use of the previously mentioned prompts within a given workflow to obtain output from AI models and to refine those outputs iteratively.
- Spatial environment management tasks: the curation of results from AI operators, in an increasingly automated fashion, and the furnishing of 3D spatial computing environments with the components and documents necessary for work to be effectively carried out within a given workflow.
- Human-AI Workflow engineering: making decisions as to what parts of a given workflow to implement through human labor, what parts to implement using AI, and what parts to implement in a human-supervised-AI mode. This role also includes establishing and monitoring protocols to ensure that human operators are able to intervene at optimal points in a workflow, and that the AI methods that are employed have access to the optimal external tools at the right time
- AI quality control: involves the monitoring of the performance of the system as a whole, and finding modes of operation that are increasingly performant, in close collaboration with Human-AI workflow engineers.

We note that a growing number of challenges can be expected such that they can be best solved at an organizational rather than an individual level of AI tools or human operators. Thus, the output of the organization as a whole needs to be considered, and often empirical methods can be expected to be amenable to the goal of improving the organizational performance. For example, the roles listed above are often strongly intertwined, with decisions made at some point influencing the work of several other roles. Therefore, we can expect that new methods of management will emerge to tackle functional issues at this holistic scale.

VII. Conclusions

In this paper, we discussed and proposed a definition of DCR. By reviewing relevant aspects of Digital Corporate Ecosystems, Cognitive Infocommunications, and Internet of Digital Reality, we showed that in accordance with recent trends within European research and development initiatives, the definition covers a new set of capabilities. EU's Digital Compass, digital maturity models and digital transformation literature review also highlighted that a new holistic viewpoint is required in that digital technologies, humans and organizations are investigated together. Digital corporate ecosystems were defined as loose networks of corporate actors; customers, suppliers, distributors, outsourcing partners, makers of related products and services, technology providers, and a host of other organizations that affect and are affected by the creation and delivery of a company's offering. Connective, analytical and intelligence capabilities are core enablers of DCE.

The primary goal of CogInfoCom is to provide a systematic view of how cognitive processes can co-evolve with infocommunications devices so that the capabilities of the human brain may not only be extended through these devices, irrespective of geographical distance but may also be blended with the capabilities of any artificially cognitive system. The Internet of Digital Reality 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. Corporate ecosystems and cognitive ecosystems are influenced and transformed by digital technologies on the road towards digital reality. This synergy led to the concept of Digital & Corporate Cognitive Reality.

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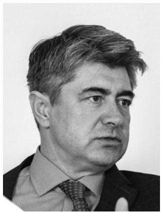

Péter Baranyi established the Cognitive Infocommunications (CogInfoCom) concept around 2010.
CogInfoCom has become a scientific discipline focusing on the new cognitive capabilities of the blended combination of human and informatics. It has an annual IEEE International Conference and a number of scientific 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 integrating 3D Web, 3D Browser, 3D Store, and 3D Cloud services. His research group published a number of journal papers which were the first to report that users could achieve 40-50% better effectiveness in 3D digital environments.

Estimating and Visualizing Drivers' Emotions Using the Internet of Digital Reality

Jinshan Luo, Haruka Yoshimoto, Yuko Hiramatsu, Madoka Hasegawa, and Atsushi Ito

Abstract—**Recently, the development of self-driving technology has progressed rapidly. However, self-driving cars have not yet become widespread. Thus, with an aging population, accidents such as road rage and acceleration and brake accidents are likely to continue. Stress is one key reason for such dangerous driving. Thus, technologies must be developed to provide mental support to drivers as required. In this study, we considered estimating driver emotions as a first step along these lines. To this end, we developed a technology to estimate emotions by collecting data on biological signals such as brain waves, heart rate, body movement, and data on a driver's operating status while they are driving. In addition, we introduce a Positive and Negative Affect Schedule (PANAS) to express the psychological states experienced by drivers. We further present the results of an analysis of data on a driver's emotions from PANAS and data obtained from electroencephalogram (EEG) readings and other biological signals from a car. In addition, the relationship between this experimental environment and the Internet of Digital Reality (IoD) is described.**

Index Terms—**Brainwave, EEG, Heartbeat, ECG, Accelerometer, CAN, Driving Simulator, Emotion Estimation, PANAS, IoD, CogInfoCom**

I. Introduction

Although various driver assistance technologies are being developed, human beings remain the primary drivers of road vehicles. Naturally, people can be influenced by various emotions and may drive dangerously or make mistakes, as shown in Fig. 1. In addition, new technologies designed to help drivers feel comfortable and safe while sharing the road must be widely developed and adopted in the future. Road rage [1] and other dangerous driving behaviors have been increasing in recent years. In June 2017, a driver who exhibited road rage on a highway was arrested for killing victims [2]. Anger and other driving factors may have led to this behavior.

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Therefore, considerable research has recently been conducted on the effects of emotions on driving behavior. For example, a study at Hiroshima University determined that anger and sadness tend to cause excessive driving speed, whereas neutral emotions contribute to speed suppression. In addition, positive emotions such as happiness did not correlate with driving speed [3]. According to one study [4], driver behavior in anger-arousing situations on the road was characterized by "aggression," "suppression," and "hostility." The study also showed that drivers who had never been involved in a traffic accident were more likely to be angry. Therefore, we aimed to develop a service designed to reduce driver fatigue by estimating drivers' psychological states and encouraging them to take breaks or change their environment. Therefore, to measure a driver's emotions, we constructed an environment to collect biometric signals such as electroencephalogram (EEG) and electrocardiogram (ECG) data. In addition, we collected data related to driving operations recorded using a driving simulator (DS). These data were analyzed to obtain an index for measuring driver stress, as shown in Fig. 2.

The remainder of this study is organized as follows. Section 2 describes related research. Section 3 presents the results of some previous experiments, and Section 4 describes the experimental setup of the present work. Section 5 provides an overview of the experiments and discusses their results. Finally, Section 6 concludes by summarizing our findings and suggesting some avenues for future research.

II. Related works

A. Drivers' emotions on the road

Drivers' emotions are a major cause of traffic accidents. Emotions such as hurriedness, impatience, and irritation are believed to trigger dangerous driving behaviors. Several studies have addressed driver hazard avoidance. In many cases, researchers have provided safe driving functions such as sounding an alarm when dangerous conditions such as drowsiness are detected. While these methods detect visible external behaviors, some studies have also attempted to estimate emotions from brain waves. However, to the best of our knowledge, no system has been developed to estimate drivers' emotions, although some preliminary solutions have been proposed to determine drivers' emotional state [5]. Estimating a driver's emotions using facial expression recognition is challenging. However, a combination of emotion recognition from facial expressions and biometric signals representing the electrical characteristics of the skin is effective.

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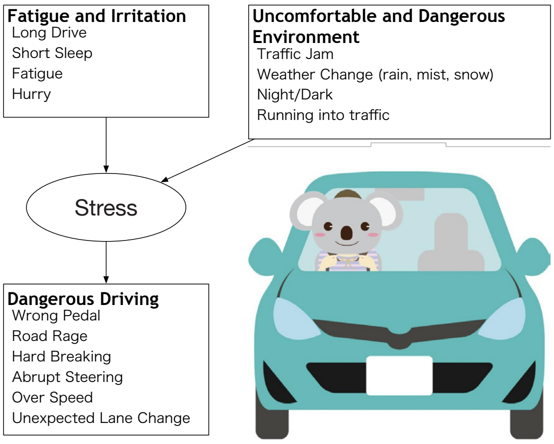


Fig. 1. Research target.

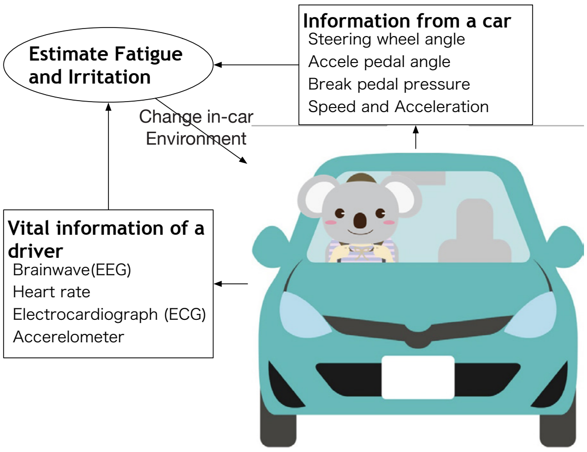


Fig. 2. Developing technologies.

In [6], the authors showed that their results were 114% better than those obtained using facial expressions and 146% better than using the electrical activity of the skin alone. Some studies have attempted to read emotions from ECGs. However, these data are imprecise and can only be used as a support [7]. Several studies have been conducted on the use of EEG signals. The National Institute of Technology developed a portable EEG system and used a driving simulator to characterize brain waves before a person begins driving in a dangerous situation [8].

B. IoD and CogInfoCom

Recently, a new concept called the "Internet of Digital Reality (IoD)" was proposed [9, 10]. In this study, we define IoD as follows. "The Internet of Digital Reality is a set of technologies that enables digital realities to be managed, transmitted, and harmonized in networked environments (both public and private), focusing on a higher level of user accessibility, immersiveness, and experience with the help of virtual reality and artificial intelligence. Connections among various cognitive entities are also handled at the end-user level of virtual reality displays and software and at the levels of network protocols and network management, physical media (wired or wireless), hardware interfaces, and other equipment." IoD is an extension of cognitive info-communication (CogInfoCom) [11, 12].

CogInfoCom considers the link between the research areas of info-communications and cognitive sciences and various engineering applications that have emerged as a synergic combination of these sciences. Information and Communications Technology (ICT) convergence involves three traditional fields, including media, informatics, and communications [13]. CogInfoCom is placed between cognitive informatics and communication to realize a virtual world.

Several studies have been conducted on driver support using CogInfoCom and the IoD. For example, [14] introduced hybrid driving strategy optimization, which is a simulation method combined with CogInfoCom. Another study [15] reviewed existing standards and guidelines and explained the gap between the system and a complete description of the system and its environment, that is, in the context of CogInfoCom, the user. In addition, [16] integrated advanced information technologies such as eye tracking, virtual reality, and neural networks for cognitive task analysis as a precursor to behavioral analysis of humans. In Section IV, we explain the present work from the perspective of IoD and CogInfoCom.

III. Our Previous Work

We conducted a prior study on estimating drivers' mental states in 2019 [17]. We measured the EEG signals of drivers while driving using a DS on September 20 and 26, 2019. The participants were three students attending Utsunomiya University, three employees of Utsunomiya University, and five employees of Toyota Customizing and Development Co., Ltd. We used a single-electrode EEG sensor developed by Mindsall Inc. [18]. This EEG sensor is lightweight and can send a signal to a receiver, such as a PC, via Bluetooth Low Energy (BLE). In the EEG sensor, a brainwave sensor application-specific integrated circuit (ASIC) called TGAM [19] was used, the primary chip of which detected brainwave data and calculated attention and mediation values. In the experiment, the test subjects drove 12 laps in a DS while wearing an EEG sensor. The course was a motor-racing circuit from a real-life scenario. The weather conditions varied during the drive. In some cases, it also rained. To provide additional excitation and influence user behavior, a loud noise was generated using an amplifier and played in the last corner of the test field.

Fig. 3 shows the attention and mediation data of an examinee familiar with driving. The following information can be observed from the figure:

- attention was stable,
- it was unaffected by rain or noise, and
- during the accident (course out), attention was lost.

Fig. 4 shows the attention and mediation data of an examinee who was unfamiliar with driving. Attention and mediation are outputs of TGAM. Attention reflects the strength of the beta wave over one second, and mediation reflects the strength of the alpha wave over one second. The following information may be observed from the figure.

- Attention increased with laps.
- Drivers were affected by noise.
- When it started to rain, attention decreased immediately.
- During the accident, attention was lost.

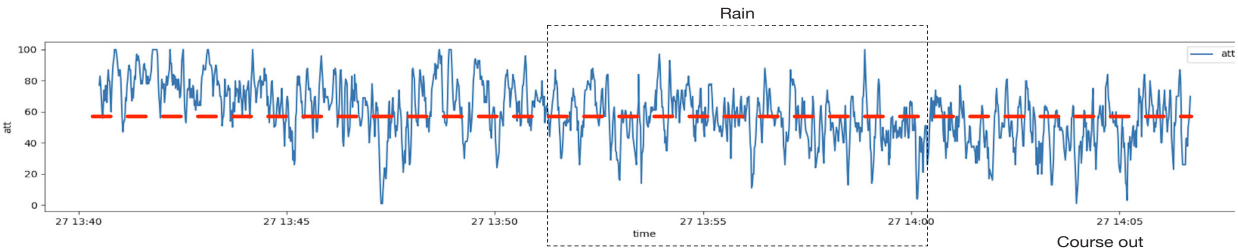


Fig. 3 Brainwave data (attention) of a driver familiar with driving.

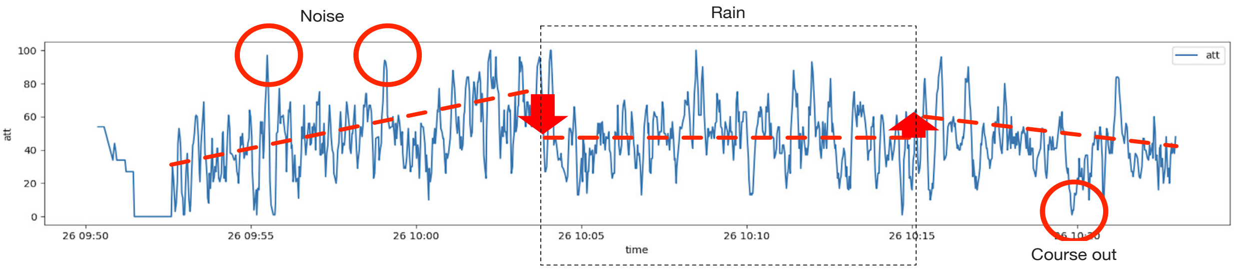
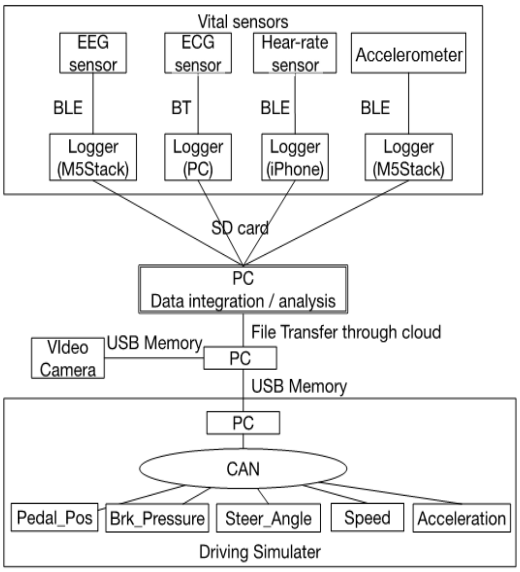


Fig. 4 Brainwave data (attention) of a driver unfamiliar with driving.

- Attention recovered when it stopped raining. However,



it gradually decreased. We believe that this was caused by fatigue.

From these results, we inferred some aspects of the drivers' mental states from the EEG data.

IV. Experimental Setup

A. Overview of the experiment

First, we designed an experimental environment to achieve the following:

- measure the movement of a driver using an accelerometer that could send data via BLE.
- record the drivers' EEG readings, and
- measure their heart rate.

Biosignals related to mental states can be measured in various ways, such as by measuring cortisol levels in saliva. However, to measure the biosignals continuously, we chose the above three datasets, including movement, EEG signals, and heart rate information.

TABLE I
POSITIVE AND NEGATIVE AFFECT SCHEDULE (PANAS)

Positive affects	Negative affects
Attentive	Hostile
Active	Irritable
Alert	Ashamed
Excited	Guilty
Enthusiastic	Distressed
Determined	Upset
Inspired	Scared
Proud	Afraid
Interested	Jittery
Strong	Nervous

TABLE 2
OVERVIEW OF PANAS

	Positive affect	Negative affect
High Score	Concentrated Fun Active	Painful Discomfort
Low Score	Lethargy Sadness	Relaxed Calmness

From the DS, we collected the following data:

- accelerator pedal position,
- brake pressure,
- steering angle, and
- speed and acceleration.

Fig. 5 shows an overview of an experimental system. We primarily used BLE and M5stack [20] to collect biosignals. Driving data from the DS were collected through a controller area network (CAN, ISO 11898-1, and ISO 11898-2) [21, 22].

B. Estimating mental state using PANAS

The Positive and Negative Affect Schedule (PANAS) is a scale of emotions represented by 20 keywords that contain positive and negative emotions [23]. Table I lists the keywords used in this study. In addition, the positive and negative effects can be roughly recognized, as described in Table II (according to [24]). A high positive effect indicates an active situation, and a low negative effect indicates relaxation. In other cases, this situation means that the subject is not happy. We defined biosignals and information regarding the car's operation as relevant to the driver's mental state. However, all information must be linked to understand the driver's mental state in order to achieve the goals of this study. Unfortunately, the data from brainwaves, motion sensors, and information from the DS are analog. Another key is thus required to explain the mental state and add meaning to the data. Therefore, we decided to use the PANAS to investigate how drivers' mental states changed before and after driving in the DS. That is, we considered how fatigue from driving affected drivers.

Several studies have used the PANAS to estimate mental states. The authors of [25] explained the results of measuring stress during commuting using EEG data and PANAS. The results showed a high correlation between the EEG and PANAS scores. Reference [26] explained the effect of nonverbal biometric cues and signals in online communication using biometric data and PANAS, and [27] explained the effects of biofeedback on stress management. The PANAS was used to measure psychological effects before and after intervention. Reference [28] explained the results of measuring emotions in older patients with dementia using biosignals. They used the K-PANAS (the Korean version) as a measurement tool.

TABLE III
COURSE SETTING FOR TOKYO METROPOLITAN EXPRESSWAY ON DS

Time set for brightness	Duration (min.)	Weather, Light
14:00	5	Daytime, Fine, Light OFF
16:00	10	Twilight, Rain (70%), Fog(80%), Wet road (70%), Light OFF
18:00	10	Evening, Rain (70%), Fog(80%), Wet road (70%), Light OFF
20:00	10	Night, Rain (70%), Fog(80%), Wet road (70%), Light OFF
21:00	10	Night, Fine, Light ON,

TABLE IV
COURSE SETTING OF PARIS ON THE DS (COMBINATION OF TRAFFIC AND PEDESTRIANS)

Traffic
Traffic jam
Stop at traffic light
Increase Traffic
Lane change

Pedestrian
Walking
Running
Stop

C. Relation between IoD/CogInfoCom and this research

Fig. 6 shows the relationship between this study and IoD/CogInfoCom. The left-hand side of the figure concerns this study. Various pieces of information were gathered from the driver and the DS. The data were sent to the measurement environment through an ad hoc network using BLE and then analyzed. In addition, the PANAS data were added to the analysis. As shown in Fig. 6, the part of the measurement environment shown on the left illustrates a function of the IoD that provides driver information regarding the route to take and road conditions to change stress levels. On the right, various devices that provide stimulation to the driver, such as music,

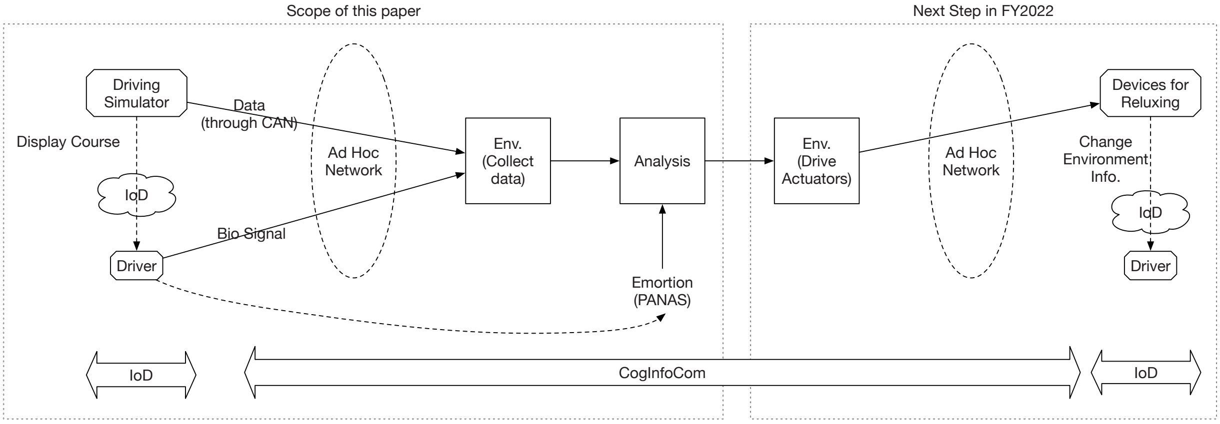


Fig. 6 System diagram for experiments.

fragrance, and lighting, present another function of the IoD. Information flow in the intervention process can be understood as CogInfoCom.

Based on the results of this analysis, signals were sent to devices (actuators) to control environmental variables such as music, fragrance, and lighting to provide drivers with awareness and stimulation and to reduce stress and fatigue.

D. Experiment courses

We set up two courses for the experiment, one representing part of the Tokyo Metropolitan Expressway and the other simulating part of a road in Paris.

1) Tokyo Metropolitan Expressway

As shown in Table III, the course of the Tokyo Metropolitan Expressway was set to darken as the day turned to night using the image-processing functions of the DS. In addition, weather variations such as rain, fog, and road surface reflections were added. By stimulating the driver with these changes and making the situation more stressful, the system was set up to facilitate the understanding of changes in biological signals such as brainwaves and body movements.

2) Paris

Simulation of Urban Mobility (SUMO) [29], an open-source road traffic simulator, was used to generate various traffic in the DS video and conditions similar to actual roads. We used SUMO to set up two situations on Paris roads that closely resembled driving on real roads. One involved a person suddenly jumping into traffic, and the other presented a situation in which the traffic gradually became congested, similar to actual road conditions. The reason for these two settings was to create situations in which the driver must be very careful while driving and pay attention.

V. Experiment and Results

This experiment was performed for three days (2021.12.7, 2022.1.12, and 2022.1.18). We conducted the experiment on two simulated test courses, including the Tokyo Metropolitan Expressway and the streets of Paris. Each driving session lasted 45 min.

The experimenter was a student who occasionally drove (female, age 21). Before and after driving in the DS, the participants completed a PANAS checklist on a 20-point scale. The results of the biosignal, DS data, and PANAS analyses in various cases are provided as follows.

A. Accelerator Pedal and Mental State (Paris)

Figs. 7 and 8 show the data of the accelerator pedal position before and after driving in the DS on the Paris course in 2022.1.18. The driver appeared to be driving carefully in the first lap, stepping on the accelerator pedal six times (Fig. 7). In

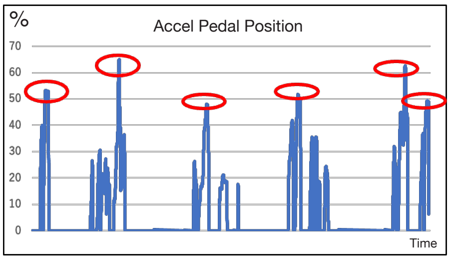
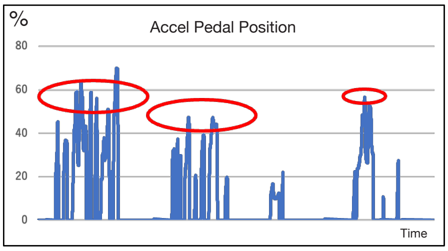


Fig. 7. Accelerator pedal (start).



Fig, 8. Accelerator pedal (end).

TABLE V
PANAS*

	Upset	Scared
Start	7	1
End	8	10
Difference (End-Start)	1	9

*Only items with large differences in PANAS are shown.

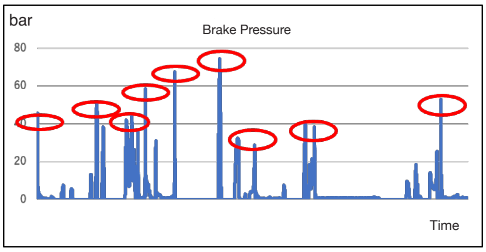


Fig. 9. Brake pressure (2021.12.7).

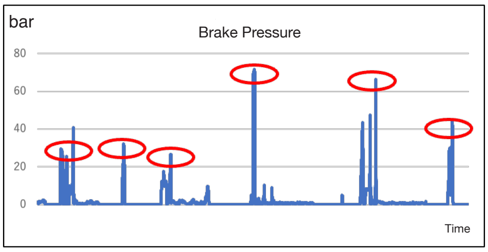


Fig. 10. Brake pressure (2022.1.18).

TABLE VI-1
PANAS (2021.12.7)

	Jittery	Attentive
Start	1	1
End	8	12
Difference (End-Start)	7	11

TABLE VI-2
PANAS (2022.1.18)

	Jittery	Attentive
Start	5	3
End	1	1
Difference (End-Start)	-4	-2

contrast, at the end of the final lap, the driver continued to step on the accelerator pedal, attempted to adjust while stepping on the accelerator pedal, and showed an affect that was not calm during the operation (Fig. 8).

Towards the end of the driving simulation, the roads often become crowded, and people sometimes jump into traffic. Here, drivers should proceed more carefully because of fatigue from driving for long periods or under stressful conditions, such as pedestrians jumping on the road unexpectedly. The PANAS showed that after driving, some values of the PANAS items indicating tiredness, such as "upset" and "scared," were higher (Table V). This suggests that a relationship may exist between accelerator pedal data and PANAS.

B. Brake Pedal and Mental State (Paris)

We compared the brake pressure data for 2021.12.7 (Fig. 8) and 2022.1.18 (Fig. 9). Comparing Figs. 9 and 10, the number of braking events in Fig. 9 was nine, whereas that in Fig. 10 was six. The braking strength exceeded 40 bars eight out of nine times, as shown in Fig. 9, whereas in Fig. 10, half of the cases were below 40 bars.

We now focus on the "jittery" and attentive items in PANAS, which indicate significant changes. In the situation shown in Fig. 9, a significant difference may be observed in the positive direction for these two items at the end of the drive (Table VI-1). In contrast, the situation shown in Fig. 10 was slightly negative (Table VI-2). This result indicates that the frequency and intensity of braking are related to emotions such as nervousness or attention. Higher frequency and intensity of braking may indicate increased tension and accelerated fatigue, as it shows an increased sense of nervousness and attention. Conversely, less frequent or weak braking may indicate less attention and more dangerous driving. In either case, if the change is more significant than usual, some stimulus must be provided to the drivers to get their attention and encourage them to be careful.

C. Accelerator Pedal and Mental State (Tokyo)

Here, we explain the relationship between the accelerator pedal and PANAS values when driving on the Tokyo Metropolitan Expressway course based on an experiment conducted on 2021.12.7.

As shown in Fig. 11, the driving and accelerator pedal operations were stable. Rainfall during the subsequent 20 min led to poor visibility. Thus, the driver's operation of the accelerator pedal was less intense, and she focused on driving. Near the end of the drive, the depression of the accelerator pedal tended to exceed 40° in a few locations, while it was nighttime, and the weather had improved. Rough driving can be attributed

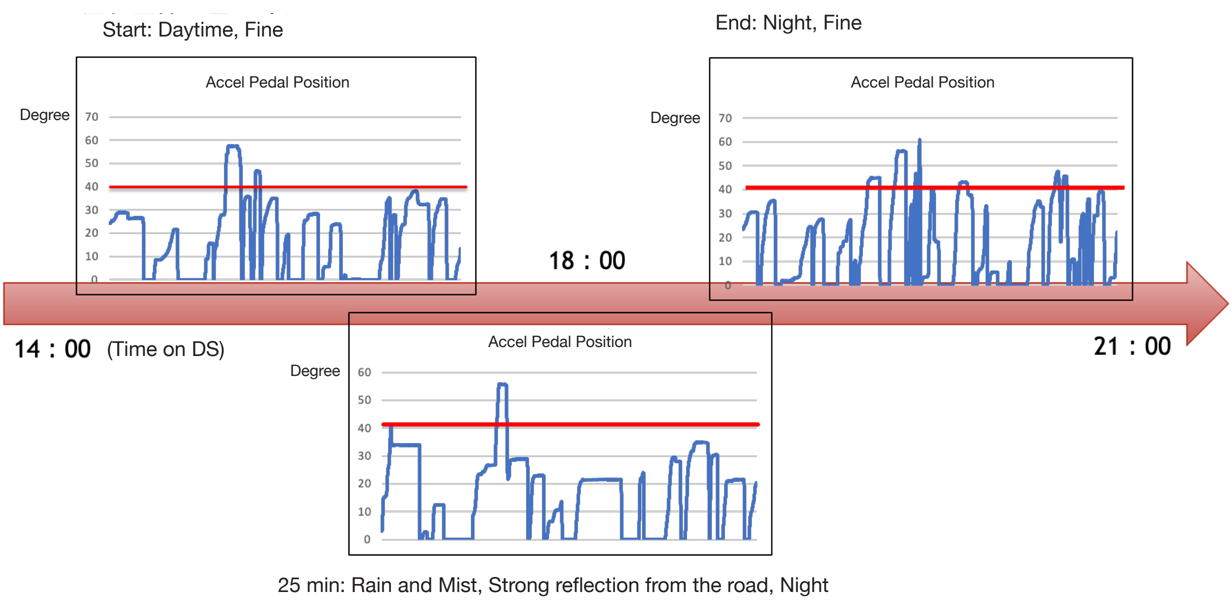


Fig. 11. Accelerator pedal (2021.12.7).

TABLE VII
PANAS (2021.12.7)

	Positive						Negative				
	Active	Enthusiastic	Interested	Excited	Proud	Attentive	Irritable	Jittery	Afraid	Guilty	Scared
Start	13	11	14	13	17	15	3	1	15	1	1
End	1	1	1	1	1	1	18	18	20	19	18
Difference (End-Start)	-12	-10	-13	-12	-16	-14	15	17	15	17	17

to fatigue caused by long-distance driving and poor concentration while driving in rainy weather.

Table VII presents the PANAS analysis results. After driving, positive affect scores decreased, and negative affect scores increased. This indicates that the driver was tired after driving for a long distance. Therefore, the Tokyo Metropolitan Expressway course differed from the Paris course in its lack of people and traffic, and attention significantly decreased after driving. This significantly differed from the conditions of the Paris simulation. Conversely, we infer that the presence of people and cars results in more cautious driving.

In addition, the driver's attention appeared to decrease over time, particularly as feelings of fatigue, upset, and fear intensified.

D. Brainwaves and Mental State (Tokyo)

We analyzed the relationship between brainwaves and PANAS based on an experiment conducted on 2022.1.12. Fig. 12 displays the values of the alpha wave (from 8 to 14 Hz) and beta wave (from 14 to 30 Hz), which are the results of the Fast Fourier Transformation (FFT) of the brainwaves. As shown in Fig. 12, the beta wave increased and the alpha wave decreased in the second half of each lap. Based on this result, the driver was evidently concentrated at the end of the lap, and her stress level increased.

The results of PANAS shown in Table VIII indicate the following.

- No change was observed in the Upset or Scared affects, which indicated negative effects such as fatigue.
- The Irritable item score was one before driving and 18 after driving, indicating that significant stress occurred.

E. Heart rate and Mental State (Tokyo, Paris)

Finally, we conducted a comparative analysis of heart rate and PANAS. As shown in Fig. 13, the driver's heart rate increased at the beginning of both the Paris and Tokyo Metropolitan Expressway experiments. However, at the end of the drives, her heart rate decreased when driving on the Tokyo Metropolitan Expressway and increased when driving on roads in Paris.

The PANAS data showed that the positive affect scores after driving were lower with a decreasing heart rate (Table IX-1) and higher with an increased heart rate (Table IX-2). There may be a correlation between an increase in heart rate and positive affect scores. We infer that the variations in heart rate and changes in positive effects are correlated.

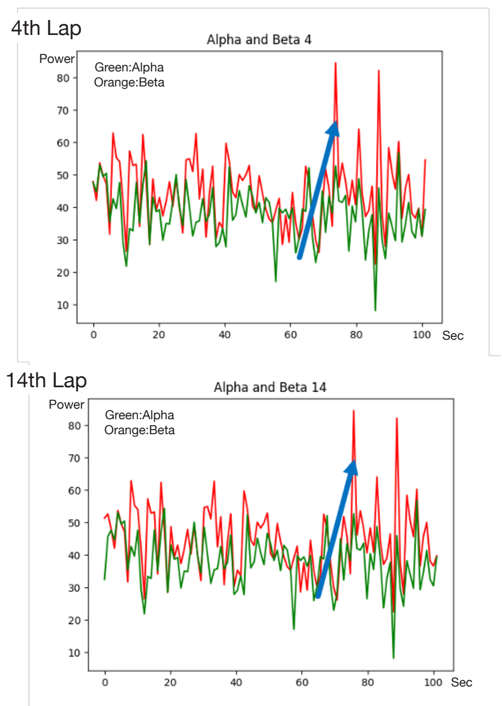


Fig. 12. Brainwaves (2022.1.12).

TABLE VIII
PANAS (2022.1.12)

	Irritable	Afraid	Upset	Scared
Start	1	1	1	1
End	18	1	1	1
Difference (End-Start)	17	0	0	0

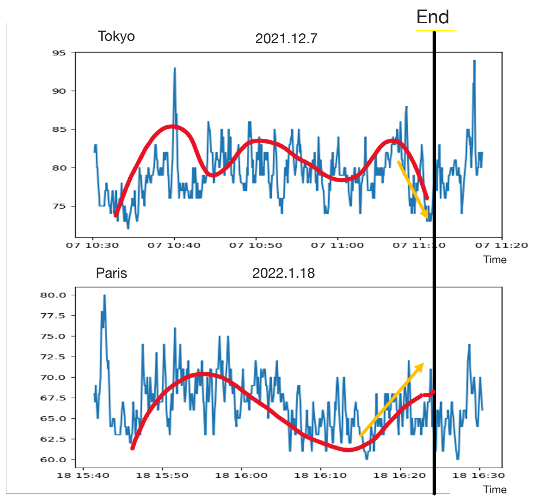


Fig. 13. Heart rate (2021.12.7 and 2022.1.18).

TABLE IX-1
PANAS (TOKYO)

		Strong	Inspired	Alert	Determined
Tokyo	Start	3	12	6	6
	End	1	9	1	1
	Difference (End-Start)	-2	-3	-5	-5

TABLE IX-2
PANAS (PARIS)

		Strong	Inspired	Alert	Determined
Paris	Start	1	1	1	1
	End	10	10	10	11
	Difference (End-Start)	9	9	9	10

VI. Conclusions

In this study, we have presented the results of an analysis of data on a driver's emotions obtained from PANAS, EEG readings, and other biological signals, as well as data from a car. In addition, we have explained the relationship between the experimental environment and the IoD.

Owing to the difficulty in visualizing the driver's emotions from biosignals and vehicle data alone, PANAS data were analyzed using other sensors to estimate emotions. The results show that the PANAS can be used as an indicator for estimating a driver's emotions.

This research provides a method for obtaining information on psychological states from car operation data and heartbeat information, which can be obtained relatively easily without special devices.

Although stress varies individually, most drivers typically experience some stress, regardless of their level of familiarity or experience with driving. Providing a comfortable driving environment for all drivers is possible by estimating stress and developing specialized technologies for this purpose.

Based on these findings, we can describe some promising directions for future studies.

Because the ECG sensor did not work well in the experimental environment, the ECG data were analyzed with PANAS to obtain a more detailed relationship between the drivers' emotions and the data from ECGs, EEGs, other biosignals, and driving.

Given that the PANAS questionnaire can only be administered before and after the test drive, we plan to investigate methods to administer the questionnaire while participants are driving.

Moreover, the extent to which brain waves and other biosignals would differ when obtained while a subject was driving a real car compared to a DS must be investigated.

In future work, we aim to contribute to the development of devices that change abient aspects such as light, fragrance, lighting, music, and conversation according to a driver's estimated mental state. Moreover, we plan to investigate how brainwaves change in response to these factors and the degree of improvement in terms of mental state that may be expected.

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A Novel Idea Generation Method for the Internet of Digital Reality Era: The Spinning Aufheben Method

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***Abstract*—Internet of Digital Reality (IoD) will be one of the essential next-generation information technologies. The content and presentation of information are the most important aspects that will make IoD work efficiently. However, the generation of ideas for IoD has not much progress in discussion because formalizing it is difficult. This paper presents an outline of the Spinning Aufheben (SA) method, which is a novel idea generation method, its application and model, validity, actual cases of the first application of the author, and potential social impact. *Aufheben* is one of the common mechanisms for generating ideas from two elements. This method enables the infinite generation of ideas by rotating three elements of a dialectic. We also present the result of pilot projects on 51 university students to determine its effectivity as an application for helping them determine future career plans after graduation. As a result, 46 students identified their career goals. The students expressed appreciation of the career search results using the SA method.**

***Index Terms*—CogInfoCom; Idea generation; Internet of Digital Reality; Kneading idea; Spinning Aufheben**

I. Introduction

Generating ideas is vital for economic activities. Therefore, scholars propose various methods for idea generation [1-3]. People need to generate ideas for various purposes such as business, creative work, and career design. Great innovation is rooted in great creativity. Reference [4] cites that "creativity is the invention or origination of any new valuable thing. It is a process of producing something that is both original and worthwhile and is one of the hardest human intelligence abilities." Therefore, creativity essentially underlies the generation of ideas.

In the ear of Internet of Digital Reality (IoD), generating ideas is important. IoD presents numerous possibilities. However, creating new services in IoD is becoming difficult, which can be analogized to finding a grain of sand in the ocean.

When generating ideas, two aspects should be considered.

(1) The number of ideas that can be generated within a limited time; and

(2) Consolidation of ideas.

The first author is currently a film director and writer, but he is involved in many fields such as management consulting, education, entrepreneurship, and advertising. These fields are seemingly very diversified, but, essentially, the core of his activities in each field remains the same, that is, idea generation. Especially, generating many ideas and selecting and improving them are important to his activities. For this reason, a method that supports this idea generation process is required. Through various experiences, we proposed a unique idea generation method called Spinning Aufheben (SA) [5], with which aufheben can be made multiple times for the same issue. This method was invented to solve two problems in idea generation based on *aufheben* and an infinite loop of dialectic. Aufheben is one of the common mechanisms for generating an idea from two elements.

This study provides details of the SA method, a mathematical model, and two actual cases. The remainder of the paper is structured as follows. Section 2 presents the outline of the SA method, whereas Section 3 cites related works. Section 4 describes the modeling and implementation. Section 5 explains the cases, and Section 6 discusses the details of a pilot project. Section 7 concludes.

II. The Spinning Aufheben Method

Combining two elements to generate ideas is a commonly used approach. When combining two elements, people intend to make an *aufheben* happen. The Oxford Dictionary of Philosophy defines aufheben as follows: "In the philosophy of Hegel, dialectical progress occurs when each of a thesis and its antithesis are aufgehoben, or overcome by a synthesis that builds only on the good bits of each." Thus, aufheben differs from the mere combination of two elements. In fact, it involves a third element, that is "value(s)," because it needs a certain direction to *progress*, as defined in the dictionary.

The SA method is used to generate ideas by consciously utilizing the value(s) as the third element. It is conducted in the following steps:

(1) Defining three elements for *thesis*, *antithesis*, and *synthesis*;

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(2) Finding key words for thesis and antithesis;
(3) Combining these key words to generate ideas;
(4) Defining these ideas and evaluating them from the point of view of the *synthesis* in the phase;
(5) Conducting a research and find a means to improve these ideas from the point of view of synthesis and polish them if applicable;
(6) Spinning the three elements of aufheben;
(7) Identifying new key words for each element for the new thesis and new antithesis;
(8) Generating ideas by combining the key words;
(9) Repeating Steps (2) to (7); and
(10) Undergoing steps (1) to (9) in loop until satisfactory ideas based on points of views with the three elements are found. The three elements can be changed or amended if necessary.

By introducing loop, we can infinitely generate ideas (solve problem (1)) and easily consolidate ideas by applying aufheben many times (solve problem (2)).

III. Related Works

A. Methods for Generate Ideas

"A technique for producing ideas" (James Webb Young, 1940 [1]) is a bible for people in the advertising industry. It says, "An idea is nothing more nor less than a new combination of old elements." However, it never mentions the process of combining ideas with an explanation: "This part of the process is harder to describe in concrete terms because it goes on entirely inside your head." It introduces five steps as follows.

Step 1: gather raw materials;
Step 2: working over these materials in your mind.
Step 3: the incubating stage, let something apart from the conscious mind do the work of synthesis;
Step 4: actual birth of the idea or the Eureka! I have it! stage.
Step 5: final shaping and development of the idea to practical usefulness.

This approach does not elucidate the process of implementing from Steps 3 to 5, whereas the SA method aims to solve a problem using the 10 abovementioned steps.

Another well-known technique for idea creation is the KJ method, which was introduced by and named after Jiro Kawakita. In his book entitled *Hasso-hou* (Abduction) in 1967 [2], the author says that, "This abduction method was originally developed for field research. It is especially true for the issues when trying to let the data speak by itself as an enlightened summary based on the data gathered by observation." According to Kawakita, the KJ method has four essential steps:

(a) label making;
(b) label grouping;
(c) chart making; and
(d) explanation.

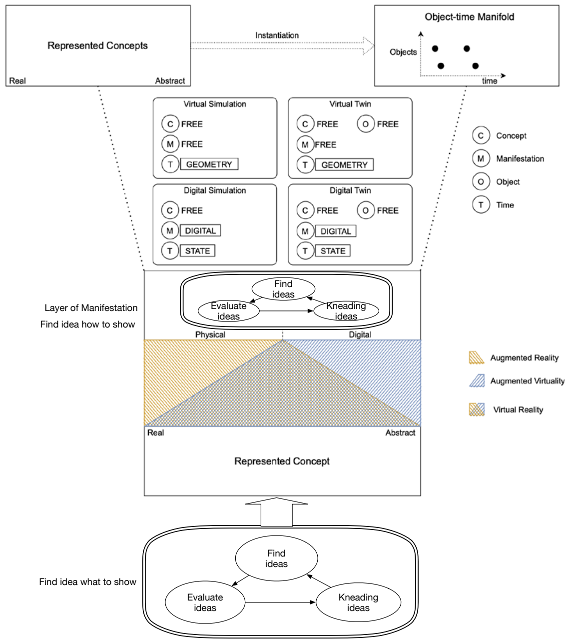


Fig. 1. Extended concept of IoD

nderstanding the KJ method can be conducted using various means: "The narrow-sense KJ method consists of three steps: brainstorming, grouping ideas into islands and writing a conclusion composition." [6], " The KJ method was developed as a result of having difficulties in interpreting ethnographic data in Nepal. The KJ method builds upon Charles Pierce's notions of abduction and relies upon intuitive non-logical thinking processes" [7]. The KJ method is used for variety of issues [8], [9].

Therefore, the KJ method is a helpful tool for understanding complex issues, for thinking through them using charts and language description, and for obtaining clues for ideas. However, as an approach, it does not help people use dialectic development, although a few people are developing software using the KJ method, which is similar to the objective of the SA method [4][10].

The SA method is a unique approach and is extremely different from two abovementioned approaches. In a sense, it helps people generate ideas using the three elements by rotating elements in the aufheben, such that people can combine multiple elements. Dialectic development is frequently used consciously or subconsciously to combine two elements for idea production. However, we realized a third element is always hidden, because people generate ideas by combining two elements. The reason is that people frequently lack ideas based on certain value(s). If the value(s) as an element is counted, then it becomes the third element, because the final ideas that people use must have at least three elements, namely, thesis, anti-thesis, and synthesis. The SA method can be used to consciously generate ideas that revolve around these three elements. The SA method also features kneading processes that utilize analytic hierarchy process (AHP), which is a quantitative decision-making technique that involves multiple competing criteria.

The SA method is similar to the approach suggested in the book *A Technique for Producing ideas*. However, The SA method is different in a sense that it has the utilization of the quantitative decision-making approach of AHP and the qualitative approach by describing to knead ideas consciously and utilizing dialectic development by revolving with the third element.

B. Internet of Digital Reality and Cognitive Infocommunication

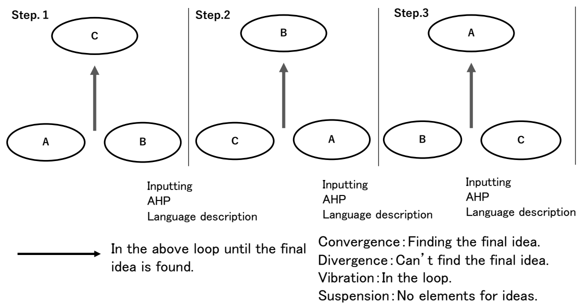
Recently, [11] and [12] propose a new concept called IoD. The author explains IoD as follows: "the Internet of Digital Reality (IoD) is a set of technologies that enables digital realities to be managed, transmitted, and harmonized in networked environments (both public and private), focusing on a higher level of user accessibility, impressiveness and experience with the help of virtual reality and artificial intelligence. Connections among various cognitive entities also have to be handled at the end-user level of virtual reality displays and software and at the levels of network protocols and network management, physical media (wired or wireless), hardware interfaces, and other equipment." In addition, IoD is an extension of cognitive infocommunication (CogInfoCom) [13] [14]. CogInfoCom investigates the link of the research areas infocommunication and cognitive science with various engineering applications that emerged as a synergic combination of these sciences. Communication is composed of three components, namely, media, informatics, and communication. CogInfoCom is situated in the region between cognitive informatics and cognitive communication to realize the virtual world.

In the paper [11], page 232, a Figure. explains the key concept of IoD. However, the current study opines that ensuring the effectivity of this framework is crucial. Moreover, providing high-quality and precise ideas to be presented by IoD is important. Fig. 1 displays an extended framework to which we added two parts. One is the bottom of Fig. 1 depicts idea creation as the rotation among idea creation, idea evaluation, and kneading to determine an idea of a presentation using the IoD framework. In addition, the same process is added to the layer of manifestation to determine an idea for demonstrating a concept.

Thus, we propose this idea generation and evaluation process called the SA method. This idea generation method is compelling and applicable to solutions for different problems.

C. Potential Social Impact

Society increasingly requires creativity. "No matter how advanced AI is, humans must have a realm of jobs. That is an ability to produce something from 0. The ability humans need to live 21st century where AI has prevailed is '*Koso Ryoku*', an ability to create new visions where nothing exists" [15]. The SA method can generate ideas According to our definition, visions are also ideas with objectives. If the SA method is enhanced with IoD, it can radically help people generate ideas or visions, which could significantly impact society.



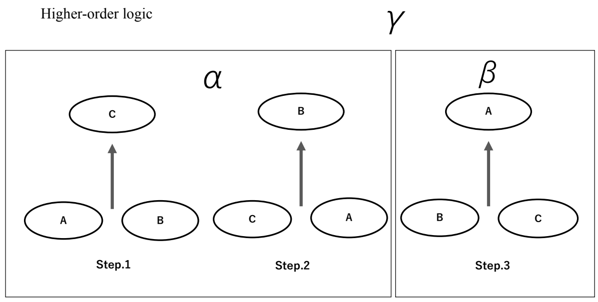


Fig. 3. Bird's eye view of SA method.

IV. Modeling and Implementation

A. Modeling the SA Method

As shown in Fig. 2, the SA method considers three elements, namely, thesis, antithesis, and synthesis, in dialectic development and ensures that each element is treated as synthesis at least once in the process of idea generation. Convergence refers to the "determination of the final idea; divergence means cannot find the final idea; vibration stands for "in the loop"; and suspension denotes "no elements for ideas." "Inputting" and "kneading and language description" are conducted at each dialectic development, and each element is examined.

Fig. 3 presents a bird's eye view of the SA method. Each synthesis from the dialectic development Steps.1 and 2 is used for another dialectic development. Using this dialectic development, "α" is generated as a synthesis. We have another dialectic development with the same elements as those of Step.1 and Step.2. However, in a way, the element for synthesis differs from that from Step.1 and Step.2. Through this dialectic development, "β" is generated as "synthesis." Now, "α" and "β" are used for another dialectic development in higher order. With this dialectic development, "γ" is generated as synthesis. As a result of this process, the final "idea" that incorporates the three elements is generated.

B. Mathematical Model

Fig. 4 depicts the mathematical model of the SA method. The diagram shows that the SA method has two inputs and one output: Input 1 for A, Input 2 for B, and output for C. Each input consists of *N* ideas. By combining them (up to *N* times *N*), ideas are generated in the middle of the process. By selecting ideas, the output is reduced to *N*.

The model has three functions: F1 generates ideas by combining A and B. F2 selects items from the result of F1. Therefore, the number of ideas is reduced from *N* times *N* to *N*. Moreover, F3 is changing the position of each element in the order, for example, from A–B–C to B–C–A.

C. Validity of the Model

Any idea must present multiple aspects, and if the aspects are counted as elements, then any idea is a combination of elements. Therefore, all ideas are pre-existing and are dependent on whether or not humans are aware of them. The SA method is a method for generating ideas, which is a process of finding a usable combination of elements from a pool of possible combinations of elements of which a person is unaware. Therefore, if a sufficiently robust computer can collect all information through a sufficiently extensive network, in theory, then any possible ideas or combinations must be found. If no necessary element exists for any particular idea, then the element is not generated or, accurately speaking, not found yet. The SA method helps people find certain combinations of elements that they particularly need in the scope of their needs. As suggested by the mathematical model, the person is in the loop until it finds the ideas. Therefore, if the person cannot generate an idea, then the combination for which the person is looking does not pre-exist.

D. Implementation using the Analytic Hierarchy Process

Saaty [16] introduced the AHP to solve unstructured economics, social sciences, and management: "The Analytic Hierarchy Process (AHP) is widely used by decision makers and researchers. The definition of criteria and the calculation of their weight are central in this method to assess the alternatives. [17]." Moreover, "the AHP (analytical hierarchy process) method is a method in the decision-making process. This method performs a hierarchical structure calculation where the top level in the hierarchy is the goal to be achieved, then the hierarchy below in the form of criteria in achieving goals, and the lowest level is the alternatives in achieving goals" [18]. It "is appropriate for those fields where intuition, rationality, and irrationality in connection with risk and uncertainty can be found" [19]. Frequently, AHP is used in creative decision-making [20]. Alternatively, even used in the decision-making process of major selection at college [21]. The abovementioned methods for using AHP are within the *decision-making* scope. Against this background, the current study intends to use AHP for two purposes, namely, (1) selecting and (2) understanding ideas better in the sense of specific hints for improvement, which is called *inspirations* or findings. In other words, people can determine whether or not they are happy about ideas while selecting ideas with AHP. Inspirations and findings should then be noted to help in idea generation at a later time.

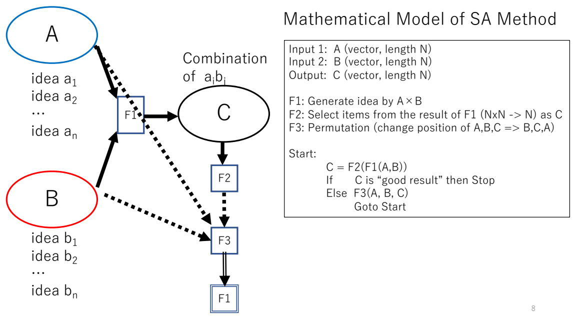


Fig. 4. Mathematical model of SA method

E. Future With the SA Method in IoD Era,

The SA method can create a large impact on society through various means such as education, entrepreneurship, manufacturing, creative work, and even daily life. With the mathematical implementation of the SA method, AI can automatically generate ideas using a few inputs from humans. For example, engineers can easily formulate product ideas using the mathematical implementation of the SA method as they work on vast information network of the Internet. Once the SA method with advancement in IoD (e.g., AI and network) is able to find necessary key words for humans, humans will no longer need to find key words by themselves and select from the list of ideas recommended by the SA method.

V. Cases

A. Sardine Man (*Career Development*)

The study presents an actual case the application of the first author of the SA method for the career development of a student. He taught filmmaking at a specialized training college in Osaka from 2014 to 2016. He began holding a form of online make-up class with two students for two sessions per week. One of them was T (aged 19 years), who dreamed of becoming a screenplay writer. He joined the writer's program at the school year but considered that finding a job would be difficult if he were to stay in the program for two whole years. Thus, he transferred to a movie/drama production program taught by the first author in the hopes of finding a job after graduation. The first author continued to advise him for two years and even one year after his graduation.

The first step: The first author asked him about his dream job, to which he provided a simple answer: "I want to write scripts for a series like 'Ultraman'. Thus, the first author decided to help him make an aufheben happen in a dialectic development using two elements, namely, uniqueness/strength and income. Uniqueness/strength needs to be cultivated, because he was still young and lacked professional skill as a screenplay writer. The first author taught him how to develop a story and write a screenplay. If he could write a professional screenplay, then he could earn an income. In the end, he fulfills a social need; in other words, he contributes to society. This notion was the first plan. However, merely possessing *story development and writing skills* does not make him a professional writer. As such, the first attempt to make a dialectic development with aufheben did not succeed with the elevation necessary to achieve his goal. At this point, he is only a young man with a few writing skills.

The second step: The first author considered various means to help his student achieve his dream. When the first author was researching on the Internet, he found a video on YouTube about crab fishermen in the Bering Sea. The job is very dangerous but pays extremely well. This concept became the input of the first author as an advisor to his student. He revolved the following elements for dialectic development: social contribution and uniqueness/strength for income. Social contribution should be interpreted as a broad term similar to social needs. The first author assumed that if his student had a similar experience to the crab fishermen in the Bering Sea, then the student could write a sufficiently appealing story. However, as working as a crab fisherman in the Bering Sea was extremely dangerous, the student decided to work as a sardine fisherman instead for one month in Shikoku Island across the tranquil inland sea from Osaka, his hometown.

An aufheben with sufficient elevation did not occur in the second dialectic development. People need to write approximately 50 ten-minute scripts for one year as a practice for being a screenplay writer based on the experience of the first author. In this manner, one can acquire the habit of looking for story ideas all the time and to become very observant. However, the student went to the sardine fishery without having written a sufficient amount of short scripts, because he wanted to find a job. When he returned, he found that he lacked material to write a good story. He failed to gather sufficient information for writing while working as a sardine fisherman. However, he became a young man with certain writing skills and an interesting experience.

The third step: The first author experienced an opportunity to appear in a TV show. In a meeting with an executive of a production company, the first author mentioned the student as “one of his students have some writing skills and an interesting experience with sardine fishery.” The executive told him that she wanted to meet him. Now, the student obtained a job at her company as an assistant director. Thus, one could say, “the first author arranged job matching,” but the interpretation of this study is different. The student gathered market information through the first author and made the third dialectic development, that is, income and social contribution through his uniqueness/strength.

As of 2022, the student has been with the company for several years. Whether or not he revolves the dialectic development further in his future is dependent on the student. He told the first author that if he has a chance, he wants to try sardine fishery again to add to his knowledge. A probability exists that the student is on his way to becoming a writer through the experience. His nickname at his job is “Iwashi Otoko,” which means sardine man. Using the SA method, an idea becomes better with each dialectic development, which is similar to a snowball, as the elements of the dialectic development revolve.

VI. Pilot Project

A. Research Methodology

To determine whether or not the SA method is effective as an application, we conducted a pilot project on 51 participants, specifically 45 third-year students majoring in engineering at Utsunomiya University and 6 first-year undergraduate multinational students majoring in economics at Chuo University. We requested the students to determine their career goals through the application of the SA method. We modified the dialectic development using specific three elements, namely, personal uniqueness/strength, income, and social contribution to revolve as the thesis, antithesis, and synthesis elements, respectively, for each of the three dialectic developments. The participants were provided with a fill-in instruction on Google Forms and a spreadsheet with calculation formulas. We tasked the participants with generating 25 ideas and selecting 10 ideas for each dialectic development. Lastly, they selected three out of 30 ideas based on their weighted sum. The students were given a week to finish their tasks. Afterward, we asked them to answer three questions using a 10-point Likert-type scale and asked them to add their comments to the following questions:

1. Are you happy with the result?
2. Did it help you to have a clearer idea?
3. Do you think you can utilize this method for other purposes apart from determining your career goals?

B. Result

After the project, the 45 students at Utsunomiya University and two out of six students at Chuo University completed the questionnaire. Figs. 5 to 7 represent the responses from the two schools, which were aggregated for the three figures. The figures depict the averages and standard deviations of the scores. The responses of the participants are widely dispersed. Fig. 5 indicates that the average is 6.46, and the mode is 7. Therefore, the SA method relatively led them to the right direction about their career goals. Fig. 6 presents that the average is 5.3, and the modes are 3, 5, and 6, which are widely dispersed. According to the quality analysis, which we will introduce later, a few students experienced difficulty in finding their unique ness/strength, whereas the others understood themselves better. Moreover, certain students conducted their research to understand issues better, whereas others felt the needs to conduct more research. The different responses to the same issues may have created various responses to the questions. Fig. 7 illustrates that the average is 4.65, and mode is 1, which are the lowest average and mode, respectively. We did not allow the students to flexibly change the element, which is the case of the first author did with the sardine man. For this reason, Fig. 7 may have provided the lowest mode.

According to the qualitative analysis of the additional comments, many students expressed difficulty in producing the 25 ideas for each phase, because doing so was time-consuming. Simply put, the number of ideas we requested them to generate for each step was very large. However, a few students reported

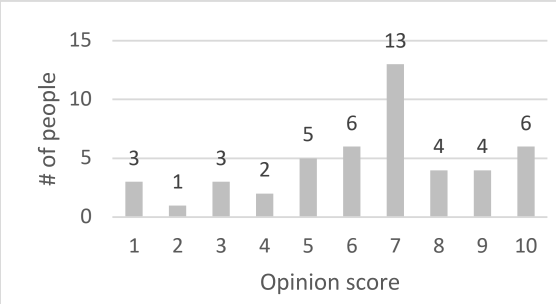


Fig. 5. Are you happy with the result? (n=47)
Average=6.46 S.D.=2.47

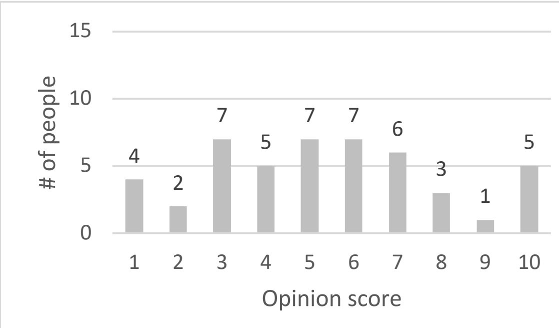


Fig. 6. Did it help you to have clearer idea? (n=47)
Average=5.35 S.D.=2.59

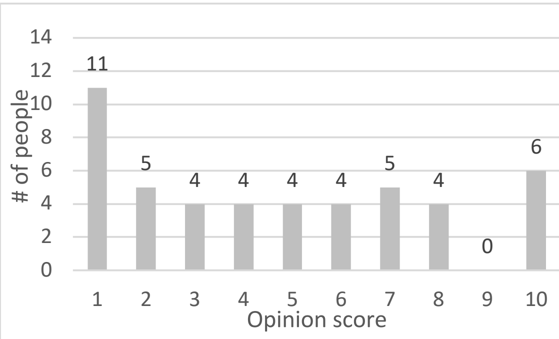


Fig. 7. Do you think you can utilize this method for other purpose? (n=47)
Average=4.65 S.D.=3.11

appreciation for the SA method as a solid strategy for producing ideas and considering issues in a step-by-step manner. The kneading process, which utilizes AHP, is working well, and the decision-making method is interesting for several students. This method helped students expand their list of ideas, and a few students produced career goals that they never previously considered. A few selected these career goals as their final ones through the pilot project. The SA method is very new to all students. For example, one student suggested the possibility of using the SA method for group work. Another student suggested that receiving input from friends, siblings, and parents could be helpful.

VII. Conclusion

This paper presents the outline of the SA method, which is a novel idea generation method for the IoD era. First, we defined two problems related to support tools for idea generation, namely, (1) generate a number of ideas within a short time and (2) consolidate ideas during generation. To solve these problems, we defined the thinking process of the SA method and described the relationship between the SA method and IoD/CogInfoCom. We then presented the mathematical model of the SA method and presented the effectiveness of the method using a case of career development. In addition, we presented the results of the pilot project to extract hidden problems in the application of the SA method for general purposes.

The following points constitute future tasks for improving the SA method.

First, a former professional in the advertising industry developed the SA method for generating ideas for various industries such as film and business. In the advertising industry, idea is everything. People spend billions of dollars on advertisements. Professionals in the advertising industry generate hundreds of ideas overnight for clients. However, the participants lacked experience. Therefore, perceiving that the SA method is difficult to use is relatively natural for them. In this regard, reducing the number of ideas to generate may be suitable for this population group in producing each phase.

Second, we did not provide sufficient research opportunities for the pilot project. If we provided students with comprehensive instructions on how students should conduct research, then the experience may have been different. A well-scheduled instruction design with a phase of research could significantly improve the SA method.

Third, if the students were to work with this method over a longer period, then the experience may also be very different. A career decision is a serious matter for students, who may require more time.

Lastly, the necessity and motivation for students to use the SA method vary according to individual differences. When students need to generate ideas, they may mostly utilize the SA method. The study proposes that the SA method holds a great potential in the IoD Era; however, it is still in its embryonic stage, such that further refinement is required through additional pilot projects on various samples.

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Design and Development of a Mobile-based Caretaking System for the Elderly People in Thailand: A Design Thinking Approach

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***Abstract*—As the ageing population has become a global phenomenon in the past few decades, it has brought several issues to many countries (e.g., aged care). Thailand has one of the highest ageing populations in the region, which has challenged society to find a feasible solution for promoting the elderly's quality of life while considering the vital role of caregivers in the aged care context. Thanks to the advances in ubiquitous mobile computing, mobile-based applications have become promising for the aged care sector. However, a limited number of mobile-based applications can cater to the needs of the elderly and caregivers, particularly in Thailand. Using the design thinking approach, we developed an innovative elderly caretaking system called 'Aegis' to effectively manage aged care by caregivers. Using this system, the elderly can effectively communicate with their caregivers, while the latter can easily support what the elderly need. We conducted a usability evaluation of 'Aegis' with three elderly-caregiver pairs in Thailand. The findings show that the 'Aegis' is useful in promoting the quality of life for the elderly and caregivers while considering the importance of user-friendly interface design and experiences. The usability recommendations suggested by this study can help HCI researchers understand design guidelines for intergenerational digital technologies.**

***Index Terms*—user interface design; usability; user experience; ageing; caregivers; mobile applications; design thinking**

I. Introduction

As people's life expectancy has increased over the past decades, the ageing population has become a global issue. According to the United Nations, it is predicted that by 2050, 1 in 6 people in the world will age 65 years or above [1]. This global phenomenon might bring challenges for many countries, such as inadequate healthcare systems and in need for social policies for aged care and elderly-friendly environments. Thailand is not an exception in these countries, with one of the world's most rapidly increasing ageing populations [2]. In 2022, Thailand transformed from an aging society to a senior community. Furthermore, it is also predicted that Thailand will be one of the first developing countries to transition to a hyper-aged community by 2035 [3]. As the ageing population is rapidly increasing in Thailand, it has concerned not only the government but also the individuals and families to provide adequate care for the elderly people. In this study, the elderly in Thailand refer to those 60 years or above [4].

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With increasing age, the elderly face age-related health complications, including chronic diseases (e.g., diabetes and hypertension) and a decline in their physical and cognitive health [5]. Hence, the elderly, who are in need of healthcare commodities, amenities, and services, may require assistance from others to perform daily tasks (e.g., house chores) while taking care of themselves (e.g., taking medicine). In Thailand, caregivers, who closely take care of the elderly, are mostly the adult family members of a household or their close relatives. The potential issue caregivers encounter in aged care in Thailand is that they cannot devote their time to aged care due to their limited time (e.g., full-time jobs). The approaches and tools in aged care in Thailand include conventional and digital means such as face-to-face communication, instant messaging, and voice and/or video calls. Although having benefits, these approaches are highly limited in effectively keeping track of the elderly's condition throughout the day, as caregivers may be often responsible for other tasks as well [6]. At times, the elderly may even be entrusted to take care of themselves without a caregiver's presence. This situation gives rise to many risks from unexpected health problems or physical accidents.

Over the past few decades, researchers and developers have used up-to-date technologies to replace traditional methods for aged care. For instance, they have used assistive technologies (e.g., social robots) [7], game-based exercises [8], and wearable technologies [9]. Furthermore, the increase in smartphone ownership in Thailand [10] and advancements in internet and mobile technologies have suggested that a smartphone-based application may be an alternative and a feasible solution to aged care. Using such intelligent technologies, not only can caregivers easily communicate with the elderly, but also, they can provide adequate care for the elderly. According to [31], in the 2nd quarter of 2022, 70.1% of the age group (50+ years) used smartphones in Thailand, and this trend is expected to grow in the upcoming years. The literature also describes that elderly smartphone users are increasing in Thailand [11]. The use of smartphones for aged care has also been growing due to their accessibility, convenience, portability, and affordable prices [12].

Although mobile-based health management systems, in general, are promising for aged care, the existing tools are not explicitly designed for the elderly in Thailand. Furthermore, such devices do not address the cultural needs of the elderly in Thailand (e.g., language). Also, the existing tools in aged care mainly target elderly users. To the best of my knowledge, a limited number of applications cater to the elderly and caregivers in Thailand. Hence, in this study, we aimed to innovate a mobile-based application that will help caregivers quickly and effectively monitor and manage the elderly's health and activities of daily living. Furthermore, it can help the elderly manage themselves (e.g., reminders or health data recording) and communicate effectively with their caregivers.

To achieve our goals, in this study, the '*design thinking*' approach was adopted in which we empathized, designed, and developed an innovative system in a human-centric way to address unmet users' needs [13]. Through the iterative process, we designed, developed, and conducted a pilot usability evaluation of '*Aegis,'* a customizable mobile-based caretaking system. The main objectives of the study include: 1) to understand users' needs in aged care in Thailand, 2) to design and develop a user-friendly and innovative mobile-based system for both stakeholders, and 3) to evaluate the usability, user experience, and usefulness of '*Aegis'* so that it can contribute to future design and development of caretaking systems in aged care.

II. Related studies

Regarding related studies to this project, in [40], the researchers used the commercial Nintendo Wii games and controllers as an entertainment and socialization tool for improving the mental and social health of the elderly in Singapore. The findings from their study reported that commercialized digital games (e.g., Wii and its controllers) are promising for helping the elderly improve their quality of life. According to [41], the researchers designed and developed a digital social activity space for the elderly in Singapore and investigated how elderly users socially interacted with peers on a virtual social platform. Their findings reported that digital-based social activities could enhance the elderly users' social interactions, particularly intergenerational ties (e.g., older and younger generations). Similarly, in [5], the researcher suggested that digital game-based physical exercises could enhance the Finnish elderly people's participation and engagement in exercise activities. Such intervention could help them feel motivated in exercise adherence. Also, in [32], the researchers advocated the use of exergaming for improving the elderly's social interaction, and their findings report that different types of social interaction and competitive information provided by exergames could affect the elderly players' motivation and attitude toward playing exergames. By using three different activity settings: exergames, conventional non-digital exercise, and non-exercise daily activities of the elderly, the researchers [33] measured the outcome from three various interventions and reported that exergames are promising for improving the physical functionality of the elderly, as well as their cognition in doing exercises (e.g., attention and memory). In terms of effective communication between the older and younger generations, interventions such as intergenerational digital games could help enhance the relationship between the two generations [34, 43]. Although the existing research shows promising results of using digital technology for the quality of life for the elderly, there is limited study in the context of Thailand and Thai elderly people and caregivers. Specifically, to the best of the authors' knowledge, no existing application can effectively solve the communication gap between the elderly and their caregivers regarding healthcare and management. Furthermore, there is no all-in-one system that can cater to aged care, such as reminder system, health management, emergency contact, emotion tracking, etc.

In recent years, as ubiquitous communication and related technologies have become advanced, the research area of cognitive infocommunications (CogInfoCom) has attracted many researchers in different research areas to study how users' cognition can co-evolve with infocommunications devices such as mobile, tablets, and wearable devices, and Internet of things (IoT) sensors [35]. As stated in [36], *CogInfoCom* is a relatively young research area; however, due to its agility, many research areas overlap with *CogInfoCom*, such as interaction design, human-computer interaction (HCI), artificial intelligence, human-centric computing, and data science. Over the past few years, researchers from different disciplines have studied *CogInfoCom* by combining it with specific research areas. For instance, in [38], the researchers designed and implemented a metaverse-like virtual space for organizations to conduct business events and functions (e.g., meetings and seminars). They studied how users interacted with each other, focusing on the cognitive aspects of users (e.g., attention and memory).

Similarly, in [37], the researchers developed a game-based exercise system to improve the elderly's mental well-being regarding their cognitions (e.g., attention, memory, and learning). In [39], the researchers studied the importance of users' cognition in using VR-based exercise systems for their physical health. The findings showed that VR-based games could help users engage in exercise activities. In [42], a virtual evaluation to assess users' driving acuity and spatial perceptual capacity was designed and developed. Then, the researchers discussed how this tool could be utilized mainly for training driving skills and various purposes in cognitive neuroscience.

The existing literature highlights the importance of user cognition in using digital technologies and communication systems; hence, one of the objectives of our study is to investigate how the system's interface design can impact users' cognition in terms of their attention, memory, and learning. For instance, we aimed to understand if elderly users could quickly learn and use the system without having cognitive complexities. Similarly, we would like to study whether caregivers found the system user-friendly, usable, and useful. Furthermore, we applied existing HCI guidelines, UX laws, and principles to ensure the system is user-friendly and supports users' cognition regarding attention, memory, and learnability. To achieve these objectives, in this study, we adopted the *'design thinking* methodology to design and develop a user-centric mobile application that tackles the issues discussed earlier. During the process, we would gain the requirements and needs of users through empathy-based user research (e.g., interviews, questionnaire, and observation), followed by designing and developing the application that conforms to the user experience and interfaces design principles. Eventually, we conducted the usability evaluation of the system with users (both the elderly and caregivers) to understand their user experiences and how the interface design impacts users' cognitions. The findings from this study can help researchers and practitioners in HCI, *CogInfoCom*, and gerontechnology (technology for ageing) and create opportunities for future research.

III. Design Thinking

In this study, we employed '*design thinking*,' a principle that uses an iterative process to deliver user-oriented solutions to solve pre-existing problems. According to the Interaction-Design Foundation [28], using design thinking approach, designers and teams understand their target users, empathize with their needs and pain points, create assumptions, redefine the existing problems, and innovate human-centric solutions to prototype and test. This methodology is also effective in uncovering and tackling unknown or unclear user problems. Also, IDEOU [29], one of the pioneers in design thinking, also highlights that this methodology can help organizations and design teams understand the unmet needs of the target audience while encouraging the creative potential of designers and teams. Also, it allows designers deeply understand the existing and underlying problems and target users' goals [14]. In [30], the author also points out that design thinking can invoke designers' analytical and creative thoughts to solve problems that consider context, users' requirements and preferences, logistical issues, and cost.

Understanding the users allows us to tackle the problem at its root and help them create an effective user-oriented product. In this study, one of the objectives is to design and implement a user-friendly mobile application for the elderly and caregivers in health management. Hence, an in-depth understanding of our target users, the elderly and caregivers, is crucial in this study. While understanding their pain points, we aimed to develop practical solutions to address their unmet needs. Considering all these, we chose the 'design thinking' methodology due to its human-centric nature and creativity that contains five stages: Empathize, Define, Ideate, Prototype, and Test. First, in the '*Empathize*' phase, we conducted an empathy-based interview study in which we listened to, discussed, and empathized with our target users' existing problems and pain points. The interview study consisted of 20 sessions with ten elderly people and ten caregivers to understand our target users in-depth. The interview covered the existing methods in aged care, tools, and, more importantly, barriers they had. Afterward, we reviewed and analyzed the interview data. The findings from the user interviews highlighted that currently, there is no effective and unified method in healthcare management for elderly people and caregivers particularly in Thailand. As a result, the communication between the elderly and the caregivers are ineffective and delayed. Also, healthcare management (e.g., health records and reminders) is inefficient mainly due to the busy schedule of caregivers and the young family members of a household, particularly in Thailand. For instance, most caregivers use various methods to remind the elderly to take medicine on time (e.g., daily diabetes medication) and record their health data (e.g., blood pressure). More importantly, in emergencies, the elderly can only use traditional methods, including making a phone call or sending messages through chat communication systems (e.g., LINE). These findings from the user interviews clearly showed a need for an effective system for the elderly and caregivers in terms of communication, health management, and records.

In the '*Define*' stage, based on the findings from the interview data, we created a persona for each stakeholder: the elderly and the caregiver. According to [15], the persona is a fictional character that helps us understand our target users' needs, experiences, behaviors, and goals. In this study, the elderly persona (see Figure 1) depicts the frustrations of elderly people in terms of communication with their caregivers and the lack of practical solutions. It also illustrates their needs and goals. Similarly, the caregiver persona (see Figure 2) demonstrates the pain points of caregivers in managing the elderly's health and support while highlighting their needs and goals. In addition to the user personas, to effectively define our target users' needs, we employed the '*empathy map*' in which a visualization tool was used to show insights into users' emotions, needs clearly, and wants. Furthermore, it helped us articulate what we knew about our users and justified and empathized with the reasons behind each user's needs and wants.

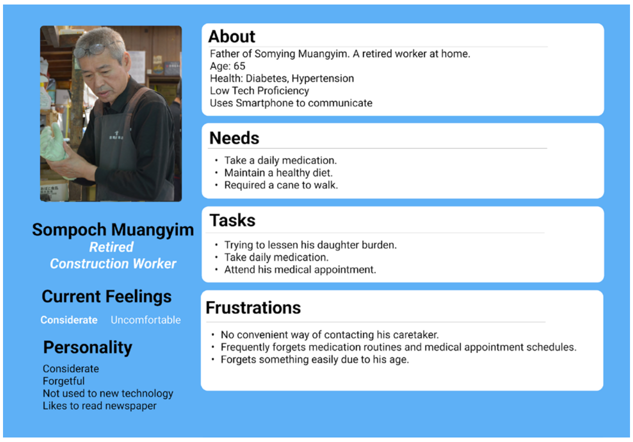

Fig. 1. The elderly persona [44]

Fig. 2. The caregiver persona [44]

Afterward, we created a customer journey map (CJM) for each person to understand what users experienced when interacting with a particular service, product, and system [16]. In this study, we created a CJM for each persona: the elderly and the caregiver. The CJM for the elderly describes how they interact with various touch points in their journey in terms of performing a user's tasks, such as communication, healthcare management, and records. It also depicts their emotions along the trip (e.g., positive and negative). It clearly shows the gaps to be addressed and what to improve regarding user experiences and their feelings.

Before moving to the '*Ideate*' phase, we revisited and identified the important user needs and pain points based on the *'Define'* phase findings. Then, using the features matrix technique, in the '*Ideate'* phase, we determined the system's features with respect to our target user's needs derived from the empathy map, user persona, and user journey map. For instance, in this study, based on the users' needs, we created a module called *'reminder'* for both the elderly and caregivers to communicate with each other in terms of healthcare and communication management effectively. Similarly, we also created the '*health record'* module in which both the elderly and caregiver users can effectively and efficiently keep track of the health-related data of the elderly. The *'emergency alert*' module is designed for elderly users to immediately and easily notify their caregivers and immediate family members when they are in an emergency. The *'memory recall*' module is designed for the elderly and caregivers to support the former's cognitive abilities through well-designed game-like questionnaires. Lastly, the *'emotion tracking*' module,

After the '*Ideation'* phase, we continued to the '*Prototyping'* phase, in which we designed and developed the '*Aegis'* system. First, we developed a low-fidelity prototype, followed by a quick evaluation with our target users. Based on the early feedback from the users, we then prototyped the high-fidelity functional system of '*Aegis,'* which consists of five modules for both the elderly people and caregivers, namely '*reminder,'* '*health record*,' '*emergency alert,'* '*memory recall*,' and '*emotion tracking'*. Figure 3 shows the conceptual diagram of '*Aegis'*.

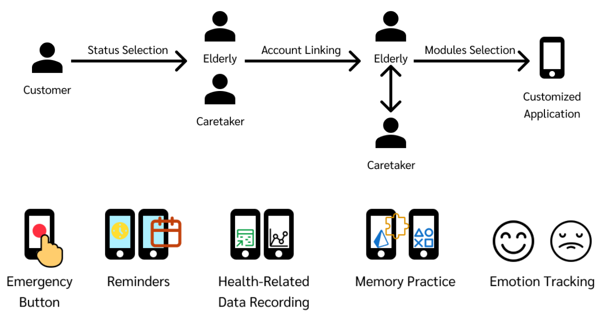

Fig. 3. The conceptual diagram of '*Aegis.'*

In the '*reminder'* module, both the elderly people and caregivers can mutually set up a reminder for various purposes (e.g., medical appointments). In the '*health record*' module, the elderly and caregivers can record health-related inputs such as daily blood pressure. In the '*emergency'* module, when the elderly person needs immediate help, they can alert the caregiver by pressing the '*emergency'* button (see Figure 4-left). In the '*memory recall'* module, the caregiver can set up a simple cognitive assessment for the elderly. For instance, the caregiver can create simple questions such as '*When is the name of the temple we visited last week?*' so that the elderly can choose a relevant answer from the given options.

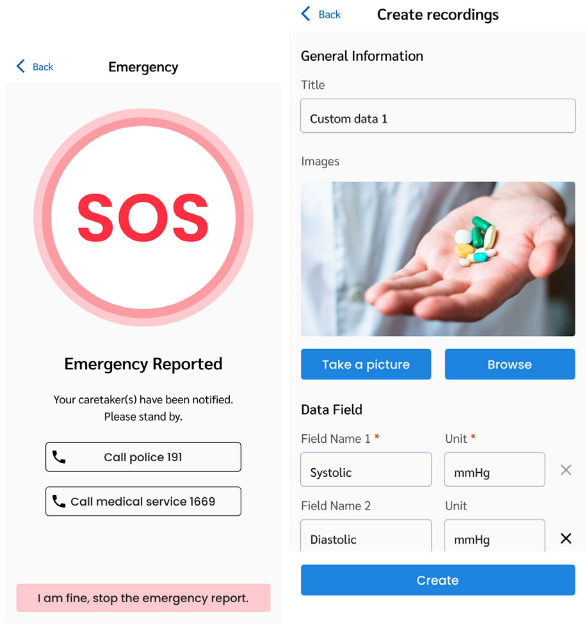

Fig. 4. Aegis' emergency (left) and health record modules (right)

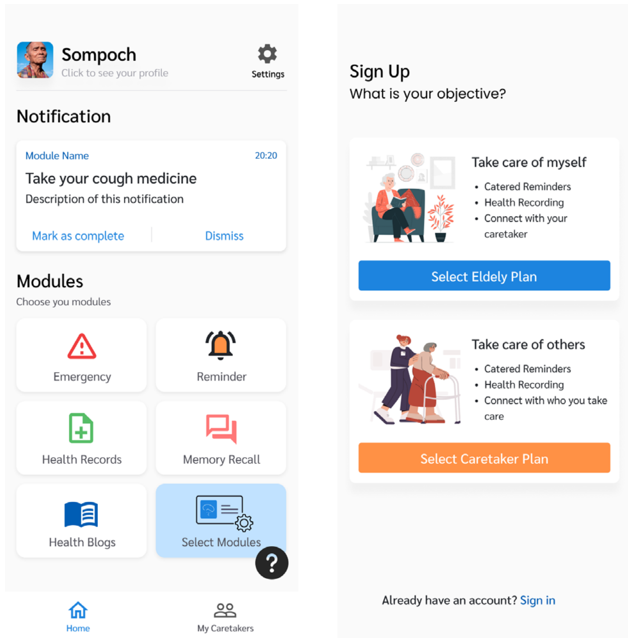

Fig. 5. Aegis' elderly module

Lastly, in the *'emotion tracking*' module, the system will encourage the elderly to respond to their current emotion by choosing an emoticon, and the caregiver will be able to track the elderly user's present emotions. The system also supports authentication and profile management for both the elderly and caregiver users, as well as a linkage system to synchronize and communicate with each other effectively. Furthermore, it supports an '*analytical module*' that helps the elderly and the caregiver gain insights into the physical and mental status of the elderly. Figure 5 shows the elderly module of *'Aegis'*.

One of the goals of this study is to provide an effective and user-friendly or age-friendly system for our target users. Hence, in designing '*Aegis,'* we applied the existing and widely-accepted human-computer interaction (HCI) and usability guidelines to the high-fidelity user interface based on three principles: easy-to-use, modular, and non-disruptive, on top of the low-fidelity design. Examples of the application of the design principles include good color contrast, appropriate text size, minimum steps to complete a task, customizable functionality modules, and non-intrusive advertisements. Moreover, user experience design laws were extensively considered as the target user groups, the elderly and caregivers, were not very familiar. Hence, they needed the most comfortable user journey to use the application. For instance, we applied *Fitts's law* by creating touch targets that are large enough for our target users to select them quickly and accurately [17]. Also, we used *Jakob's law*; for instance, the log-in page of the system was based on the standard log-in page design that can be familiar to our target users [18]. In addition, we applied other laws, including *Hick's law* (minimize choices for user's decision), *Miller's law* (smaller chunks to help target users process the task), and *Gestalt principles* of UX design (e.g., laws of proximity) [18].

We also used the heuristics guidelines by Nielsen [19] as follows. First is the visibility of system status; for example, on the onboarding page, the number of pages is displayed. Second, for '*user control and freedom*', users can freely include or exclude functional modules and customize reminders, health records, and profiles. Third, for '*consistency and standards*', the whole application is designed in a single-color theme. Moreover, many user interface components are reused throughout the application. Fourth, for '*error prevention*', feedback and information are displayed with understandable and clear messages for general users using easy-to-understand descriptions. Fifth, for '*recognition rather than recall'*, for example, every text input has an intuitive hint so that users can easily recognize it rather than recall it when they revisit the system. Sixth, for '*help and documentation*', for example, there are tour guide pages in every functional module that will automatically introduce the users to the module's capabilities and usage on their first visit, and the users can revisit them. Lastly, for '*reduce cognitive load*', for example, components unrelated to the current functional module and components that add additional complexities to the primary usage are kept hidden by default.

As displayed in Figure 6, in the '*Aegis'* system, we applied the 3-tier architecture. The servers are dedicated to processing and data storage, which would be deployed via Google Cloud Run and Google Cloud Platform's compute engine, respectively. For the technologies we used in this system, React Native framework was the primary technology used for this application development. At the same time, Nest.js was the leading software package for the dedicated service, operated in the background. MySQL database system was chosen as the database in this application. The application would run on Android 10.0 or above for the operational software requirements, which is one of the most popular mobile operating systems among elderly users in Thailand, according to our user research. The applicable device would be equipped with sufficient RAM and storage, and it would be connected to Wi-Fi or a cellular network with a standard data rate or above. The system would always have a stable network connection to enable real-time database updates.

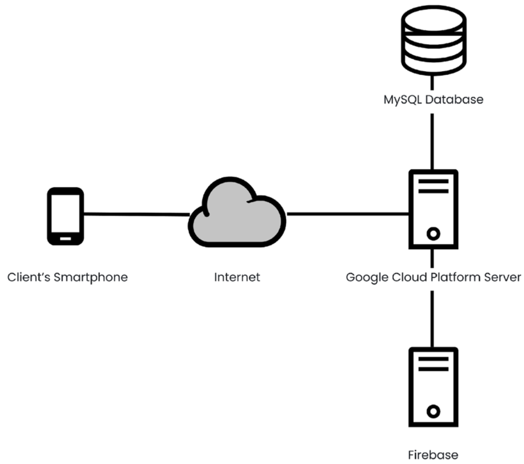

Fig. 6. Technical diagram of 'Aegis.'

IV. Pilot usability testing

After designing and implementing the functional system of '*Aegis,'* we conducted a pilot usability testing to investigate whether our target users could perform the designated tasks. Also, we aimed to understand the usability and user experiences in using it and to explore whether the chosen UI principles are suitable for elderly users and caregivers. According to [20], '*usability testing*' refers to evaluating a system or product by testing it with target users in which participants will perform and accomplish typical tasks. At the same time, UX researchers watch, listen, and take notes on the interaction between users and the system. The ultimate goal of the usability test is to identify any usability problems encountered by users, gather qualitative and quantitative data, and investigate if participants are satisfied with the product. Generally, usability testing constitutes learnability, efficiency, memorability, errors, and satisfaction [21]. This study conducted a pilot usability test with three elderly people and three caregivers who voluntarily participated in the trial. The number of participants was three per group of users, as suggested in [22]. The participants were recruited based on the user personas defined in the '*Define'* phase. For the inclusion criteria of the participants, the elderly must be between 60 and 80 years old, and they must be taken care of by family members. The caregiver participants must be less than 60 years old and have at least one elderly-in-care member.

In this case, we conducted the test in a natural setting at the elderly participants' homes. Each participant performed the usability testing individually at their home in the most comfortable settings, in a quiet environment, and used their Android smartphone. The duration of each usability test was approximately 60 minutes. At the beginning of the usability testing, an introduction to the project and instructions about the usability testing were given to the participant. The participant was also informed about the voice recording and use of data for the analysis. Then, with the help of a UX researcher, each participant was required to fill in the pre-study questionnaire, which asks for age, gender, health conditions, occupation, and the number of caregivers and elderly care. Next, the participant was asked to perform a list of tasks that covered the main functionalities of the '*Aegis'* application. While performing the tasks, we adopted the '*Think-aloud'* technique, which requires the user to verbally express their thoughts or planning, with their voice recorded. At the same time, the UX researcher filled in the feedback capture grid for each task the participant was performing. The feedback capture grid is a grid that collects information about the things the participants liked, constructive criticism, questions that arose, and additional ideas from the test [18]. After completing the tasks, the participants were asked to fill in the post-study questionnaire. The team used the *System Usability Scale* (SUS) to gain a quantitative measurement of the application's usability. According to Sauro [22], *SUS* is the most used questionnaire-based instrument for measuring the usability of a system or product, consisting of 10 questions and five response options (5-point Likert scale) that measure from *strongly agre*e to *disagree strongly*'' SUS is an easy tool due to its simple scaling system. It can be used in small sample sizes [23]. Table I shows the design and procedures of the pilot usability testing.

TABLE I
USABILITY TESTING DESIGN AND PROCEDURES

No.	Step-by-Step Testing Procedures			
	Task Description	***The Elderly***	***Caregiver***	***Duration***
1	Introduction to the usability testing and Informed consent	Yes	Yes	5-mins
2	Pre-study questionnaire	Yes	Yes	10-mins
3	User testing Task 1: Sign up	Yes	Yes	10-mins
3.1	Feedback Capture Grid for Task 1	Yes	Yes	10-mins
4	User testing Task 2: Navigate to the personal QR code screen to link with the elderly or caregiver	Yes	Yes	10-mins
4.1	Feedback Capture Grid for Task 2	Yes	Yes	10-mins
5a	User testing Task 3: Add Health Record Module and Memory Recall to the module list	Yes	No	10-mins
5b	User testing Task 3: Create a health record table to keep track of blood pressure and add one record (filling in the upper value with 120 and the lower value of blood pressure with 80)	Yes	Yes	10-mins
5.1	Feedback Capture Grid for Task 3	Yes	Yes	5-mins
6a	Using testing Task 4: Press the emergency button to report the emergency	Yes	No	10-mins
6b	User testing Task 4: Check the emergency notification and view the elderly's location	No	Yes	5-mins
6.1	Feedback Capture Grid for Task 4	Yes	Yes	5-mins
7	Post-study Questionnaires SUS	Yes	Yes	10-mins
8	Post-study Interview	Yes	Yes	10-mins

V. RESULTS AND FINDINGS

In this study, the responses from the pre-study questionnaire, SUS, feedback capture grid, and notes from post-study interviews were analyzed to understand if '*Aegis'* is usable and user-friendly for our target users: the elderly and caregivers. More importantly, based on the results, we researched and discussed if the participants could successfully execute all the tasks in the pilot usability testing. Afterward, we also analyzed and discussed if the '*Aegis'* was well-accepted by both stakeholders. Lastly, we explored the user's satisfaction with using this system and their intention to adopt it in future aged care. According to the findings, the average age of the elderly participants is 65 years, ranging from 62 to 72 years old. The average age of caregivers is 53, and the range is from 51 to 57. There were two male and one female elderly participant, while one female and two caregivers participated in this study. All elderly participants have chronic health conditions (e.g., diabetes), while the caregivers are generally healthy. The elderly participants had prior experiences in using mobile phones and apps, while the caregivers were also familiar with such technologies. Table II shows the user profiles of the individual participants. Participants' profile

TABLE II
PARTICIPANTS' PROFIL

	Elderly Participants			***Caregivers***		
	E1	***E2***	***E3***	***C1***	***C2***	***C3***
Age	72	62	62	51	57	51
Gender	M	M	F	F	M	M
Occupation	Retired Business Owner	Public Officer	Public Officer	Hous ewife	Business man	Business man
Health Conditions	High blood pressure, overweight	Heart condition	Hypertension Pre-diabetes	-	Physical Pain	-

The overall usability of the application could be deduced mainly from the SUS scores (see Table III). The SUS scores were calculated using the SUS scoring formula provided in [24]. For each response, the scores of all odd items were summed together before being subtracted by 5. Then, 25 was subtracted from the sum of all actual items. Finally, the two values were summed together before multiplying them by 2.5 to give the SUS score. The average score of the '*Aegis'* mobile application is 72.1 points, which corresponds to the adjective rating of '*Good*' and falls into the acceptable range [25]. The sample standard deviation was calculated to be 19.5 points. The 80% confidence interval of the '*Aegis'* SUS score is from 60.4 to 83.8 points. The 60.4 and 83.8 falls in marginal and acceptable acceptability ranges, respectively. The result from the SUS questionnaire indicates that the usability of the current prototype of the '*Aegis'* application is acceptable. However, further improvements could still be made to the design to enhance the user experience and make the application more attractive and usable to the users. Table III displays the SUS scores of the individual participants and overall scores.

TABLE III
SUS Scores

	Elderly Participants			*Caregivers*		
	E1	*E2*	*E3*	*C1*	*C2*	*C3*
I want to use this application frequently.	5	5	5	5	3	5
I found the application unnecessarily complex.	2	2	4	2	3	1
I thought the application was easy to use.	4	4	3	4	2	5
I think that I would need the support of a technical person to be able to use this application.	5	1	4	3	1	1
I found the various functions in this application were well integrated.	3	5	4	4	1	4
I thought there was too much inconsistency in this application.	1	1	2	2	2	1
I imagine that most people would learn to use this application very quickly.	4	4	3	5	3	5
I think that I would need the support of a technical person to be able to use this application.	5	1	4	3	1	1
I found the various functions in this application were well integrated.	3	5	4	4	1	4
I thought there was too much inconsistency in this application.	1	1	2	2	2	1
Overall SUS Scores	65	87.5	55	80	47.5	97.5

Qualitative data from the feedback capture grids and post-study interviews were analyzed by grouping feedback with related topics into the same categories. The frequency that each topic occurred among each group also signified the importance of the topic towards the system's usability and user satisfaction. Based on the findings, we discussed the following issues. Both the elderly participants and caregivers agreed that '*Aegis'* is a promising application that could improve the overall communication between the elderly and caregivers in terms of elderly care both social, mental, and physical care. terms of elderly care both social, mental, and physical care. For instance, the elderly and caregiver participants recommended that the reminder be one of the most valuable features of the '*Aegis' application*. Not only does it help the elderly participants perform their tasks effectively, but also it helps the caregivers manage the elderly care effectively and efficiently.

Furthermore, both user groups mentioned that '*health data record'* is an essential and useful module in which the elderly and caregivers could easily monitor and keep track of their previous health status. Furthermore, the emergency module is useful for the elderly and caregivers in an emergency, for instance, if the elderly falls at home while no one is around, they can quickly press the button to notify their caregivers. The '*memory recall'* functionality could improve the elderly's cognitive health and maintain social communication between two user groups. Lastly, they both recommended that the *emotion tracking* feature is simple but helpful in expressing the elderly's current emotions, which their caregivers can easily track and provide emotional and physical support to the elderly.

The qualitative feedback on the usability and user interface design by the elderly and caregiver participants suggests that '*Aegis'* has offered a simple, age-friendly user interface suitable for both user groups. They all agreed that although they used the system for the first time, they could easily learn and perform the tasks without difficulty. Both participant groups highlighted the simplicity and familiarity of the interface design of '*Aegis', which* led to the easy execution of the functions. Specifically, they emphasized that the information architecture (e.g., the grouping of related items) is straightforward to learn. Furthermore, the instruction and feedback provided by the system are primarily free-of-jargon and easy to understand. Especially the design and layout of the application are suitable for the elderly who may have limited vision and memory. Lastly, they mentioned that they were satisfied with the user interface design and the features and functionalities of '*Aegis.'* Most elderly participants said that they would use this application in daily life because the modules available in '*Aegis'* are helpful for them to manage their health. At the same time, the functionality of '*Aegis'* that makes this application attractive to caregivers is that caregivers can link and monitor their elderly effectively. Hence, they recommended the future adoption of the system in their daily lives, particularly in aged care.

Although promising, some usability and user experience issues were discovered during the pilot usability testing that can be insightful for future enhancement and further development of aegis. The findings from the study confirm that the visibility of system status is important in designing, particularly for elderly users. This is in line with the existing research [25]. For instance, one elderly participant was unsure if the sign-up was complete and if linking with a caregiver was done after reaching the QR code page. Some elderly participants were concerned that the feedback after pressing the emergency button was unclear; thus, they were unsure if the task was successful. Also, the findings suggest that clear and accurate information, feedback, and message are essential for elderly users, consistent with the existing research [25]. We noticed during the usability test that there existed some inappropriate wordings. For instance, some elderly users had a difficult time understanding the meaning of some Thai words such as 'ฟีเจอร์' (features) or 'ดูการวิเคราะห์' (view analytics), which can be considered technical.

Furthermore, an elderly participant also questioned what '*taking care of yourself*' meant on one of the onboarding pages. Besides the minor issues we discussed, the elderly participants and caregivers suggested adding more features to the system. For example, most participants recommended adding more features to the emergency module, and they suggested adding an option to call a nearby hospital or an immediate video call functionality.

VI. Discussion and conclusion

Thailand is predicted to transform into a hyper-aged society soon, meaning that the country will have a higher elderly-to-worker dependency ratio in the near future. This increasing ratio will generate more responsibility for family members to care for their aging elders. Also, as the age of the elderly increases, more chronic diseases and deterioration of their physical health will be more extreme, causing specific daily tasks such as house chores or traveling to be limited, and caregivers' help will be needed. However, due to the demands of modern life, caregivers have limited time and resources to take care of their elderly family members constantly. The existing approaches (e.g., phone calls, text messaging, or face-to-face communication) require time and do not guarantee the success of task completion. As suggested in the literature [10], there has been an upward trend in the use of mobile phones among elderly people in Thailand. Furthermore, recent improvements in internet technologies (e.g., 5G in Thailand) have made the adoption of mobile apps for aged care possible [26]. Hence, the application of such a mobile-based elderly-care system has become practical and feasible for both the elderly people and caregivers in Thailand. Thus, the '*Aegis*' application was implemented using the design thinking approach to provide a feasible solution for caregivers to take care of the elderly effectively and to increase the overall well-being of the elderly.

The findings from the pilot usability testing indicate that the mobile-based application can effectively facilitate elderly caretaking, particularly in Thailand. This study has confirmed the existence of the need for an innovative and feasible method to effectively promote the well-being of elderly people while helping caregivers reduce their burden in aged care. Through this study, we discovered that effective communication between elderly people's caregivers could be achieved by using ubiquitous mobile technologies. Using the '*Aegis*' application can help caregivers manage elderly care easily without a physical presence, while the elderly people themselves may gain confidence in managing their activities of daily living. Through the findings from the interview study, we have also learned that physical health and support and emotional and mental health support for elderly people are equally important. We can achieve this aim using the latest technologies (e.g., ubiquitous mobile apps). Other than the usefulness of the features and functionalities of '*Aegis*', we have also learned that due to its human-centric nature, the '*design thinking*' methodology is suitable for designing an innovative system or product for users with distinct needs (e.g., the elderly), which is consistent with the existing literature [27]. The study also shows the importance and significance of user interface design and user experience considerations when designing an application for elderly people with distinct limitations, such as low technology literacy and health conditions like eyesight and dry fingers. For instance, we applied the existing and well-established user interface design guidelines and usability heuristics in this study.

Interestingly, we found that these UX/UI guidelines and laws suit the elderly. The findings suggest that these guidelines (e.g., Nielsen's ten heuristic guidelines) can be applied to designing an interface for elderly people. Furthermore, the well-established and widely-accepted Fitts's Law is suitable for mobile-based applications and for developing an age-friendly application/system. With that in mind, it is suggested that the user interfaces, particularly for the elderly, must be easy to use, uniform, and follow UX/UI rules not to create confusion for the elderly and caregivers.

In conclusion, this study has shown that a mobile-based caretaking system has a high potential to solve the pain points of elderly people and caregivers in Thai society. Using the '*design thinking*' approach, the aim to create an innovative solution for the elderly-care can be achieved. The key takeaways of the study are as follows. First, to create an elderly caretaking system that can address their needs, we should pay great attention to the distinct limitations of two groups of users with different needs and conditions. Second, empathy-based '*design thinking* is an effective technique for the elderly. Third, the existing HCI guidelines, such as Nielsen's ten heuristics, are suitable for designing an interface for elderly people. Fourth, the current UX Laws (e.g., Hick's and Miller's Law) are promised to be used to design age-friendly systems and products. However, due to the study design and limitations, further research is recommended to understand if the existing UX/UI laws and principles (e.g., Fitts's law) are suitable for elderly user groups. Lastly, modern technologies, including ubiquitous mobile computing, are the potential for aged care. This study had a few limitations. First, the sample size was small due to the availability of participants. Second, the study duration was short. If we can conduct a longitudinal study in the future, the results can elaborate more on the usability and usefulness of the system. Third, the currently available modules are limited in the '*Aegis*' application. Lastly, the type of data collected in this study was limited. For instance, collecting more qualitative data to understand user experiences and usability issues better is essential. Despite having some limitations, the findings from this study can create insights for UX/UI designers, researchers, and developers in designing and developing an age-friendly system for elderly users. Furthermore, this study suggests the promise of using technologies effectively and efficiently for the aged care sector in Thailand and worldwide.

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Cognitive Aspects of 2D Content Integration and Management in 3D Virtual Reality Spaces

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Abstract—**The advent of 2D graphical user interfaces in the 1980s shifted user interactions from line-based terminals to icon-based interfaces. As smartphones emerged in the 2010s, portable 2D graphical interfaces became a reality, liberating users from being confined to a single location when accessing digital services. These transformations have profoundly altered our understanding of digital information systems, with impacts that cannot be easily quantified. Current advancements in virtual and augmented reality (VR/AR), the Internet of Things (IoT), and artificial intelligence (AI) are on the verge of ushering in the next significant leap in cognitive expansion, introducing portable and highly contextual spatial interfaces, also sometimes referred to as Digital Realities (DRs). As a result, users now anticipate the ability to engage with an increasing array and variety of digital content in ways that are more contextualized and tailored to their needs, taking into account factors such as time, location, personalized goals and user-specific histories. In this paper, we aim to give an overview of cognitive aspects relevant to content integration and management specifically in DR environments, and to propose solutions and / or best practices to address them. Our discussion is centered around a paradigm called the Doing-When-Seeing (DWS) paradigm, which we propose for the design of Digital Reality interfaces. We demonstrate the applicability of this paradigm to the design of interfaces for creating content, organizing content, and semantically representing and retrieving content within 3D Digital Reality environments.**

Index Terms—**content management; digital reality; cognitive aspects of virtual reality**

I. Introduction

Technological development has played a significant role in shaping human civilization, from the earliest tools and machines to the modern-day innovations that are transforming the world [1], [2], [3]. Two of the most prominent technological trends in recent years is the rise of artificial intelligence – including machine learning and deep learning – on the one hand [4], [5], and advances in 3D spatial technologies on the other [6]. Machine learning and deep learning technologies are being used across industries to analyze data, automate processes, and make predictions [7] – a tendency motivated by multiple factors, including the need for more automation, the desire to improve decision-making, and the need to accomplish this in the face of a growing volume of information. In turn, virtual reality and other 3D spatial technologies – including even 3D digital twins – have been shown to be instrumental tools in presenting users with more information at a lower cognitive load, thereby increasing the interpretability of complex physical-digital scenarios [8], [9], [10], [11]. The merging of these fields is rapidly leading to new synergies, as demonstrated for example in the definition of Digital Reality and Internet of Digital Reality [12], [13].

A key challenge in the use of digital realities is how to provide users with the information they need at the right time and location. Such questions are increasingly important due to a confluence of multiple factors:

- With the growing prevalence of mobile as opposed to desktop computing, users have become less tethered to any single location; hence, context-aware information retrieval is becoming the norm. This problem can be referred to as *finding the content set appropriate to the given context*;
- With the growth of data volume in users' digital life, two further trends can be observed:
  - Users are increasingly motivated to organize and manage their own information spaces; this means that users expect to be able to curate and organize their own digital content within their (3D) digital applications instead of merely consuming content created by others
  - It is increasingly challenging to present to users all of the information relevant to a given context, which can be difficult to find (i.e., filter out based on semantic relevance) and also risks inducing a high cognitive load

  Together, these two trends create the challenge of *organizing content sets and making them amenable to intuitive exploration.*

With respect to the first factor – i.e., the need for context-aware content curation – 3D digital environments can be hugely effective, as they are already spatial in nature, in a way that closely mirrors human thinking through spatial metaphors [6]. To formulate this in everyday terms: A 3D virtual classroom environment can be easily conceptually associated with the activity of learning; while a 3D virtual home

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cinema environment can be easily conceptually associated with leisurely activities such as watching films or listening to music. In this way, content relevant to an appropriate context can be easier to organize and retrieve [14].

The second factor – i.e., the data deluge that increasingly surrounds users – also brings about a unique set of challenges, especially when it comes to users inhabiting 3D virtual environments. In this regard, key aspects range from the mechanics of laying out content within a 3D virtual environment, all the way to the high-level organization and retrieval of information from large content sets. For example, a 3D virtual classroom might host content sets relevant to a large variety of subjects. Depending on the number of subjects available and the number of lessons within each subject, the classroom as a physical location might lose its relative importance, and the main challenge would become finding the particular lesson a user wants to work with at any given time. Clearly, there is a tradeoff here between creating new spaces and adding content to an existing space. However, even when adding new content to an existing space, the question of what operations should be available to users in helping them to lay out their content is far from trivial.

In this paper, we introduce a paradigm which we refer to as the "***Doing-When-Seeing (DWS) paradigm***". DWS is a generic design philosophy and methodology that can help address a variety of challenges, including those of 3D content layout creation, 3D content set organization, and contextual-semantic content retrieval.

The paper is structured as follows. In Section II, we briefly introduce some key nomenclature with respect to virtual reality spaces that can help readers better understand the discussion in later sections. In Section III, we introduce some of the key cognitive challenges we have identified in the context of 2D content integration and management in 3D digital realities. This is followed by an introduction to the Doing-When-Seeing paradigm, in Section IV. Finally, in Sections V–VII, we demonstrate the viability of DWS by providing examples of all of the aforementioned applications along with a set of associated experimental validations.

II. Key Definitions

To facilitate further discussions on the topic of 2D content integration and management, we introduce the following terms:

Virtual camera: The unique viewpoint in a 3D virtual space through which the 3D scene appears to the user's eyes at any given time. The virtual camera is characterized by a 3D location (x,y,z spatial coordinates) and a spatial orientation (determined by a 4-dimensional quaternion).

2D display panels (or 2D displays): Bounded rectangular surfaces within a 3D space that are used to display 2D content, including e.g. PDF files, webpages, images or videos. A 2D display panel is characterized by its 3D location (x,y,z spatial coordinates of its geometric center), a spatial orientation (determined by a 4-dimensional quaternion), a width and a height.

2D content layouts: Sets of 2D display panels appearing in the same 3D space at the same time. One can think of a content layout as a project containing 2D documents that are laid out on rectangular display panels in a 3D virtual space.

2D content integration and management: A set of tasks associated with the specification, creation and retrieval of 2D content layouts, together with their constituent 2D display panels.

III. Cognitive Challenges Behind 2D Content Integration and Management

In this section, we provide a brief overview of key cognitive challenges we have identified with respect to 2D content integration and management in Digital Reality spaces.

A. Challenges associated with the creation of 2D display panels

Based on an overview of the literature and currently widely adopted best practices, we have identified two main challenges that pertain to the creation of 2D display panels in particular, which we refer to as the *camera-object independence dilemma* and the *lack of higher-order structural operations*. These two terms can be defined as follows:

- The term **camera-object independence dilemma** describes the tension that arises between the desire to position 2D display panels in relation to the virtual camera (as it is positioned and oriented at the current point in time), and in relation to the surface normals of 3D objects within the environment. In particular, if the location / orientation of the virtual camera is changed, so as to enable the 2D display panels to be aligned with the surface of an object more precisely, the former goal – which relies on the camera pose remaining stationary – is immediately undermined. This challenge is particularly clear when a so-called 3D gizmo is used to edit the pose and scale of objects in a 3D virtual scene. In this case, the virtual camera either remains stationary, in which case it is impossible to see whether the object being manipulated is properly aligned with its surrounding objects; or the camera viewpoint changes, in which case the user then has to find a suitable location from which the gizmo can be accessed again (Figure 1);
- The term **lack of higher-order structural operations** describes the lack of support on many commonly used interfaces for the intuitive manipulation of higher-order structures within 2D content layouts. In particular, the operations carried out during the creation of 2D display panels and 2D content layouts can become tedious without the ability to change the scale at which manipulations can be made.

B. Challenges associated with content retrieval in digital realities

Based on a literature review in [15], we have shown that an overwhelming majority of current solutions towards semantic document retrieval depend on predetermined semantic connections, either explicitly defined or extracted from human-created datasets.

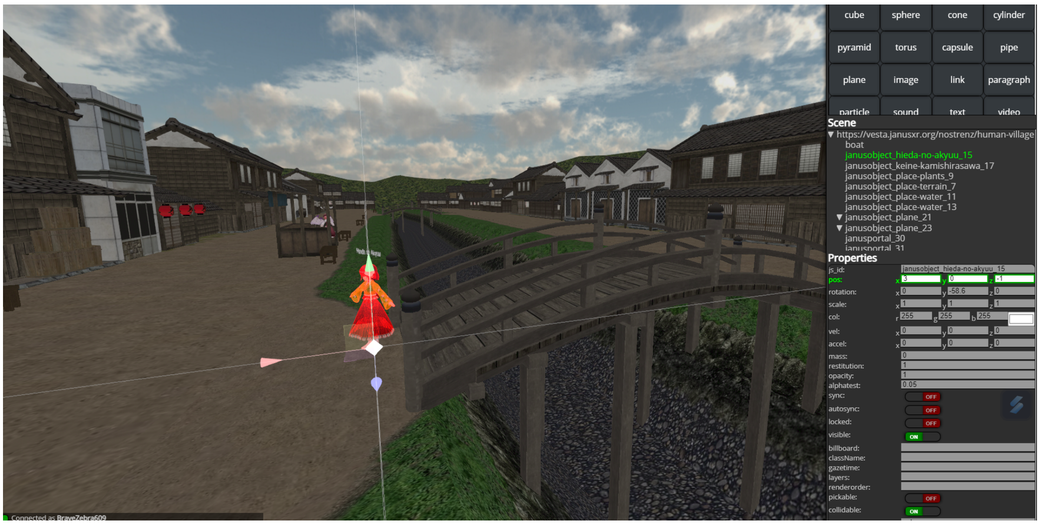

Fig. 1. Example of a 3D gizmo used to change the position of an object in the scene. The camera-object independence dilemma is generated by the fact that conceptually for the user, the camera and the object should be independent (allowing users to change their viewpoint in order to ascertain whether the object being manipulated is properly aligned with its surroundings), whereas the use of the gizmo tethers the camera to the object and the 3D gizmo, making it cumbersome to change the virtual camera orientation and to access the gizmo again.

However, it can be expected that users' thinking and memory recall will often be guided by associative and episodic factors. This means that, for instance, users will often recall content sets based on memories of the time, location or topic in the context of which they last accessed them. This suggests that instead of relying exclusively on similarity of meaning, a retrieval system might also rely on past episodes of interaction as a surrogate for semantic similarity – including, for example, by linking unsuccessful search entries to subsequent search entries resulting in successful document retrieval. Such a system would be capable of generating personalized, evolving semantic labels through the course of its normal use.

When it comes to creating document store and retrieval systems with adaptive semantic labels, we have identified the following 3 challenges:

- **syntactic saturation:** the number of associations in a semantic retrieval system reaches a point where several search entries have a similar syntax, thereby becoming easy for users to mistype;
- **semantic saturation:** the number of documents in a semantic retrieval system reaches a point where several documents have semantically similar search entries associated with them;
- **pragmatic saturation:** provided that a semantic retrieval system is configured so as to learn from user inputs (as documents are being retrieved), an increasing number of queries supplied to the system can result in a web of associations so complex that it reduces the availability of new semantic labels. We refer to this kind of saturation as pragmatic because it relates to the way in which search queries are entered into the system.

The three-fold problem of syntactic, semantic and pragmatic saturation can be characterized – from a simplified perspective – as problems having to do with "*too many search entries*" (i.e., syntactic saturation), "*too many documents*" (i.e., semantic saturation), and "*overfitting from too many user interactions*" (i.e., pragmatic saturation), respectively.

IV. The Doing-When-Seeing Paradigm

We propose the ***Doing-When-Seeing (DWS) paradigm*** as a general set of principles for the design of content management related interactions in Digital Reality – including 3D virtual – spaces.

The paradigm consists of the following types of operations, which can be carried out in a loop, always executed in the order $1 \to 2 \to 3$ or $1 \to 3$:

1) A set of *selection operations*, in which the user performs an interaction that can serve as a uniquely identifiable '*target*' during subsequent operations. Examples could include the selection of an element or group of elements on an interface (depending on the application domain), or the submission of a keyword or search term in a text box; in all of these cases, the element(s) or the text entered can serve as a uniquely identifiable 'target';
2) A set of *retrieval operations*, in which the user 'retrieves' the previously selected 'target', thereby effecting an operation in connection to it. Examples could include duplicating the previously selected element, or conceptually linking a previously entered text with a new element.
3) A set of *update operations*, in which the user can 'modify' a previously selected 'target'.

The name 'Doing-When-Seeing' arises from the logic of these operations: one can only select as a target an entity that one sees; and one can only perform retrieval or update operations whenever one has seen and selected the target entity.

At face value, DWS can simplify many operations from a cognitive perspective because it removes the need to effect

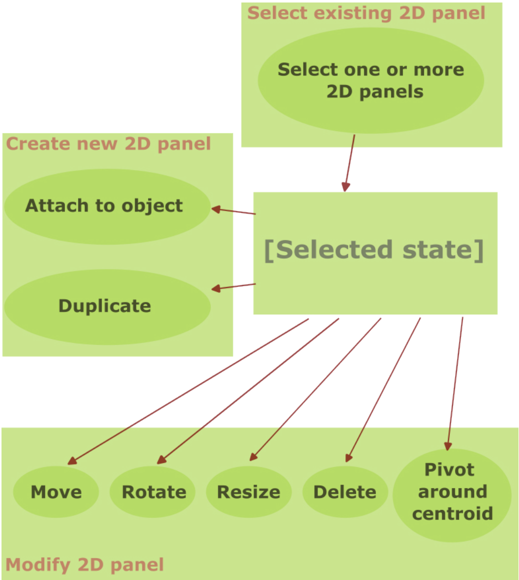

Fig. 2. Doing-When-Seeing operations proposed in [16] for creating and editing 2D display panels.

changes that are not based on something that is already visible or available to the user (here, visibility can be interpreted more broadly as being in the purview of one's cognition).

In the remainder of the paper, we demonstrate the applicability and viability of DWS in the use cases outlined earlier in the introduction.

V. Example Applications of DWS: Creating 2D Display Panels

A. Use of DWS to create 2D display panels

Using the Doing-When-Seeing paradigm, in [16] we proposed a novel method that includes a set of operators categorized as selection operators, addition operators, placement operators, manipulation operators, and persistence operators for the editing of 2D display panels and 2D content layouts in 3D virtual spaces. The specific states and commands within the workflow are shown in Figure 2.

Prior to accessing addition operators, the user needs to choose a location and orientation. Since specifying orientations can be challenging, the user can simply point the 3D cursor at a surface within the space. Next, the user can issue the 'Attach to object' command to create a new 2D display panel.

An alternative method to 2D display panel creation is to select one or more existing panels, and to duplicate them ('Duplicate' command). In this case, the position, orientation and size of the existing panel will help determine the respective parameters of the new panel (while orientation and size can be kept, generally it is a good idea to place the new panel directly beside the existing one).

Additionally, a 2D display panel that has just been selected, or just been created can be further manipulated via the placement and manipulation operators. These include the 'Move', 'Rotate', 'Resize', 'Delete' and 'Pivot around centroid' commands – the latter enabling a group of panels to be rotated around a single point such that their relative positions and orientations do not change.

We note that this interface design respects the principles of the Doing-When-Seeing paradigm in that new 2D display panels can only ever be created based on an existing panel ('Duplicate') or an existing object and its surface normal ('Attach to object'). Since a 2D panel can never be created in mid-air, the camera-object independence dilemma is circumvented, as the need for panel positions to be radically altered is obviated.

B. Experimental validation

Through usability tests, we validated the proposed method within 3 different VR spaces inside the MaxWhere VR Platform. MaxWhere VR is an extensible desktop VR platform, built over the OGRE graphical engine, that provides a dynamic document model (known as the Where Object Model, or WOM), together with a Javascript based API for creating interactive 3D spaces. MaxWhere also provides a concept of 2D display panels, referred to as smartboards, which can hold PDF files, audio-visual files, or any other web-based content that could normally be rendered inside a Chrome browser.

Based on our experiments, we showed that the proposed method and the operators it includes were all found to be useful by users, and at the same time were sufficient for the re-creation of existing 2D content layouts. We reported on this experiment in detail in [16].

In the experiment, 10 test subjects were given the task of re-creating existing 2D content layouts in 3 different virtual reality spaces based on screenshot images of the original layouts. Following the experiments, we validated the speed and precision with which the layouts could be re-created.

Results showed that test subjects were able to re-create the layouts at a rate of less than 45 seconds per 2D display panel, and excepting outliers, at a root mean squared accuracy of less than 20 cm in terms of 2D display panel position, as well as less than 0.01 radians in terms of 2D display panel orientation.

The question of whether 45 seconds spent on the creation of each individual 2D display panel is a long or short time can be argued from many different perspectives. Nevertheless, in post-experiment interviews, subjects found the editing method to be intuitive and easy to use. Additionally, considering other digital operations relevant to 2D content integration and management, such as selection of appropriate documents, selection of a location in which to place the documents or navigation in the 3D space, in empirical terms 45 seconds is not an inordinately long period of time.

VI. Example Applications of DWS: Creating 2D Content Layouts

A. The concept of the 3D File System

Whereas in the previous section, we outlined a set of operations in which individual 2D display panels could be created and duplicated, we further extended the application of the DWS paradigm to the duplication of existing 2D content layouts as a higher-level entity [17]. This approach, if shown to be practical, would be an example of higher-order structural operations.

The operations outlined in the previous section do in fact include the selection of multiple 2D display panels and their duplication as a unit. However, in [17], a further step was taken in that existing groups of 2D layouts were associated with a unique project name, along with other semantic attributes such as topic, date and location at which the project was created. Such metadata attributes can potentially help trigger episodic memories, helping users to recall the project that should be loaded for duplication. We labeled the proposed concept as a "3-Dimensional File System", and called our proposed implementation the "MaxWhere File System v0.1", based on our reference implementation on the MaxWhere Platform [17].

B. Experimental validation

Validating the viability of the proposed approach to duplicating 2D content layouts again raises some questions of epistemology: after all, the question of whether it is faster to duplicate (and then modify) an existing 2D content layout than to create a new one based on individual 2D display panels and their duplicate versions will depend on: a.) how many 2D display panels are included in the layout, b.) how easy is it to recall and retrieve the content layout – among many other candidates – for duplication.

Clearly, no hard and fast rules can be formulated and there is a tradeoff between the two extremes of duplicating complete layouts and building new ones from scratch. However, it is also possible to consider whether there are reasonable cases where layout duplication can be faster. If the answer is yes, this will provide an existence proof for the potential superiority of higher-order structural operations.

To this end, we proposed a benchmark protocol for the standardized evaluation of layout creation methods. We showed that while the benchmark protocol encapsulates a trade-off between the time required to position individual display panels (favoring layout duplication) and the time required to find the appropriate layout to duplicate (favoring manual creation of individual display panels), it can be used to derive an existence proof for increased effectiveness of the proposed 3D file system method in that it provides a set of viable use-case scenarios for 2D content layout creation.

Using the proposed benchmark protocol, we gave an existence proof for the potential superiority of the proposed project duplication method, by showing that users were able to create new 2D content layouts based on existing layouts significantly faster than when having to manually create each individual 2D display panel. In the experiment, 3 conditions were compared:

- Scenario A ("no retrieval control group"): test subjects were asked to create all content layouts anew
- Scenario B ("retrieval group"): in the case of some content layouts, duplication of existing content sets was allowed, but users were not told which content sets to duplicate, only that they had to duplicate an already existing layout
- Scenario C ("deep retrieval group"): similar to scenario B, with the difference that test subjects could study the content and layout of each project for 2 minutes after having created it

Table I shows the comparison between Scenarios A and B; while Table II shows the comparison between Scenarios A and C. Prior to the analysis, the normality of the data was confirmed using the Shapiro-Wilk test. Based on the comparisons, then, an independent samples T-test revealed that the subjects from the retrieval group achieved significantly lower creation times per 2D display panel (N = 80, M = 72.725, SD = 15.290) than subjects from the control group (N = 80, M=96.058, SD= 10.518), ($t(140) = 11.245, p < 0.001$); similarly, the subjects from the deep retrieval group achieved significantly lower creation times per 2D display panel (N = 64, M = 74.708, SD = 10.392) than subjects from the control group (N = 80, M = 96.058, SD = 10.518), ($t(142) = 12.168, p < 0.001$); In both cases, the effect size was large (Cohen's $d = 1.778$ and 2.041, respectively).

A third interesting comparison would have been the difference between the retrieval group and the deep retrieval group. However, contrary to our expectations, in this case, the average time taken by subjects within the deep retrieval group was actually somewhat greater than the time taken by subjects within the retrieval group (though not to a significant extent). It is possible that further investigations in an ecologically more valid scenario (e.g., by having subjects work with the content sets over a longer period of time) could uncover an advantage to subjects being acquainted with the layouts they need to retrieve for duplication.

VII. Example Applications of DWS: Retrieval of 2D Content in 3D Virtual Environemnts

With the increasing volume of data surrounding users, as described in the introduction, effective content retrieval is becoming an ever-more pressing issue on many computing platforms. In a research article by Ames and colleagues [18], which predates the recent upsurge in VR and AI technologies, it was observed that merely the swift expansion of storage capacity and the growing accessibility of cross-platform multimedia content have contributed to a significant increase in the quantity and diversity of digital materials gathered by users. The authors emphasize that while Internet search capacities have greatly outperformed local search on desktop systems, the conventional file-folder hierarchical arrangement of files is ill-equipped to tackle the problem in a broader sense.

A. The Graph-Indexed Tensor Structure (GITS) model for semantic retrieval

In [15], we proposed a graph-tensor representation based document retrieval model, referred to as the Graph-Indexed Tensor Structure (GITS), that is pragmatic in the sense that it does not make any assumptions with respect to semantic relationships defined a priori; instead, associations are created as the model is used.

The general architecture of GITS can be seen in Figure 3. The core of the model is a tensor, the dimensions of which can represent any kind of semantic dimension, such as time, location or topic. The documents, in turn, are stored within

TABLE I

COMPARISON OF AVERAGE TIME TAKEN TO CREATE A 2D DISPLAY PANEL FOR THE CONTROL GROUP AND RETRIEVAL GROUP. THE INDEPENDENT SAMPLES T-TEST – USING WELCH CORRECTION DUE TO INEQUALITY OF VARIANCES – SHOWS THAT THE DIFFERENCE BETWEEN THE TWO GROUPS IS SIGNIFICANT.

	Test	Statistic	df	p	Mean Difference	SE Difference	Cohen's d	SE Cohen's d
Seconds/SB	Student	11.245	158.000	$< .001$	23.333	2.075	1.778	0.212
	Welch	11.245	140.091	$< .001$	23.333	2.075	1.778	0.212

Assumptions check: Test of equality of variances (Levene's)

	F	df_1	df_2	p
Seconds/panel	29.994	1	158	$< .001$

TABLE II

COMPARISON OF AVERAGE TIME TAKEN TO CREATE A 2D DISPLAY PANEL FOR THE RETRIEVAL GROUP AND DEEP RETRIEVAL GROUP. THE INDEPENDENT SAMPLES T-TEST SHOWS THAT THE DIFFERENCE BETWEEN THE TWO GROUPS IS SIGNIFICANT (IN THIS CASE, NO WELCH CORRECTION IS REQUIRED).

	t	df	p	Mean Difference	SE Difference	Cohen's d	SE Cohen's d
Seconds/panel	12.168	142	$< .001$	21.350	1.755	2.041	0.233

Assumptions check: Test of equality of variances (Levene's)

	F	df_1	df_2	p
Seconds/panel	0.214	1	142	0.644

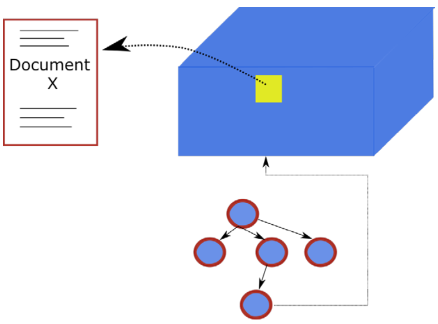

Fig. 3. Schematic view of the graph-indexed-tensor concept. While the directed graphs which are used to index the tensor in each dimension could have a variety of structures, this diagram shows directed acyclic graph, similar to a radix trie.

the tensor (i.e., can be indexed via a specific coordinate in each of the dimensions of the tensor). However, to ensure that multiple values in a dimension could potentially be used to index the same document, and to be able to model richer forms of associativity than merely sequential relationships afforded by the proximity of coordinates within a tensor, the GITS model also includes an index graph corresponding to each of the dimensions of the tensor.

Depending on the type of graph that is used, several variations of GITS can be conceived of, such as:

- the keyphrase-based index graph, which uses text-based keywords or keyphrases and employs a radix trie to store them, such that leaves of the trie point to different coordinates within the corresponding dimension;
- the hierarchical index graph, which can be used to model hierarchical concepts such as location or time (e.g., dates within the same week, or at around the same time of the year, or on the same day of the week would then be 'closer' to each other than other, more general pairs of dates)
- the associative keyphrase-based index graph, which is similar to the keyphrase-based index graph, but also can include associations between leaves of the radix trie; such a model can be used to link together the key phrases, i.e. a keyphrase leading to too many search results can subsequently be linked to the next keyphrase entered which returns useful results.

The associative keyphrase-based variant of GITS conforms especially well to the key ideas behind the DWS paradigm, since all search actions by users – besides serving their primary purpose – also specify a '*target keyphrase*'. In case the target keyphrase is not immediately useful, it can still be subsequently linked to keyphrases that are useful, but did not immediately come to the user's mind.

B. Experimental validation of the associative keyword-based GITS model

To verify the extent to which associativity can be useful within the GITS model, we conducted an experiment comparing the keyphrase-based variant with two different ways of using the associative keyphrase-based variant.

1) Preliminaries: Prior to the experiment, multiple screenshots were prepared, capturing different views of the content inside a 3D virtual reality space, such that in each screenshot, a single 2D display panel was highlighted as showing the target content. The content was related to 3 distinct, but related topics: Sports, Football and Hungarian Football.

A '*baseline GITS model*' was also prepared containing 3 keyphrases for each 2D display panel which described the content displayed in the panels using everyday terms. In the case of this experiment, the GITS model had only 1 index dimension – therefore, the tensor component could be conceived of as a vector, such that it is indexed by some kind of an index trie (associative or not).

Each of the keyphrases were entered into the model in different variations, such that each variation started with a different word within the keyphrase. For example, for the keyphrase "Pele holds a ball", the keyphrases "Pele holds a ball", "holds a ball", "a ball" and "ball" were all added, so that users could potentially start with any word within the keyphrase when searching, and would not be limited by the grammatical structure of the keyphrase.

2) Experimental design: Subjects were then tasked with typing in a keyword corresponding to the highlighted panel. Careful selection of screenshots ensured that the content of the targets was clearly visible, and some repetition was incorporated to assess the subjects' ability to recall previously entered phrases. All subjects were shown the same content in the same order, however, each of the subjects belonged to 1 of 3 groups:

- Scenario A ("*Simple search method*"): subjects used the basic keyphrase-based index trie model without associativity to search for the appropriate 2D display panels within the baseline GITS model.
- Scenario B ("*Personal search method*"): subjects performed the same task on their own personal copy of the baseline GITS model, such that the model was also adaptive to their search queries.
- Scenario C ("*Collective search method*"): subjects perfomred the same task on a collective copy an adaptive GITS model, which was initially a cloned version of the baseline GITS model, but evolved to eventually include all of the unsuccessful keyphrases entered by the test subjects. In this scenario, we hypothesized that the task of subjects using the model at a later stage in the experiment would become easier.

In the case of each individual search task, we recorded the number of times the user entered a keyphrase before the search returned 3 or less search results. In case the search returned more than 3 search results, nothing was displayed to the subjects and they were asked to try again. In each case, subjects could try again at most 4 times (after the 5th keyphrase, subjects were asked to proceed to the next display panel).

3) Results: A total of six test subjects participated in the experiments (2 subjects per scenario).

Due to the deviation of the results from the normal distribution, instead of conducting a T-test, we opted to perform the Wilcoxon Signed-Rank Test, which is a non-parametric analogue of the T-test. Results of the test are shown in Table III. The results indicate that in a statistically significant sense, users in Scenario A required more trials compared to users in Scenario B, and users in Scenario B required more trials compared to users in Scenario C to search for the same content.

The effect sizes, based on the rank-biserial correlations, were not very large. However, this could be due to the relatively small number of subjects and small number of trials. Nevertheless, the results go to show that associativity within the GITS model can help reduce the time taken to search for the same documents.

C. Addressing the challenges of syntactic, semantic and pragmatic saturation

1) Quantifying syntactic saturation: To automatically determine the degree to which *syntactic saturation* can be a problem in a specific GITS model, we have proposed a Shannon entropy-based detection method in [15]. According to this method, the Shannon-entropy of a node at any given layer (i.e., corresponding to any given prefix) in the index graph can be computed based on the information contained in the next character that is typed with respect to the resulting content set:

$$E(n_i) = -\sum_{o=l}^{O} \frac{\sum_c I_{c\to o} f_{c\to o}}{C} \log_2 \frac{\sum_c I_{c\to o} f_{c\to o}}{C}. \quad (1)$$

where O is the number of possible outcomes (i.e. number of potentially different search results), C is the number of possible characters that can be entered (e.g. all alphanumeric characters), $I_{c\to o}$ is an indicator function whose value is 1 if typing character c as the next character may potentially yield the search result o, and $f_{c\to o}$ is the fraction of subsequent paths in the keyphrase-based index graph that begin with character c and eventually terminate in the search result o.

By calculating the average Shannon-entropy per node in a given layer, as described above, an entropy value can be associated with each layer in the index graph. This value, as well as if and by how much it is reduced from one layer to the next, can provide a comparative indication as to how syntactically saturated an index graph is.

2) Quantifying semantic saturation: Semantic saturation arises when the documents in a GITS model are too numerous per category, i.e. many documents with a similar semantics exist. In such cases, using keyphrases that describe the documents at a different semantic level may be a viable approach (for example, if a document store has 50 videos on birds, the keyword 'bird' may be less useful than a more specific keyword, like 'blue jay' or 'cardinal').

To quantify the degree of semantic saturation in a document store, a viable solution is to log the number of times the user searches unsuccessfully for a document (we call this the *search length*), and the number of documents each search operation returns (we call this the *multiplicity*). A candidate metric, then, which we refer to as the *semantic saturation index*, can be computed based on the difficulty of selecting a document from a multiplicity of M for any given search iteration i:

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TABLE III
WILCOXON SIGNED-RANK TEST. FOR ALL TESTS, THE ALTERNATIVE HYPOTHESIS SPECIFIES THAT MEASURE 1 IS GREATER THAN MEASURE 2. FOR EXAMPLE, SCENARIO A IS GREATER THAN SCENARIO B.

Measure 1		Measure 2	W	z	p	Hodges-Lehmann Estimate	Rank-Biserial Correlation	SE Rank-Biserial Correlation
Scenario A	–	Scenario B	1577.500	3.015	0.001	1.000	0.427	0.141
Scenario B	–	Scenario C	953.000	4.507	$< .001$	1.500	0.763	0.168

Assumptions check: Test of normality (Shapiro-Wilk): significant results suggest a deviation from normality

Measure 1		Measure 2	W	p
Scenario A	–	Scenario B	0.772	$< .001$
Scenario B	–	Scenario C	0.661	$< .001$

$$D_i = I_{M_i>0}(1 - \frac{1}{M_i}) + I_{M_i=0} \tag{2}$$

where i is the index of the search iteration, M_i is the multiplicity of documents returned for that iteration, and $I_{M_i>0}$ and $I_{M_i=0}$ are indicator functions the return 1 when the multiplicity is greater than 0, or equal to zero, respectively (and 0 otherwise). In this case, D_i is the difficulty of selecting a document in the given iteration, which becomes increasingly closer to 1 as the multiplicity increases (and is 1 if the multiplicity is 0).

For an entire search length, then, comprising I iterations, the average difficulty can be taken as a basis for semantic saturation:

$$SemSat = \frac{1}{I}\sum_{i=1}^{I}\left(I_{M_i>0}(1 - \frac{1}{M_i}) + I_{M_i=0}\right) \tag{3}$$

For example, for a search length of 2, with 4 documents and 2 documents returned, respectively, the semantic saturation value would be 0.625. For a search length of 3, with 8 documents, 6 documents and 3 documents returned, the semantic saturation value would be 0.78. On the other end of the spectrum, for a search length of 2, with 2 documents and 1 document returned, respectively, the semantic saturation value would be 0.25.

3) Quantifying pragmatic saturation: Pragmatics has to do with the relationship between a language and its speakers, or users. The GITS model is to a large degree pragmatic, in that it does not (necessarily) make use of any existing notions of semantic similarity, but instead builds associations based on usage patterns from the past. Pragmatic saturation arises when an associative keyphrase based index tree begins to hold associations that cause conflicts in some sense; when the root of the association (i.e. the search phrase that is typed instead of another) closely resembles one or more other search phrases, either in a syntactic or semantic sense. In either case, it may be difficult for users to separate the search terms at a cognitive, conceptual level.

Based on this description, it is clear that the assessment of pragmatic saturation is closely related to, and can be reformulated in terms of the assessment of semantic and syntactic saturation.

VIII. CONCLUSIONS

Rapid advances within the fields of 3D spatial technologies (VR, AR, MR), artificial intelligence and others have led to the emergence of new synergies, often characterized as digital realities. Key aspects of digital realities include, among others, users being less and less tethered to any specific physical location (via mobile platforms); users wanting to work with an increasingly complex web of contextual information; and users increasingly wanting to work within spatial computing environments based on spatial interaction metaphors. Trends such as these have led to the challenge of organizing heterogeneous digital content sets and making them amenable to intuitive exploration.

In this paper, we introduced a paradigm which we refer to as the "***Doing-When-Seeing (DWS) paradigm***". DWS is a design philosophy and methodology that can help address the challenges of 3D content layout creation, 3D content set organization, as well as content retrieval in 3-dimensional digital realities. DWS relies on the basic steps of selection operations, retrieval operations and update operations. A key feature of the approach is that retrieval and update operations can only be applied entities that have first been selected; therefore, it obviates the need to create new entities outside of an existing context.

To demonstrate the viability of the DWS paradigm, we gave several examples in the paper, in which DWS was used to design a 2D display editor interface, a 2D content layout creation interface, as well as an adaptive semantic digital document store and retrieval model. In each case, we verified the usefulness of the proposed solution through usability experiments and statistical evaluations. In the latter case of the digital document store and retrieval model, we also proposed a set of analytic methods to evaluate different kinds of saturation issues that can arise when the store contains too many documents, too many documents that are similar, or too many semantic search entries that are in some sense similar.

Based on the examples, we showed that the Doing-When-Seeing paradigm in general, and the proposed solutions in particular can be useful in designing new digital reality interfaces.

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