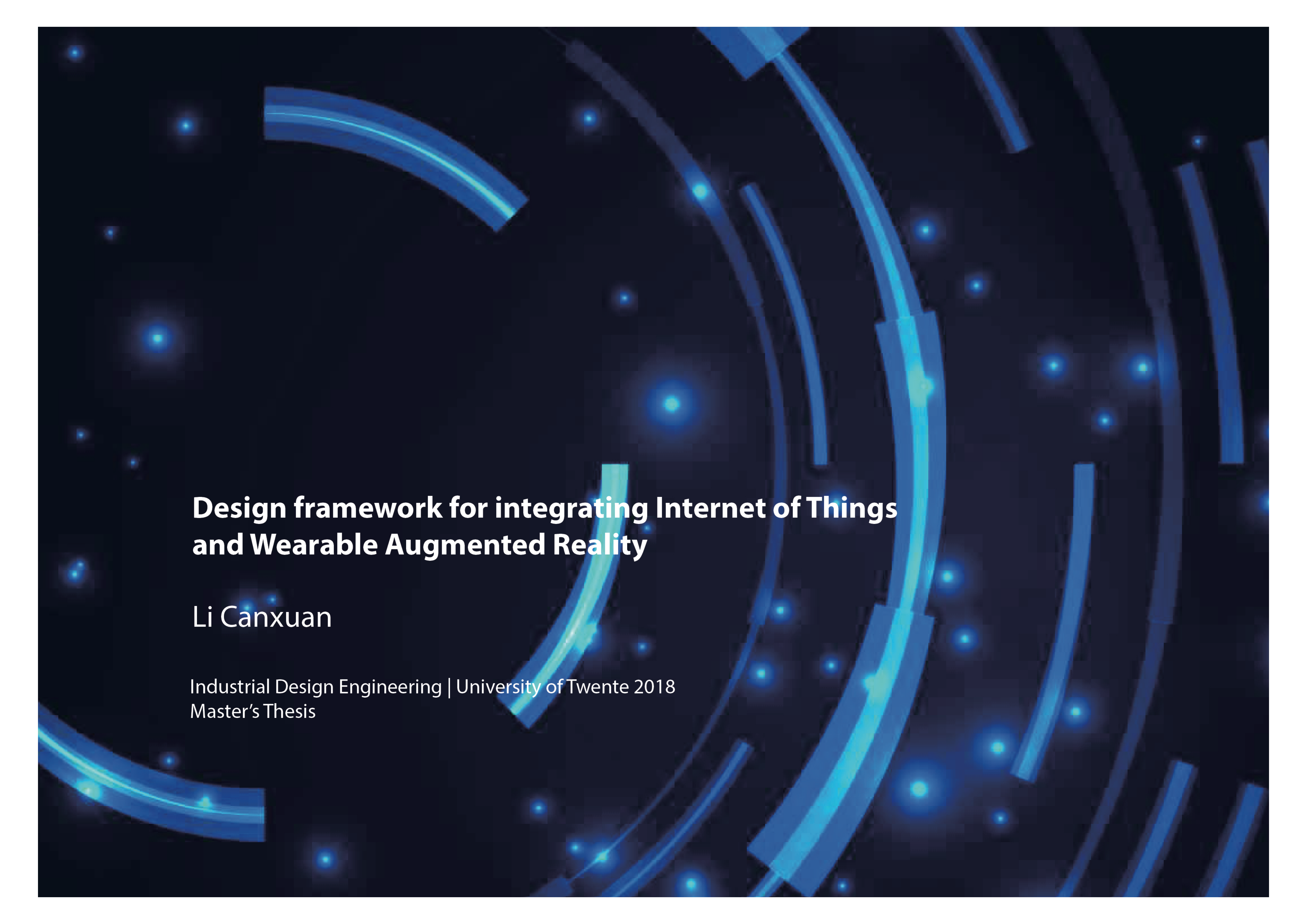




Design framework for integrating Internet of Things and Wearable Augmented Reality

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Industrial Design Engineering | University of Twente 2018
Master's Thesis

ABSTRACT

Handling data becomes one of the critical challenges and failure reasons of IoT implementation. Many research efforts go to the integration with other technology in order to cope with data better. Augmented Reality (AR) is one of the most promising integration. It has the ability of blending the digital world and the physical world thus is useful for improving interaction with IoT data. However, such integration is having a lack of design frameworks or guidelines for designers. Therefore, this assignment conducts research on IoT, AR and their integration and tries to propose a theoretical framework that aims to improve this situation. The framework focuses on interaction design of such systems that integrates AR and IoT (AR-IoT). It explains interaction aspects of AR-IoT systems as well as associate with the technical aspects so that helps interaction designers understand AR-IoT system and create intuitive and natural interaction. Two cases of design practice are used as extra tools to explain and demonstrate this framework.

Keywords: Internet of Things, Augmented Reality, Human-computer interaction, User Experience, Wearable

RELEVANT CONCEPTS

Internet of Things (IoT) is the network of physical devices, vehicles, home appliances, and other items embedded with electronics, software, sensors, actuators, and connectivity which enables these things to connect, collect and exchange data.

Augmented reality (AR) is an interactive experience of a real-world environment whereby the objects that reside in the real-world are "augmented" by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory.

Human-computer interaction (HCI) researches the design and use of computer technology, focused on the interfaces between people (users) and computers. Researchers in the field of HCI both observe the ways in which humans interact with computers and design technologies that let humans interact with computers in novel ways.

User Experience (UX) refers to a person's emotions and attitudes about using a particular product, system or service. It includes the practical, experiential, affective, meaningful and valuable aspects of human-computer interaction and product ownership.

Ubiquitous computing (or "ubicomp") is a concept in software engineering and computer science where computing is made to appear anytime and everywhere. In contrast to desktop computing, ubiquitous computing can occur using any device, in any location, and in any format.

Wearable Technology are smart electronic devices (electronic device with micro-controllers) that can be incorporated into clothing or worn on the body as implants or accessories.

AR-IoT systems are Internet of Things systems equipped with Augmented Reality as user interface. The goal is to assist stakeholders interacting with IoT data intuitively and naturally.

CONTENT TABLE

Report Structure	- - - - -	3	2.3 IoT systems with AR interface	- - - - -	29
Introduction	- - - - -	4	2.3.1 Interaction hierachy	- - - - -	29
1. Internet of Things	- - - - -	5	2.3.2 Interface core elements	- - - - -	29
1.1 Overview	- - - - -	5	3. Design framework for AR-IoT	- - - - -	34
1.1.1 Values	- - - - -	7	3.1 Representative AR design principles	- - - - -	34
1.1.2 Technology Stack	- - - - -	9	3.2 Representative AR framework	- - - - -	39
1.2 Challenges and future directions	- - - - -	12	3.3 Interaction design framework for AR-IoT	- - - - -	42
1.2.1 Challenges	- - - - -	12	3.3.1 User Interaction level	- - - - -	42
1.2.2 Future directions	- - - - -	13	3.3.2 System level	- - - - -	44
1.2.3 Zoom into AR for IoT	- - - - -	17	3.3.3 Use guideline	- - - - -	44
2. AR design for IOT	- - - - -	18	3.3.4 Case study A	- - - - -	44
2.1 IoT interaction design	- - - - -	18	3.3.5 Case study B	- - - - -	46
2.2 Augmented Reality	- - - - -	20	4. Discussion	- - - - -	48
2.2.1 Overview	- - - - -	20	5. Conclusion	- - - - -	49
2.2.2 Wearable AR	- - - - -	22	6. Reference	- - - - -	50
2.2.3 Interaction capabilities of wearable AR	- - - - -	24			
2.2.4 Interaction capabilities expansion	- - - - -	25			

ACKNOWLEDGEMENT

I would like to express my deep gratitude to Roy Damgrave, my thesis supervisor, for his patient guidance, enthusiastic encouragement and useful critiques of this research work. I would also like to thank Wouter Eggink, for his advice and assistance for finding a suitable graduation thesis in the very beginning.

My grateful thanks are also extended to the secretary of IDE department for their help in accessing the VR Lab during my thesis, to Fjodor van Slooten, who helped me with Arduino and to Wu Xiangyi, Micheal Vos, Marijn Rivière, Yanick Brezet, Rens den Hertog for their support in programing and research.

Finally, I wish to thank my family and my friends, especially my sister and Yikai for their support and encouragement throughout my study.

REPORT STRUCTURE

This report has an introduction, three main chapters, discussion and final conclusion. The introduction gives an overview of this assignment by giving out the research background and question as well as concluding the research process and results. Chapter one specifically focuses Internet of Things (IoT) by showing the research about background, value creation and technology aspects. This provides a solid understanding on the technology thus ensure further research. Chapter two emphasizes the research of Augmented Reality, especially wearable AR and its interaction design. Moreover, it also includes research about integration of AR and IoT. Chapter 3 steps further about the integration. It shows representative design principles and framework for AR user interface design and tries to adapt to AR-for-IoT. Finally, it proposes the desired design framework of this assignment with explanation, use guidance and two cases of design practice. The discussion part generally discusses the limitation of this framework and future research direction, while the conclusion part gives a summary of this research assignment.

INTRODUCTION

As an emerging technology, Internet of Things (IoT) has been gaining a growing momentum year by year for its benefits of making our lives smarter, securer, efficient [1]. To further unlock its potential, it is getting integrated with other technologies to provide more powerful solutions. One of the most promising integration goes with Virtual Reality (VR) and Augmented Reality (AR). The direction is to create VR or AR interfaces for IoT systems so that user interaction for IoT systems can be improved. Among the researches of such integration, there is a lack of actionable interaction design framework for designers. **To improve this situation, the main research question of this assignment is to build such a framework that can assist interaction designers creating Wearable AR interface for IoT products.** This framework is expected to help interaction designers acquire a fundamental understanding on such system and more importantly a reliable framework for interaction design. Finally, designers can build up interactions effectively.

In order to build the desired framework, this assignment first investigates the background, value, technology stack, challenge and future trends of IoT. This thorough research contributes to an understanding on the necessity and direction of IoT synergy with other technologies. Next, research is extended to AR, especially its interaction capabilities which help reveal the possibilities of integration. Current research about the integration is also reviewed and discussed for being input of building the desired framework. Furthermore, research reviews design principles and framework of AR which are also critical input for final outcome of this assignment. All the previous research results contribute to the final framework proposal. To better explain the framework, two cases of design practice are presented at the end.

CHAPTER 01

INTERNET OF THINGS

This chapter focusses on Internet of Things (IoT). It starts with an overview introducing the technology in order to obtain a background for this project. Since the topic is the integration of IoT and Augmented Reality (AR), this chapter then investigates the technical basics of IoT to reveal directions of integrating these two technology appropriately. Moreover, a study on IoT future trends and challenges can make sure the integration is promising and expected by the research communities and industries stakeholders. This chapter lays a foundation for the following chapters which discuss the integration with AR further (chapter 2) from a Human Computer Interaction perspective (HCI) and the outcome framework (chapter 3) that is able to facilitate the integration specializing interaction aspects.

1.1 Overview

The term “Internet of Things” is first claimed in the project of Auto-ID Labs of the Massachusetts Institute of Technology (MIT) on networked radio-frequency identification (RFID) infrastructures (Atzori et al. 2010; Mattern and Floerkemeier 2010). After years of revolution, It gradually goes beyonds the area of RFIT technologies and has a wide expansion. Because of its rapid growth and broadness, there are a large number of definitions for IoT. International Telecommunication Union (ITU) now defines the Internet of Things as “a global infrastructure for the Information Society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable in- formation and communication technologies” (ITU 2012). It is defined as the Internet extended into

1.1.1 Values

Wortmann et al. mentioned in their paper Internet of Things: “At its core, Innovation in the Internet of Things is characterized by the combination of physical and digital components to create new products and enable novel business models.” It is now able to extend functions and capabilities of industrial-age physical products to the digital world, with the contribution of increasingly efficient power management, broadband communication, reliable memory and advances in microprocessor technologies (Yoo et al. 2010). Figure 1 demonstrates that IoT solutions typically hardware and software to create its value. Consequently, the critical capabilities of physical products can be enhanced by the digital extensions with which can be interacted at both a local level and a global level. For example, the Nest Thermostat (Figure. 5) provides IoT services for traditional thermostats and enhances their primary function of home climate control by enabling it to save energy according to users activities. This service can be accessed locally through the Nest Thermostat embedded touch screen but also through the smart phone app by users. Similarly, Philips Hue (Figure. 6) transforms traditional light bulb into an entertaining lighting device by integrating IoT technologies. Traditional light bulb has the only function of lighting, while IoT-based Philips Hue not only allows users to have different lighting scenarios but has the ability of adapting to different situations automatically without operation from users. Amazon Echo (Figure. 7) turns a bluetooth speaker into a smart assistant at home with IoT and other advanced technologies like artificial intelligence and machine learning. A basic speaker is

only able to play sounds while Amazon Echo, embedded with IoT softwares and connected with the cloud, is able to provide useful information, to reply emails and messages, to do groceries for users online etc. information, to reply emails and messages, to do groceries for users online etc.

THING	+	IT Hardware Software	=	Thing-based Physical Local function	+ IT-based Digital Global service
 Bulb		IoT stack	→	Light	Security
 Bin		IoT stack	→	Storage capacity	Automatic replenishment
 Tractor		IoT stack	→	Towing vehicle	Predictive maintenance, optimization

Figure 1.3: IoT-product-services logic (by Wortmann et al.2015)



Figure 1. 4: Nest Thermostats (From Apple)



Figure 1.5: Philips Hue (From Philips)



Figure 1.6: Amazon Echo product family (From Amazon)

Benefits of IoT technologies can deliver is not restricted within individual connected products. When each similar or compatible product gets connected and forms a product system, IoT is able to create a greater impact by getting functions of all the system components empowered by each other. Look back at the example of Amazon Echo, it can build a smart home system by connecting with Philips Hue, SungSang smart refrigerator, Nest Theomostat, smart babysitter camera and other smart home products. Users are allowed to operate these products and let them work together just by talking to Alexa, the AI assistant embedded in the Amazon Echo. Porter and Heppelmann even point out that several IoT systems can form systems of systems getting over industries boundaries and making significant impacts.



Figure 1.7: Amazon Echo acts as a smart hub (From Amazon)

It is critical to clarify the add-on value of IoT before making IoT products. Keeping in mind what values can IoT delivered is helpful for companies to take advantage of the IoT technologies and integrate into their current products properly. When the value of IoT can be well revealed, It is able to turn the value of the product to real business impact. The Mickiny Global Institute concludes 9 settings where IoT has been implemented and predicted to create significant business impact in the near future.(Figure. 9)

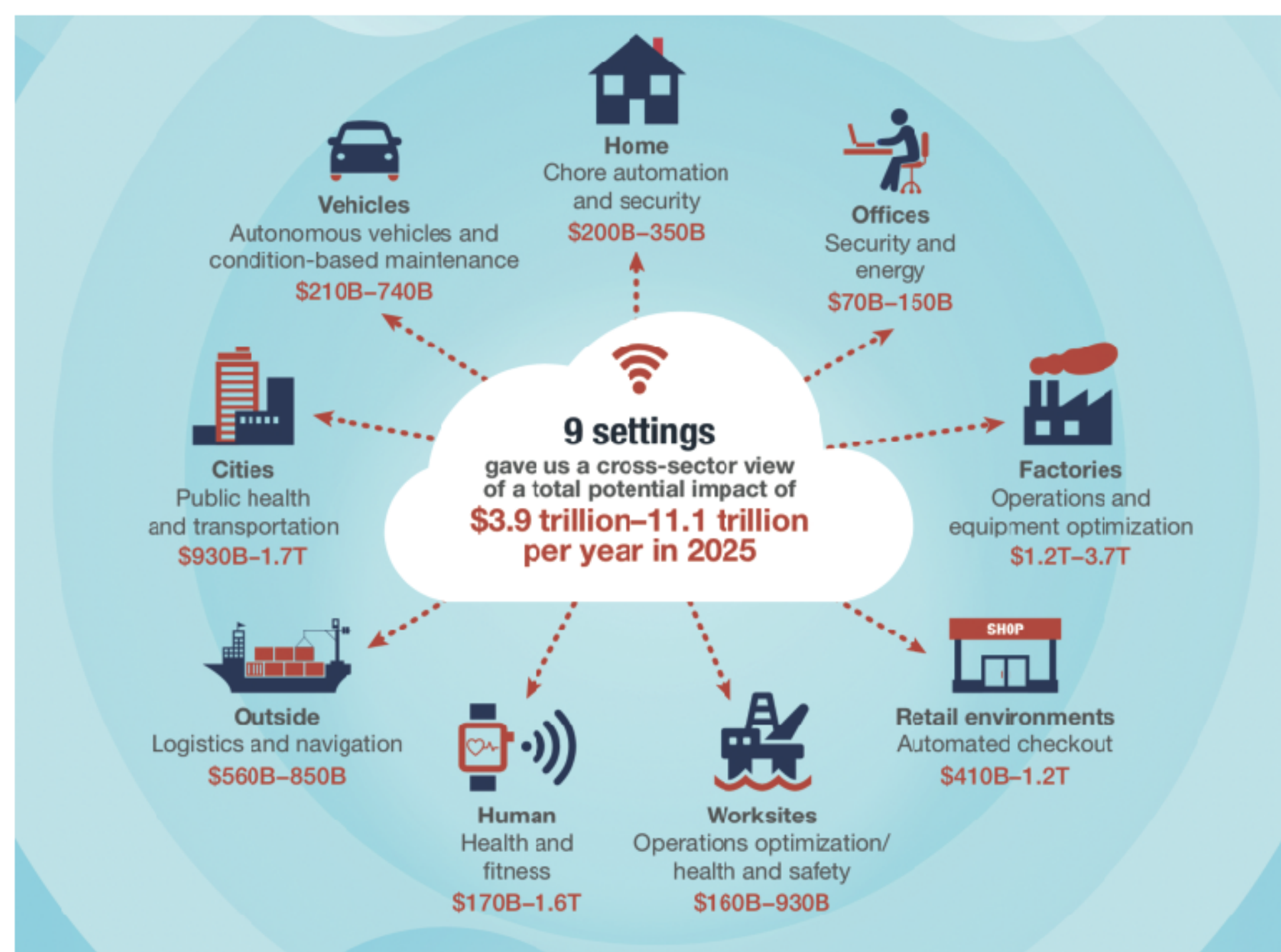


Figure 1.8: 9 IoT settings have predictable business value by The Mickiny Global Institute

1.1.2 Technology Stack

To implement IoT, It is important to understand it from a technological perspective. Typically, an IoT system has a multi-layer technologies stack which combines a number of software and hardware components. (Wortmann et al.2015) Figure 3 illustrates such an IoT technology stack which has three main layers, in terms of the thing or device layer, the connectivity layer and the IoT cloud layer:

- The device layer contains IoT-specific hardware and embedded software. On this layer, existing physical devices, which only have core hardware but no internet empowerment, get integrated with IoT specific components such as additional sensors, actuators or processors that supports IoT-specific functions. Apart from hardwares, the physical devices also get embeded software. These software gets modified or integrated to enhance functionality of the physical things.
- Connectivity layer commits to communication protocols that enable communication with the cloud and other IoT empowered physical devices. Forexample MQTT support communicate between physical devices and the cloud.
- The cloud layer contains a group of software, in terms of communication and management software, application platform, data analytics and management software, process management software and IoT application software. Communication and management software is responsible for communicating with, predicting and coordinating the

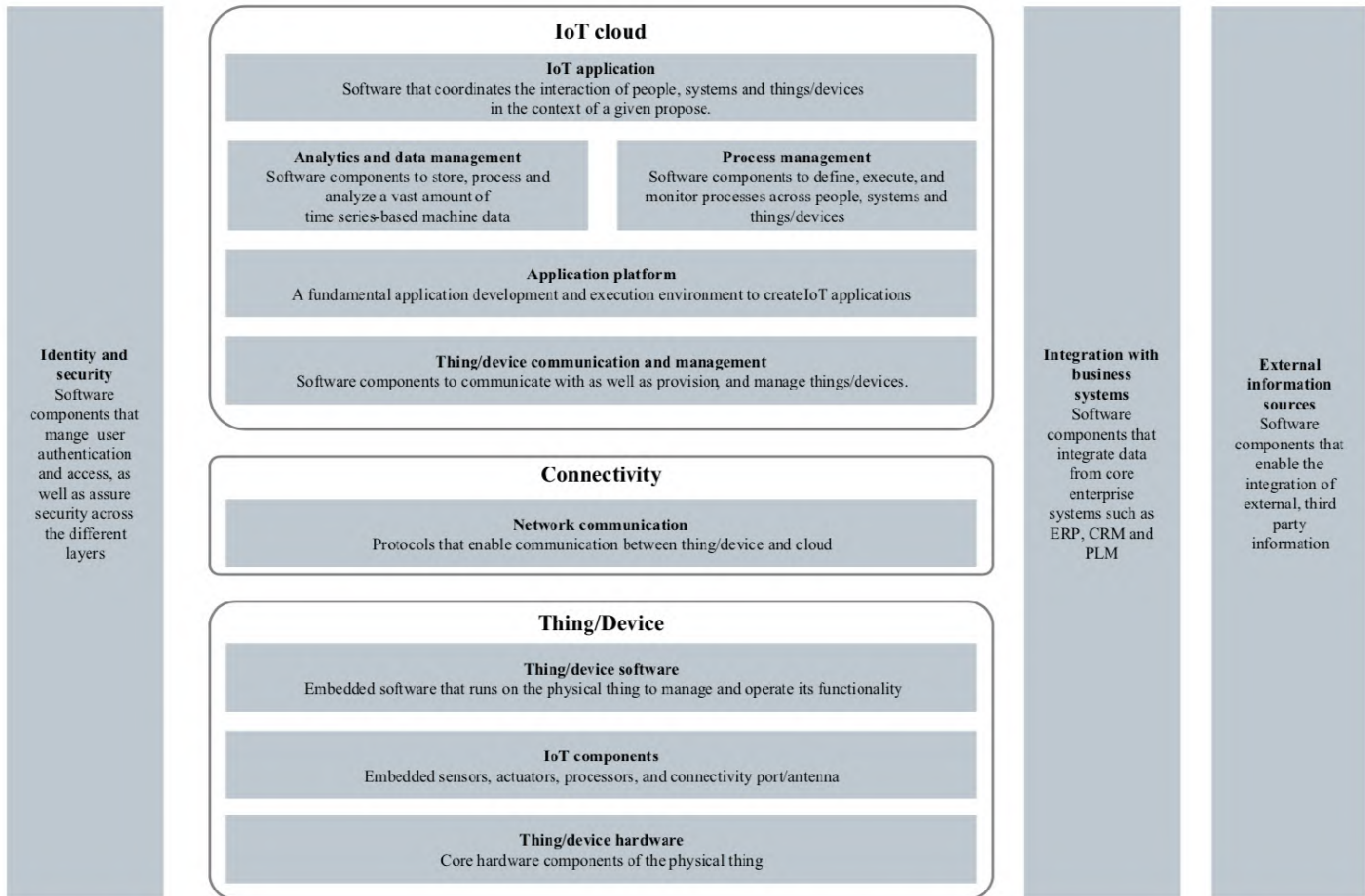


Figure 1.9: IoT Technology Stack by Wortmann et al.

connected physical products. The application platform is a fundamental application development and execution environment that helps create IoT applications. In the research area of computing, the term “platform” itself is a relatively broad concept, which has, e.g., been defined as “a group of technologies that are used as a base upon which other applications, processes or technologies are developed” (Janssen 2015). In the scope of Internet of Things, IoT platforms are essentially software products, which offer comprehensive sets of application independent functionalities that can be utilized to build IoT applications (Wortmann et al. 2015). In the IoT industry, individual IoT platforms may vary considerably because platform providers stress on different aspects of the IoT technology stack and correspondingly create platforms that have diverse sets of functionalities. Therefore, there is no standard configuration of an IoT platform, but a diversity of IoT platforms exists, which handle specific demands and application areas. Analytics and data management software are used to store, process, and analyze the data generated by the connected things. Process management softwares are components used to define, execute and monitor processes across people, systems and things. Last but not least, IoT application software manages the interaction of people, systems and things for a given purpose. Currently, integration is most applied on the cloud layer, especially the IoT application domain, and expected to have more future improvement since AR has a major implementation as user interfaces.

-There are also software components that go through all layers. Some of them can handle identity and security aspects by managing user authentication and access and assuring security across the different layers. Some of them can address the integration with business systems by collecting and processing data, for example ERP or CRM. The rest work on the integration with external information sources (Porter and Heppelmann 2014).

In conclusion, a robust IoT system has a technology stack composed of core hardware and IoT specific hardware, communication protocol, IoT platforms and a variety of softwares.

1.2 Challenges and Future Directions

To achieve the above great value of IoT, there are challenges that need to be resolved, mainly of two aspects which are business and technology.[6] Accordingly, challenges stand for existing problems of IoT and reflect parts of the future directions of IoT in addition to new expectations and opportunities. Since challenges and future directions are too broad, it is necessary to get the whole picture before identify a specific area for further investigation.

1.2.1 Challenge

From a business perspective, companies have to consider opportunities, potential threats and business model adaptation at the strategic level when integrate IoT solutions with their existing products and services. At the implementation level, companies need to take into account IoT technologies and services provider, technical details of adding new digital services, talents and development teams, customer services, marketing methods, new design principles etc.(Fleisch et al. 2014; Porter and Heppelmann 2014). From a technological perspective, developing IoT products requires integration of hardware and software as well as multiple technologies which sometimes even out of the IoT scope, for example Artificial Intelligence and Machine Learning. Therefore, IoT adopters has to face some important challenges which relate to, e.g., device level energy supply, identification and addressing, Internet scalability, security and personal privacy, as well as standardization and harmonization (Atzori et al. 2010; Mattern 2013; Vermesan et al. 2014).

For example, in report Unlocking the business value of IoT in operations from Capgemini Digital Transformation Institute, the research found four challenges that stops companies move towards full scale IoT from pilot projects, in terms of security threats and privacy concerns, lack of a solid business case, lack of structured data and analytics capabilities, absence of uniform standards and protocols poses a serious challenge. In their survey, 62% of the organizations that are struggling to scale up IoT applications cited cybersecurity and data privacy threats as a top concern (Figure. 10). They found that about half of organizations are experiencing challenges with establishing a clear business case (Figure. 10), making it difficult to secure funding and leadership support.

Figure 3. Struggling firms face business case and cybersecurity/privacy challenges

Share of organizations facing challenges in IoT implementation



Source: Capgemini Digital Transformation Institute, IoT in Operations survey, N = 316 companies that are implementing IoT in operations, October 2017.

Figure 1.10 Share of organizations facing challenges in IoT implementation by Capgemini Digital Transformation

1.2.2 Future Directions

As mentioned before, challenges also indicate future directions for IoT development. After trials and errors of IoT implementations, there are also more rational expectations. New opportunities arise as other technologies are emerging and growing. All these challenges, expectations and opportunities point out some directions in IoT evolution.

Massive adoption of platforms

First, IoT is going to see a massive adoption of platforms. According to The Forrester Wave [11], 60% of decision makers from business and infrastructure and operations already use or intend to implement IoT-enabled applications over the next two years. However, adoption of IoT is complicated because of regulation and standardization of emerging technology and protocols. Before mass adoption, it is necessary to address “fragmented sets of hardware, protocols, software, applications, and analytics solutions.” Leading IoT software platforms by IBM, Amazon, Cisco, General Electric and other giants will develop more and more multiplier solutions to help with mass adoption by simplifying design, creation, integration and management of IoT infrastructure and enterprise data. These multifunctional solutions are expected to well manage IoT-enabled technology at large scale. Intensive competitiveness between these companies gives rise to continuous innovation and improvement. For example, edge devices have edge computing ability by running trained machine learning models developed by AWS IoT. IBM Watson IoT platform provides robust cognitive capabilities for IoT infrastructure. While Azure IoT Suite from launches new developer-friendly features for device man-

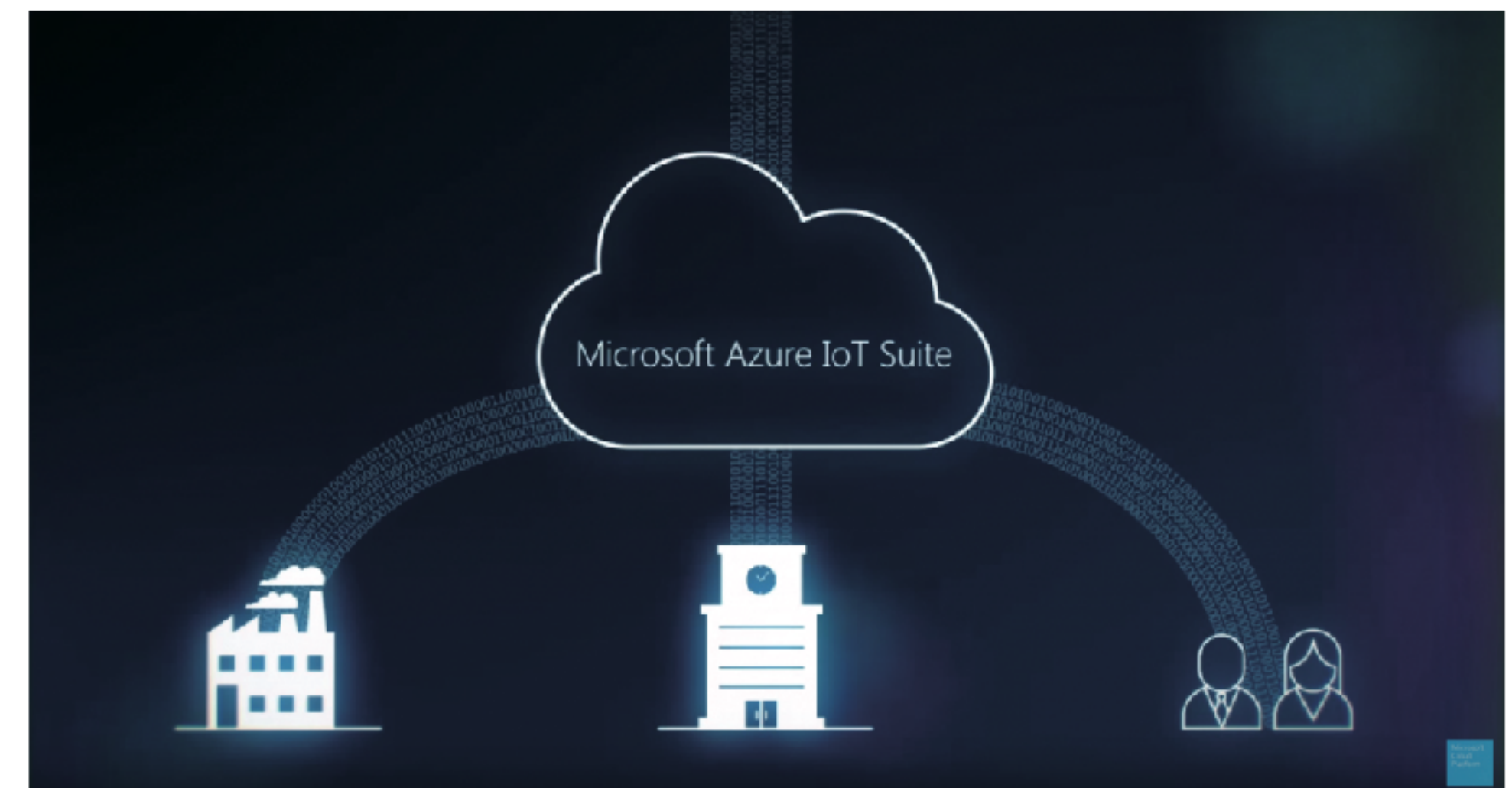


Figure 1.11 IoT platform of Microsoft Azure IoT Suite (From Microsoft)

agement. It is far simpler to integrate connected devices to current enterprise infrastructure.

Second, IoT will seek opportunities of value creation by excelling data. It is obvious that data is an important product of IoT-enabled systems and services. It is the essential determinant for value creation of IoT. While In the report *The Internet of Things: Mapping The Value Beyond The Hype*(2015), The McKinsey Global Institute (MGI) points out that most IoT data collected among current use cases are not used, and the data that are used are not fully exploited. This is also one of the main challenges mentioned before. Generally, to gain an understanding IoT data, there are three steps: storing data, analyzing data and acting on data [13]. They all have challenges and make data excelling difficult to IoT adopters.

For storing and analyzing data, data intelligence, data application and monetization are expected to have new variation to tackle this problem. [14] This year, IOTA, which is an open-source distributed ledger, starts to create a data marketplace, where any connected device or sensor could securely transfer valuable data. However, there is a challenge of mining valuable data and prepare them from such transfer. If the challenge of data mining and preparation is well addressed, the marketplace can expect to provide cost-efficient and well-prepared data to billions of IoT-powered enterprises. This marketplace is expected to get bigger and bigger in the upcoming years with more and more IoT giants joins the game like Cisco, Orange, Daimler, Accenture, Deutsche Telekom, EWE, Tine, PwC, Schneider Electric, DNV GL, and others.[15] Tech giant Google also offers solutions for managing connected devices and integrate with data and analytics services by launching Google Cloud IoT Core. It is a fully managed cloud service designed to securely connect devices to the Google Cloud Platform [16].

For acting on data, IBM researchers are doing rule engines which use the insights discovered from IoT data through analytics, and apply rules to produce accurate, repeatable decisions. Regardless of the engine's implementation, they also emphasize rules encode conditions that are used to trigger actions that autonomously make adjustments to a system to work around issues, maximize performance, or optimize costs.[13] Moreover, human judgment is required to make IoT data actionable in applications. This calls on focus to build visualizations and user interfaces that synthesize large amounts of data into

formats that can be easily understood by human decision makers [15]. Formerly inconvenient features in terms of decision makers identifying patterns and drawing insights from various data streams become more accessible thanks to the new generation of data visualization based on AR and VR technology. Both highly specialized platforms like Virtualitics and grand masters like IBM stress on AR and VR technology to provides immersive visualization with brand new benefits for business and the whole industries.

Synergy with AI, ML and AR/VR

Technology always develops with facilitation of other technologies. IoT will become more beneficial to enterprises by integrating with machine learning capabilities, artificial intelligence, augmented reality, block-chain and other technology synergy. This assignment has a strong correspondance with such trend by integrating IoT and augented reality.

For this trend, there are numerous projects which implement it practically to expand IoT application capabilities. Previously mentioned IOTA blockchain teams with major IoT players and plans to secure invisible micropayment transactions which will be handled between smart devices autonomously.If a machine is applied with an IOTA node, it will be transformed into an 'economically independent machine' which has ability to transact with other machines and to manage its own profit and loss statement aumatically. As a result, in the near future, we can expect that a IoT empowered machine will be able to pay its assembly, its maintenance, its energy and also for its

liability insurance by giving data, computing power, storage or physical services to other machines. On the other hand, delivering an usable and secure IOTA to the general public is challenging. IOTA faces several security challenges in terms of protocol, implementation, operations and infrastructure that require proactive scrutiny and solving.

Built on the integration of machine learning into IoT infrastructure, predictive maintenance wins the comment of most promising applications of IoT in manufacturing and consumer markets. Thanks to machine learning, both real-time and legacy data generate insights and predictive models together able to predict machinery wear, execute automate maintenance, prevent malfunction and cut unnecessary cost. In order to succeed such predictive maintenance, there challenges in front to be overcome. For example, Sebastian, et al. listed the following challenges when they tried to predict the failure of an air compressor in a complex system containing many components.

1. Deal with large amount of diagnostic data that has unusual properties, i.e. inhomogeneous data distribution.
2. Extract a valid ground truth from three given datasets to find out exactly when the compressor failures happened by searching for indications for that type of failure and recognizing unnecessary workshop layovers (i.e. through premature indication of failure by the diagnostic system).
3. Recognize errors, incompleteness and imprecision in the data and derive methods to deal with them.

4. Create meaningful features that emphasize the underlying effects that indicate an upcoming failure.
5. Set up a labelling process for time-series data that enables classifiers to anticipate impending failures early enough to allow for corrective reactions.
6. Define an evaluation procedure that maximises the outcome with respect to given criteria in order to achieve optimal prediction.

3D data visualization space enables IoT adopters to create an intuitive environment that helps data scientists understand and analyze more data streams efficiently, observe data from multiple dimensions, identify previously infeasible dependencies and manipulate data by natural interaction. Moreover, team collaboration on decision making is also benefited because these tools allow virtually 3D data visualization. For example, Virtualitics grabs \$7M in funding to drive its VR data visualization platform. Zappar AR platform cooperates with Erythng to explore the possibilities of adding value to both business and consumers by designing interesting interaction for everyday application of smart devices. PTC use AR to facilitate ThingWorx IoT platform in the application of smart factory. ThingWorx is a great tool for aggregating information from sensors and controllers and various other pieces of hardware. With AR, it can also bring in data from other digital resources, such as CAD and PLM and even ERP, and allowing to create a digital twin of what's happening out there in the physical world. A digital equivalent enable people to understand how the machinery being operated, to predict when it's going to fail, to make sure it's operating most efficiently. Although being beneficial, IoT data

visualization through AR and VR is also challenging. Similar to the previous AI integration with IoT, AR also need to address the technical problems of data preparation. Creating intuitive and natural interaction for users are full of challenges as well. For example, a great amount of data requires designers to pay extra attention to scalability and dynamism of graphic representations which can be considered as two of the main challenges of big data visualization. [20] More interaction possibilities are beneficial while sometimes also bring higher complexity to deliver good user experiences. Designers need to assign

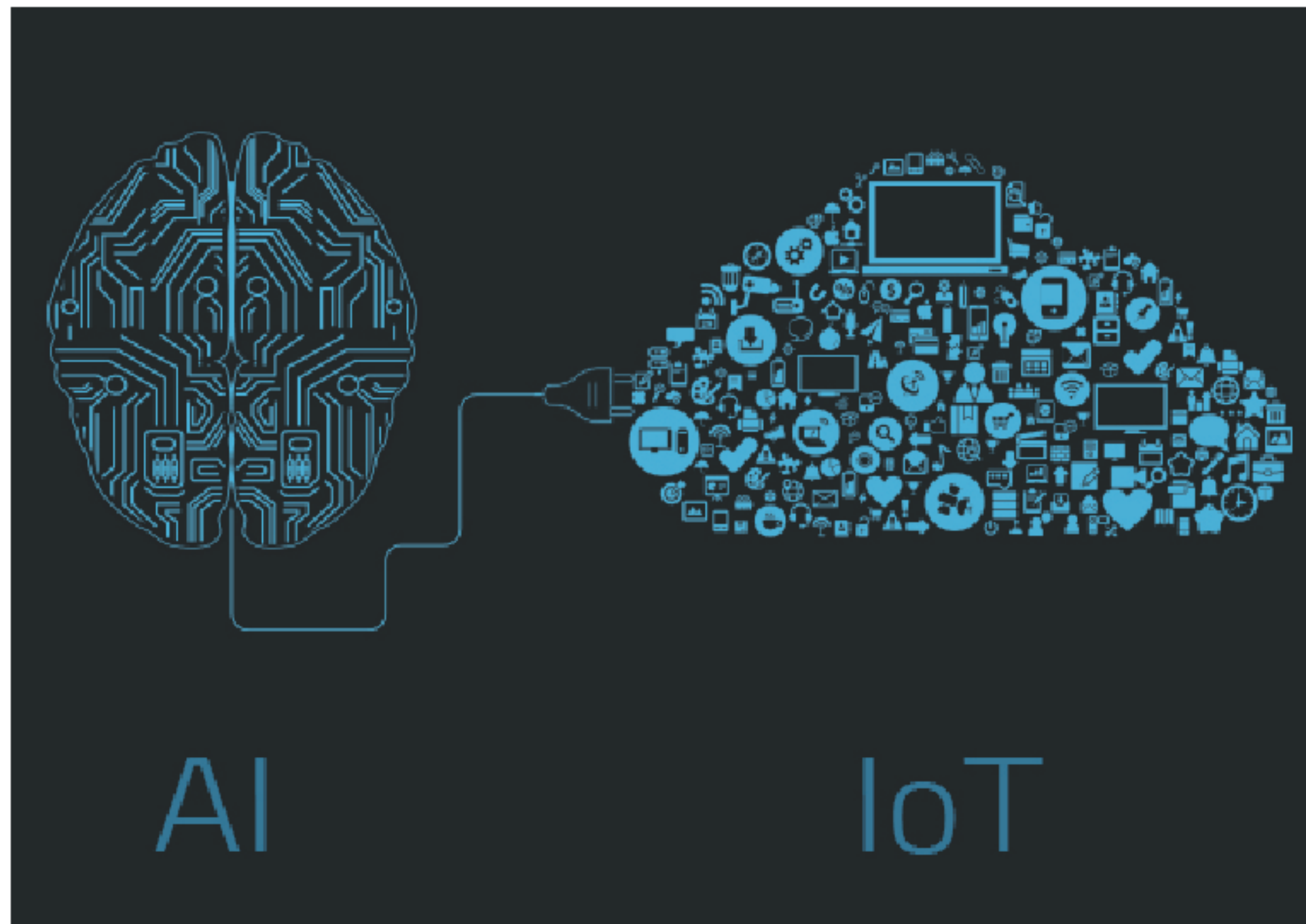


Figure 1.12: IoT integrate with AI. Image credits: Google

appropriate interactions for different situations when interacting with IoT systems.

In conclusion, addressing the IoT data issues, like processing, analyzing, utilizing and interacting with data, are main objective of the integration between IoT and other technologies, but at the same time the challenge itself for such integration.

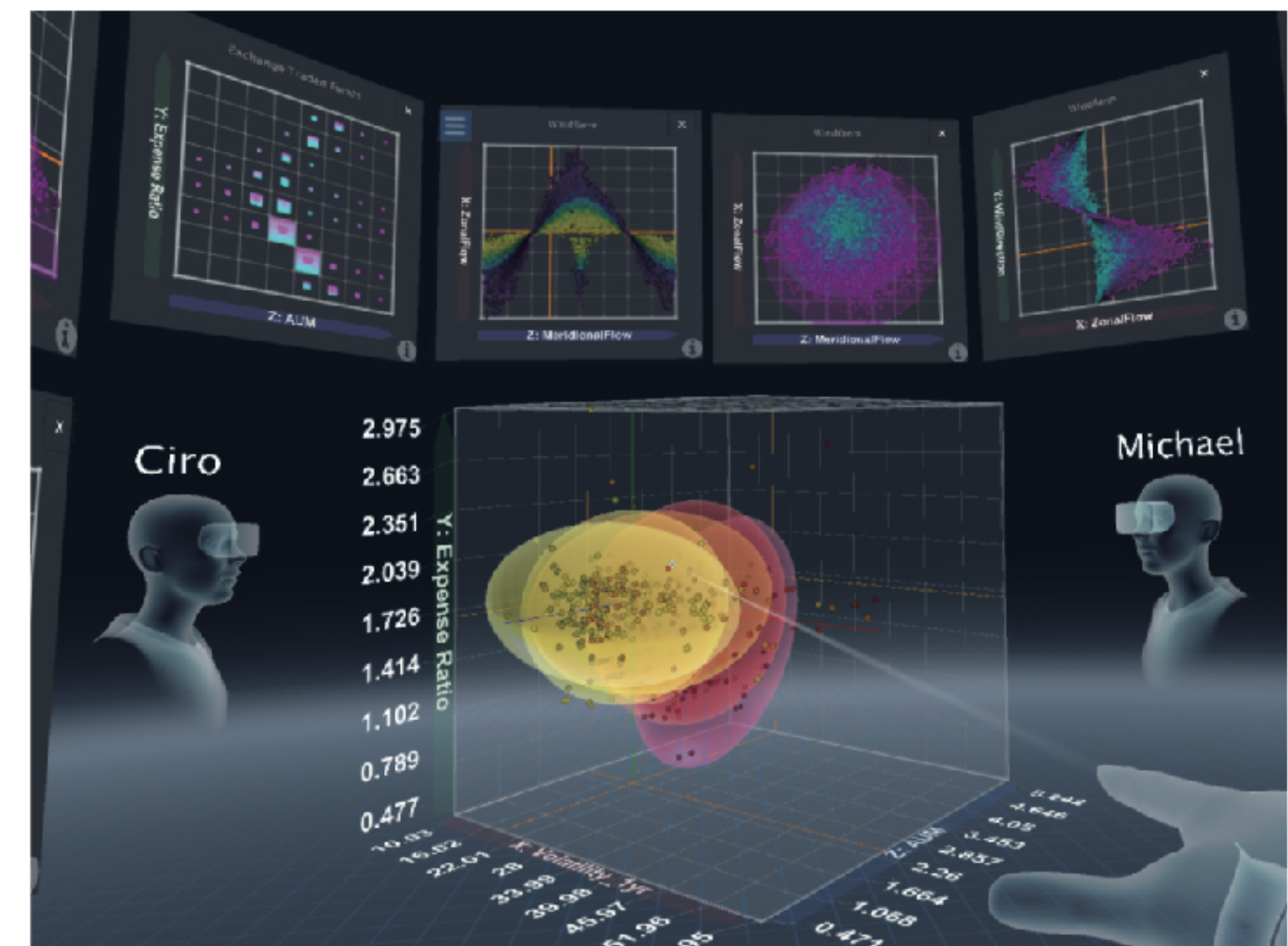


Figure 1.13: IoT integrate with AR/VR. Image Credits: Techcrunch.com

1.3 Zoom into AR for IoT

As introduced in previous sections, IoT is becoming a broad area after years of development and still sees a great number of challenges and opportunities of getting its value delivered. It is not realistic to get this assignment covers all aspects of IoT. Therefore, the focus of this assignment is placed on the integration of IoT and AR. It aims to make a contribution to such an Integration which would empower IoT.

According to the research, in this chapter, It is accountable to think that IoT will get facilitation from the integration with AR. On one hand, the Augmented Reality (AR) technology, discussed in chapter 2, is typically implemented as human computer interfaces to realize an intuitive and natural interaction between human users and computing systems. On the other hand, the top of the IoT technology stack lays IoT applications which essentially manage the interaction of people, systems and things for a given purpose. These IoT applications show the technological possibilities of an AR-IoT integration by using AR as interfaces for IoT systems. More over, It has been discussed that data use challenge of IoT seeks solutions to make IoT data more action-able for human decision maker with more efficient and effective user interfaces. Last but not least, research and implementation indicates that IoT sees future trends in synergy with AR and VR for 3D visualization and spatial interaction.

To realize such an AR-IoT integration, It is required to have further research on AR and the integration which will be presented in the next chapter.

Conclusion

As the essence of this assignment, IoT gets a general introduction in this chapter. By forming a technology stack of hardware and software, IoT enables the link from the physical world to the Internet and creates value in different business setting. Today, IoT still faces many challenges before it gets matured. At the same time, there are emerging opportunities to bring IoT to a new level by conquering the challenges and collaborating with other technologies. Augmented Reality, as another trending technology, is expected to have a win-win integration with IoT. This combination will require more research effort and practical implementation.

CHAPTER 02

AR DESIGN FOR IOT

Chapter 2 is mainly about the integration of AR and IoT from an interaction design perspective. In order to find out how to apply AR in IoT products, it zooms in the interaction design of IoT systems and has a general study on AR and a specific focus on wearable AR which is more advanced and has more future potential. The interaction capabilities will be discussed so that we can envision what potential interaction benefits for having AR interfaces in IoT systems. Next, this chapter researches how to implement AR interaction design for IoT. This will clarify what researches about AR-IoT integration have been done and provide fundamentals to step further in the interaction design field of such integration.

2.1 IoT Interaction Design

Given the study on IoT in chapter one and AR in this chapter, this section will zoom into the interaction design of IoT, mainly about its interaction design and the possibilities of integrating AR into its interaction. Apart from designing information architecture, physical device, security and protocol, amongst others, there are many human-centred issues of IoT needs to get attentions. This belongs to the interaction design of IoT systems, including how to present the data collected from the real world in the most appropriate manner and make it meaningful to stakeholders. To handle this issue, it is appropriate to look at it from the Human Computer Interaction perspective (HCI). The Internet of Things concept originates from a broad HCI research topic, ubiquitous computing. In 1991, Mark Weiser, considered nowadays the father of ubiquitous computing, envisioned that technology would disappear to our sight and integrate into our daily routines [17].

According to Mark Weiser's classification, an ubiquitous computing system has two fundamental characteristics: namely ubiquity and transparency, see [Weiser, 1993]. Ubiquity refers to the scenarios where the interaction with the system is available wherever the user needs it. Transparency requires the system to be non-intrusive and integrated into the everyday environment. In 2001, Maffioletti analyzed the requirements for an ubiquitous computing infrastructure and presented the general idea of a middleware that provides the basic functionality for modeling interactive environment applications is presented. They define:

A ubiquitous computing system consists of a heterogeneous set of computing devices, a set of supported tasks, and some infrastructure on which the devices rely on in order to carry out their tasks.

When elaborate further, this ubiquity leads to a number of almost identical concepts, such as "pervasive computing", "ambient intelligence" and "the Internet of things". In practice, the differences between these terms are of rather an academic nature. They are all technologies that can be turned into solutions with the goal of assisting people and a continuous optimisation and promotion of economic and social processes by computing systems integrated into the environment. In [Salber et al, 1999b], based on Weiser's classification, Maffioletti identified two dimensions that provide a clear boundary for ubiquitous computing systems and illustrate the relationship with other emerging research areas such as mobile computing, augmented reality and wearable computing, namely user mobility and inter-

face transparency. User mobility reflects the degree of freedom that the user has to move about when interacting with the system. Interface transparency applies to the system's interface and reflects the conscious effort and attention that

the system requires of the user, either for operating it or for perceiving its output. The spatial arrangement in the diagram 2.1 expresses that ubiquitous computing tries to maximize the user mobility and the interface transparency, while in contrast, desktop computing offers no user mobility and mostly no transparency to the end user.

Matched with ubiquitous computing, Augmented reality and wearable computing also aims to increase the two dimensions. It is reasonable to believe the integration of IoT and AR is in accordance to the interaction nature of both technology and possible to deliver new values. In order to have this promising technology integration, it is necessary to have a study on AR as well.

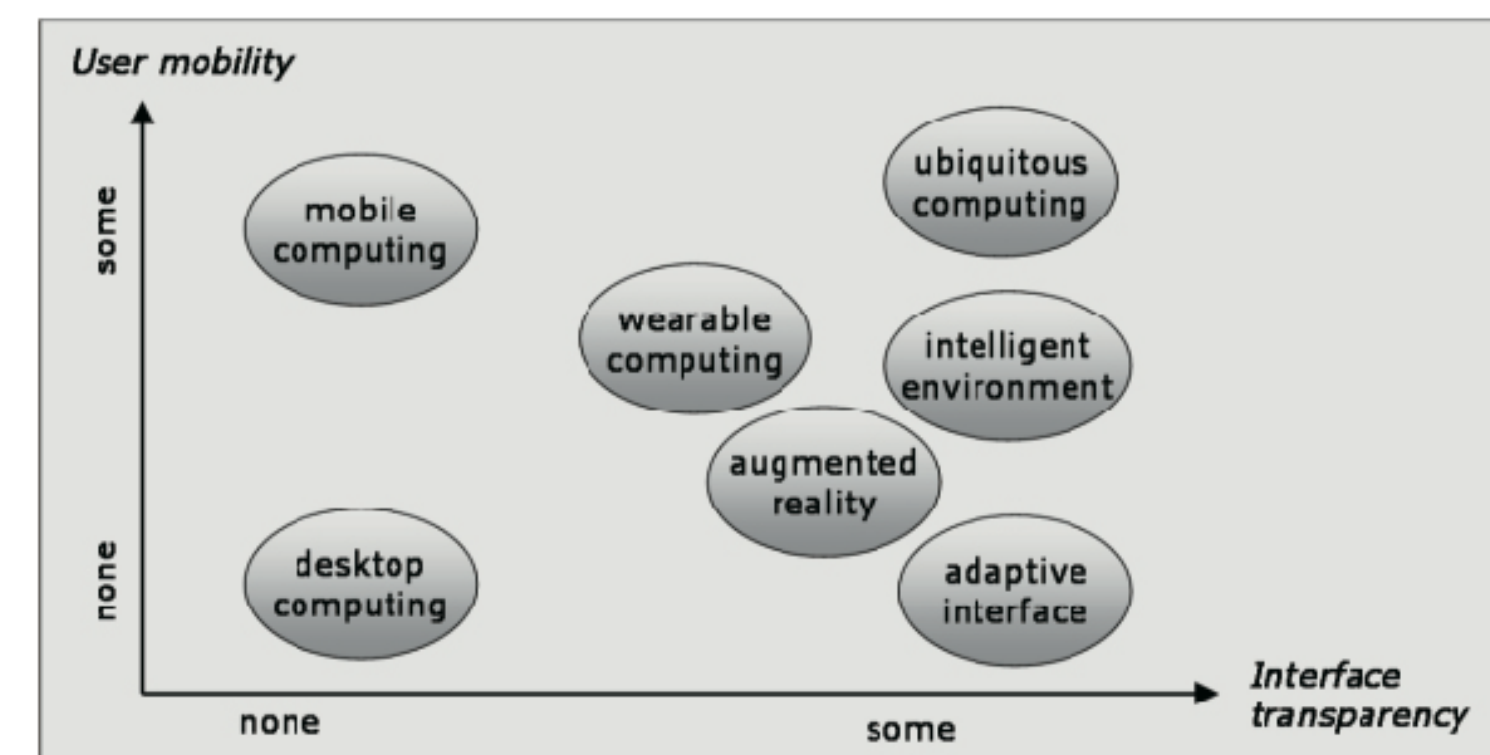


Figure 2.1: User mobility and interface transparency dimensions that characterize research streams relevant to ubiquitous computing, according to [Maffioletti, 2011]

2.2 Augmented Reality

In 1995, Milgram et al. [22] introduced a widely adopted Reality-Virtuality continuum, which classifies AR in relation to traditional Virtual Reality (VR) (Figure 2.2). The continuum ranges from a real world without any modification to purely virtual world. Mixed Reality (MR), which involves AR and VR, is placed in between the complete reality and virtuality. AR is specified closer to the real world, because it blends digital layers to the real world presentation which remains as the essence of this AR setting.

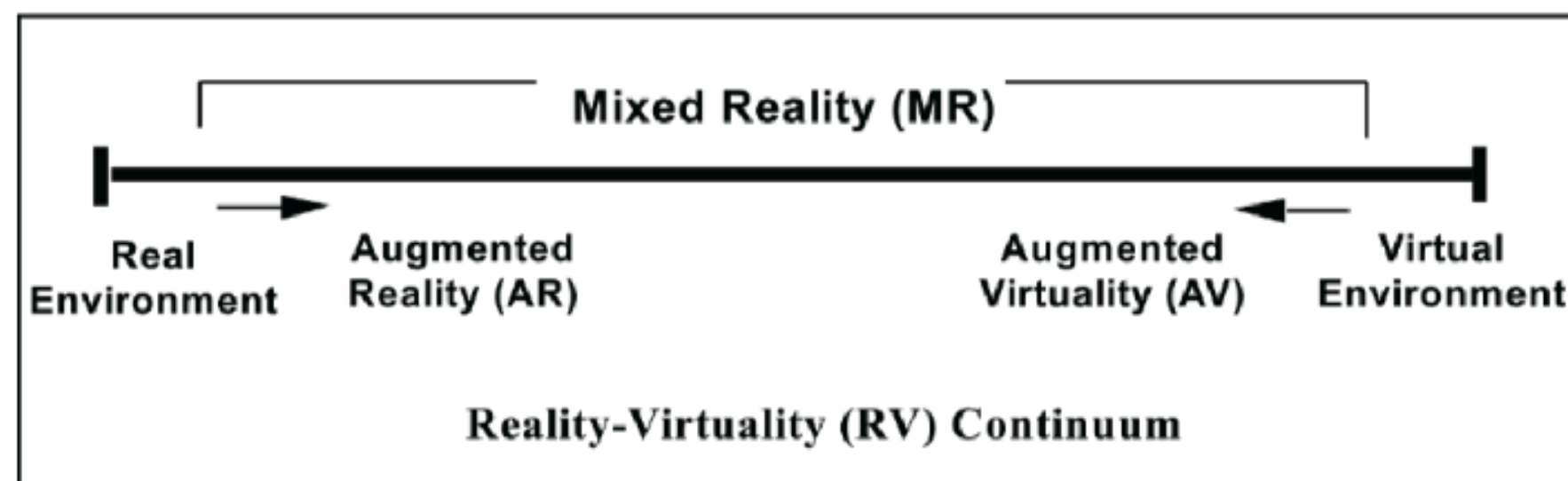


Figure 2.2: Reality-virtuality continuum (Image taken from Milgram et al. [95]).

2.2.1 Overview

The most accepted definition of AR is proposed by Azuma [23], who defined AR applications as 3D-registered interactive applications that combine the real world and the virtual world and run in real time. Both Milgram et al. [22] and Azuma [23] explicitly claimed that AR can be implemented with different display technologies. As a result, their definitions and classifications are device-oriented. According to projects about AR applications, they can be displayed through different devices using very different technologies and platforms, such as a Head-Mounted Display (HMD) [24], a mobile phone [25], or by using a projector system [26]. Like any other technologies, AR takes time to become how it looks like today. Date back to the early 1990s, the first functional systems that offer Augmented Reality experiences to users were invented. More precisely, it started with the Virtual Fixtures system which is developed at the US Air Force's Armstrong Laboratory in 1992 [27]. Even though firstly used for military purpose, it is now expanded on everyday life and commercial scenarios, like entertainment and game, businesses, knowledge sharing, education, team collaboration, creative industry and so on. Moreover, it is also widely implemented with different devices like laptop, smartphone, tablet and Headset. The most well-known cases would be Pokemo-go and Snapchat which are both smartphone AR applications with great popularity among users and successful business performance. The success of these applications is facilitated by leading technology companies like Apple and Google, who both launched their software developer kit (SDK) for smartphone AR application and supportive smartphone

hardware. These developments make the creation of AR experience much easier and thus encourages more developers and designers to create further innovative AR applications. The introduction of AR Kit (SDK by Apple) and AR Core (SDK by Google) confirms the consumerism of Augmented Reality which has long only been in the eyes of tech companies and startups.

Apart from smart phone, Augmented Reality are expected to have potential in the market segment of Headset, which is also known as Wearable AR. There are also competitive players trying to push Augmented Reality Headset further and win the future market of wearable Augmented Reality devices, like Microsoft and its mixed reality product line, Magic Leap who has high expectations from investors just launched its first hardware 2018 and Meta AR who already has its second generation of AR headset. Compared with AR experiences of smartphone or other hand-hold devices, the most outstanding advantage of wearable AR is its most impressive and hands-free experience provided by realistic and engaging projections of digital holograms and spacial sounds which mimic the sound happens in real world positions.



Figure 2.3: Apple and Google push the evolution of Augmented Reality Technology further in the consumer market

2.2.2 Wearable AR

Since Wearable AR stands for the most advanced and natural AR experiences, It will be the main focus of discussion of this assignment, especially smart glasses. Before we zoom into smart glasses, It is helpful to know what is the difference between different types of AR. Although there is a various of classification, this section takes a device-oriented perspective which classifies AR into 4 categories. They are Head up displays (HUD), Holographic displays, Smart glasses, Handheld AR.

Handheld AR

Although handheld AR uses video-see-through technology, it should be specially mentioned. In handheld or mobile AR, all you need is a smartphone to have access to a online host of AR experiences. The technology becomes truly pervasive when handheld AR rises up. After laugning augmented reality developer toolkits like ARKit, ARCore, MRKit, sophisticated computer vision algorithms are available for anyone to use.

Holographic displays

Holographic displays generate three dimensional forms of objects in real space through light diffraction. Holographic displays allow users to be free from any gear to view holographics which is one of their greatest advantages. These type of displays have always been in the realm of science fiction like the Star wars series, Minority report and the Iron man series in the recent times. They have recently started real implementation with products like Looking Glass and Holovect.

-Heads up displays

Heads up displays originated from mission critical applications like flight controllers and weapons system dashboards. Essentail information is projected on transparent screens mounted in front of the pilot. With heads up displays, pilots are able to look forward outside rather than looking down inside the cockpit. HUDs tried to address the problem of shifting focus by using a type of collimating projector. The pilot's eyes do not need to refocus to view outside the cockpit because the information projected is collimated (parallel light rays) focused on infinity. A regular HUD contains three major components: a projector unit, a viewing glass (combiner) and a computer (symbol generator). HUDs help increase situational awareness by reducing the shift of focus for pilots. Heads up displays have been increasingly finding ways into new automobile designs.

-Smart glasses

As the technology transitioned from critical applications in defense and aviation to commercially available products, smart glasses have become one of the more popular types of augmented reality devices. Like their name suggests, these are glasses that augment your vision. Smart glasses are of two types:

-Optical see through

In Optical see through glasses, the user views reality directly through optical elements such as holographic wave guides and other systems

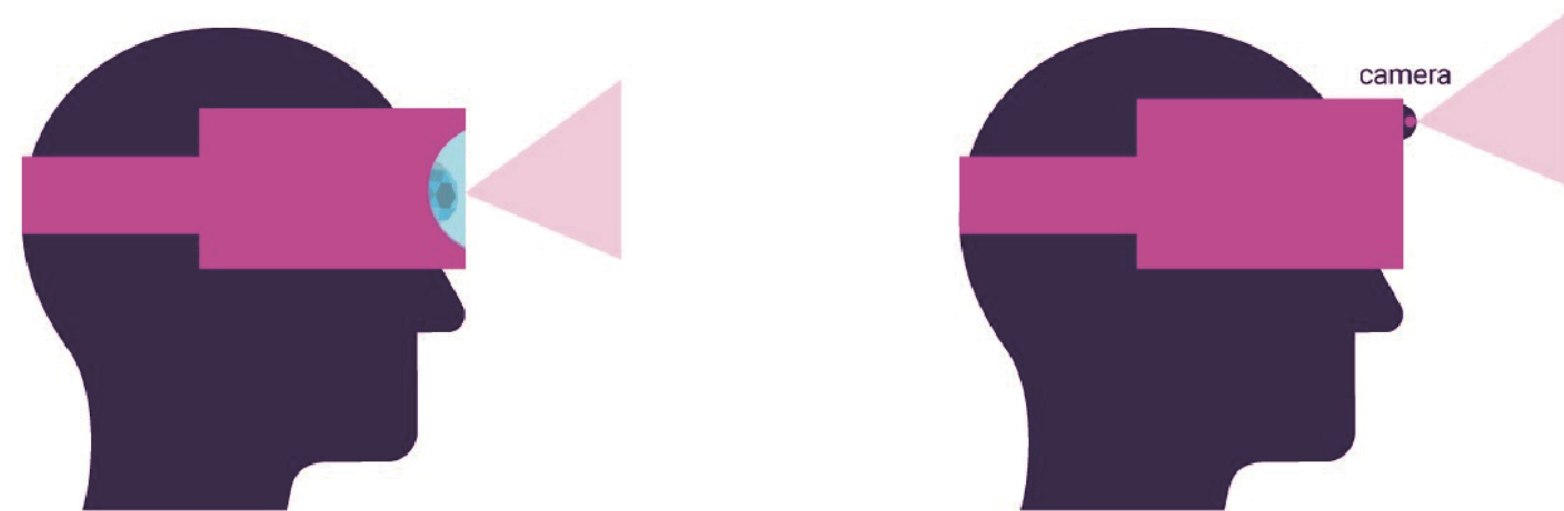
that enable graphical overlay on the real world. Microsoft's HoloLens, Magic Leap One and the Google Glass are recent examples of optical see through smart glasses.

-Video see through

With these type of smart glasses, the user views reality that is first captured by one or two cameras mounted on the display. These camera views are then combined with computer generated imagery for the user to see. The HTC Vive VR headset has an inbuilt camera which is often used for creating AR experiences on the device.

Smart glasses is also known as Wearable AR which is a hybrid research area of Augmented Reality and Wearable Computing. In the paper of Augmented Reality Through Wearable Computing, Starner, et al. Referred a wearable computer as a networked, multimedia computer that can be worn as clothing or is built into the user's clothes [29]. As a result, wearable computers have a closer association with users by synchronizing what users see, hear and sense and modeling the users to predict their next actions or states. This enables such wearable computers to create location and context specific AR experiences, using head-up displays and earphones to overlay graphics, text and sound in the physical world.

Wearable AR technology is the basis for the most advanced and immersive mixed reality experiences. Going beyond the "AR under glass" aspects of smartphone-based solutions, wearable AR rigs open up the possibility of deeply engaging projections, virtual holograms that can fill the field of vision more or less completely. Wearable AR headsets have some advantages over smartphone AR: better immersion thanks to dedicated visual projectors and the possibility of better integrated audio are the most salient. However, they do have the disadvantage of require dedicated hardware, which is currently bulky, somewhat expensive and far from fashionable.



Optical see through displays

Video see through displays

Figure 2.4: Two types of AR smart glasses. Image credits: UX Collective

2.2.3 Interaction Capabilities of Early Wearable AR

Starner, et al. [29] 1997 further featured 3 specific capabilities of wearable AR which later inspires the interaction design of the modern AR headset like Google Glass, Microsoft HoloLens, Magic Leap, Meta. First one can be described as the extension of traditional computers' capability. Wearable AR is able to augment memory of the users by using a virtual Remembrance Agent (Rhodes and Starner, 1996) who stores user-relevant data and assisting users to perform certain tasks with these data. For example, when the user is writing a paper, the RA will suggest relevant references. When a user is reading an email and scheduling a meeting, the RA will suggest relevant constraints. More than providing timely information, RA can also help with personal organization when playing the assistant. When the user wants to contact a colleague, the RA will suggest the one have most contacts. Apart from memory augment, the capability extension also includes using finger tracking as pointing device. Having video cameras, wearable AR devices enable users to have a more intuitive input approach of just using gesture. Even though, today's AR headset uses will gaze of user as a pointer, the gesture tracking remains as a main interaction technique.

The second capability of wearable AR is to create a camera-based realities. Starner, et al. [29] Shows three examples, in terms of physically-based hypertext, 3D graphical overlays and active tags as well as inherent visuals. Physically-based hypertext adheres a text with hyperlink on a physical world object for users to have related informa-

tion. 3D graphical overlays and active tags could for example, show an animated arrow pointing to a problematic component of a laser cutting machine. Inherent visuals are able to place digital information on the proper position for an object. These examples all stress on closely relating the digital information with the physical objects and the environment in order to make the visualization as situated as possible. In other words, information that relates to the real world can be displayed and explored directly in the spatial reference frame of the real world environment. White and Feiner [31] later refer to this type of visualization as situated visualization in 2009.

The third one is user sensing and modeling. In order to provide user an unobtrusive AR experience, the headset must model its user's knowledge, actions, goals and even emotions. With sensors and user models, the AR headset is able to adjust its behavior, according to the user tracking result. For example, when a guest is giving a presentation, the AR headset understands that its user does not want to be interrupted, then will handle the incoming phone calls and messages.

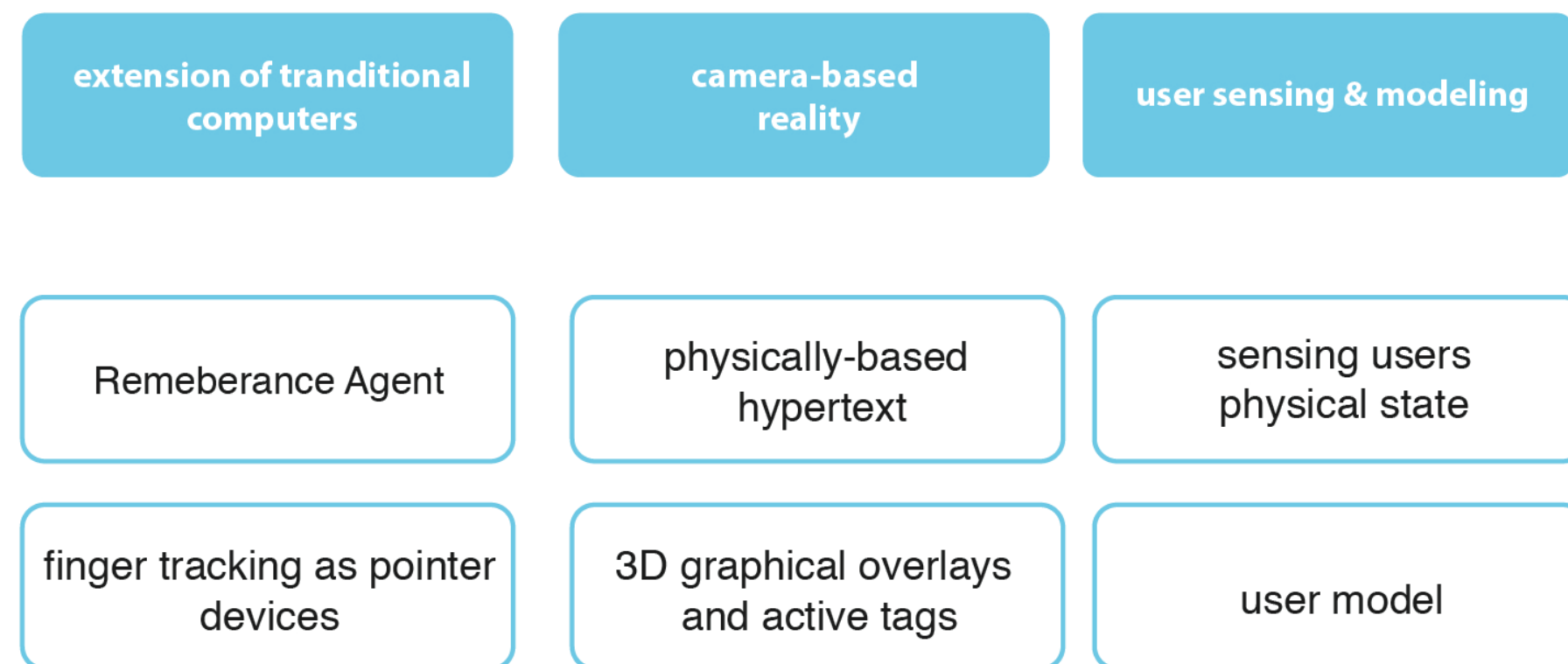


Figure 2.5: Interaction capabilities of early wearable AR suggested by Starner, et al. 1997

2.2.4 Interaction Capabilities Expansion

Two decades after, interaction capabilities of AR has been expanded to a wider scope. According to a 2014 survey on AR by Billinghamurst et. al. [32], there are five types of human computer interactions that has been integrated into AR. in terms of information browsers, 3D user interfaces, tangible user interfaces, natural user interfaces, multimodal user interfaces. This section will briefly review the AR implementation of each of these interaction styles.

- 1) Information Browsing: Interfaces for showing AR information on the real world
- 2) 3D Interaction: Using 3D interaction techniques to manipulate content in space
- 3) Tangible Interaction: Using real objects to interact with AR virtual content
- 4) Natural Interaction: Using natural body input such as free hand gestures
- 5) Multimodal Interaction: Using combined speech and gesture input

1) Information browsing considers AR as a window for directly displaying digital information blended with the physical world environment. It gives users a main task of interacting with the display window and filtering and browsing information. These digital information is registered to the physical world references and has interaction situated in the real world. This type of interaction is also known as situated visualization. It is now one of the important interaction techniques for current wearable AR systems.

3D interaction refers to interacting with AR contents directly in 3D space. This interaction technique is adopted from traditional 3D user interfaces, which provide direct interaction with 3D objects in virtual environments [Bowman et al., 2004]. Bowman et al. summarizes various types of 3D in- attractions into three categories: (1) navigation, (2) selection, and (3) manipulation which all have been implemented in modern AR headset, like Microsoft HoloLens. With Hellenes mounted on a face, the users are able to move their bodies and navigate through the AR world and use gesture with one hand or two hands to select or manipulate the AR objects. (Figure 2.6)

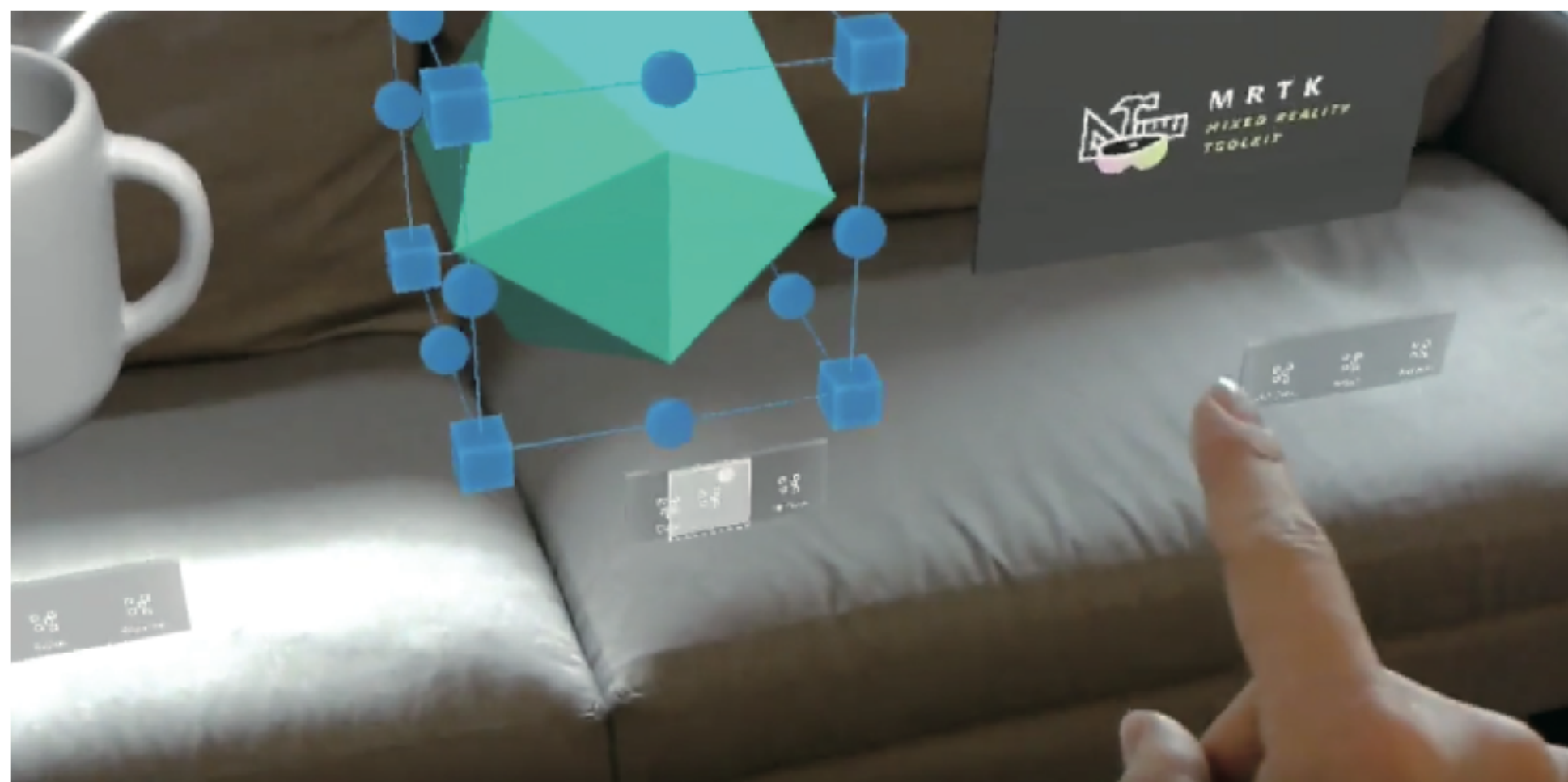


Figure 2.6: Use "airtap" gesture to select a AR object through HoloLens

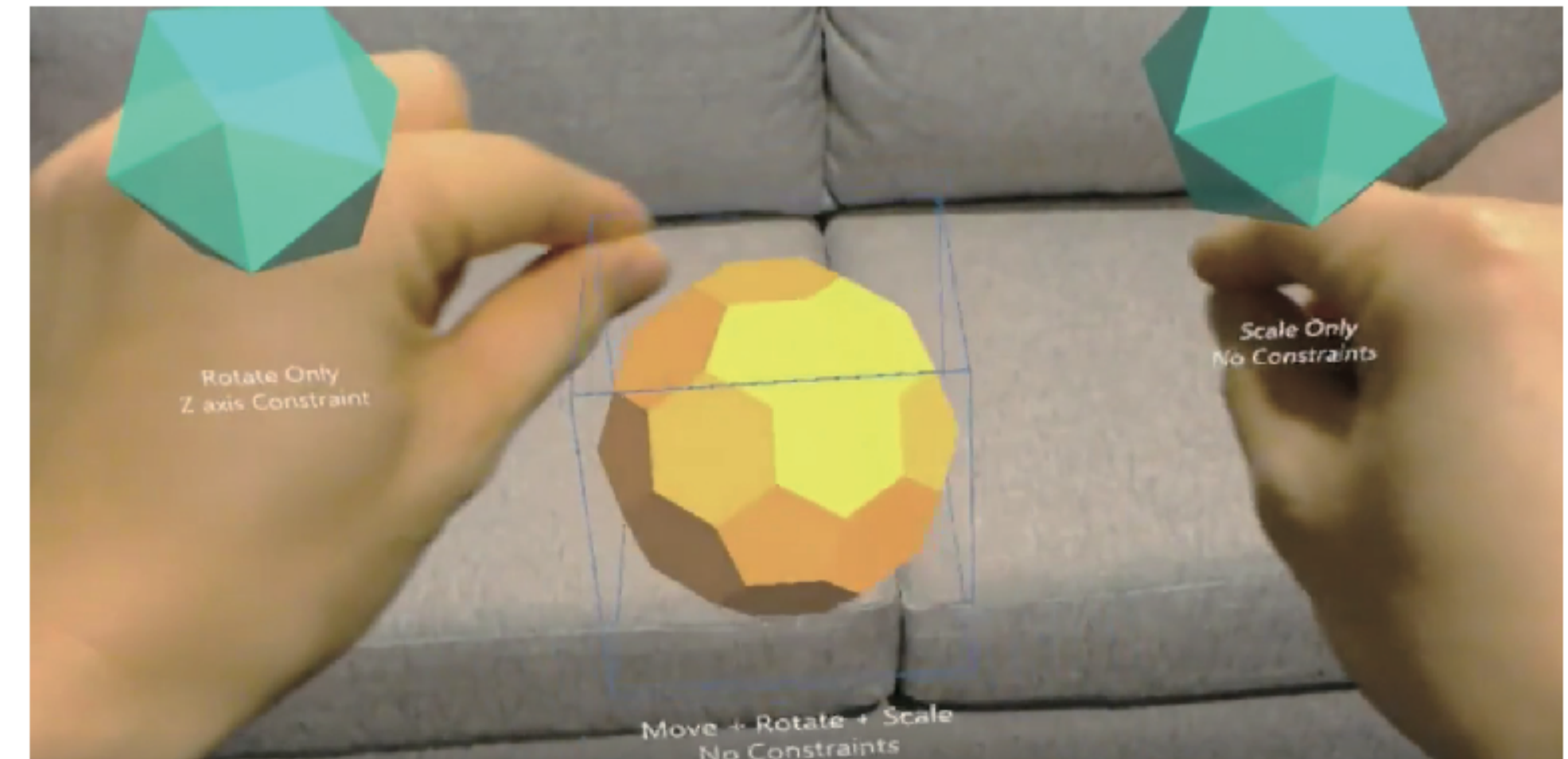


Figure 2.7: Use two hands manipulation to rotate and scale AR objects through HoloLens

3) Tangible Interaction use physical objects as a medium for interacting with computers [Ishii and Ullmer, 1997]. The concept is normally referred to as Tangible User Interfaces (TUI). It has been one of the main themes in modern human-computer interface technology research. Kato et al. [2000] proposed the concept of Tangible AR (TAR). In order to reduce the gap between the interaction methods for virtual and physical objects. TAR uses tangible real world objects as input interaction metaphor while using AR for visualizing virtual information overlaid on the physical object. Figure 2.8 shows a typical example of a Tangible AR interface from before that uses a physical keyboard with a marker on it as a Tangible UI while visualizing virtual objects overlaid on it through an AR headset. In this case, the TAR interface seamlessly merged together with the interaction space and the display space. Billinghurst et al. [2005] defines the characteristics

of Tangible AR interfaces as 1) each virtual object being registered to a physical object, and 2) the user interacting with virtual objects by manipulating physical objects. The basic goal of designing a Tangible AR interface is to map physical objects (input) with virtual objects (output) using an appropriate interaction metaphor. Similar to how physical tools are designed, Lee et al. [2007] summarized that Tangible AR interfaces have two different design approaches, or a combination of both methods. One approach is space multiplexed interfaces where each physical object is assigned to only one function, and the other is time multiplexed interfaces where a physical object can be dedicated to many functions and purposes depending on the situation. Because space multiplexed interfaces map each function to a certain physical object, it is considered to be more intuitive for users. Multiplexed interfaces require a learning process since it could have different function for one objects.

4) Natural Interaction uses natural body as input such as body movement or hand gestures. When adapted to AR, it is closely relevant to the mentioned 3D interaction. With advances in computer vision technology, AR headsets became capable of recognizing user's body motion and gesture in real time without requiring the user to wear any extra sensors. For example, Hellenes allows users to rotate and scale an AR object with the intuitive gesture that similar to pose of rotating and scaling a real world object. (Figure 2.7). In the Hololens game RoboRaid, users can move their body to dodge attacks from the AR Robots, while use gesture to shoot back. (Figure 2.9)



Figure 2.8: Vuforia demonstrates displaying a virtual model on a carbond marker throught an AR headset.

5) Multimodal interaction

In order to provide more intuitive interactivity in AR applications, there have been efforts to combine different models of input and output. Inspired by human-to-human communication in the real world, multimodal Interaction is proposed to have a more natural human computer interaction. It generally makes use of multiple HCI techniques of integrating multiple human modalities into the interaction. Chatty [38] gives a summary of definitions for multimodal interaction, which is defined systems that have multiple input devices (multi-sensory inter



Figure 2.9: RoboRaid deploy body movement and hand gesture to offer user a dodge and shooting game experience. Image Credits: Microsoft

action) or multiple interpretations of input issued through a single device and integrated in a meaningful way. Today, it is also adapted to the interaction design of the AR, especially AR headsets. Among different combination of input modalities, speech and gesture recognition combined is one of the most widely and actively researched combinations. [39] Previous research has shown that multimodal interfaces (MMI) that combine speech and gesture input can be an intuitive way to interact with 2D interfaces and 3D graphics on the desktop [Bolt, 1980, Hauptmann, 1989, Cohen et al., 1997]. This isomodalities are complimentary, with speech being good for quantita-

is because input modalities are complimentary, with speech being good for quantitative input, while gesture is ideal for qualitative input [Cohen et al., 1989]. Despite these early researches, MMI adoption is also seen in the interaction design of commercial products like Meta AR glasses, Magic Leap and Microsoft HoloLens. For example, the Hellenes have a multimodal input system which allows user to use gaze, gesture and voice as input, while has an AR visual and spatial audio feedback from users as system output. (Figure 2.9)



Figure 2.10: HoloLens guides users to user voice commands. Image Credits: Microsoft

In conclusion, wearable AR is becoming more and more mature after integrating different interaction techniques into its interface, making it more intuitive and natural for users. As mentioned in chapter one, AR is seeing a trend of merging with IoT as application interfaces for IoT systems. It is reasonable to explore how these five interaction capabilities of wearable AR can facilitate the interaction design IoT systems.

2.3 IoT systems with AR interface

When elaborate from the previous mentioned dimensions chart of Maffioletti, wearable computing and augmented reality come together and forms wearable AR, while the other hand, IoT systems are typical ubiquitous computing systems. One can see the accordance between IoT systems and wearable AR for they both have a relatively higher interface transparency and user mobility. Moreover, previous sections show that the wide expansion of interaction capabilities of wearable AR that provides a more natural and intuitive interaction. This could dramatically enrich how users can interact with the data of IoT products. It is reasonable to expect that the integration with these two could have a festive impact.

2.3.1 Interaction Hierachy

In fact, there are researches that explore the integration possibilities and influences. In 2016 Ilic and Fleisch proposed a product-service interaction hierarchy that illustrates how AR can empower IoT on three levels. (Figure.2.11)

- Identification service: retrieving a digital identifier of a physical object and thereby enabling monitoring and other higher level services.
- Control services: connecting to a smart object to read or change the state of the object.
- Lifecycle services: retrieving related services to an identified object (e.g. ordering of spare parts). See Xu & Ilic (2014) for a comprehensive overview.

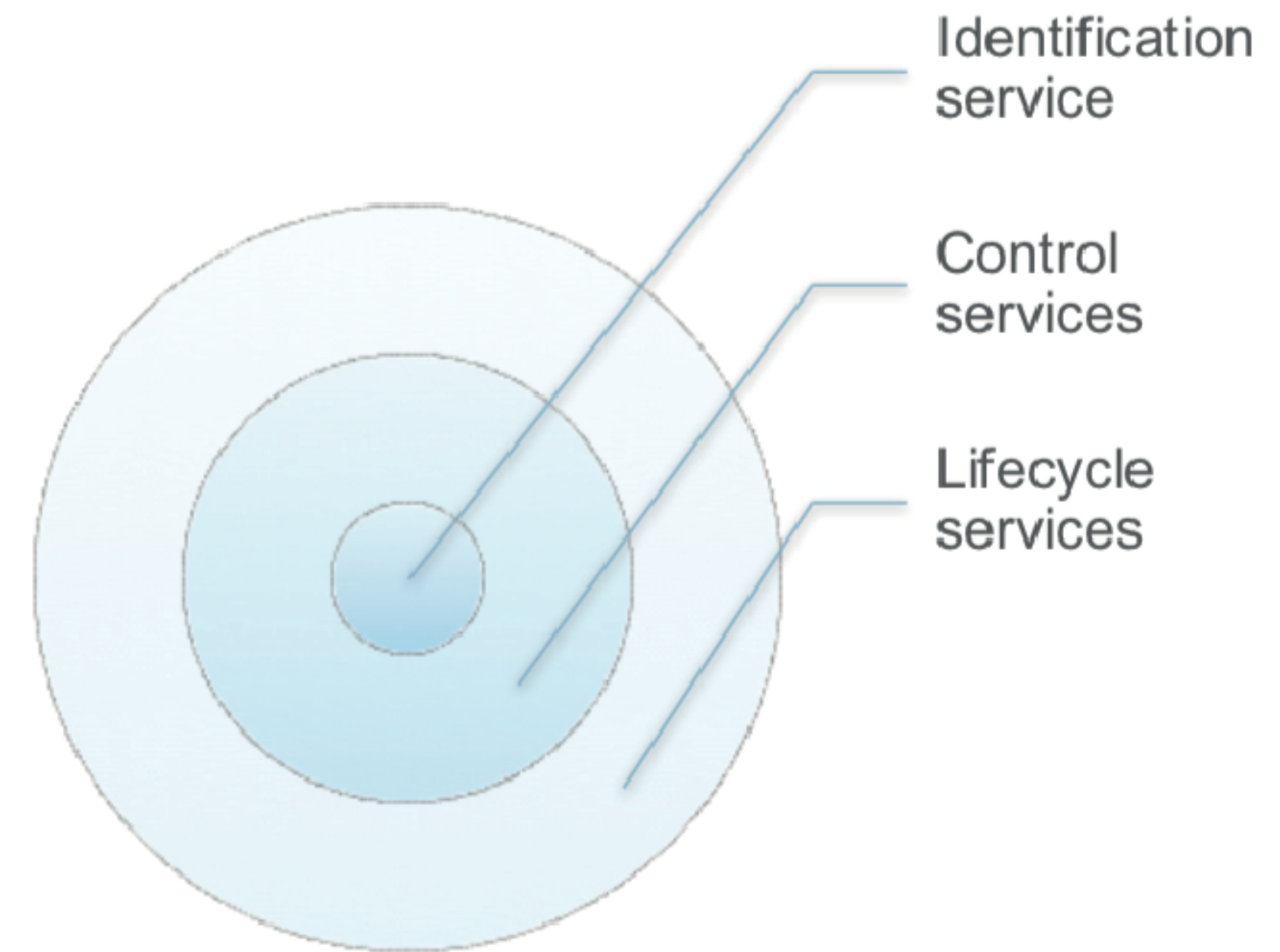
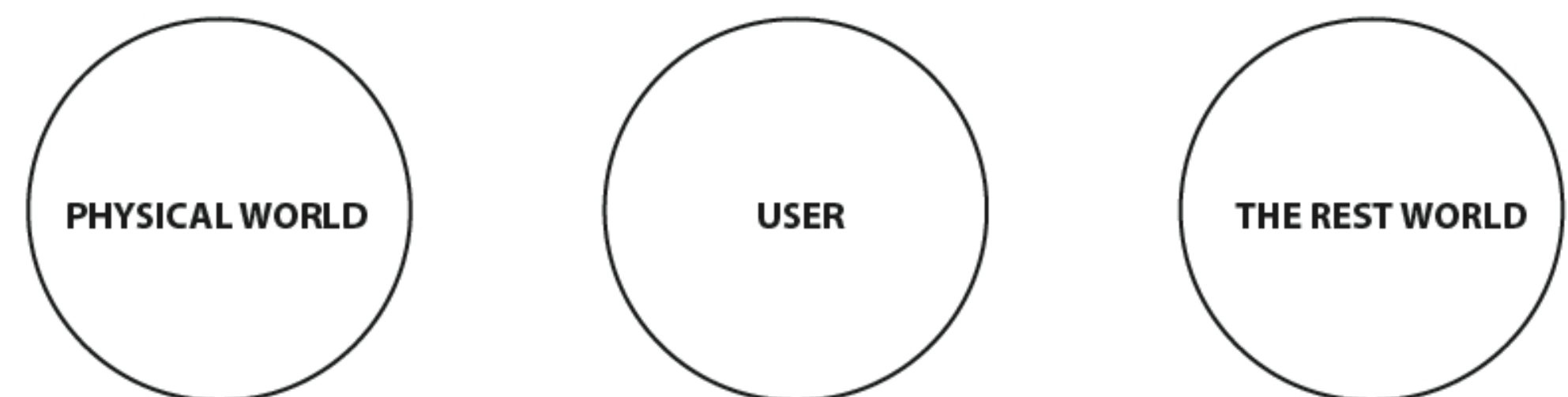


Figure 2.11: Product-Service Interaction Hierachy

2.3.2 Interface core elements

Apart from this hierarchy, they also proposed a taxonomy of AR interface for its system and broke down the interface into three elements: the interface to the physical world, the interface to the user, and the Internet interface to the rest of the world.



The physical world interface uses physical object identification as the access of digital services. These specific physical objects are further classified as three types of objects: smart objects, tagged objects and plain objects. Smart objects integrates a computing, communication, sensing, and/or an actuating unit. The digital identifier is unique and part of the product. Smart objects provides a digital communication interface for interaction and control with the product. They also may have a direct communication link to the Internet. The number of smart Devices are estimated to exceed 25 billion units¹ by 2020 and thereby representing the smallest group of objects in this categorization. Tagged objects refer to products which retain their original state and functionality, but a tag is physically attached or integrated with the object. The digital identifier is retrospectively added to the product with the tag and can be read wirelessly or optically. Since the tag is just co-located, there is no control interface for changing or reading the state of the product, which the tag is attached to. The last type is the plain objects which are not prepared in any way for the Internet of Things. In comparison to the other two types, this will still be by far the largest group of objects. Cisco estimates that currently 1.5 trillion (99.4%) of all physical objects are yet to be connected.

The second core element of the AR interfaces is the connection to the Internet. Its systems are generally not restricted to individual users, but greatly benefit from a connection to the rest of the world. There are four main possibilities when looking for a global scale. First, An AR-IoT system is able to discover and invoke remote services by

using digital identifiers of objects and offering a metadata context. Then the system can instantly access suitable services by third parties on a global scale. Second, connecting with other users. There are implementations that use social and collaborative aspect of AR, such as remote support or virtual meetings. Third, leverage global databases and collective intelligence. When combined with global databases and repositories, AR-IoT systems can collect, analyze, and enrich Local information. Users are allowed to share their contents through the network and thus help to build a better representation of the physical world to the Internet. Forth, create global optimization and prediction by fusing the data of multiple users, predictive algorithms in a global scale can help optimize a system and surpass the ability of any local optimization. For example, a smart heating system of a building would make the adaptation differently if it collects and analyzes data from multiple users and habits in a long time span compared to the limited possibilities of local control.

The last core element is the interface to the user concentrates on the user side of the Interaction. This layer of interface is expected to learn the preference and context of users and provide personalized experiences to users. In this layer, AR is an opportunity for enabling an impressive, personalized user for enabling an impressive, personalized user experience. With today's smartphones, AR applications are already available for the massive market. However, smartphones are not specifically designed for AR interactions either able to provide such natural experience. When smartphones are replaced by new

personal computing devices. (eg. Smart glasses). Not only form and interaction modalities that will be influenced, the scale of user measure will get elevated to a new level and bring more interaction possibilities. The measurement is able to give valuable insights into the user's cognitive, emotional, and behavioral patterns, enable the design of mind-changing and more natural applications in the IoT. For example, digital biomarkers – the digital counterpart of classical biomarkers (Strimbu & Tavel, 2010) – represent a new class of physiological and behavioral measures. They can be monitored with consumer devices and serve as indicators for Physio-pathological, neurological, and behavioral conditions. Moreover, AR interface could also bring decision-making behavior of users to a whole new level, because they can not only interact with users in a subtle way, but also potentially convince the users' brain visually when experiencing digital objects similar to physical ones. This is also known as what the psychologists call presence (Figure 7). Presence was proposed by Minsky (1980) over 30 years ago and gained great popularity in the past few years since the rise of mainstream virtual reality and augmented reality applications (Sheridan, 2016). In other words, an AR world is perceived as real in head of users when perfect presence is achieved.

The perfect presence experiences is also strongly relevant with what ubiquitous computing researchers called situated interaction which aims to enable computers to reason more deeply about their surroundings, and engage in fluid interaction with humans in physical

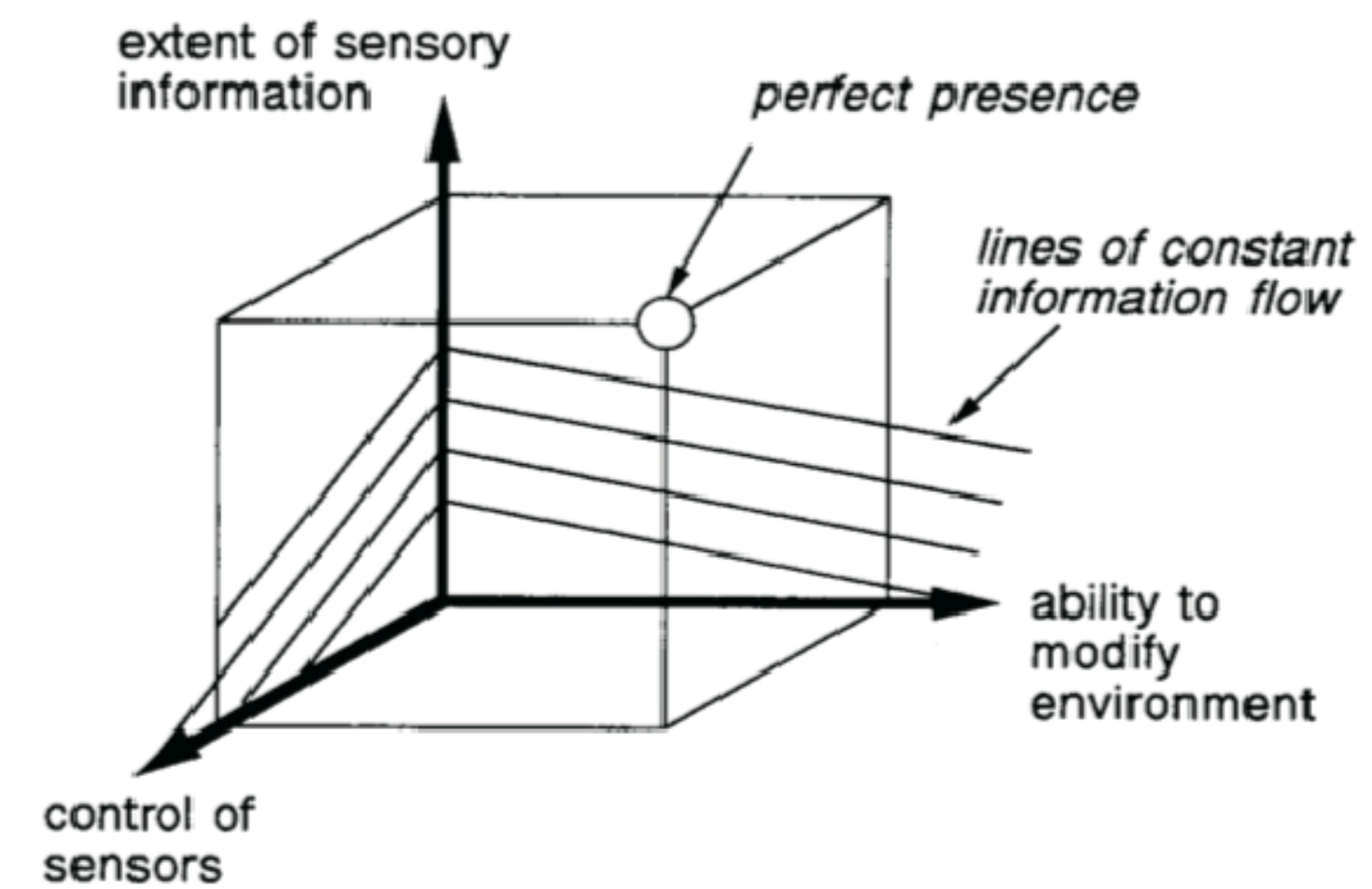


Figure 2.12: Illustration of the concept of presence (Sheridan, 1992)

ly situated settings. In the book *Ubiquitous User Modeling*, Dominikus illustrates a architecture for situated interaction and the system's situation model for mobile computing.[Figure 2.13] In this architecture, a situation of a certain system is mainly made of three parts which are user-related factors, system/device-related factors and environment-determined factors. They can be categorized and termed as situational factors. User factors are relevant with a specific user, the abilities, goals, personal traits, etc. Together, they can form user models in a situation modeling stage. Environment factors, which lead to context models, are independent to all users but have influences on them. System/ device factors normally determine the resources models together with user factors or affect contextual models with environment factors. Interactions between these factors are modeled

as situated interaction which includes explicit user interaction with the system, implicit user interaction with the system and indirect user interaction with the context. This architecture is also further adapted with user-adaptivity, context-awareness, resource- adaptivity and neighbor and history awareness.[Figure 2.14] Finally, Dominikus gives a preliminary definition of *situated interaction*:

Situated interaction denotes the explicit, implicit and indirect interaction between a human and an intelligent environment (or systems and their interaction devices), that take situation- awareness into account.

Situation-awareness denotes the combination of user-adaptivity, resource-adaptivity, context-awareness, neighbor-awareness and history-awareness.

Either the concept of presence or situated interaction implies that an AR-IoT system needs to provide users a natural and intuitive interaction and get closer to how human interact with each other and physical objects in the real world setting. When people interact with each other, they engage in a rich, highly coordinated, mixed-initiative process, regulated through both verbal and non-verbal channels. Hence, AR-IoT systems should become a new generation of situated systems that are capable of fluid interactions and collaborations with people.

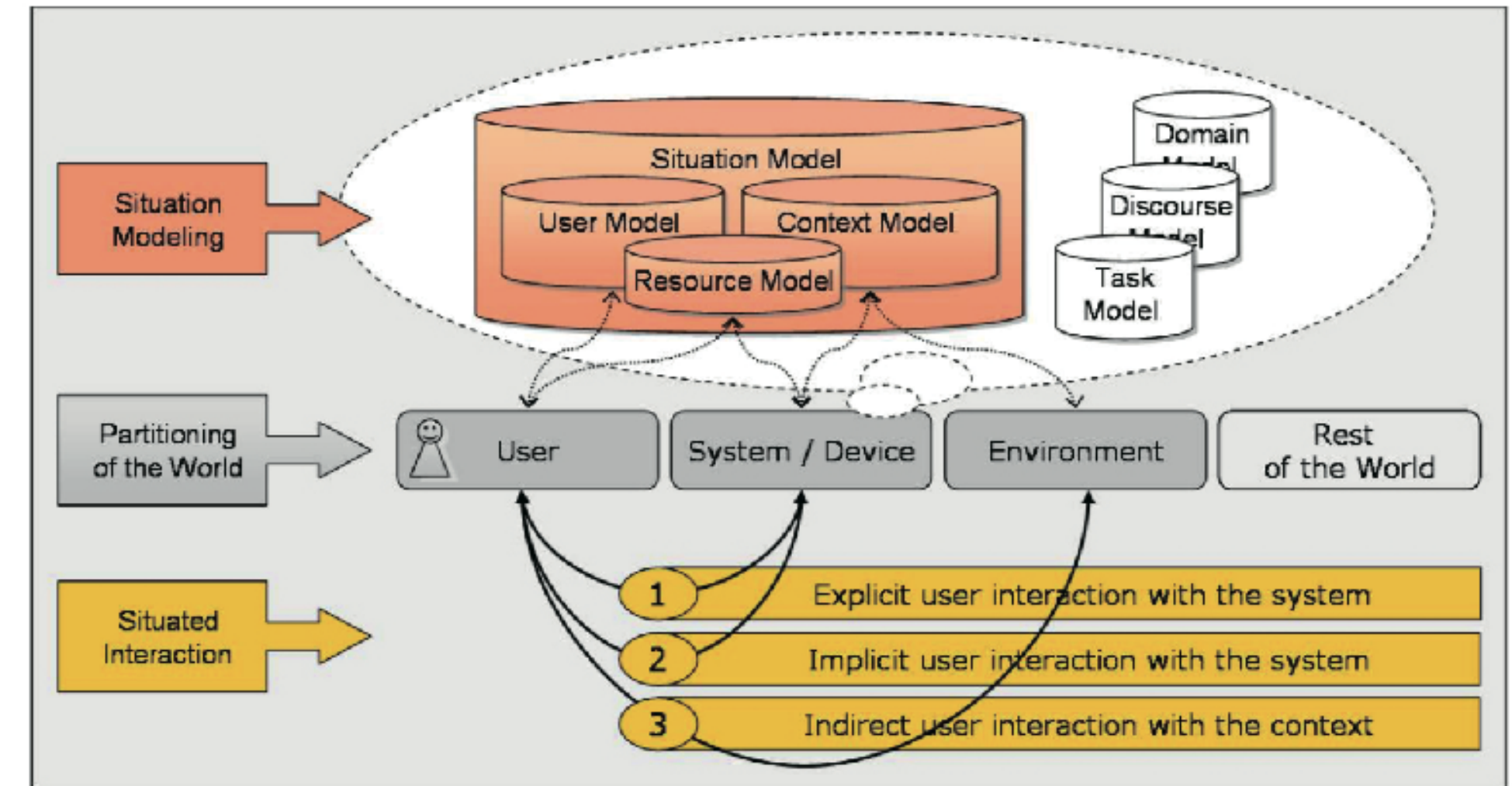


Figure 2.13: Situated interaction and the system's situation model for mobile computing by Dominikus

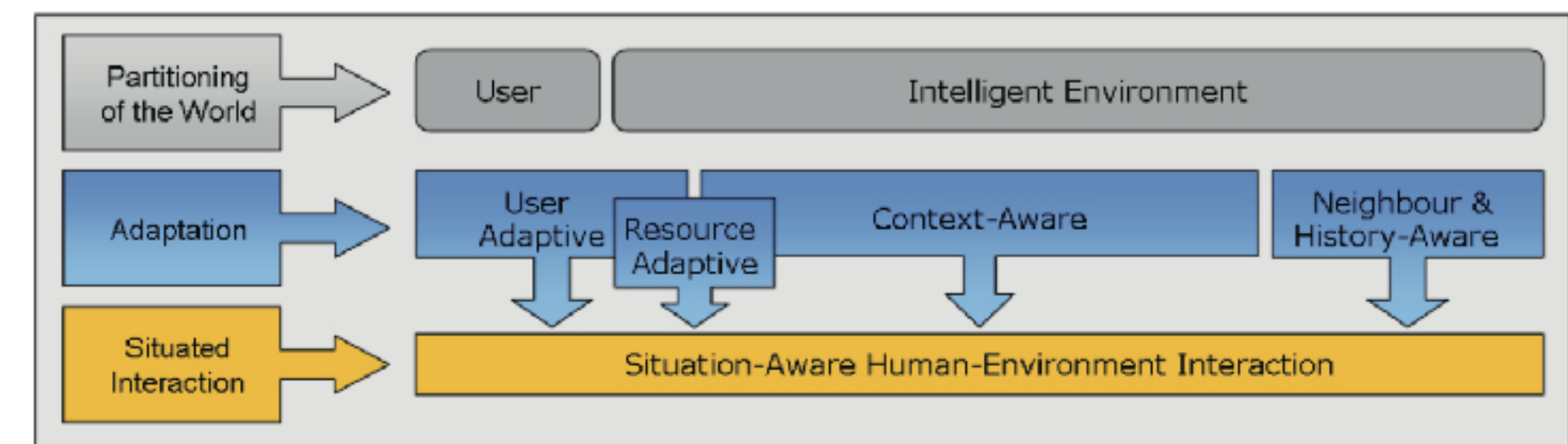


Figure 2.14: Situated interaction within ubiquitous computing also incorporates neighbor and history awareness by Dominikus

Conclusion

IoT is a representative type of ubiquitous computing systems. It makes a strong relation with AR considering its ubiquity and user mobility. On the other hand, AR develops a diverse interaction capabilities from the day it emerged. Giving AR interfaces to IoT systems have potential value but requires appropriate design and development effort to make natural and intuitive interaction. However, there is few researches that can offer guidelines to design such an AR experience for IoT systems. It will be constructive and helpful to explore this research area further. Therefore, next chapter will present and discuss a framework based on the study and research of the first two chapters.

CHAPTER 03

DESIGN FRAMEWORK FOR AR-IOT

Last chapter has a study on the AR and the current research of AR-IoT integration as well as reveals a possible direction of building a framework for its interaction design, so that help designers create a more natural and intuitive interaction effectively for AR-IoT systems. This chapter will propose such a framework based on desk research and discussion. The desk research seeks for design principles of AR and tries to envision the possibilities of applying the AR-IoT systems. Meanwhile, the research outcome of the last chapter will be brought into the study scope together in order to build the desired framework. Finally, this chapter use two cases of design practice to demonstrate the framework in use.

3.1 Representative AR design principles

Although the focus of the assignment is Wearable AR, it will be helpful to start the research of design guideline from a typical AR perspective. To have a more thorough result, the research also includes principles and framework for designing the interaction of AR systems. There are two representative papers directly discussing about the design principles for augmented reality (Dünser, et al. 2007, Kourouthanassis, Boletsis and Lekakos 2013). To deliver a more reliable research outcome, the principle-relevant parts of these two paper will be reviewed briefly. In the paper of Dünser, et al. they investigated general HCI principles related to AR application design:

- Affordance

The concept of affordance [40, 41] suggests that there is an inherent connection between a user interface and its functional and physical

properties. AR systems incorporate new ways of interacting with digital media by overlaying meaning onto the real world. Accordingly, designers use interaction metaphors derived from real world examples. The use of real world interaction metaphors may in fact facilitate the designer to comply with this guideline as it provides a low learning curve for the user.

- Reducing cognitive overhead

As mentioned before, user interface design strives to enable the user to concentrate on the actual task and to reduce cognitive overhead needed to interact with the application. For the example of VR systems with new kinds of interaction techniques (e.g. giving the user “magic” or superhuman like interaction abilities) Rizzo et al. [4] argue that the extra non-automatic cognitive effort required to interact with the system could serve as a distraction. This might reduce the value of a system for accomplishing a specific set of goals.

- Low physical effort

Users should be able to accomplish a task with a minimum of interaction steps. Using the systems should not involve making “unnecessary” interventions by the user. A system should react efficiently reducing the likelihood of fatigue. In order to facilitate a rewarding experience with the system and to decrease chances of fatigue, user worn parts of the system should be as lightweight and comfortable as possible [43].

- Learnability

It should be easy for the user to learn how to use a system. Issues with the learnability of 3D user interfaces can impact the acceptance and use of such systems by potential “everyday” users without prior training with such technology [44] Using AR as a computer interface allows system designers to realize novel interaction techniques that users have not experienced and applied yet. These may be different from how people would interact in and with real environments and problems. Thus they need to be learned before the user can use the system efficiently. Intuitive interaction techniques and methods that are akin to real world behaviour or similar to what the users already are used to (e.g. interaction techniques similar to traditional computer interaction techniques) can limit the learning needed.

- User satisfaction

The perceived user experience is a large factor and becomes more important the closer an AR system engages the user in activities rather than solving tasks. The usability of an interface not only depends on objective measurements. The subjective user perception of interacting with the system should also play an important role during the development of an AR interface [45]. Data on these criteria can be gathered during informal user testing, observations throughout demonstrations or formal lab evaluations.

Flexibility in use

When designing AR user interfaces researchers should be aware of different user preferences and abilities. An interesting feature of AR technology is the possibility of integrating different kinds of input and output devices. Thus there is a potential to integrate different modalities to accommodate individual user preferences. On the one hand, certain input modalities are more useful to accomplish specific tasks. On the other, supporting different interaction modes provides the user with more choice.

Responsiveness and feedback

Users only tolerate a certain amount of system lag [46]. For example, if commands are not executed after a certain amount of time it is difficult for users to build up a persistent model of cause and effect. Using feedback to keep the user informed can help to minimize problems induced by poor responsiveness.

Error tolerance

Most AR systems are still in the early development stages and thus quite prone to instability. Developers still have to solve technological related issues before such systems may really be error tolerant and comply with this design guideline.

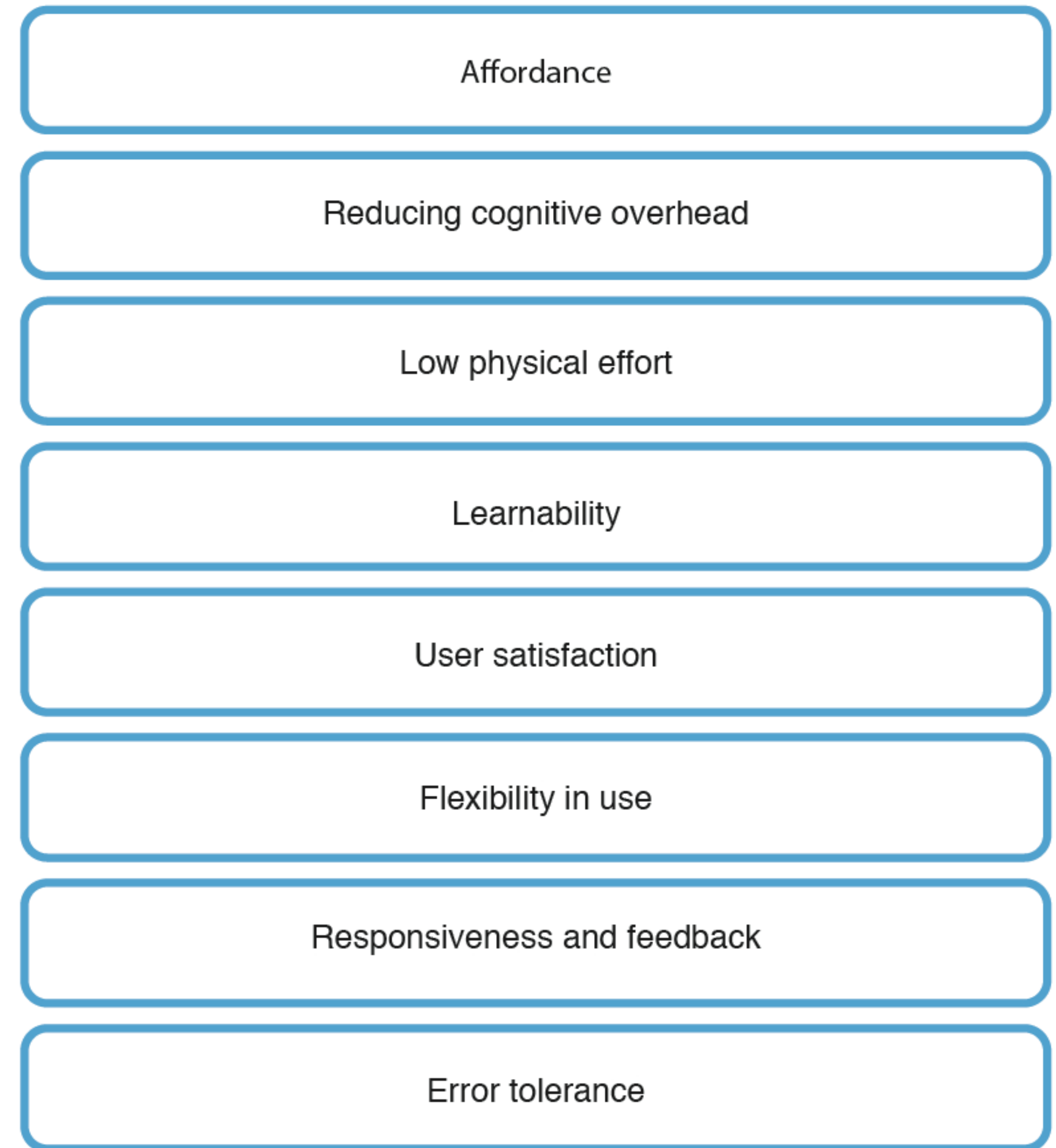


Figure 3.1: AR design principles by Dünser, et al.

On the other hand, Kourouthanassis, et al. investigated the design principles for AR, more specifically relevant to mobile AR (MAR):

-Use the context for providing content

Deploying sensor and marker technologies to collect contextual information (i.e. user location, user orientation, object in-focus properties, current task) in order to augment real-world objects with contextual information.

-Deliver relevant- to-the-task content

Filter (or personalize) interactive content based on multiple contextual criteria.

-Inform about content privacy

Design the functionality around different privacy spheres (i.e. public versus private content).

-Provide feedback about the infrastructure's behavior

The application should inform users regarding its current state or regarding changes in its state.

-Support procedural and semantic memory

Employ familiar icons and/ or interaction metaphors to communicate the application intended functionality and ensure smooth user interactions.

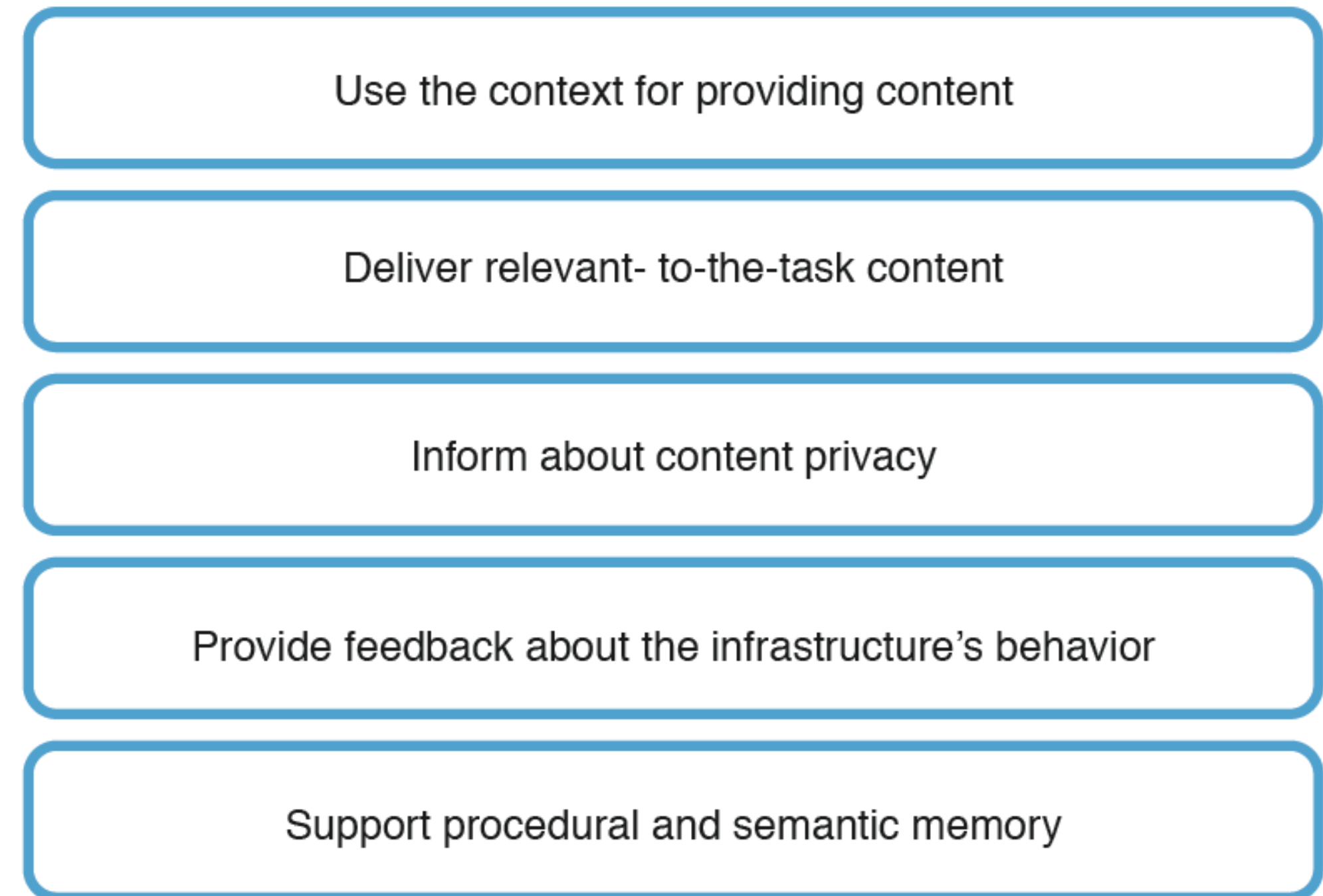


Figure 3.2: Mobile AR design principles by Kourouthanassis, et al.

By comparing these two representative papers, we can find that the principles from Dünser, et al. are similar to the ones from Kourouthanassis, et al. but more abstract and general. For example, the principle of *affordance* covers the *support procedural and semantic memory* one. The principle of *Reducing cognitive overhead* can be elaborated to the principle of *Use the context for providing content* and *Deliver relevant- to-the-task content*. *Responsiveness and feed-*

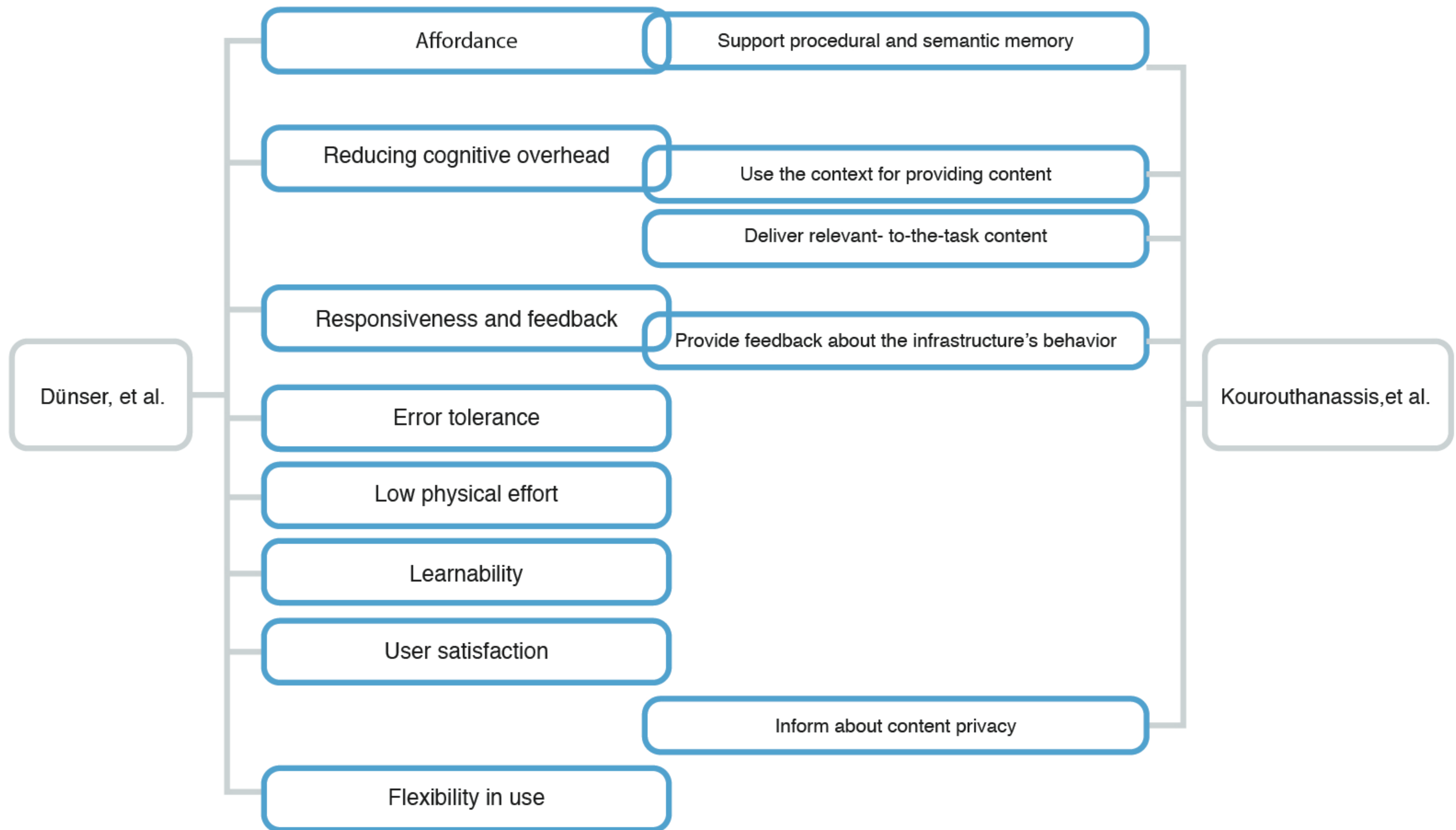


Figure 3.3: Relevancy between the design principles of Dünser, et al. and Kourouthanassis, et al.

back is relevant with the principle of providing feedback about the infrastructure's behavior. At the same time, these two sets of principles are also complementary to each other. For example, Dünser, et al. also suggest considering *Learnability*, *User satisfaction* and *Error tolerance* while Kourouthanassis, et al. suggest informing about *content privacy*. This one could also be an elaboration of *user satisfaction*. Therefore, it is reliable to take Dünser, et al. principles as a major input for the framework of this assignment but also keep in mind the Kourouthanassis, et al. principle which contributes elaborations and complementarity.

3.2 Representative AR framework

Besides design principles, there is also a representative theoretical framework identifying aspects of AR that can potentially affect user experience. In 2011, Ritsos, et al. proposed such framework named Ux4AR Theoretical Framework (See Figure 3.4). They suggest using the framework as a roadmap for standard AR UX aspects as well as applying it for design assessment in different scenarios through analysis, identify the underlying patterns and correlate factors that affect the user's overall experience.

According to the Ux4AR framework, the first major aspect is input which has five categories, in terms of visual, auditory, haptic, kinaesthetic, sensory modalities. Visual input usually implies the use of a camera for tracking and context identification. The auditory channel can also be useful as input, both for direct voice commands as well as

inferring the user's context [48] which refers to from ambient noise levels, patterns or detected frequencies. Tactile, in this framework, is classified to all interfaces that require contact (touch) with a surface, either a keyboard, a touch-screen, a joystick or a mouse. Kinæsthetic is another natural input. Recent advancement in motion tracking have led to various implementations like the Kinect series from Microsoft. Sensory Modalities are another type of input that is using sensors to detect the user's and the environment's context. Combining more than two sensors into complementary fashion is an approach taken by many researchers.

The second aspect is output which can be separated in three main categories, in terms of visual, auditory and haptic. Visual output is probably the most important aspect of augmented reality, ever present through the history of the field and in almost all incarnations and concepts. However, the type of visual information ranges from simple informational annotations to complex 3D architectural and humanoid modelling. Auditory output is another major interaction output of AR systems. It is normally implemented as spatial sound which keeps accordance with the visual input in the space in order to render a vivid experience for users. Although synthetic visual and audio paradigms are presented throughout AR, examples of haptic interfaces, where the user is able to touch and feel objects are limited [49] and are usually found in the form of force-feedback [50, 51] systems, such as the ones found in gaming console controllers and in medical applications [52, 53].

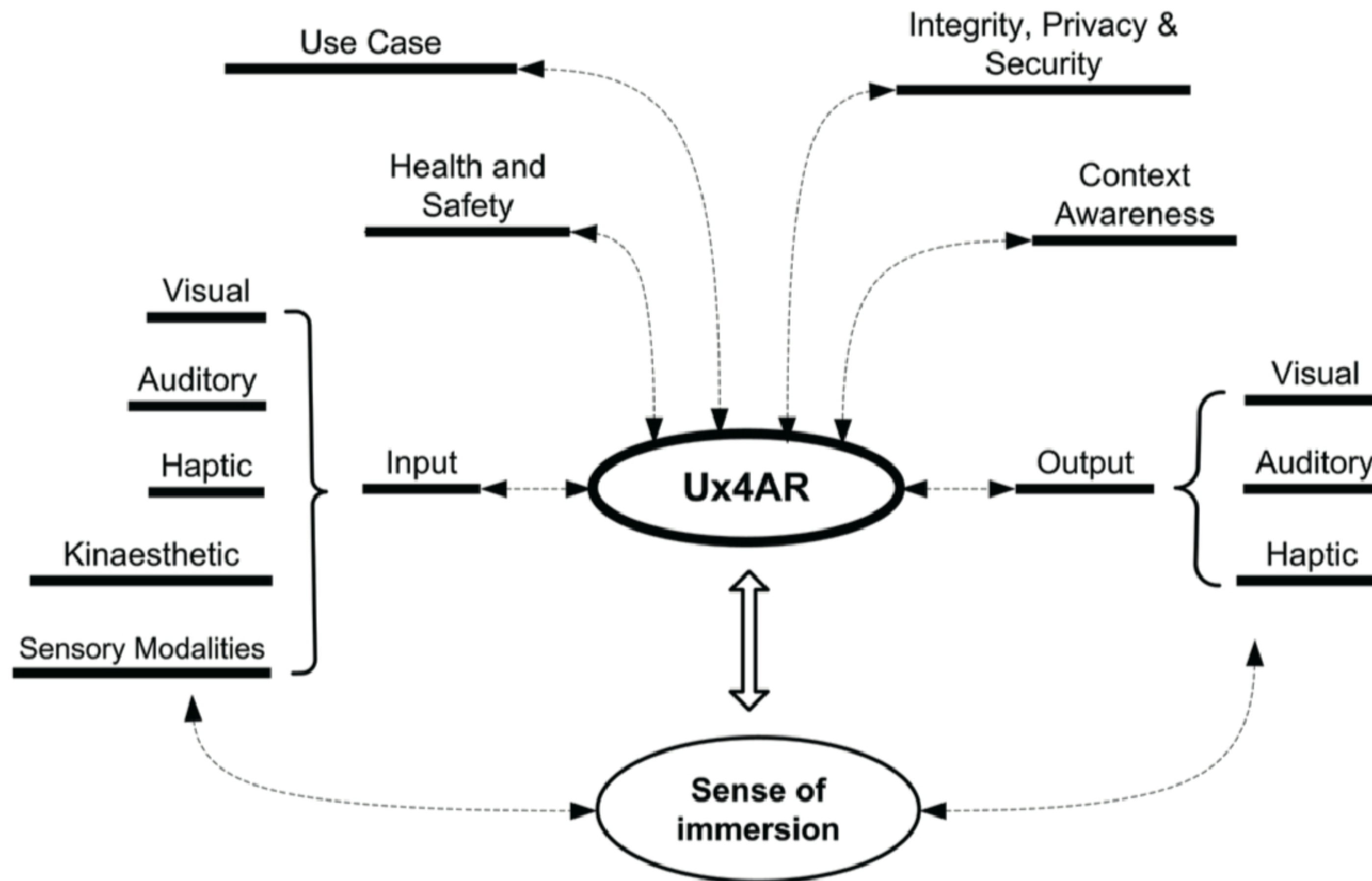


Figure 3.4: Ux4AR Theoretical Framework by Ritsos , et al.

The third major aspect is context awareness. AR's contextual and in situ nature demonstrates how the concept overlaps with Context Awareness (CA). A system with context awareness extracts information about a user's location, posture, intentions as well as environment. This information has direct influence to how synthetic information is utilised and 'placed' spatially and temporally. The main aspects of context are: where you are, who you are with, and what resources are nearby [54]. It is comprised of more than the user's location, including, lighting, ambient noise, tethering, bandwidth and social conditions. Detecting these 'features' accurately, in real-time remains one of the fundamental challenges in AR.

The fourth one is use cases. Use cases describe how the users realize their goals by a step by step interaction with the system. In the vast majority of contexts, use cases should be used to capture what the software does, not how the software does it. Another way of saying this is that they are implementable – meaning a software developer clearly knows what needs to be built – without specifying the implementation details such as what coding language to use, how to connect various technical components, or what database fields to add. A well defined use allows designer to keep a clear objective of value creation and a path towards it.

The fifth one is health and safety which are of critical importance, in all AR implementations. This requires designers to carry on well-thought AR to enhance one's reality because inappropriate implemen-

tations can be potentially disruptive, result in accidents and in extreme cases have health risks. Therefore, it is necessary to take safety into account.

Last but not least, Integrity, Privacy and Security. Although AR currently implementations happen within the 'personal' experience to a great extent, multiplayer AR experience is emerging from different implementation scenarios which users tend to meet in shared space and interact with the shared AR contents. Nonetheless, shared environments have intrinsic integrity, security and privacy implications. Just as Vernon Vinge describes in *Rainbows End* [56], sharing or accessing someone's 'view' of things may or may not always be desirable.

All of the above five aspects contribute to varying degrees of what we call "sense of immersion", otherwise known as "presence". Many assessments, concerning both VR and AR environments try to quantify immersion [59, 60] denoting its importance. One would say that the sense of immersion is the integration of attitudes towards a system, evaluated by the user in terms of importance. It is obvious that this framework obviously can apply to the AR interfaces of IoT system because it exactly links to what the last chapter discussed about the desirable result of integrating IoT and AR, a great sense of immersion, or in other words a perfect presence.

3.3 AR-IoT interaction design framework

Current researches about integration of AR and IoT is more high level hence they are not actionable enough for interaction designers. It will be valuable to propose a design framework that enables interaction designers to understand the fundamentals of such AR-IoT integration as well as the specific interaction design aspects. Therefore, interaction designers are capable of creating reliable user interaction for AR-IoT system efficiently and effectively. The proposed framework presented in Figure 3.5 has the Interaction level and the system level which offer interaction designers a roadmap of a typical AR-IoT system and its user interactions.

3.3.1 User Interaction level

The user interaction level specifically focuses on the user interaction design in order to show the most relevant issues for interaction designers. It classifies the user interaction of AR-IoT systems into three elements: user, physical interface and AR interface. It also illustrates the suggested correlation among these three elements. When users provide their input, two types of interface provide their responses which should be consistent and highly relevant with each other through their communication. Closely bridging the output of these two is essential to create intuitive interactions. Moreover, input of one interface can also trigger output of the other one through communication between these two interface. Users are allowed to give their input through multiple modality channels, in terms of visual, auditory, haptic, kinaesthetic and sensory modalities. The interfaces

are able to give their responds through multiple channels as well.
Haptic output is mainly delivered through the physical interface, while
the visual and auditory ones can be through both interfaces.

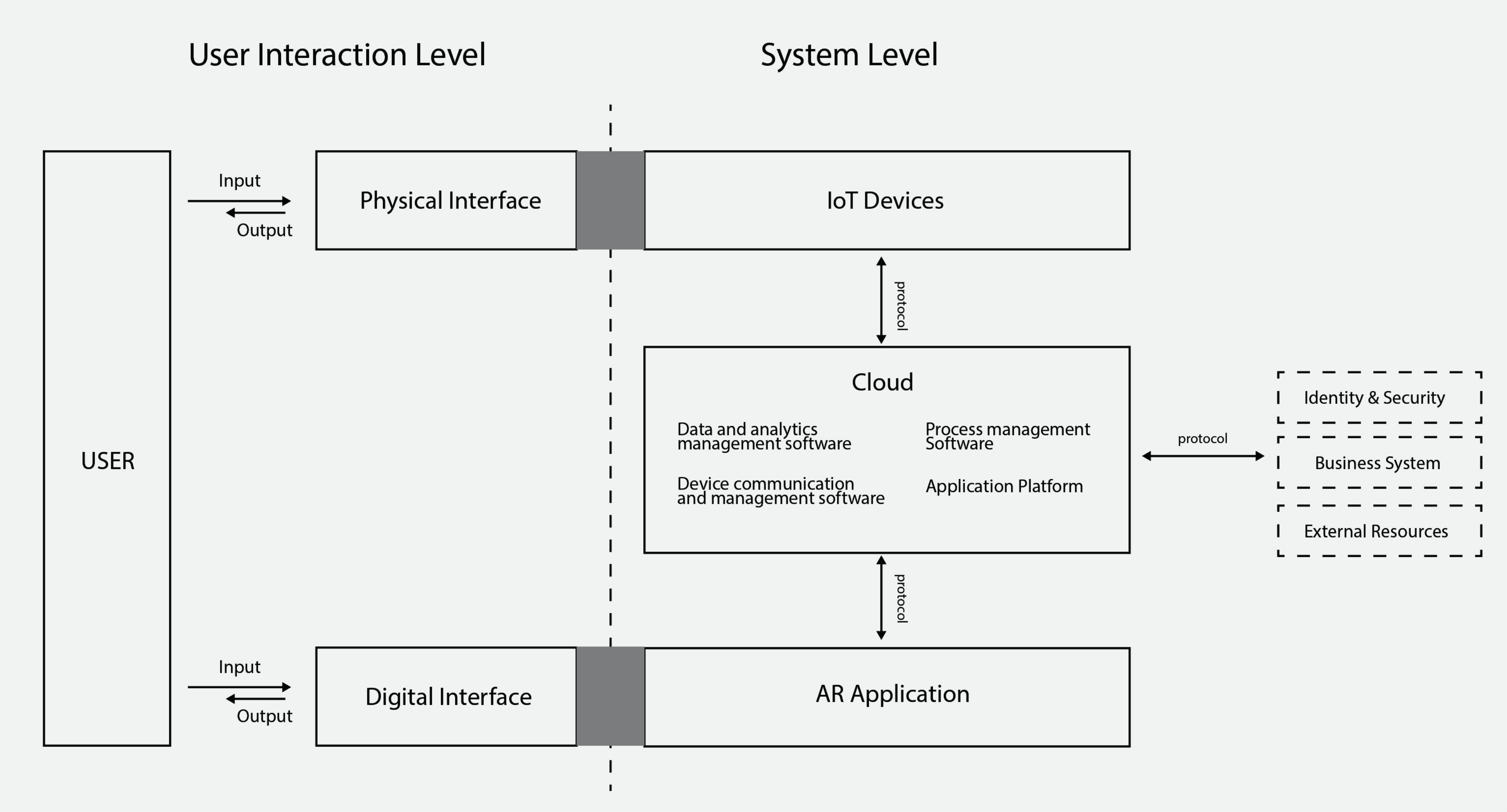


Figure 3.5: AR-IoT interaction design framework

3.3.2 System level

The system level focus on the system elements of the AR-IoT integration in order to give interaction designer a clear overview on the system architecture of a typical AR-IoT system. It illustrates for interaction designers how the system enables the user interactions. The physical interface relates to IoT devices while the digital interface is associated with the AR application. To bridge two types of interface on the interaction level, the system need to build communication between the IoT devices and the AR application. The communication needs protocol as well as cloud services to transfer and process data. The cloud includes application platforms and various software. These software is responsible for data and analytics management, process management, device communication and management. The cloud also manages data from identity and security software, business software and external information software.

3.3.3 Use guideline

For interaction designers, we suggests using this framework as a starting point for designing interaction of their AR-IoT systems. The system level can help them obtain a overview on the technology stack which enable them to create feasible solutions. The system level can be a roadmap as well for interaction designers to have further research on each system element if necessary for their cases. For example, one can research about what is the most suitable application platform for their AR application or what data analytics and management software meets their demands. On the other hand, on the interinteraction level, designers should endeavor to build a user experi

ence tha blurs the boundary between ditigal interface and physical interface. We recommand keeping the output of both interface consistent to acheive the fusion of two interface. We identify two common interaction patterns that can achieve the consistency. 1) Holographics change as soon as possible according to how the relevant device changes, and vice versa. 2) AR contents have strong affordance of their relevant IoT devices and strong mapping with them in the 3D space. These two patterns are able to reduce users' perception on the seperation of digital interface and physical interface and to have a uniform and immersion experience. These two patterns will be demonstrated in the following cases of design practice.

3.3.4 Case study A

To better demonstrate the AR-IoT design framework, this assignment made two cases of design practice. In the first case, users are able to operate the colour of lighting through an AR-IoT system that mainly has a Microsoft Hololens application and a Lanbox lighting device. Users are able to operate the colour of lighting through this system. The AR application provides a digital interface which directly gets user input through the visual and kinaesthetic channel. The lighting device provides a physical interface which has indirect input from users. In other words, it gets input from users through the digital interface. The output of the physical interface is colour changing that can be perceived through the visual channel, while the digital interface use holographics and spatial sound as output through the visual and auditory channel. These two interfaces keep a strong relation with each other. For example, when users gaze at the meeting hologram,

they will find the hologram bigger than others. This means they can have further interaction with the hologram. If they give a airtap gesture to select it, the system will highlight it by giving a glowing frame as well as change the lighting device color (Figure 3.6). The holographical colour plate of lighting is placed together with the device and has a digital representation of the device in order to have a strong mapping between each other (Figure 3.7) and thus reduce cognitive effort. Moreover, the AR contents use representations of lighting device to increase the affordance level. The colour changing feedback of lighting devices is synchronized with colour picking feedback of the holographical colour plate. This strong relation on the user interaction level is enabled by the communication between two interfaces which supported by cloud services on the system level. In this case, cloud services include a Wifi network and the Lanbox software.



Figure 3.6: Get instant feedback and responsiveness

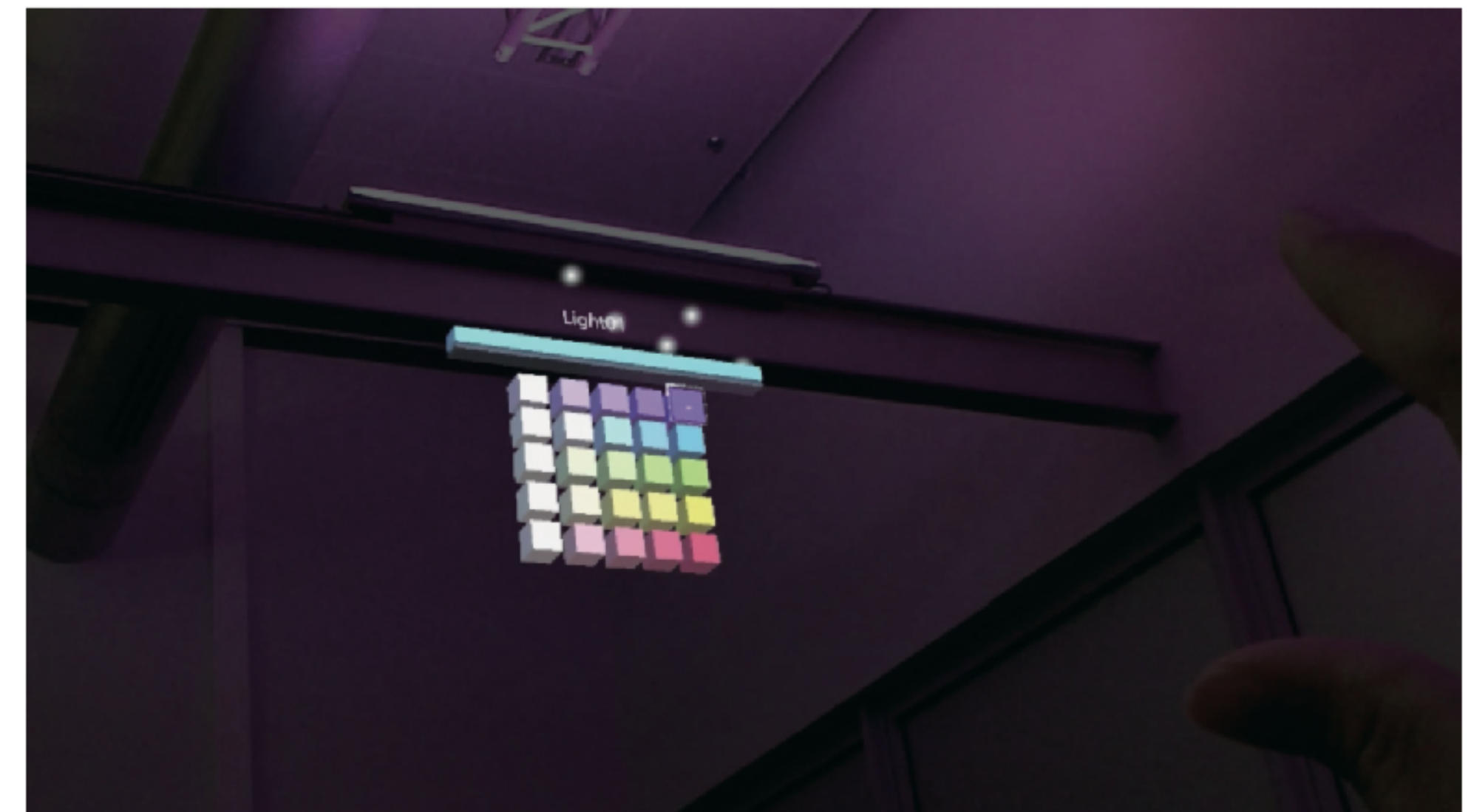


Figure 3.7: Mapping holographic colour plate with the lighting device.

3.3.5 Case study B

The second case shows another AR-IoT system that has a Microsoft Hololens application and an Arduino robot car. Users are capable of changing position of the Arduino robot car through this system. The robot car provides a physical interface which uses haptic input and visual output. The Hololens application provides a digital interface that gets the visual and the kinaesthetic input and responds with visual output. The communication between the two interfaces enable users to change position of the robot car through the attached Hologram, and vice versa. The same as case 1, these two interfaces keep a strong relation with each other. For example, it uses visual as input channel which allows users to access the AR contents of the Arduino car by just gazing at the attached marker. In other words, the holo-gram sphere is always closed attached with the robot car. Users are allowed to move the AR sphere of the Arduino car by directly dragging it in the 3D space but also moving the car. Meanwhile, they can also move the Arduino car by directly moving the car or dragging its attached AR sphere. This increases the use in flexibility of interaction to a new level without making it difficult for users to learn. The car will move to the position assigned by the hologram flag (Figure 3.9). This strong relation on the user interaction level is enabled by the communication between two interfaces which supported by cloud services and the AR application on the system level. In this case, cloud services include a Bluetooth connection between the Hololens head-set and the Arduino robot car, while the AR application tracks a graphic marker.

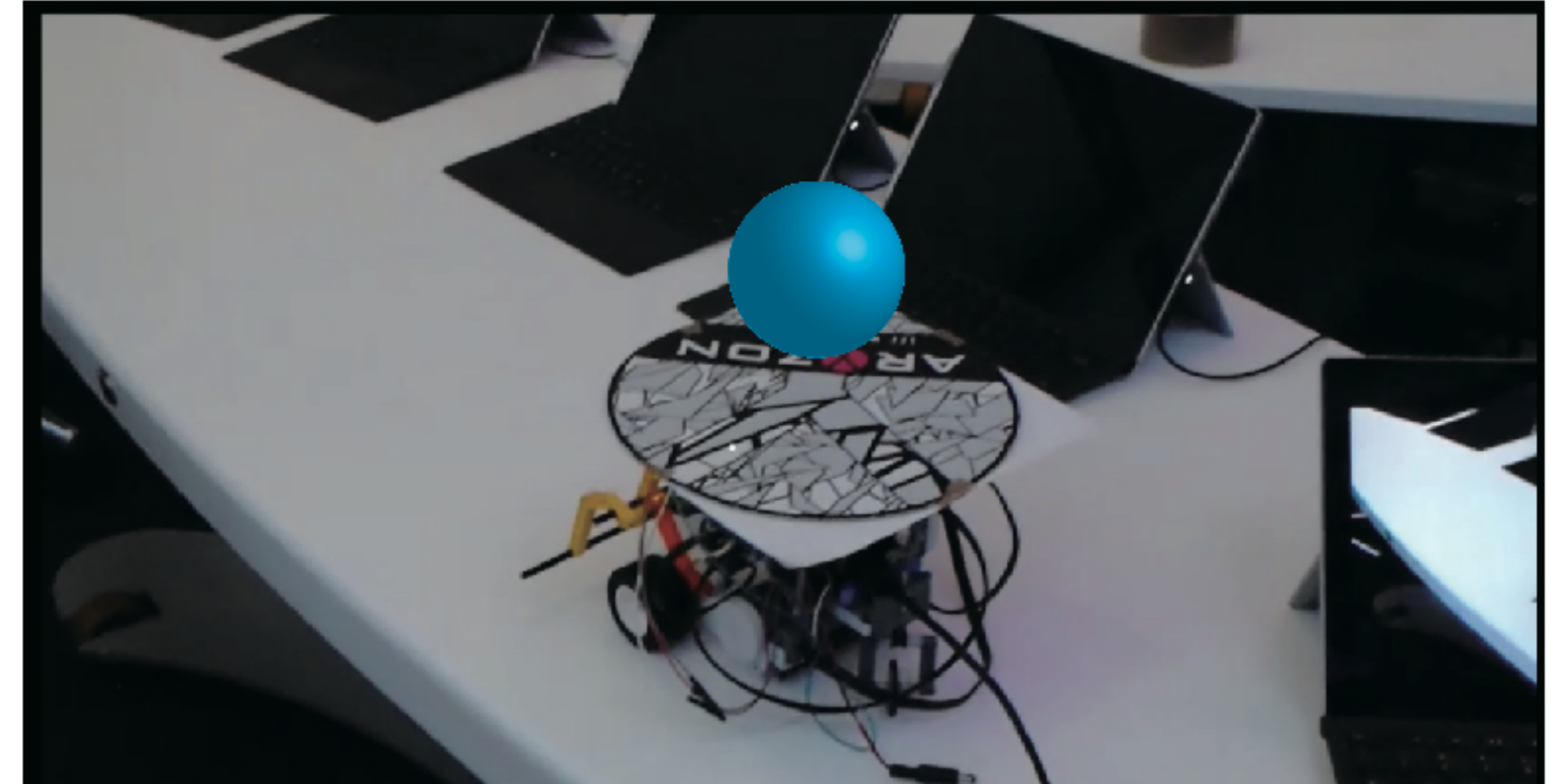


Figure 3.8: Access the AR contents via marker

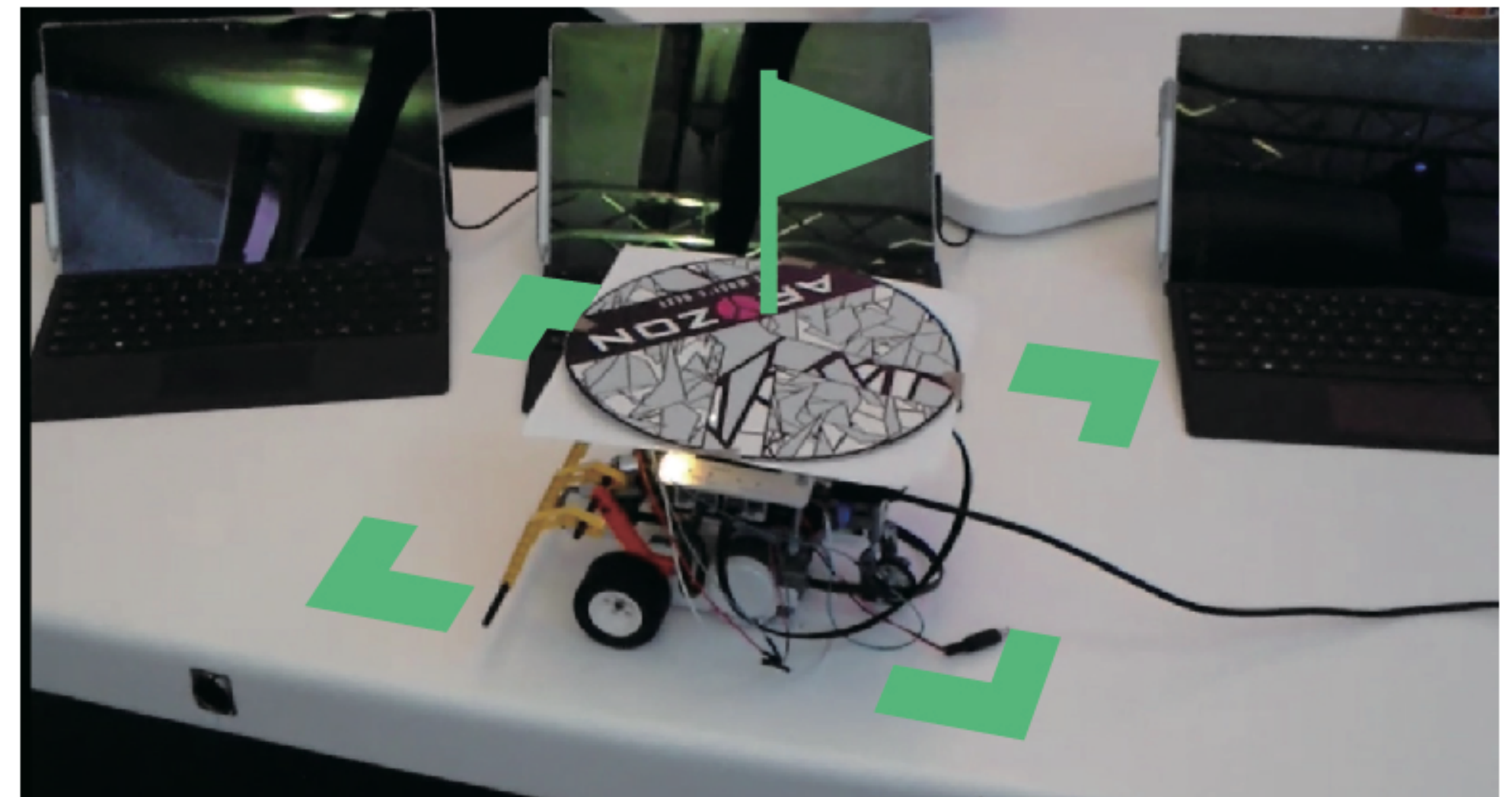


Figure 3.9: The Arduino car arrives target position as response to users operation via AR contents

Conclusion

In order to design user interactions for AR-IoT systems, it is necessary to follow certain design guidelines, principles or framework. Research in this chapter revealed a set of representative principles and a framework for AR user interface design. Although they are not actionable enough for interaction designers to apply in AR-IoT systems, they are reliable resources for developing specific design framework for such systems. Based on all the research of this assignment, the final framework comes with a two level structure that links the technical aspects and the interaction aspects of AR-IoT systems. It provides technical knowledge of such systems as well as interaction design insights. Therefore, interaction designers are capable of creating reliable user interaction for AR-IoT system efficiently and effectively. Especially, the proposed framework can be used as a design tool of user experience designers who are building AR user interface for IoT products. If they are new to AR user interface design or IoT products, this framework is able to reveal the critical aspects for them. It can be used in the design research phase as a research roadmap which enables designers to identify specific system and interaction elements in their cases. It can also be used in the design phase to guide ideation of the user interaction. The framework does not include principles of user experience design. Therefore, designers in the design phase are suggested using this framework together with design principles which help shape user-friendly experience.

DISCUSSION

More interaction elements

Because of time and resources limitation, the proposed framework is restricted to some extents. Currently, the interaction level only discusses input and output for core interaction elements. Therefore, the framework can be more reliable and thorough when future research integrates more interaction elements like context, use case, privacy, safety, etc. The UX4AR framework by Ritsos , et al. is a good input because it has a comprehensive dicussion on these elements [47].For example, bringing in the element of context awareness requires study on where users are, who they are with, and what resources are nearby [42]. User interaction might include extracting information about a user's location, posture, intentions as well as environmental features whcih has direct consequences to how synthetic information is utilised and 'placed' spatially and temporally.

Principle implementation

Moreover, another future direction can be specifying how to apply design principles [12] on a more detailed level through a larger number of design practice. These effort can further remove the boundary between physical interface and digital interface in such AR-IoT system. For example, the research question can be: what interaction patterns can acheive a high level of affordance? or what interaction patterns can significantly reduce cognitive effort.

Multiplayer Experience

Last but not least, it is valuable to expand this framework for multiplayer experience which is important for IoT implementation on collaborative working environment. When there are more than one player, the interaction can be complex. For example, interaction patterns need to consider the situation where two player is interacting with the same virtual contents.

CONCLUSION

As an emerging technology, IoT is gaining more and more momentum for its potential. There are possibilities as well as challenges for exploiting this promising technology. Physical objects can get connected and empowered by IoT extension. An IoT device network generates data and opens many possibilities. However, handling a great amount of data is a challenge. It determines the IoT implementation outcome and requires more further effort. In order to make good use of data, the implementation of Internet of Things is evolving by integrating with other technology. Augmented Reality is one of the promising options because of its ability of blending the digital world and physical world. Applying AR user interface for IoT systems allow stakeholders to interact with IoT data in a natural and intuitive way.

To design AR user experience for IoT systems, it is helpful to follow certain design guidelines, framework or principles. Although there are such materials for AR design, they are not actionable enough for interaction designers when designing for AR-IoT systems. Therefore, this assignment came up with a design framework for them based on desk research and design practice. This framework aims to assist interaction design of AR-IoT system by offering a roadmap of typical

IoT system elements (the system level) and interaction elements and patterns (the interaction level). We expect it to help interaction designers understand the technology as well as design satisfying user interaction. For future improvement, it is valuable to involve more interaction elements or to explore design principle implementation or to investigate multiplayer AR-IoT systems.

REFERENCE

- [1] Atzori L, Iera A, Morabito G (2010) The internet of things: a survey. *Comput Netw* 54:2787–2805
- [2] ITU (2012) New ITU standards define the internet of things and provide the blueprints for its development. <http://www.itu.int/ITU-T/newslog/>
- [3] Santucci, Gérald. "The Internet of Things: Between the Revolution of the Internet and the Metamorphosis of Objects" (PDF). European Commission
- [4] Markit, IHS. "Telecommunications." British Standards Institution (BSI) Standards | IHS Markit, Mar. 2016, ihsmarkit.com/industry/telecommunications.html.
- [5] Gartner, Inc. "The Global IoT Market Opportunity Will Reach USD4.3 Trillion by 2024." Apr. 2015, machinarysearch.com/news/the-global-iot-market-opportunity-will-reach-usd43-trillion-by-2024/.
- [6] Wortmann, Felix & Flüchter, Kristina. (2015). Internet of Things. *Business & Information Systems Engineering*. 57. 221-224. 10.1007/s12599-015-0383-3.
- [7] Porter ME, Heppelmann JE (2014) How smart, connected products are transforming competition. *Harv Bus Rev* 92:11–64
- [8] Yoo Y, Henfridsson O, Lyytinen K (2010) Research commentary – the new organizing logic of digital innovation: an agenda for information systems research. *Inf Syst Res* 21(4):724–735

- [9] Fleisch E (2010) What is the internet of things – an economic perspective. Auto-ID labs white paper. <http://www.im.ethz.ch/education/HS10/AUTOIDLABS-WP-BIZAPP-53.pdf>. Accessed 20 Feb 2014
- [10] Vermesan O, Friess P, Guillemin P, Sundmaeker H, Eisenhauer M, Moessner K, Arndt M, Spirito M, Medagliani P, Giaffreda R, Gusmeroli S, Ladid L, Serrano M, Hauswirth M, Baldini G (2014) Internet of things strategic research and innovation agenda. In: Vermesan O, Friess P (eds) Internet of things – from research and innovation to market deployment. River Publishers, Aalborg, pp 7–142
- [11] Forrester, Inc. “Predictions 2018: IoT Moves From Experimentation To Business Scale.” Forrester.com, Nov. 2017
- [12] Manyika, J. The Internet of Things: Mapping the Value beyond the Hype. McKinsey Global Institute, 2015.
- [13] Gerber, Anna. “Making Sense of IoT Data.” IBM Cognitive Advantage Reports, IBM Corporation, 3 Jan. 2018, www.ibm.com/developers/library/iot-ip301-iot-manage-data/index.html.
- [14] Digitum Team. “IoT Trends to Keep up with in 2018.” Digitum Blog, 07 Dec. 2017, <https://www.digitum.com/iot-trends-2018/>
- [15] IOTA, Inc. “The IOTA Foundation.” The Next Generation of Distributed Ledger Technology | IOTA, www.iota.org/the-foundation/the-iota-foundation.
- [16] “Google Cloud IoT - Fully Managed IoT Services | Google Cloud.” Google, Google, cloud.google.com/solutions/iot/.
- [17] Weiser, M. The computer for the 21st century. Sci. Am. 1991, 265, 94–104. [CrossRef]
- [18] Maffioletti, S. (2001). Requirements for an ubiquitous computing infrastructure. Cultura Narodov Prichernomoria journal, 3:35–40. Mezhvuzovskii publisher, Simferopol, Ukraine, ISSN 1562-0808.
- [20] Salber, D., Dey, A. K., and Abowd, G. D. (1999a). The context toolkit: Aiding the development of context-enabled applications. CHI, pages 434–441.
- [21] Coen, M., Philips, B., Warshawsky, N., Weisman, L., Peters, S., and Finin, P. (1999). Meeting the computational needs for intelligent environments: The metaglow system. In Nixon, P., Lacey, G., and Dobson, S., editors, Proceedings of the First International Workshop on Managing Interactions in Smart Environments, pages 201–212. Springer London.
- [22] Maffioletti, S. (2001). Requirements for an ubiquitous computing infrastructure. Cultura Narodov Prichernomoria journal, 3:35–40. Mezhvuzovskii publisher, Simferopol, Ukraine, ISSN 1562-0808.
- [23] Milgram, P., Takemura, H., Utsumi, A., and Kishino, F. (1995). Augmented reality: A class of displays on the reality-virtuality continuum. In Telemanipulator and Telepresence Technologies, volume 2351, pages 282–292.
- [24] Azuma, R. (1997). A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments, 6:355–385.
- [24] Ho Ilerer, T. and Feiner, S. (2004). Mobile augmented reality. CRC Press.

- [25] Mohring, M., Lessig, C., and Bimber, O. (2004). Video See-Through AR on Consumer Cell-Phones. In Third IEEE and ACM International Symposium on Mixed and Augmented Reality, pages 252–253. IEEE.
- [26] Bimber, O. and Raskar, R. (2005). Spatial Augmented Reality: Merging Real and Virtual Worlds.
- [27] Rosenberg, L.B. (1992). "The Use of Virtual Fixtures As Perceptual Overlays to Enhance Operator Performance in Remote Environments". Technical Report AL-TR-0089, USAF Armstrong Laboratory, Wright-Patterson AFB OH, 1992.
- [28] UX Collective. "Understanding the Different Types of AR Devices – UX Collective." UX Collective, 9 Sept. 2018, uxdesign.cc/augmented-reality-device-types-a7668b15bf7a.
- [29] Starner, Thad & Mann, Steve & J. Rhodes, Bradley & Levine, Jeffrey & Healey, Jennifer & Kirsch, Dana & Picard, Rosalind & Pentland, Alex. (1997). Augmented Reality Through Wearable Computing.. Presence. 6. 386-398. 10.1162/pres.1997.6.4.386.
- [30] Rhodes, Bradley J., and Thad Starner. "Remembrance Agent: A Continuously Running Automated Information Retrieval System." Association for the Advancement of Artificial Intelligence, 1996, www.aaai.org/Library/Symposia/Spring/1996/ss96-02-022.php.
- [31] White, S. and Feiner, S. (2009). SiteLens: situated visualization techniques for urban site visits. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '09, pages 1117–1120, New York, NY, USA. ACM.
- [32] Billinghurst, Mark & Clark, Adrian & Lee, Gun. (2015). A Survey of Augmented Reality. Foundations and Trends® in Human-Computer Interaction. 8. 73-272. 10.1561/11000000049.
- [33] Doug A Bowman, Ernst Kruij, Joseph J. LaViola Jr, and Ivan Poupyrev. 3D user interfaces: theory and practice. Addison-Wesley, 2004.
- [34] Hiroshi Ishii and Brygg Ullmer. Tangible bits: towards seamless interfaces between people, bits and atoms. In Proceedings of the ACM SIGCHI Conference on Human factors in computing systems, pages 234–241. ACM, 1997.
- [35] Hirokazu Kato, Mark Billinghurst, Ivan Poupyrev, Kenji Imamoto, and Kei-hachiro Tachibana. Virtual object manipulation on a table-top ar environment. In Augmented Reality, 2000.(ISAR 2000). Proceedings. IEEE and ACM International Symposium on, pages 111–119. Ieee, 2000.
- [36] Mark Billinghurst, Raphael Grasset, and Julian Looser. Designing augmented reality interfaces. ACM Siggraph Computer Graphics, 39(1):17–22, 2005.
- [37] Gun Lee, Gerard Kim, and Mark Billinghurst. Interaction design for tangible augmented reality applications. Emerging Technologies of Augmented Reality: Interfaces and Design, pages 261–282, 2007.
- [38]. S. Chatty, Extending a graphical toolkit for two-handed interaction, ACM UIST'94 Symposium on User Interface Software and Technology, ACM Press, 1994, 195–204.

- [39] Duenser, Andreas & Grasset, Raphael & Seichter, Hartmut & Billinghamurst, Mark. (2018). Applying HCI principles to AR systems design.
- [40] James Jerome Gibson. The Ecological Approach to Visual Perception. Boston: Houghton Mifflin, 1979.
- [41] Donald Norman. The Psychology of Everyday Things. New York: Basic Books, 1988.
- [42] Albert A. Rizzo, Gerard J. Kim, Shih-Ching Yeh, Marcus Thiebaut, Jayne Hwang, and J. Galen Buckwalter. Development of a Benchmarking Scenario for Testing 3D User Interface Devices and Interaction Methods. In 11th International Conference on Human Computer Interaction, Las Vegas, Nevada, pages, 2005.
- [43] Hannes Kaufmann, Geometry Education with Augmented Reality, in Ph.D. Thesis. Vienna: Vienna University of Technology, 2004, pp. 179.
- [44] Albert A. Rizzo, Gerard J. Kim, Shih-Ching Yeh, Marcus Thiebaut, Jayne Hwang, and J. Galen Buckwalter. Development of a Benchmarking Scenario for Testing 3D User Interface Devices and Interaction Methods. In 11th International Conference on Human Computer Interaction, Las Vegas, Nevada, pages, 2005.
- [45] Donald A. Norman. Emotional Design: Why We Love (or Hate) Everyday Things: Basic Books, 2003.
- [46] Colin Ware and Ravin Balakrishnan. Reaching for objects in VR displays: lag and frame rate. ACM Transactions on Computer-Human Interaction, 1(4): 331-356, 1994.
- [47] D. Ritsos, Panagiotis & Ritsos, Panagiotis & S. Gougoulis, Antonis. (2011). Standards for Augmented Reality: a User Experience perspective.
- [48] N. J. Newman. Systems and Services for Wearable Computers. PhD thesis, University of Essex, 2002.
- [49] S. Munch and R. Dillmann. Haptic output in multimodal user interfaces. In Proceedings of the 2nd international conference on Intelligent user interfaces, IUI '97, pages 105–112, New York, NY, USA, 1997. ACM.
- [50] M. Bouzit, G. Burdea, G. Popescu, and R. Boian. The Rutgers master ii-new design force-feedback glove. Mechatronics, IEEE/ASME Transactions on, 7(2):256 –263, June 2002.
- [51] S. Winter and M. Bouzit. Use of magnetorheological fluid in a force feedback glove. Neural Systems and Rehabilitation Engineering, IEEE Transactions on, 15(1):2 –8, 2007.
- [52] G. Bianchi, C. Jung, B. Knoerlein, M. Harders, and G. Székely. High-fidelity visuo-haptic interaction with virtual objects in multi-modal ar systems. In ISMAR 2006, October 2006.
- [53] S. Jeon, B. Knoerlein, M. Harders, , and S. Choi. Haptic simulation of breast cancer palpation: A case study of haptic augmented reality. In Proceedings of the IEEE International Symposium on Mixed and Augmented Reality, pages 237–238, 2010.
- [54] B. N. Schilit, N. Adams, and R. Want. Context-aware computing applications. In In Proceedings of the workshop on Mobile Computing Systems and Applications, pages 85–90. IEEE Computer Society, 1994.

- [55] R. Azuma. A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, 6(4):355–385, 1997.
- [56] Vernon Vinge. *Rainbows End*. Tor Brooks, 2006.
- [57] R. Campbell, J. Al-Muhtadi, P. Naldurg, G. Sampemane, and M. Dennis Mickunas. Towards security and privacy for pervasive computing. In *Software Security Theories and Systems*, volume 2609 of *Lecture Notes in Computer Science*, pages 77–82. Springer Berlin / Heidelberg, 2003.
- [58] A. Kapadia, T. Henderson, J. Fielding, and D. Kotz. Virtual walls: Protecting digital privacy in pervasive environments. In *Pervasive Computing*, volume 4480 of *Lecture Notes in Computer Science*, pages 162–179. Springer Berlin / Heidelberg, 2007.
- [59] B. Avery, W. Piekarski, J. Warren, and B. Thomas. Evaluation of user satisfaction and learnability for outdoor augmented reality gaming. In *Proceedings of the 7th Australasian User interface conference*, pages 17–24. ACS, 2006.
- [60] R. Pausch, D. Proffitt, and G. Williams. Quantifying immersion in virtual reality. In *Proceedings of the 24th annual conference on Computer graphics and interactive techniques, SIGGRAPH '97*, pages 13–18, New York, NY, USA, 1997. ACM Press/Addison-Wesley Publishing Co.