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Arguably augmented reality : relationships between the virtual and the real

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Summary

In recent years, virtual content has become part of our everyday environment in a profoundly new way. Virtual objects no longer solely appear on the screen of computers, tablets, mobile phones or advertisement screens. Rather they have started to appear right here, in our everyday environment: With the right mobile application, we can view virtual creatures flying through our surroundings or see site-specific information, such as where to find nearby restaurants, floating right in front of us. Wearing a head-mounted display, we can invite virtual characters into our house or turn our living room into the venue of a partially real and partially virtual adventure.

The phenomenon of virtual content being part of and appearing in the real world has a name: augmented reality (AR). By now, a wide variety of so-called AR applications exists. In many respects, these AR applications could not be more diverse. They make use of a broad variety of different technologies, such as headsets, projectors, headphones and tactile displays. In line with this, they present different kinds of sensory stimuli, like visuals, sounds and scents and provide various types of virtual content, among which 3D models, textual information, photographs and sound recordings. They alter our experience of the real world in various ways; for instance, by seemingly removing physical objects from our view or by integrating additional elements into it. They are designed for many different contexts, such as work, entertainment and education. Accordingly, they serve a variety of purposes. For instance, some AR apps are here to inform us about our surroundings while others exist to keep us entertained.

In their totality, existing applications provide a rather blurry picture of AR and therefore raise the questions: *"What is augmented reality?"* and *"What forms can AR take?"*. In this thesis we address these questions and explore the fundamental characteristics and potential manifestations of AR.

In [chapter 1](#), we take an initial glance at examples of AR. We illustrate the diversity of the AR landscape and consequently raise the question "What is augmented reality?".

In [chapter 2](#), we investigate how existing research answers this question. We review existing definitions and descriptions of AR and identify three common ideas about augmented reality: First of all, AR is

generally considered a technology. Second, AR is widely understood in terms of visual virtual overlays that are presented on top of a participant's view of the real world. Third, AR is considered to spatially align virtual content with the real world in three dimensions (this gives virtual objects a position in the real world).

At the same time, our review of existing AR literature also reveals many divergent and *broad*er understandings of AR. For instance, we encounter research that also considers non-visual virtual content (such as sound) in the context of AR and researchers that explicitly argue against seeing AR as a technology. In their totality, the various reviewed positions suggest that AR *can* involve technologies that overlay virtual images onto a participant's view and that align these images with the real world. At the same time, we get a strong sense that there is more to AR than such technologies. Thus, the review leaves us wondering, what, if not just a technology, AR is or can be.

In [chapter 3](#), we respond to existing definitions, challenge commonly accepted views and argue for new (or at least different) perspectives on AR. First, we depart from the understanding of AR as a technology. Instead, we claim that AR technology enables augmented reality. We focus on the resulting augmented reality environments and experiences rather than on the technologies that enable them. Second, we approach AR as a multimodal and interactive environment and argue that AR engages all our senses. Rather than focusing on what a user or participant sees, we focus on non-visual, multimodal and interactive aspects of both the real world and virtual content. Third, we see AR as a result of the relationships between the virtual and the real. Whereas AR is generally assumed to involve the spatial alignment of virtual content with the real world in 3D, we suggest that other types of relationships between the virtual and the real are possible, potentially leading to other and new forms of AR. These three ideas are synthesized and culminate in our definition of AR as an interactive and multimodal environment where a participant experiences a *relationship* between virtual content and the real environment.

In [chapter 4](#), we explore and illustrate the different ways in which the virtual and the real can relate to (and thus augment) one another. With this, we address the second key question of this research: "What forms can AR take?". On a fundamental level, we distinguish AR from scenarios where participants do not experience any link between the virtual and the real. We then identify *spatial relationships* between the virtual and the real (here, virtual content seemingly exists in real space) and *content-based relationships* between the virtual and the real (here, the virtual relates to the real on the content-level) as the two core relationships that facilitate AR. Subsequently, we question how virtual content can affect its real surroundings. Based on the role that the virtual content plays in the real space, we distinguish five forms of AR:

Extended reality: scenarios where the virtual supplements the real environment.

2. *Diminished reality*: cases where virtual content seemingly removes real elements from the real environment.
3. *Altered reality*: environments where the virtual information changes the qualities of the real world.
4. *Hybrid reality*: scenarios where the virtual completes a physical environment that would be considered incomplete without the virtual additions.
5. *Extended perception*: cases where unperceivable but real aspects of the real world are translated into virtual information that we can perceive with our senses.

We then focus on scenarios where virtual objects seemingly exist in and extend the real world. We notice that the presence of virtual objects in real space opens up possibilities for influences and interaction between the virtual and the real. On this level, we distinguish among two main forms of relationships between the virtual and the real: (1) *physical relationships* (the virtual and the real seemingly affect each other physically) and (2) *behavioral relationships* (the virtual and the real sense each other and react to one another on a social or behavioral level).

Subsequently, we briefly discuss other possible relationships, such as temporal relationships between the virtual and the real and musical relationships between virtual and real instruments.

Chapter 5 focuses on one particular relationship between the virtual and the real, namely interaction between the two. Based on the fact that virtual objects do not have to adhere to physical laws and cannot directly apply forces to real objects, we ask the following questions: What types of interaction between the virtual and the real are both possible and believable? We explore (1) whether virtual objects can interact with physical objects in a realistic manner as well as (2) whether they can interact in imaginative but believable ways. In order to answer these questions, we follow both a theoretical and a practical approach. We review existing research and AR works, conduct our own initial series of practical experiments as well as reflect upon these experiments. This leads us to the conclusion that virtual and real objects can believably simulate real-world influences as well as influence each other in imaginative ways that have no equivalent in the physical world.

Chapter 6 builds on the idea that virtual objects can differ from real objects. We explore whether virtual objects can also be perceived differently from how we perceive real objects. In order to study and illustrate such possibilities, we develop and present a prototype of what we call sonically tangible objects. More concretely, we present a virtual, invisible and non-tactile cube that is placed in a real, physical

space. This cube can be experienced through exploratory hand gestures and gives sonic feedback. Touching the cube with one's fingers triggers binaural sounds that appear to originate from the exact spot where the object is touched. Our initial experimentation suggests that this sound- and movement-based approach can result in tactile-like experiences and convey the presence of virtual objects in real space. We discuss the concept behind, implementation of and our experience with the sonically tangible cube and place our research in a broader context.

Chapter 7 concludes the thesis. We revisit our main questions (*"What is augmented reality?"* and *"What forms can AR take?"*) and reflect on the answers we have arrived at. Furthermore, we address pending questions that have surfaced during this trajectory (e.g., *"What is augmented in AR?"*) and that we can answer now, after having obtained a thorough understanding of existing research, after having gained hands-on experience with AR and after having developed our own comprehensive theory of AR. In addition, we summarize insights that can guide the design of AR experiences. Moreover, we discuss methodological and technological limitations of our study and present possible directions for future AR research and development. Among other things, we propose to focus less on mimicking our existing reality, and instead, to create new, imaginative and creative forms of AR that have no counterpart in a purely physical world.