Multi-Reality Games: an Experience Across the Entire Reality-Virtuality Continuum

Llogari Casas*
Edinburgh Napier University

Loïc Ciccone*
ETH Zurich

Gökçen Çimen
ETH Zurich

Pablo Wiedemann
Edinburgh Napier University

Matthias Fauconneau
Edinburgh Napier University

Robert W. Sumner
ETH Zurich

Kenny Mitchell
Edinburgh Napier University

Figure 1: (*i.*) Our Multi-Reality game starts with objects and characters from the real world. (*ii.*) Physical assets get animated using photo-realistic AR. (*iii.*) Moving a step forward in the RVC, the user interacts with a scene where physical and virtual assets coexist. (*iv.*) Finally, our game ends with a fully virtual scene with only CG-assets.

ABSTRACT

Interactive play can take very different forms, from playing with physical board games to fully digital video games. In recent years, new video game paradigms were introduced to connect real-world objects to virtual game characters. However, even these applications focus on a specific section of the Reality-Virtuality Continuum, where the visual embodiment of characters is either largely static toys in the real world or pre-animated within the virtual world according to a determined set of motions.

We introduce a novel concept, called *Multi-Reality Games*, that encompasses interactions with real and virtual objects to span the entire spectrum of the Reality-Virtuality Continuum, from the real world to digital and/or back. Our application on real-virtual game interaction makes an evolutionary step toward the convergence of real and virtual game characters. Rather than static toys or pre-built and unconfigurable virtual counterparts, we bring together technologies from the entire Reality-Virtuality Continuum to target new game experiences.

We showcase our framework by proposing a game application on a mobile device. Without the need to change the location or set, we enable intuitive and seamless interactions between physical, augmented and virtual elements. The experience brings both worlds closer, and enables the user to customize the virtual scenario according to physical references.

*Co-First Authors

CCS CONCEPTS

• **Human-centered computing → Interaction design theory, concepts and paradigms**; • **Computing methodologies → Mixed / augmented reality**;

KEYWORDS

Reality-Virtuality Continuum, Mixed Reality, Games, Mobile devices

ACM Reference Format:
Llogari Casas, Loïc Ciccone, Gökçen Çimen, Pablo Wiedemann, Matthias Fauconneau, Robert W. Sumner, and Kenny Mitchell. 2018. Multi-Reality Games: an Experience Across the Entire Reality-Virtuality Continuum. In *International Conference on Virtual Reality Continuum and its Applications in Industry (VRCAI '18), December 2–3, 2018, Hachioji, Japan.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3284398.3284411

1 INTRODUCTION

The term *Mixed Reality* (MR) refers to a set of technologies that aim to present the real and the virtual worlds unified in the same space and time. This concept was first defined by Milgram et al. [Milgram et al., 1994] as a connection between the real and virtual environments, forming the *Reality-Virtuality Continuum* (RVC). This linear scale starts from the real environment itself and covers technologies such as Augmented Reality (AR) and Augmented Virtuality (AV) until reaching a fully virtual environment (see Fig. 2).

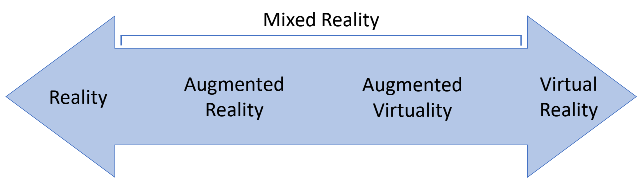

Figure 2: Illustration of the Reality-Virtuality Continuum and the position of AR, AV, VR and MR in it.

With the ever growing trend towards virtualization of everyday life experiences, Mixed Reality systems have become a main area of interest, both in research and in the industry. Such systems are applicable to a wide range of areas, including the automotive sector, surgery, office environments and entertainment. To enable convincing immersive experiences, a seamless inclusion of the virtual content is required. Moreover, many applications require real-time interactions on low-powered devices, such as smart-phones or tablets, which due to their limited computational resources demand refined implementations of efficient algorithms.

Recently, significant advances have been made in the development of Mixed Reality applications, gradually enhancing interactions between virtual and real content. However, if many of these technologies find a relevant place in the Reality-Virtuality Continuum, seamlessly transitioning between them — and therefore spanning the entire continuum within a single application — remains an open challenge.

Our research introduces a concept, that we call *Multi-Reality Games*, that encompasses interactions with real and virtual objects throughout the spectrum of the RVC. We bring together some of the latest technologies in 3D scanning, object augmentation and character control to build a diversified and engaging application. The user is seamlessly driven through the entire RVC, which enables a progressive immersion into the virtual world, as well as a variety of interactions and customizations. In Section 4, we demonstrate our framework with a mobile game implementation.

2 RELATED WORK

2.1 Mixed Reality experiences

The concept of enhancing the real world with additional content has been present since the beginning of the 20th century. The first documented reference to this idea dates from 1901, when L. Frank Baum described in his novel "The Master Key" an approximation of what we now know as Augmented Reality [L. Frank Baum, 1901]. In this short novel, Baum introduced the idea of using electronic screens to superimpose characters in the real world.

Over half of a century later, in 1968, this idea became a reality. The first Head-Mounted Display (HMD) connected to a computer was invented by Ivan Sutherland. This, de facto, introduced the first virtual-generated content into the Physical World [Sutherland, 1968]. The HMD device was named "The Sword of Damocles", due to the heaviness and uncomfortableness of it, as an allusion to the classical Greek mythology of homonymous name.

The technological improvements of the late 1990s and early 2000s allowed an extended use of AR and VR to a broader scope of researchers and users. Hand-held AR is clearly proof of this, as it emerged from the first generation of mobile phones with cameras in the early 2000s [Wagner and Schmalstieg, 2003]. Its main advantage over other types of AR technologies is the wide availability of mobile devices in the general public. Ever since then, there has been a need and interest to bridge the gap between reality and virtuality for different devices and scenarios.

Potential applications for MR experiences vary across a broad spectrum of fields: context aware applications [Lehtonen and Harviainen, 2016], industrial tools [Besbes et al., 2012], commercial games [Zarzycki, 2012] or augmented creativity [Magnenat et al., 2015]. Our framework makes use of several of these techniques, such as simultaneous localization and mapping (SLAM) to track the environment [Khairuddin et al., 2015]. Specifically, we enable Multi-Reality games with the use of pre-defined three-dimensional real-world targets in the form of point clouds. Such approach allows to start the travel from reality to virtuality without the need to place additional markers on the scene.

2.2 Spanning the RVC

Spanning the Reality-Virtuality Continuum is relatively an isolated field of research. In 2003, Davis et al. presented the first research in this domain [Davis et al., 2003]. They proposed a Continuum of virtual environment experiences for the book Alice's Adventures in Wonderland. They presented an adapted version of this classic transitioning between realities throughout the story. This initial prototype was followed by work on virtual avatars along the RVC. Participants were captured in the real-world and ported to the virtual one allowing the participants to experience themself throughout the continuum [Nijholt, 2005]. This was further extended with engaging conversations between synthetic and human agents [Andre, 2006].

Our research presents a novel approach to this concept in which the user can interact throughout the RVC using only a mobile device in a single scenario. Previous experiences required multiple sets and devices to be able to experience the different realities across the continuum, which does not allow a seamless transition between them.

2.3 Trans-Reality gaming

The key aspect of *Trans-Reality* games is to combine the components of real life with the virtual one [Lindley, 2005]. This genre of play is often found in location-based games, such as pervasive [Kasapakis et al., 2013], mixed reality [Jantke et al., 2013] and augmented reality [Zarzycki, 2012] ones, or in cross-media games, such as simulation [Klopfer and Squire, 2008], role [Karl et al., 2010] and alternative reality [Gutierrez et al., 2012] ones. Popular examples of Trans-Reality games are Pokemon GO [Niantic and Company, 2016] and Birdly [Rheiner, 2014].

Each Trans-Reality game enables physical experiences in a virtual environment, or vice versa, up to a specific degree. We extend this concept with what we define as Multi-Reality games, where the player evolves across the entire Reality-Virtualtiy Continuum.

3 APPROACH

We propose Multi-Reality experiences as a natural, fluid and seamless approach to travel throughout the Reality-Virtuality Continuum. In this section, we detail the interest of going from reality to virtuality. Nonetheless, this could also be experienced in the opposite direction, from virtuality to reality.

Real-world games, such as puzzles or quizzes, help children learn how to interact with others and develop skills that are essential for life. Active play helps them with cognitive, creative and communicative skills. Our approach proposes combining those benefits with the advantages of virtual gaming through mobile devices. We enable the user to interact with physical objects anywhere in the real world. These can be assembled manually from pieces, built from scratch, be fully customized or even printed in 3D. This flexibility allows the user to improve their creativity while being able to better understand the foundations of game design.

Once the user has chosen the physical components necessary for the game and their position in the real world, we propose to enhance the gamplay through a mobile device. Following the RVC, we present a progressive immersion from reality to virtuality. From our initial real-world, we transition to Augmented Reality, where virtual objects are now coexisting with the physical ones. The user can now interact with both real and virtual objects at the same time. Hence, physical items can be re-arranged at best convenience according to the recently overlaid virtual ones. As we propose a seamless blending within the entire RVC, we contemplate both worlds to interact with each other. For predefined physical objects, we even encompass enlivened real-world game assets. These are pre-registered targets that through the use of an animated mesh that has exactly the same shape as the physical object and the use of few image processing techniques, make the illusion of coming alive through the screen of the mobile device.

After some interaction with the Mixed Reality environment, we propose a smooth transition to the completely virtual world. In this alteration of reality, the real world scenario vanishes and the environment becomes completely virtual. The user can now experience the game in a parallel reality that allows a Multi-Reality experience throughout the Reality-Virtuality Continuum.

For a fluid and natural experiences across the RVC, we need a device in which all degrees of reality and virtuality can be experienced. We propose to use mobile devices, because in contrast to other types of device such as Head Mounted Displays or See-Through Glasses, hand-held devices are capable to cover the entire spectrum of the RVC and provide a diversified experience to the participant. Additionally, smartphones are today very common and do not require any special setup, which allows Multi-Reality games to target a large public.

4 APPLICATION

In our specific application, we propose an adventure game that travels throughout the RVC. The goal is to solve a quest to restore freedom in the hidden world of *Tasbada*. Please refer to the accompanying video for visualizing the complete gameplay. Following our approach described in section 3, we enable the user to start the game in the physical world. We let the user decide where the Multi-Reality experience will take place and select the physical objects that will compose the real-world scene.

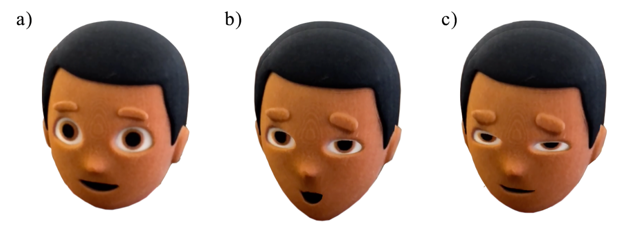

Figure 3: *a)* Static and inanimate 3D printed narrator. *b-c)* Narrator speaking to the user through photorealistic Augmented Reality using a mobile phone.

As soon as the user has defined a location and the real-world assets for the gaming experience, we start travelling across the RVC. We use a predefined 3D printed object to incorporate a narrator into the game (as shown in Fig. 3). We use *Props Alive* [Casas et al., 2017] to create the illusion of movement of static objects from the real world with photo-realistic renderings. Additionally, when these animated real-world objects cast shadows, we use *Shadow Retargeting* [Casas et al., 2018] to account for their deformation. Hence, our application enhances the user's imagination by presenting extended capabilities, such as speech and movement, to inanimate objects in the real world.

Figure 4: The user's initial pose and the representative color of their clothes are applied to the virtual character of the game.

Once the narrator has explained the mission to the player, we ask him to take a photo of himself (or a friend) to be transported into the game. Extending [Nijholt, 2005], we use virtual avatars for this Multi-Reality game experience; this brings closer the physical and augmented worlds as the user can feel connected to the virtual character. We use *AR Poser* [Cimen et al., 2018] to capture the user's initial pose, and we additionally extract the representative color of the clothes to apply on the avatar (Fig. 4).

Now that the player is embodied into the virtual character, he is asked to solve a quest by unlocking several milestones in the augmented world. We use *PuppetPhone* [Anderagg et al., 2018] to let the user control his avatar with the movement of the phone. Once the milestones are accomplished and the final goal of the game is reached, we embark the user in a fully virtual world, as a reward for their achievement.

In this final stage, the player can explore the liberated world of Tasbada through the mobile phone and interact with it. Virtual objects present in the augmented reality scene remain, but the real-world scenario becomes overlaid with a fully virtual setting. This last transition allowed the user to smoothly progress on step further in the RVC, from AR to VR. The user started the game at the real end of the continuum and ended it on the totally virtual side of it.

5 DISCUSSION

In this paper we showed that the Reality-Virtuality Continuum can be seamlessly traversed, yielding new user experiences. To illustrate that theory, we successfully implemented and assembled recent techniques in Mixed Reality to provide a game where the player is progressively immersed into a virtual world.

Future advancements in MR technologies would contribute for even more immersive applications of the concept we developed, and particularly in the two following domains. Firstly, object recognition (and augmentation) is currently restricted to predefined geometries, such as the head in our application, which limits the interaction with the real world. If a system was able to recognize any object that is seen through the camera, it would enable more diverse experiences that could be adapted to any physical environment. Secondly, having to hold a device in order to observe virtual elements can be distracting. Advancements in light-weight AR glasses or holographic technologies would make the distinction between physical and virtual elements even less discernible.

We believe that storytelling can also benefit from our approach. Indeed, spanning the RVC does not only enable new interactions with physical and virtual elements, but also provides a different format to tell a story. In our example in Section 4, Multi-Reality contributed to the gradual exploration of the imaginary world we called Tasbada.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 642841. We would like to thank Matthias Sala and all other people from Gbanga who contributed valuable ideas and feedbacks on the application.

REFERENCES

Raphael Anderagg, Loïc Ciccone, and Robert W. Sumner. 2018. PuppetPhone: Puppeteering Virtual Characters Using a Smartphone. In *Proceedings of ACM SIGGRAPH Conference on Motion, Interaction and Games*.

E. Andre. 2006. Engaging in a Conversation with Synthetic Agents along the Virtuality Continuum. In *2006 IEEE/WIC/ACM International Conference on Intelligent Agent Technology*. 19–20.

B. Besbes, S. N. Collette, M. Tamaazousti, S. Bourgeois, and V. Gay-Bellile. 2012. An interactive Augmented Reality system: A prototype for industrial maintenance training applications. In *2012 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*. 269–270.

Llogari Casas, Matthias Fauconneau, Maggie Kosek, , Kieran Mclister, and Kenny Mitchell. 2018. Image Based Proximate Shadow Retargeting. In *Proceedings of the Computer Graphics and Visual Computing (CGVC) Conference 2018*. Swansea, Wales, United Kingdom.

Llogari Casas, Maggie Kosek, and Kenny Mitchell. 2017. Props Alive : A Framework for Augmented Reality Stop Motion Animation. In *2017 IEEE 10th Workshop on Software Engineering and Architectures for Realtime Interactive Systems*.

Gokcen Cimen, Christoph Maurhofer, Bob Sumner, and Martin Guay. 2018. AR Poser: Automatically Augmenting Mobile Pictures with Digital Avatars Imitating Poses. In *12th International Conference on Computer Graphics, Visualization, Computer Vision and Image Processing 2018*.

L. Davis, J. Rolland, F. Hamza-Lup, Yonggang Ha, J. Norfleet, and C. Imielinska. 2003. Enabling a continuum of virtual environment experiences. *IEEE Computer Graphics and Applications* 23, 2 (2003), 10–12.

Lucio Gutierrez, Eleni Stroulia, and Ioanis Nikolaidis. 2012. fAARS: A Platform for Location-Aware Trans-reality Games. In *Entertainment Computing - ICEC 2012*, Marc Herrlich, Rainer Malaka, and Maic Masuch (Eds.). 185–192.

K. P. Jantke, O. Arnold, and S. Spundflasch. 2013. Aliens on the Bus: A family of pervasive games. In *2013 IEEE 2nd Global Conference on Consumer Electronics (GCCE)*. 387–391.

Bergstrom Karl, Jonsson Staffan, and Bjork Staffan. 2010. Undercurrents: A Computer-Based Gameplay Tool to Support Tabletop Roleplaying. In *DiGRA Nordic: Proceedings of the 2010 International DiGRA Nordic Conference: Experiencing Games: Games, Play, and Players*.

Vlasios Kasapakis, Damianos Gavalas, and Nikos Bubaris. 2013. Pervasive Games Research: A Design Aspects-based State of the Art Report. In *Proceedings of the 17th Panhellenic Conference on Informatics*. 152–157.

A. R. Khairuddin, M. S. Talib, and H. Haron. 2015. Review on simultaneous localization and mapping (SLAM). In *2015 IEEE International Conference on Control System, Computing and Engineering (ICCSCE)*. 85–90.

Eric Klopfer and Kurt Squire. 2008. Environmental Detectives—the development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development* 56, 2 (2008), 203–228.

L. Frank Baum. 1901. The Master Key: an Electrical Fairy Tale. *Bowen-Merrill* (1901), 102.

Miikka J. Lehtonen and J. Tuomas Harviainen. 2016. Mobile Games and Player Communities: Designing for and with Clans. *Design Management Review* 27, 3 (2016), 20–26.

Craig A. Lindley. 2005. Game Space Design Foundations for Trans-reality Games. In *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology*. 397–404.

Stéphane Magnenat, Dat Tien Ngo, Fabio Zünd, Mattia Ryffel, Gioacchino Noris, Gerhard Rothlin, Alessia Marra, Maurizio Nitti, Pascal Fua, Markus Gross, and Robert W. Sumner. 2015. Live Texturing of Augmented Reality Characters from Colored Drawings. *IEEE Transactions on Visualization and Computer Graphics* 21, 11 (2015), 1201–1210.

Paul Milgram, H. Takemura, A. Utsumi, and F. Kishino. 1994. Mixed Reality (MR) Reality-Virtuality (RV) Continuum. *Systems Research* 2351 (1994), 282–292.

Niantic and The Pokemon Company. 2016. Pokemon GO.

A. Nijholt. 2005. Meetings in the virtuality continuum: send your avatar. In *2005 International Conference on Cyberworlds (CW'05)*. 8 pp.–82.

Max Rheiner. 2014. Birdly an Attempt to Fly. In *ACM SIGGRAPH 2014 Emerging Technologies*. Article 3, 3:1–3:1 pages.

Ivan E. Sutherland. 1968. A head-mounted three dimensional display. In *Proceedings of the AFIPS '68 (Fall, part I)*. 757–764.

D. Wagner and D. Schmalstieg. 2003. First steps towards handheld augmented reality. *Seventh IEEE International Symposium on Wearable Computers, 2003. Proceedings.* (2003), 127–135.

Andrzej Zarzycki. 2012. Urban Games: Inhabiting Real and Virtual Cities. In *Proceedings of the 30th eCAADe Conference - Volume 1 / ISBN 978-9-4912070-2-0, Czech Technical University in Prague, Faculty of Architecture (Czech Republic) 12-14 September 2012, pp. 755-764.*