Conceptualizing Augmented Reality Television for the Living Room

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ABSTRACT

We examine the concept and characteristics of "Augmented Reality Television" (ARTV) using a four-step investigation method consisting of (1) an analysis of commonly-accepted perspectives on Augmented and Mixed Reality systems, (2) a literature survey of previous work on ARTV, (3) relevant connections with other areas of scientific investigation from TVX/IMX, such as Ambient Media, Interactive TV, and 3-D TV, and (4) by proposing a conceptual framework for ARTV called the "Augmented Reality Television Continuum." Our work comes at a moment when the excitement and hype about the potential of AR for home entertainment has overlooked rigorous analysis and clear-cut examinations of the concepts involved, which should be the hallmark of any exact science. With this work, our goal is to draw the community's attention toward fundamentals and first principles of ARTV and to tease out its salient qualities on solid foundations.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; **HCI theory, concepts and models**.

KEYWORDS

Augmented Reality; Mixed Reality; Interactive Television.

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1 INTRODUCTION

New forms of computer-generated content, media, and platforms [1, 5,42,53,70], anchored into and aligned with the physical world, continue to change how we perceive and interact with our surroundings. As display and sensing technology evolve, presentation of content that is photorealistic, adaptive, personalized and customizable, real-time responsive and interactive and, consequently, engaging for users becomes attainable. These developments impact how we experience various representations of reality, such as virtual [42], mediated [53], multimediated [54], amplified [26], alternate [19], augmented [2,5], augmediated [54], mixed [61,87], blended [106], extended [55], and cross-reality [70].

For instance, applied to television, Augmented Reality (AR) can immerse viewers into an interactive storytelling space that enables fantasy worlds to "break out" of the confines of the physical TV frame as well as to "bring in" aspects of the physical world. As part of the televised show, the action can extend to the living room [43,44,94,97] to create a sense of "actually being there." Therefore, the combination of AR and television creates the premises for a hybrid medium that opens new horizons for storytelling and engagement with interactive media and digital content. Imagine watching a live soccer game, where the formation of players in each team is symbolized on a miniaturized model of the game field that is rendered right in front of the TV screen, while statistics of the match are always visible right next to the TV set; see [92] (minute 02:05). Or, consider extending the field of view of the conventional TV set with synchronized video projections on the wall behind it [44,47], or putting up on the wall as many virtual TV screens as one wishes, and be able to adjust their location to match the architectural design of the room [94] with flexible control over which content is rendered where [97]. Moreover, imagine a detective TV series, where indispensable parts of the story are told through film, but before the end of each episode, the viewers' living room is transformed into the crime scene, and viewers can continue to experience the plot of the story at a new level by searching for clues with their AR-enabled smart devices, before the final resolution of the episode.

By putting television and AR together in the form of ARTV (*read*: "Augmented Reality Television"), experiential rich scenarios can become the norm of living room TV-based entertainment [31,74,75].

However, while we are seeing more and more developments in AR for television presented and discussed at top-tier venues, such as CHI, UIST, TVX, and ISMAR [43,44,73–75,79,80,97,103,104], there is large heterogeneousness in the ARTV landscape as well as in the terminology used by researchers and practitioners, revealing concepts that are not crisply defined and fully understood. A more rigorous description of *what ARTV actually is* represents thus a requirement for our community to sustain growth in this area on solid foundations. A closer look at the larger context of AR research reinforces this requirement.

1.1 The Context in AR Research for ARTV

A key observation is that *it is not just ARTV and not just the TVX/IMX community that lack the desired level of rigorousness in properly specifying computer-generated augmented realities.* In fact, the terminology used in the scientific literature, industry, and media to refer to Augmented Reality (AR), Mixed Reality (MR), and Extended or Cross-Reality (XR) is split to the extent to which it has become difficult even for experts to define these concepts precisely and confidently [87].

There are several articles and blogs attempting to clarify the differences between AR, MR, VR, XR, and other "R" acronyms for the layman reader [34,41,55,84]. However, major industrial players refer to comparable technologies using different terms. For example, Google has adopted the "Augmented Reality" terminology when addressing its community of developers, speaking about "augmented reality experiences" enabled by the ARCore platform [35]; Microsoft promotes the term "Mixed Reality" with the Windows Mixed Reality platform and the HoloLens headset [59]; while other industry players, such as Qualcomm, speak directly about XR and envision *"the convergence of the smartphone, mobile VR headset, and AR glasses into a single XR wearable"* [77]. Although a few attempts have been made to clarify the terminology [93] and to demystify the VR landscape [40], empirical evidence suggests that the interpretation of relevant terminology by experts in the field remains varied [87].

1.2 The Responsibility of the TVX/IMX Community

As the "R" realities are not crisply defined, the term television itself is starting to become a troublesome one, in need for an updated definition. In this context, ARTV is new and must be properly characterized in a space where television meets computer-generated realities. Exactly because TV and "R" realities are converging, *it is our responsibility as a community to provide an informed answer for what is the new emerging concept of ARTV* to keep up with the expectations horizon created by a fast developing industry, a creative academia, and an excited public media [84,85,91,92].

To understand the hype and context in which our contribution for specifying ARTV is needed, we provide a few examples. In a January 2019 Visual Capitalist article piece, Jenny Scribani [84] noted that *"XR brings immersive experiences to the entertainment world, and offers consumers an opportunity to virtually experience live music and sporting events from the comfort of their VR headset"*; on their web page dedicated to XR, Qualcomm talks about how *"XR could replace all the other screens in your life, like that big TV in your living room"* [77]; and, during Facebook's F8 Developer Conference of 2017, Mark Zuckerberg touched on augmented television, among other examples of how AR technology could change users' lives: *"You want to watch TV? We could put a digital TV on that wall and instead of being a piece of hardware, it's a $1 app, instead of a $500 piece of equipment"*; see the video recording of the event at [91] (minute 4:35).

It seems though that excitement and hype about AR, MR, and XR technology for home entertainment, television included, have largely overpassed rigorous examination and understanding of the intrinsic concepts of Augmented Reality and television. However, to advance on scientific grounds, we need rigorous *conceptual formalization of what ARTV is.* This paper is an attempt toward such a formalization.

1.3 Contributions of This Work

Our practical contributions are as follows:

1. We conduct the first literature survey on AR for television in order to understand past efforts, critical ideas, and key projects. We examine various perspectives on AR/MR, from which we extract key characteristics for ARTV and identify areas of investigation from TVX/IMX related to ARTV, *e.g.*, Ambient Media, Interactive TV, and 3-D TV.
2. We introduce a conceptual framework for ARTV in the form of the "Augmented Reality Television Continuum," a 2-D representation space for ARTV concepts, devices, systems, and applications inspired by the 1-D Reality-Virtuality Continuum of Milgram and Kishino [61]. We also differentiate ARTV from AVTV (*read*: "Augmented Virtuality Television"), a complementary concept equally covered by our ARTV conceptual framework.

2 THE INVESTIGATION METHOD OF THIS PAPER

Before we move on, we take a moment to describe the investigation method that we implement in this work to identify key characteristics of ARTV. Our method is composed of four steps, as follows (see Figure 1 for a visual illustration):

Step1: We start from the perspectives and definitions of general-purpose AR and MR systems, examine current classifications, and overview research and technical challenges. This step enables us to provide an answer to *What are the foundations for ARTV?*

Step2: We perform a targeted literature survey of previous work implementing AR for television to understand *What has already been achieved in ARTV?*

Step3: Having established the foundations and understood the state-of-the-art, we proceed to identifying relevant connections between ARTV and other areas of investigation from TVX/IMX, such as Multimedia Alternate Realities, Ambient Media, Interactive TV, and 3-D TV. This step enables us to understand *What makes ARTV a specific kind of television experience?*

Step4: We identify key components for ARTV, which we build into our new conceptual framework, the "Augmented Reality Television Continuum."

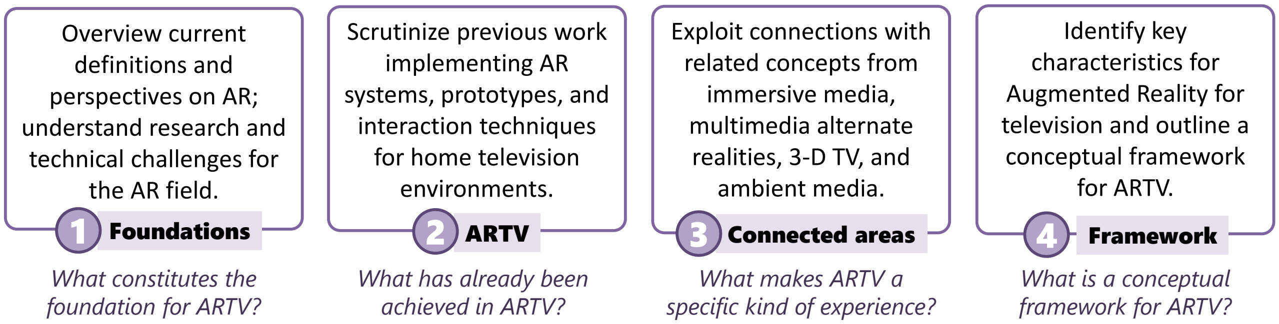

Figure 1: Our four-step method for specifying Augmented Reality for Television. Each step addresses a specific question and is covered by a distinct section of this paper, *e.g.*, Section 6 discusses *What is a conceptual framework for ARTV?*

3 FOUNDATIONS

We overview in this section first principles of VR, AR, and MR systems and environments. While VR is commonly understood as fully-immersive environments that substitute real-world sensations with simulated cues [54,61,84], the distinction between AR and MR has been less obvious [87].

The transition from fully-immersive VR toward displays that combine elements from both the physical (real) world and the virtual (computer-generated) world was represented by the first prototypes of AR systems starting with Sutherland's [89] head-mounted 3-D display; see Azuma's [2] widely referenced survey of the state-of-the-art in AR in 1997 and Billinghurst *et al.*'s [12] comprehensive overview of the field photographed in 2015. However, since the introduction of the concept, AR has received many definitions in the scientific literature corresponding to various perspectives, which are relevant to scrutinize for the purpose of our investigation. This examination of the foundations of computer-generated realities is key to draw implications for ARTV. We start with Milgram and Kishino's [61] highly-influencing "Reality-Virtuality Continuum" that distinguished MR from AR.

3.1 The Reality-Virtuality Continuum

In 1994, Milgram and Kishino [61] introduced the "Virtuality" continuum, an imaginary line having the real and virtual worlds at its opposite ends. Later, Milgram *et al.* [60,62] referred to this line as the "Reality-Virtuality (RV) Continuum," the name in use today. As one moves along the RV Continuum, the degree of interpolation between the real and the virtual changes, leading to Augmented Reality (AR) and Augmented Virtuality (AV) world mixtures; see Figure 2. In fact, the primary environment or "substratum" that is augmented determines the distinction between AR and AV. Everything in the RV Continuum, except its ends, was defined as Mixed Reality, a *"more encompassing term to supplement the existing definition of Augmented Reality (AR), which leads us to propose definitions of the associated concepts of Augmented Virtuality (AV) and then Mixed Reality (MR)"* [60].

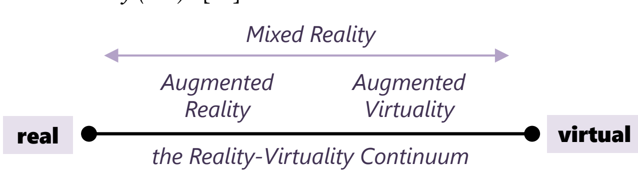

Figure 2: Illustration of Milgram *et al.*'s [60–62] RV Continuum, which we reproduce in this work since it represents the foundation for our ARTV Continuum from Figure 4.

MR has received other connotations in the recent years. For example, in a 2019 study, Speicher *et al.* [87] reported six definitions for MR from interviews conducted with experts from academia and industry as well as from a literature survey. They concluded that *"MR can be many things and its understanding is always based on one's context... there is no single definition of MR and it is highly unrealistic to expect one to appear in the future."* The authors also recognized that *"it is extremely important to be clear and consistent in terminology and communicate one's understanding of MR in order to avoid confusion and ensure constructive discussion"* [87] (p. 12). Milgram and Kishino's [61] definition of MR based on the RV Continuum was the most frequent perspective found in [87]. Thus, we also adopt this perspective in our work.

3.2 Augmented Reality *vs.* Augmented Virtuality

Milgram and Kishino's [61] formalization of the RV Continuum unveiled the concept of AV, where the virtual world is the primary environment that is augmented. Together, AR and AV specify the entire spectrum of MR worlds, *i.e.*, *"the most straightforward way to view a Mixed Reality environment ... is one in which real world and virtual world objects are presented together within a single display, that is, anywhere between the extrema of the virtuality continuum"* [61]. By analogy, we differentiate between Augmented Reality TV (ARTV) and Augmented Virtuality TV (AVTV). In the former case, it is the real world (*e.g.*, the living room) that is augmented with virtual objects; in the later, it is a virtual world that shows real objects, *e.g.*, a video feed of a physical TV set. We define Mixed Reality TV (MRTV) as ARTV and AVTV. In this work, we are interested in ARTV and, thus, we continue with an overview of definitions for AR. Sections 6 and 7 resume AVTV and MRTV for the interested reader.

3.3 Perspectives on AR and Implications for ARTV

In the following, we present a chronological examination of perspectives on AR, from which we identify key concepts, implications for ARTV, and connected areas of scientific investigation from TVX/IMX; see Figure 3 for an overview.

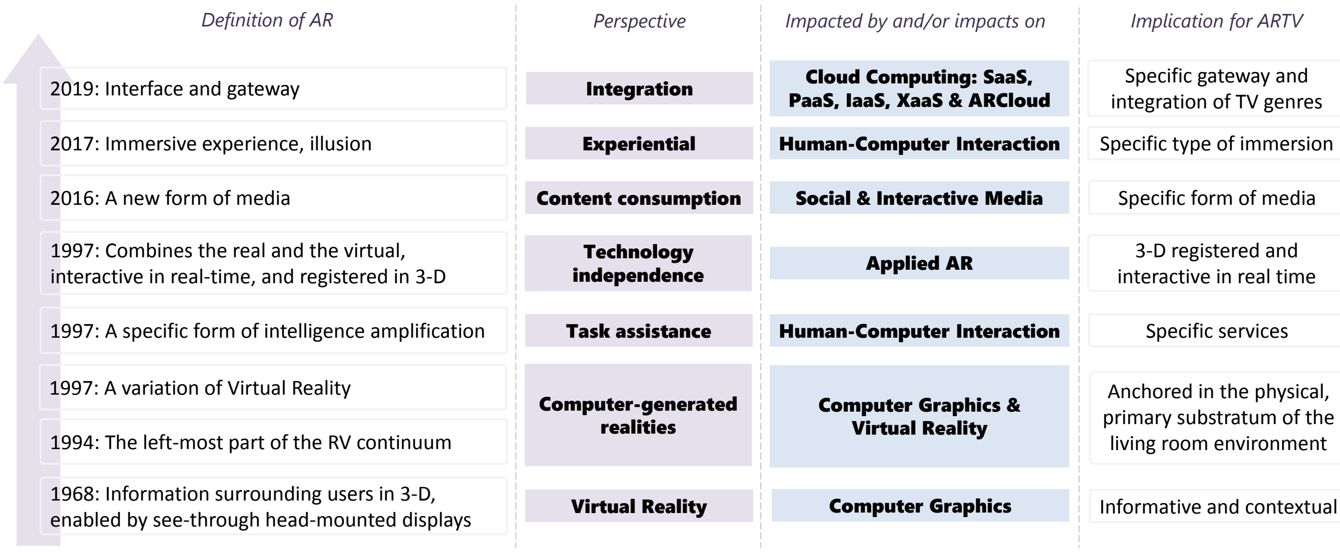

Figure 3: Evolving perspectives of Augmented Reality (left, shown in chronological order) and implications for ARTV (right).

3.3.1 ***1968: AR is 3-D information surrounding the user, enabled by wearing see-through HMDs.*** Sutherland's [89] head-mounted display (HMD) represents the first instance of an AR device and system. Although there is no mention of the term "Augmented Reality" in Sutherland's paper, one quote characterizes well the ultimate goal of Sutherland's work: *"our objective in this project has been to surround the user with displayed three-dimensional information"* (p. 757). In this context, AR is visualization of 3-D spatial information enabled by a see-through HMD, a perspective that will dominate AR research for decades. For instance, in their 1994 paper introducing the concept of Mixed Reality and the RV Continuum, Milgram and Kishino [61] remarked that the prominent use of the term AR was limited at that time to what they called "Class 3 type displays," which are HMDs with see-through capabilities [61] (p. 1322). In another work, Milgram *et al.* [62] presented a definition of AR as *"a form of virtual reality where the participant's head-mounted display is transparent, allowing a clear view of the real world,"* which had originated from a call for papers of a representative journal special issue on AR. Pointing to the limitations of such definitions, Milgram and Kishino [61] argued that the AR concept can equally be extended to other types of displays, an observation that Milgram *et al.* [60,62] resumed in their follow-up work on real and virtual world display integration.

> **Key AR concepts:** information, HMD, 3-D.
> **Implications for ARTV:** Augmented television renders relevant information in the 3-D space surrounding the viewer and, if physically present, the TV set, enabled by some dedicated visualization device.
> **Connected TVX/IMX area:** 3-D TV.

3.3.2 ***1994: The real environment is "augmented" by means of virtual (computer graphic) objects.*** This perspective was adopted by Milgram and Kishino [61] as an operational definition for AR, because it was encompassing in terms of classes of displays compared to the HMD-based approach. However, the generality of this definition generated terminology problems for Milgram and Kishino for their Class 5 and 6 displays, *i.e.*, completely graphic display environments, that made the authors ponder about the nature of the primary environment that is augmented. The result was the distinction between AR and AV as well as the introduction of the term MR to cover all mixtures of physical and virtual.

> **Key AR concepts:** virtual objects, computer graphics, real environment.
> **Implications for ARTV:** Augmented television superimposes virtual content onto the real environment, which is the primary substratum that is augmented.
> **Connected TVX/IMX area:** 3-D TV.

3.3.3 ***1997: A variation of VR.*** According to this definition and perspective from Azuma [2], *"in contrast [to VR], AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it."* Eight years later, in their book on spatial Augmented Reality (sAR), Bimber and Raskar [13] resumed this definition to specify the characteristics of AR by contrasting them with VR: *"The fact is that in contrast to traditional VR, in AR the real environment is not completely suppressed; instead it plays a dominant role. Rather than immersing a person into a completely synthetic world, AR attempts to embed synthetic supplements into the real environment (or into a live video of the real environment)."* Like Milgram *et al.* [60–62] before them, Bimber and Raskar recognized the need to go beyond the technology of eye-worn and HMD displays, and defined sAR as *"new display paradigms [that] exploit large spatially-aligned optical elements, such as mirror beam combiners, transparent screens, or holograms, as well as video projectors"* [13].

> **Key AR concepts:** superimposed, composited, supplemented reality.
> **Implications for ARTV:** Augmented television supplements the content of the primary TV broadcast.

> **Connected TVX/IMX areas:** 3-D TV, Interactive TV (iTV), Ambient Media.

3.3.4 *1997: A specific form of "intelligence amplification".*

In his 1997 survey of AR systems, Azuma [2] provides two other perspectives on AR besides the antinomy with VR. One of them, more general, capitalizes on the utility of computers to assist users in their tasks, *i.e.*, access to a higher level of human intelligence. From this perspective, AR implements a specific case of intelligence amplification [2]. The second perspective is more structured and systematic; see next.

> **Key AR concepts:** intelligence amplification, task assistance, the computer as a tool.
> **Implications for ARTV:** Augmented television assists viewers by providing new services.
> **Connected TVX/IMX areas:** Ambient Media, iTV.

3.3.5 *1997: A system that combines the real and the virtual, is interactive in real time, and registered in 3-D.*

Azuma [2] recognized the large influence of the HMD perspective on AR research and, to avoid limiting the field to a specific technology, proposed three essential properties for AR systems. These properties constituted into a structured and systematic definition of what AR is, which has been largely adopted since;[1] see, for example, Billinghurst *et al.*'s [12] survey of AR that cites Azuma's three characteristics right from the first paragraph of their chapter on defining AR.

> **Key AR concepts:** real-time interactivity, 3-D.
> **Implications for ARTV:** Augmented television is registered in 3-D and interactive in real time.
> **Connected TVX/IMX area:** iTV, 3-D TV.

3.3.6 *2016: A new form of media.*

This perspective builds on a specific challenge that has been identified for AR systems. According to Azuma [3], *"The ultimate and most important challenge facing AR [...] is experiential in nature: How will we establish Augmented Reality as a new form of media, enabling new types of experiences that differ from established media? If AR is to become ubiquitous in consumer usage, then we must [...] [develop] new types of experiences that are engaging and compelling in different ways than traditional media such as books, movies, and even Virtual Reality."* By adopting the experiential perspective, AR systems are implementers of a specific kind of ambient media with characteristics from both the real and the virtual world.

> **Key AR concepts:** new media, experience.
> **Implications for ARTV:** Augmented television is a new medium for a new digital media experience.
> **Connected TVX/IMX area:** Ambient Media.

3.3.7 *2017: An immersive experience and an illusion.*

As a direct effect of superimposing virtual 3-D objects on top of the users' direct view of the physical world, AR generates the illusion of an immersive mix-world experience [4].

> **Key AR concepts:** immersion, experience, illusion.
> **Implications for ARTV:** Augmented television is an immersive experience.
> **Connected areas:** Multimedia Alternate Realities.

3.3.8 *2019: The interface and gateway to a 1:1 correspondence between the digital and the real world.*

This recent perspective from Azuma [5] converges the Internet (as the World Wide Web, cloud computing, and access to remote repositories of content and information) with AR, and contours the vision of an "AR Cloud" representing the gateway access to persistent virtual content attached to real locations.

> **Key AR concepts:** convergence, gateway, interface.
> **Implications for ARTV:** Augmented television is a gateway to cloud-based digital content and corresponding services for television.
> **Connected TVX/IMX area:** on-demand TV, iTV.

All these perspectives on AR highlight distinct concepts, such as *immersion*, *information*, *interface*, *experience*, useful to derive implications for ARTV, as we have been doing in this section. They are also useful to identify areas of scientific investigation from TVX/IMX that connect to ARTV; we relate to these areas in Section 5. For now, we continue our examination of ARTV with an overview of the field.

4 A LITERATURE SURVEY OF AR FOR TELEVISION

We overview prior work in AR for television and discuss concepts and/or implementations for AR and the living room.

4.1 Method

We conducted a targeted literature survey to locate relevant papers for ARTV. We identified a total number of 17 papers (from 338 candidates) describing ARTV systems or concepts (see Table 1) by running the following platform-compatible query against the ACM Digital Library (N=108 papers), Scopus (N=192 papers), and IEEE Xplore (N=38 papers):

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(‘‘Augmented Reality’’) AND (Television OR TV)
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We considered papers published in conference proceedings and journals during the last 20 years (2000 to 2019) that explicitly contained our key terms in their title, abstract, or keywords.[2] Based on our experience, we also considered for inclusion other papers that were not picked up by the query, from which we selected [43] as an extension of [44].

Next, we review these papers and classify them according to Milgram and Kishino's [61] three dimensions of the taxonomy for merging real and virtual worlds, as follows:

- *Extent of World Knowledge (EWK):* how much about the world being modeled is known to the system.
- *Reproduction Fidelity (RF):* the quality with which the synthesizing display reproduces the images of objects.
- *Extent of Presence Metaphor (EPM):* the extent to which the viewer is intended to feel present within the scene.

[1] Azuma's [2] 1997 paper has been cited over 10,000 times, https://scholar.google.com/scholar?um=1&ie=UTF-8&lr&cites=17196017931627326366

[2] In cases where the same authors published evolving work in different venues over time, such as [73–75], we kept just the latest publication.

Table 1: Classification of ARTV-related papers according to their contributions, Milgram and Kishino's [61] display classes and dimensions, and Schraffenberger's [83] "ArguablyAR" categories. *Note:* papers are listed in chronological order.

Reference	Contributions made					Extent of World Knowledge	Reproduction Fidelity	Extent of Presence Metaphor	Display class	"Arguably" forms of AR
	New tech	Application	Method	User study	Design					
Stauder and Robert (2002) [88]	✓	✓	✓	–	–	where	video / video	n.a.	1	n.a - XR - Imt
Vatavu (2012) [94]	✓	✓	✓	✓	–	where	HD video / Projected video	Real time imaging	6	n.a. - XR - n.a
Jones *et al.* (2013) [44]	✓	✓	–	✓	–	where	HD video / Real-time 3D animation	Real time imaging	6	P - XR/AltR - Imt/Img
Vatavu (2013) [97]	✓	✓	✓	✓	✓	where	HD video / Projected video	Real time imaging	6	n.a. - XR - n.a.
Jones *et al.* (2014) [43]	–	–	–	–	–	world completely modeled	HD video / Real-time 3D animation	Real time imaging	6	P - XR/AltR - Imt/Img
Gómez *et al.* (2014) [33]	✓	✓	✓	✓	–	where + what	HD video / simple graphics	Monoscopic imaging	1	n.a. - XR - n.a.
Kawakita and Nakagawa (2014) [45]	✓	✓	✓	–	–	where + what	HD video / Real-time 3D animation	Real time imaging	1	P – XR - Img
Revelle *et al.* (2015) [78]	✓	✓	–	✓	–	where + what	HD video / Real-time 3D animation	Real time imaging	1	P - XR/HR - Img
Vatavu (2015) [98]	✓	✓	✓	✓	✓	where	HD video / Visible surface imaging	Monoscopic imaging	1	n.a. - XR - n.a.
Baillard *et al.* (2017) [6]	–	✓	–	–	–	where + what	HD video / Real-time 3D animation	Real time imaging	1 & 3	P - XR - Imt
Sotelo *et al.* (2017) [86]	✓	✓	✓	–	–	n.a.	HD video / Real-time 3D animation	n.a.	1	n.a. - XR - Imt
Kawamura and Otsuki (2018) [46]	✓	✓	✓	–	–	world completely modeled	HD video / Real-time 3D animation	Real time imaging	1	P - XR - Img
Kimura and Rekimoto (2018) [47]	✓	✓	✓	✓	–	world unmodeled	HD video / Generated context images	n.a.	5	n.a. - XR - Imt
Zimmer *et al.* (2018) [112]	–	✓	✓	✓	✓	where	HD video / 3D animation	Monoscopic imaging	1	P - XR - Imt
Popovici and Vatavu (2019) [75]	–	–	–	✓	–	n.a.	n.a.	n.a.	n.a.	P - XR - Imt
Geerts *et al.* (2019) [30]	–	–	✓	✓	–	where	n.a.	n.a.	6	P - XR - Imt
Saeghe *et al.* (2019) [80]	–	✓	–	✓	✓	where	HD video / Real-time 3D animation	Real time imaging	3	P - XR - Imt
Vinayagamoorthy *et al.* (2019) [104]	–	✓	–	✓	✓	where	HD video / Holographic video	Monoscopic imaging	3	P - XR - Imt

For each paper, we identify the classes of AR displays [61]: monitor-based video displays (Class 1), HMDs (Class 2), see-through HDMs (Class 3), video-based see-through HMDs (Class 4), completely graphic display environments (Class 5), and completely graphic, partially immersive environments, where real objects play a role in the virtual world (Class 6).

We also employ Schraffenberger's [83] forms of AR:

- *Presence-based AR (P):* virtual objects are shown in the physical space of the user rather than on a screen.
- *Content-based AR (C):* virtual relates content-wise to the real world, *e.g.*, by informing about real surroundings.
- *Extended Reality (XR):* virtual supplements the real.
- *Diminished Reality (DR):* virtual removes part of the real.
- *Altered Reality (AltR):* virtual transforms the real.
- *Hybrid Reality (HR):* virtual is integral to the mixed world.
- *Extended Perception (EP):* more aspects are perceived.
- *Imitative Augmented Reality (Imt):* virtual looks real.
- *Imaginative Augmented Reality (Img):* virtual objects have no equivalent in the physical world.

According to [83], the first two categories describe AR on a fundamental level; the next five distinguish between forms of AR according to how the virtual affects the real; and the last two describe how the virtual compares to the real. Thus, we characterize the ARTV-related literature by triples of AR forms, *e.g.*, Baillard *et al.* [6] is "P-XR-Imt"; see Table 1.

Also, inspired by [51,108], we group prior work according to contributions to ARTV: (1) new technology, (2) application, (3) method, (4) user study, and (5) design recommendations. Table 1 shows a summary of our literature survey.

4.2 Window-on-the-World Displays (Class 1)

Many of the papers identified in our survey implemented the "window-on-the-world" metaphor with hand-held devices. For example, Gómez *et al.*'s [33] system enabled users to browse a tree of resources linked to a physical object using hand-held AR. Kawakita and Nakagawa [45] created a system where a 3-D character appeared to come out of the TV screen when viewed on a hand-held display. Revelle *et al.* [78] proposed a transmedia game for children to learn new words. Kawamura and Otsuki [46] presented an imaginary world on TV viewable in 3-D on a hand-held display. And Zimmer *et al.* [112] immersed viewers into the story by delivering content using AR exclusively.

Besides hand-held devices, Class 1 displays have been implemented with augmentations on the TV screen itself. For example, Stauder and Roberts [88] proposed a method to ensure photometric realism when virtual artifacts were overlaid on top of the TV content, and Sotelo *et al.* [86] described a system enabling the viewer to interact with a 3-D model overlaid on broadcast video. Vatavu's [98] "Audience Silhouettes" prototype overlaid live 3-D representations of viewers' body movements directly on top of the TV broadcast.

4.3 Head-Mounted Displays (Classes 2, 3, and 4)

A few systems have implemented ARTV using HMDs. One example is Baillard *et al.* [6] that created a multi-user system where AR content was displayed on the periphery of the physical TV set, viewable using both a hand-held and an HMD. Saeghe *et al.* [80] displayed virtual animated content related to the broadcast outside the TV frame. Vinayagamoorthy *et al.* [104] described a prototype where a sign language interpreter was presented to the viewer next to the TV set.

4.4 Graphic Display Environments (Classes 5 and 6)

In 2012, Vatavu [94] proposed an interactive home entertainment system where multiple virtual TV screens were video projected on the living room wall. In a follow-up paper, Vatavu [97] introduced "AroundTV," a video projection-based system for the area surrounding the physical TV set, including graphical user interface widgets. At the same time, Jones *et al.* [44] introduced "IllumiRoom" for computer games, a system that projected visualizations of the game in the periphery of the TV screen. The follow-up "RoomAlive" [43] system was meant to transform the entire room into an immersive, augmented space. And Kimura and Rekimoto [47] proposed "ExtVision," a system that generated and displayed context images in the area surrounding the TV set.

4.5 User Study Contributions in ARTV

In our survey, we found that nine papers implemented the window-on-the-world metaphor (Class 1 displays), three papers used see-through HMDs (Class 3), and six implemented graphic environments of Class 5 or 6; see Table 1. Some papers did not present actual implementations, since they focused on user studies. For example, Geerts *et al.* [30] used a co-design approach to generate a scenario where extra content was displayed in the viewers' environment. Popovici and Vatavu [74] proposed an agenda for researchers to consider when designing for ARTV. In two follow-up papers, they elicited user preferences regarding ARTV [75] and used the findings to consolidate the original research agenda [73].

4.6 World Knowledge, Presence, and Fidelity

We used Milgram and Kishino's [61] dimensions to classify the ARTV literature. We found that all system papers used information about the location (*where*) of the modeled world, four papers modeled both the *where* and *what*, while only two papers implemented a complete model of the world [43,46]. As the spatial understanding capability of AR advances, we can expect systems to approach complex models of the displayed world. While six papers described real-time hi-fidelity 3-D animations, one paper used basic graphics [33] and another [104] employed holographic video via chroma-keying techniques. Regarding the Extent of Presence Metaphor dimension, four papers [33,98,104,112] used AR to deliver a monoscopic image, while the rest delivered real-time images with AR artifacts viable from multiple points of view.

5 TVX/IMX AREAS CONNECTED TO ARTV

Section 3 highlighted key concepts for ARTV, which led to connections to several areas of scientific investigation representative for the TVX/IMX community. We discuss these areas in this section to unveil further aspects of ARTV.

5.1 Interactive Television

Broadcasters are trying to engage TV audiences through the addition of data services on top of traditional television to increase participation and feedback [102]. This has resulted in the TV evolving from a purely audiovisual platform to one with in-built interactive services, such as teletext, electronic program guides, or red-button services. Users are increasingly opting to purchase smart TVs with IP connectivity that run applications and integrate with connected devices in the home, such as conversational user interfaces [21,107]. Besides the attractive prospect of personalizing the ways in which users might control their connected TVs, there have been ventures to personalize and augment the viewing experience itself [29,50, 102] through synchronized companion experiences based on audio watermarking, fingerprinting, and HbbTV 2.0 [105]. The potential to personalize television experiences connects iTV with ARTV, where virtual objects augment viewers' personal TV watching experience.

On the big screen itself, the move from broadcast to streaming over IP enables more interactive storytelling. The go-to obvious format has been play along quizzes and voting, but the interactive potential can go further [39]. For example, Netflix Bandersnatch [65] is a non-linear branching narrative that progresses the stories off depending on the choice the viewer makes. Object-based media (OBM) allows content to change according to the requirements of each individual audience member [38]. This affords a versatile manner in which the story is remixed according to the audience [8,22,38,49], connecting to the potential of ARTV to render new ways for the virtual story to play out. Examples of OBM experiences include immersive audio [7,27], branching narratives [15], personalized documentary [37], and personality quizzes [9]. In ARTV, future media offerings will more easily personalize to the audience, which means adding interaction and augmentation to engage the audience in the storytelling process.

5.2 3-D Television

3-D photography, cinema, and TV have a long history from the first examples of passive stereoscopic 3-D cinema in the 1990s to manufacturers involved in marketing autostereoscopic 3-D TVs in the late 2000s [58,69]. The 3-D TV display systems use a combination of a 2-D image and a depth map [36] (*i.e.*, depth image-based rendering) to synthesize new virtual views and, consequently, to augment the original image from the 2D-plus-depth data [24]. These advances in 3-D TV technology are relevant to support developments in ARTV since, according to Azuma [2], 3-D registration is one of the three key characteristics of any AR system.

5.3 Ambient Media

Research in Ambient Media has unveiled a new type of media, conceptually different from television, print, and digital media, that define the media landscape of smart spaces. According to Lugmayr *et al.* [52], *"Ambient media in a larger scale define the media environment and the communication of information in ubiquitous and pervasive environments."* Among its characteristics, ambient media is subtle, unmonopolizing, and addressing peripheral awareness [81,82], while it can morph and manifest in various ways [71,72,95]. These properties make ambient media especially relevant for ARTV where, according to a recent perspective [3], AR itself can be qualified as a specific form of new media.

5.4 Immersive Media and Multimedia Alternate Realities

Immersion, Interactivity, and Imagination (I^3) [16] are central concepts associated with the sense of presence in VR, AR, and MR with strong roots in computer-generated graphics and content. Immersion is influenced by sensory and perceptual modalities associated with "presence," *i.e.*, the feeling of being inside the computer-generated reality due to realistic feedback, participation, and social immersion [18]. Developments in immersive media in the context of interactive television have focused on audiovisual immersion, 3-D and panoramic multi-view and holographic video, spatial and stereoscopic audio, perceptual immersion and multi-sensory interaction, and interactive immersive cinema [18,19].

Chambel *et al.* [18,19] introduced the concept of "Multimedia Alternate Realities" (MMARs) as *"different spaces, times or situations that can be entered thanks to multimedia contents and systems, that coexist with our current reality, and are sometimes so vivid and engaging that we feel we are living in them ... immersive experiences that may involve the user in a different or augmented world, as an alternate reality"* [19]. To properly characterize such realities, a taxonomy with eight dimensions was proposed [19] consisting of: the alternate (*e.g.*, different space, time, context), the virtual-augmented spectrum, the real-fictional spectrum, the level of interactivity, the level of immersion (*e.g.*, presence and belonging, imagination, and engagement), the multisensorial (the media and modalities involved), the personal (adaptation to preferences and contexts), and the social dimension (individualized or shared realities). MMARs go beyond the focus of VR, AR, and MR by addressing new media and immersive experiences. In the context of ARTV, these dimensions become relevant when television is part of the audiovisual content delivered inside the MMAR. Of those, the virtual-augmented and real-fictional spectra connect directly to ARTV.

6 A CONCEPTUAL FRAMEWORK FOR ARTV

Based on our findings and discussion so far, we introduce a conceptualization for ARTV. To this end, we adopt the following three principles regarding AR technology, the real-world environment of the living room, and end users:

P1. *Independence of AR rendering technology.* Just like Azuma [2] for AR, Bimber and Raskar [13] for spatial AR, and Milgram *et al.* [60–62] for MR, we believe that the technology to render computer-generated graphics in the living room environment should not drive the concept of ARTV. From this perspective, smartphones and tablets [45,46,78], smartglasses and HMDs [103,104], video projections [94,97], and wall- and room-sized projections [43,44,47] are implicitly encompassed by our framework. All that matters is that the TV experience is augmented.

P2. *Focus on the living room.* We restrict our discussion of ARTV to the context of the living room environment [25,48,99]. Thus, we exclude mobile television [57,68], for which a proper investigation will need the context of mobile AR [23]. Our focus on the living room is motivated by TV sets being predominant in the TV landscape, *e.g.*, 93% of streamers watch traditional TV on a typical day [66] as the growth of mobile media levels out [111].

P3. *Focus on the viewers' side of ARTV.* AR has two applications in TV broadcasting: (1) TV production, which aims to increase productivity and/or reduce costs, often referred to as the "virtual studio" [32], and (2) application on the viewers' side, which aims to create novel experiences in the viewers' environment during television watching. In this work, our focus has been on the latter.

6.1 The ARTV Continuum

Our exploration from the previous sections revealed many key characteristics of ARTV. We have seen that the RV Continuum [61] (Figure 2) represents the most accepted, go-to source for defining AR and to distinguish MR from AR [87]. In the following, we adopt the RV Continuum as the basis for our conceptualization of ARTV. But, while this continuum can be successfully employed to characterize the degree of mixture between real and virtual, its 1-D design is insufficient for our purpose. By considering the TV viewing experience where a *physical TV set* is placed in a *physical living room*, we recognize the fact that each of these two entities, world and TV, can be independently augmented. By adopting this perspective, we propose and introduce a 2-D conceptual framework for ARTV; see Figure 4.

The horizontal axis of Figure 4, going from a completely real to a completely virtual environment, is Milgram and Kishino's [61] RV Continuum that applies to the living room environment (the world). The vertical axis, going from a completely physical TV device to fully virtual televised content, is our adaptation of Milgram and Kishino's RV Continuum for television. Together, these two orthogonal axes characterize the various ways in which a television viewing experience can be augmented, *e.g.*, in terms of the world, the televised content, or both. In this conceptual framework, content can flexibly flow between the living room and the TV set, while the living room and the TV set can independently flow across their

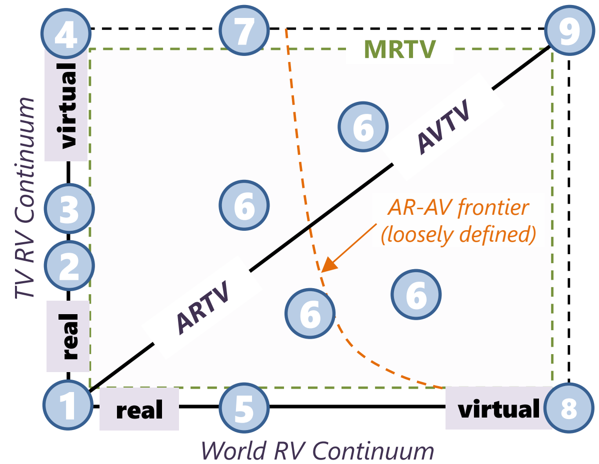

Figure 4: The ARTV Continuum. *Notes:* the orange dotted line loosely marks a delineation between ARTV and AVTV; the green rectangle pictures MRTV as the 2-D extension of Milgram *et al.*'s [60–62] 1-D MR continuum from Figure 2.

respective continua from real to virtual. We call this space the "Augmented Reality Television Continuum."

6.2 Examples of Using the ARTV Continuum

To demonstrate the utility of the ARTV conceptual framework, we enumerate various types of ARTV generated from the mixture of the two axes of Figure 4. For each category, we note examples from the literature where available and, where not, we highlight open areas for future work.

❶ *Conventional world/conventional TV.* This category represents the conventional TV viewing experience where neither the TV nor the room are augmented. The corresponding position in the ARTV Continuum is the bottom-left of Figure 4. Similar to how the RV Continuum captures the real world [61], the conventional TV viewing experience is equally captured by our framework.

❷ *Conventional world/conventional TV with on-TV augmentation.* In this category, contextual augmentations are shown on the TV screen. Examples include LinkedCulture [67], CollaboraTV [64], and Audience Silhouettes [98]. Teletext and Picture-in-Picture can also be included.

❸ *Conventional world/conventional TV with off-TV augmentation.* Different from the previous category, augmentation is now perceived to be off the TV screen, *e.g.*, on the wall behind it, in front or next to the TV set. Implementations may involve hand-held devices [45,46,78], HMDs [80,104], or video projection-based technology [43,44,47,97]. This category is also located on the vertical axis in Figure 4.

❹ *Conventional world/virtual TV.* A physical TV is not needed for this category of ARTV, where televised content is presented either in a virtual TV frame or even without a TV frame altogether. Examples include TV projected on the wall [91,94], and when the storyteller appears to be sitting in the living room [112] in the viewers' space.

❺ *Augmented world/conventional TV.* In this case, the living room is augmented directly. This often requires spatial understanding of the surfaces present in the living room for meaningful alignment of the computer-generated graphics. Viewers experience an augmented world, but watch a conventional TV screen. Nevertheless, the augmented world can offer affordances with respect to television watching, *e.g.*, the possibility to record the TV show, open a mid-air browser window with a fact sheet about the current televised content, have Skype calls with friends watching the same broadcast, etc. Opposed to the previous categories, the living room is now the substratum that is augmented, but the TV is still conventional, which places this category on the horizontal axis; see Figure 4.

❻ *Augmented world/conventional TV with augmentation.* The world is augmented and so is the TV set, either by means of on-TV or off-TV augmentation. The degree of augmentation of each component, world and TV, positions implementations of this category at various locations in the ARTV Continuum illustrated in Figure 4.

❼ *Augmented world/virtual TV.* This category is achieved when the world is augmented (as in ❻), but the physical TV is virtual (as in ❹). These characteristics position category ❼ at the top of Figure 4. For instance, in the RoomAlive [43] prototype, the room is modeled and content is projected on its surfaces directly without using a physical TV set. The home entertainment prototype of Vatavu [94] implemented virtual TV screens exclusively.

❽ *Virtual world/conventional TV.* This category resembles the Augmented Virtuality of the RV Continuum [61]: a virtual world is augmented by a physical TV set. As a use-case, imagine watching your favorite TV show as a live video feed of your physical TV screen, while wearing a VR headset but still being physically present in the same room with friends watching the same physical TV screen. Or, at-a-distance media consumption [56], for which sharing the TV experience prevails over co-sharing physical space.

❾ *Virtual world/virtual TV.* Similar to the previous category, with the exception that the physical TV set is replaced by one or more virtual screens. This includes the scenario where a virtual TV is aligned to a virtual model of a conventional TV set in order to recreate a familiar TV viewing experience in a virtual space. This category is located at the top-right of Figure 4.

Other scenarios can be imagined in our conceptual space, depending on the interpolation between real and virtual on both the world and the TV axes; see the multiple instances of ARTV category ❻ shown in Figure 4. We note that many of the categories that we discussed in this section haven't been proposed yet in the literature, which reveals the generative power [10] of our conceptual framework for ARTV.

7 CONCLUSION AND FUTURE WORK

We found that ARTV can be many things and that prior work has implemented it in various ways, from on-TV augmentations to off-TV content visualized via AR-enabled hand-held devices, HMDs, wall- and room-sized projections, and holograms. By drawing from the various perspectives and key properties that we examined, we can conclude that *ARTV reveals itself as a specific type of experience, immersion, media, service, and gateway for televised content.* While the specific implementation may vary (and, in the years to come, we are to see more innovations in this regard), what is important at this moment is to have a rigorous basis to structure future research and developments, to be consistent in our terminology, and to communicate our understanding of ARTV precisely by relating to proper frameworks. Our ARTV Continuum is an attempt toward such a systematization and toward providing the community with a common vocabulary for possible categories of ARTV systems to enable better understanding and communication of advances in ARTV.

There is also more work that lies ahead. The concepts of AVTV and MRTV should be further explored to specify them thoroughly and understand their practical applications for television. For example, AVTV is represented in Figure 4 by the region located at the intersection of the Augmented Virtuality part of the world continuum with the TV axis. However, just like in Milgram and Kishino's [60] case, the distinction between ARTV and AVTV can only be defined in loose terms, *e.g.*, *"As we venture away from the poles of the RV continuum towards the centre, we also eventually begin to encounter the problem of deciding whether in fact what we are doing is augmenting a real world with virtual graphic objects, or whether we are modifying a virtual environment by augmenting it with real data,"* and *"it it is not always [...] simple [...] to distinguish between AR and AV"* [60], which is equally true for our ARTV space. Further examination of this distinction is left for future work. Also, new modalities to interact with the TV [76,90,96,100,101,110] are interesting to explore in relation to our framework, as well as uses of the framework for specific areas of interest for IMX, such as social TV [17,28,63,98] or accessible TV [11,14,20]. Regarding accessibility, the XRAccess [109] initiative for people with disabilities is especially relevant to our ARTV space.

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