Visual Coherence for Cross-Virtuality Analytics

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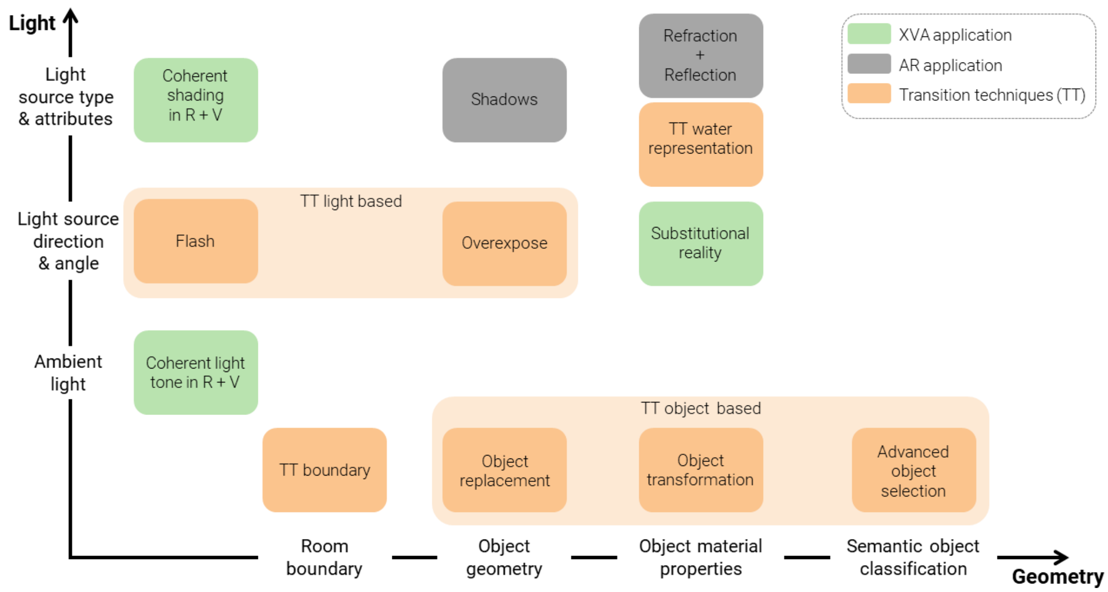

Figure 1: Requirements for different degrees of visual coherence. Geometry knowledge is mapped on the x-axis and lighting knowledge on the y-axis. The higher the knowledge about the physical world, the more sophisticated visual coherence approaches are possible. Potential novel areas of transition techniques (TT) are illustrated in orange and potential benefits for XVA applications are illustrated in green.

Abstract

The novel research field of Cross-Virtuality Analytics, where users move or interconnect stages of the Reality-Virtuality continuum to analyse data, can profit in multiple ways from the well researched area of visual coherence. In this position paper, we present initial ideas how visual coherence approaches and the data gathered by them can be used to improve Cross-Virtuality in general, what novel transition techniques could be developed and how the visual analysis process can profit from these approaches.

Index Terms: Human-centered computing—Mixed / augmented reality; Human-centered computing—Virtual reality;

1 Introduction

Cross-Virtuality (XV) [50] and especially Cross-Virtuality Analytics (XVA) [20], where transitions and interactions between the different stages of Milgrams' Reality-Virtuality (RV) Continuum [46] are possible, are two emerging fields of research. Several workshops have been held on these topics in the recent years, e.g., at ACM ISS '20 and '21 [32, 55] and ACM AVI '22 [42]. In contrast, Visual Coherence (VC) in Augmented Reality (AR) is a well researched and often discussed topic, where the real world and augmentations are shown together within a single display in a consistent and coherent manner going beyond simple registration.

We believe that XVA applications can greatly benefit from VC approaches in the area of transitions as well as visual analytics. In this position paper we therefore highlight the importance of VC for transitions in XV applications as well as visual analytics in the context of XV. We provide ideas on how to develop novel transition techniques based on the data gathered to implement traditional VC and discuss the potential benefits for visual analytics. Additionally, we classify the presented transition techniques and potential advantages of VC for XV applications inside an adaptation of Milgrams' Extend of World Knowledge (EWK) dimension.

2 Related Work

The related work on how and in which sense cross-Virtuality Analytics (XVA) can profit from visual coherence (VC) is seen in three important aspects: VC in AR, which has to be considered as well as previous work in the area of visual transitions and finally visual analytics. More details on the different areas can be found in the following sections.

2.1 Visual Coherence

To render visually coherent scenes, knowledge about the real environment needs to be gathered. Geometrical data is required to compute occlusion. Information about light sources and reflection properties, represented as material as well as geometrical data, can be used to correctly calculate shading, shadows, reflections and refraction.

Merging real and virtual content considering registration and lighting has been introduced by Fournier et al. [18] back in the early 90s. Since then, a variety of different approaches have been described to create visually coherent scenes. Most publications in that area focus on the acquisition of real world data to provide a match between the rendering and the physical environment. Agusanto et al. focus on the acquisition of the environment lighting based on light probes, which are photographed in high dynamic range and post-processed [1]. These environment maps are applied on the virtual objects. A more advanced approach is presented by Alhakamy et al. who gather real-time data from a 360° camera and analyse the respective video stream in order to approximate light source direction and angle as well as indirect lighting [2]. As an alternative, shadow detection can be used to determine the light source direction as shown by Jiddy et al. [33]. A common method to calculate outdoor shadows and lighting is presented by Barreira et al. who make use of GPS data to calculate the sun's position for generating a lighting simulation [5]. Knorr and Kurz base the lighting information on the reflections on human faces [36]. Advanced methods use artificial intelligence and make use of neural networks (e.g., Garron et al. [25]) to interpret data from light probes or use deep learning approaches, which were presented by Kan and Kaufman [37].

To further improve the rendering quality, Mandl et al. use neural networks to render the virtual content as it was perceived through the camera providing the real world video stream [40]. Kan and Kaufmann investigated advanced rendering approaches like reflection, refraction, and caustics for VC based on light source positions and intensities [38].

In order to determine the geometry of the real world and solve potential occlusion problems a plethora of approaches has been presented. Traditionally 3D scanning approaches were used with the help of stereo cameras as shown by Wloka and Anderson [65]. Holynski and Kopf base their estimation on processed point clouds based on SLAM data [29] while Roxas et al. use semantic real world information for occlusion handling [52]. A recent overview on occlusion detection and mitigation methods is provided by Macedo and Apolinario [39].

In general Collins et al. summarized visual coherence for AR [13]. All of these approaches gather data from the real world which can be incorporated to improve and enhance XVA applications.

2.2 Visual Transitions

XVA enables a seamless integration between different stages along Milgram's RV Continuum [46] to combine the benefits of each reality [6, 7, 15, 34, 35]. To support the transition process from one stage to another, visual transition techniques are required. Potential challenges and recommendations were identified recently in a state of the art report by Fröhler et al. [20] and a first classification of possible transition techniques to shift between AR and VR was introduced by Pointecker et al. [49]. Visual transitions are a common technique for scene changes in VR (e.g., Skyrim VR, Google Earth VR, The Lab and literature [43, 57, 64]) and can therefore be adopted for XV to change the reality along the RVC. The portal transition is a frequently used technique to change the scene or reorient the user [10, 12, 19, 58]. This technique provides a preview of the target environment and the door metaphor to a new environment is an easily understandable concept that is known from film (e.g., MGM's Stargate [16]) and video games (e.g., Portal [59]). Husung and Langbehn's user study revealed that the portal transition increases continuity and user acceptance when switching between VR scenes [31]. Fading is a more hidden transition where the transparency of the surrounding environment is gradually changed. Over time, the visibility of objects changes slowly to black [31, 43, 57] and then to the target environment or without an additional layer directly to the target environment [30, 31, 48]. More distinct transitions are achieved by the metaphor of a teleporter beam [30] or with a clipping plane that cuts away the surrounding environment to reveal the target environment [43].

2.3 Visual Analytics

Visual analytics focuses on analytical reasoning facilitated by interactive visualizations [66]. Literature in this area centers around the accurate representation of data, with limited considerations so far on also incorporating the surrounding environment; some works exist on accurately incorporating lighting sources. Halle and Meng for example present LightKit, a system for producing consistent lighting for visualizations, maximizing aesthetics and avoiding confusion [27]. In their survey on visualization techniques in AR, Zollmann et al. [67] also briefly touch on the perceptual challenges such as wrong occlusion between virtual and real objects. Lightness constancy in surface visualizations is addressed by Szafir et al. [61]. Diaz et al. [14] performed an experimental study on the effects of shading in 3D perception of volumetric models. However, all these systems and studies are not specifically targeting cross-device aspects, or even immersive analytics scenarios.

In summary, the literature on visual coherence with specific regards to visual analytics is very limited at the moment.

3 Data and Concepts

To implement visual coherent scenes, knowledge about the real environment is required. The following list gives an overview of the basic features including their requirement:

- Occlusion: geometry
- Shading: light
- Shadows, refraction, reflection: light and geometry

Measurements of the real world are crucial and can be achieved in many ways as indicated in Section 2. The gathered real world data that can be provided will be discussed considering geometry and lighting and a combination of both.

3.1 Geometry

Independent of the acquisition technique, ideally a high resolution mesh of the real environment should be available.

Static acquisition of room geometry can be helpful for different transition techniques. In case a more sophisticated approach is used, scanning the geometry of objects in the environment VR scenarios using substitutional reality can be implemented [56]. Knowledge about the material properties of the geometrical data could be helpful. Going beyond geometrical data semantic information about the objects in the environment could support selected transition techniques.

One challenge considering such mesh generation is the dynamic nature of the scene geometry, especially if moving objects such as humans are involved. Here a high update rate would be beneficial. A too fine grained mesh resolution could potentially cause performance problems.

3.2 Light

Data to be gathered about lighting can be complex. The most basic lighting information to be considered is the ambient light, which is provided natively by many AR APIs (ARKit [3], AR Core [26]). Potential information about the different light sources of the real environment are type (e.g., point light, directional light, cone light), position, direction, attenuation, and colour.

3.3 Geometry and Light

More sophisticated approaches would use a combination of geometry data including material properties with lighting information to calculate shadows, effects like refraction and reflection or even global illumination.

This information can be used to implement coherent transitions between real and virtual word, but also plays an important role in the visual analytics domain.

Similar to the geometry data, constant updates of the light sources will cause a performance problem. Additionally, the constant geometry updates of for example shadow casting objects would be required.

3.4 Adaptation to Milgram

In their publication on the RV continuum [46] Milgram et al. described multiple dimensions to further classify MR applications. Visual coherence approaches and their foundations to gather data about the real environment can be described on the Extent of World Knowledge (EWK) axis, which ranges from an unmodeled world to a fully modeled world. We split this axis into the two data requirements for VC.

Figure 1 illustrates the two resulting axes: light (ranging from no information at the origin to detailed information about light source positions, angle, intensity, attenuation, and other potential attributes) and geometry (ranging from no information to semantic information about the real world). Inside this coordinate space we highlight the potential benefits, which can be implemented in XVA applications (illustrated in green) as well potential novel transition techniques (illustrated in orange). VC effects from conventional AR applications that can be implemented with the degree of world knowledge are shown as a reference in black.

4 Visual Transitions

One potential issue when moving between different stages of the RV continuum is disorientation. Since fast and abrupt scene changes might occur depending on the chosen transition technique the user might feel lost and disoriented, similar to navigation in VR via teleportation [4,8]. This can be amplified by a mismatch in geometry or lighting between the real and virtual content.

4.1 Opportunities of visual coherence for transitioning in XVA

This could be partially mitigated by using visual coherence techniques to blend the virtual and physical worlds together. Real world lighting could be co-registered in the virtual environment to provide consistent lighting in both environments. To address a mismatch between virtual and real objects, a substitutional reality [56] could be implemented by mapping the geometry of the real world and its physical objects into the virtual environment.

4.2 Potential novel transition techniques

With additional knowledge about geometry and light in the real environment and a co-registration of the virtual world and the physical world, additional areas of transition techniques can be developed. Figure 1 shows possible new areas for transition techniques inside the coordinate space in orange. The arrangement of those shows the minimum necessary knowledge for a specific transition technique. Higher order is not required but may be provided to increase overall visual coherence.

4.2.1 Geometrical Knowledge

The more geometric knowledge of the physical environment is available, the more of this knowledge can be included for a transition technique. Geometry knowledge is represented on the x-axis in Figure 1. The minimum knowledge for geometry-based transitions involves the outlines of the physical space. The axis continues with knowledge about object geometry, object material properties, and the semantic classification of each object. Higher order characteristics always include those below them.

Transition Technique Boundary If the outlines of the physical environment are known, they can be used to connect the VR and AR environment. The transition is similar to a portal as it provides a preview of the target environment, but the transition layer is opened on a real surface and not in space as with a portal. As the transition layer is aware of the geometry of the given space, it can dynamically adapt to the real environment and improve the plausibility and connectivity of the two environments. One possible design for such a transition is demonstrated by meta in The World Beyond [44], where a physical wall can be selected and then filled with content from the VR environment. The user can switch to VR by selecting and filling all surrounding walls. The AR demo Skygaze [63] uses a similar approach, but instead of a fill effect, the virtual environment is unfolded. Resolution Games [11] used the knowledge about the physical position of the floor to realize the idea of interactively destroying the surrounding floor to reveal the VR environment.

Transition Technique - Object based If not only the geometry of the given room is known, but also the geometry of the objects in it, these objects can be included during the transition process. For example, real objects could be replaced by virtual ones or vice versa. If additional information about the material is available, the entire representation can be transformed. This transformation can be done by morphing, which gradually adjusts the size, texture, and shape of the object to match the target object. Another option is fragmentation, where objects are shattered into small pieces by an explosion effect. Both techniques are used by Sisto et al. [57] to switch between different VR scenes. Knowledge of lighting is not required, but can enhance the overall experience of the transition process by adding shadows and reflections, for instance.

4.2.2 Lighting Knowledge

Light knowledge is mapped on the y-axis in Figure 1 and starts with awareness about ambient light. Further attributes are the direction and angle of the light sources in the environment. With additional information about the type of light source and its properties, the highest level of light knowledge is possible, enabling coherent shading.

Transition Technique - Light based With knowledge about the direction and position of light sources, flashes can be generated from those light sources. These light flashes can gradually increase in duration and intensity until the field of view is completely overlaid. At this point, the environment changes and the light intensity slowly decreases to reveal the target environment. The fact that the illumination originates from the real light source can increase plausibility and reduce discomfort. Another possible transition technique with light knowledge is overexposure, in which the light source becomes progressively brighter and outshines the entire environment. To represent the bright-dark effect during the exposure, additional geometry knowledge about the room and its objects is required. When the scene is completely overexposed with bright light, the environment is changed and the light intensity decreases again. The technique is often used in film to create tension or introduce a dream sequence [45].

4.2.3 Geometrical and Lighting Knowledge

When both geometry and lighting knowledge are available at a high level, advanced rendering effects for transitions such as caustics and refraction can be used. This allows water effects to be rendered in lifelike quality. A water wall could be used as a clipping plane, which could be an adapted version of the SimpleCut transition. Another technique that could benefit from the enhanced rendering capabilities is the portal transition, where the inside of the portal could be rendered as water with proper caustics and refraction.

5 Visual Analytics in the context of XVA

XVA systems enable data visualization and analysis on a combination of devices along the RVC. In the context of Visual Analytics, this provides the opportunity to use new visual metaphors and analysis techniques that can support multiple users with transitional and collaborative interfaces, thereby enhancing analysis processes [20]. With the digital transformation of manufacturing/production and related industries and value creation processes (a.k.a., Industry 4.0), also the creation of tailored materials for new, cost-efficient, function-oriented, highly integrated, and also lightweight components has begun. In particular, nondestructive testing (NDT) generates large volumetric models (i.e., primary data) and derived high-dimensional datasets (i.e., secondary data). In this application case, XVA enables the analysis of both spatial and abstract data by highlighting different aspects of the data in a more natural way, depending on the technology chosen on the RV continuum [21, 23].

5.1 Opportunities of visual coherence in XVA systems

At present, very few systems exist which utilize cross-virtual analysis, and to our knowledge, none of these so far have specifically addressed visual coherence. For the future, the use and combination of the different technologies, while maintaining visual coherence, offers immense new possibilities in this field. For example, in the area of material analysis, this allows high-dimensional numerical data to be displayed through charts on 2D devices. With VR, complex volumes can be viewed naturally in 3D, and with AR it is possible to interact directly with the physical object [22, 24]. For the analysis on the object using AR, the virtual information has to match the physical geometry to enable a realistic representation. By including the current lighting, the perception of 3D structures can be improved. It is also possible to hide less relevant information in the background by using the information about the lighting and the geometric structures without affecting the tasks' performance [53].

Another application area is photorealistic visualization. Simulations of flooding, plasma confinements, or reflections of objects can benefit from the inclusion of real environmental data. This information, in turn, can facilitate the transition to a VR environment by maintaining visual coherence (sun position, light intensity, object geometry, and angle to the user) and thus enhancing the analysis.

Raw data visualizations on the other hand might not benefit directly from a high degree of visual fidelity, as that might interfere with the legibility of the information. Here, the utilization of different devices in cross-virtual analysis can be an advantage: The inherently spatial 3D data is displayed in virtual or augmented reality, while abstract visualizations such as line plots or texts are shown on 2D devices (e.g., screens or tablets) [22, 51, 54]. Alternatively or additionally, annotation techniques such as the Profile Flags [47], combined with placement techniques such as the Hedgehog Labeling [62] could be used for displaying such abstract data. The availability of information about light sources in the environment is an advantage in such a scenario; this information can be used to adapt contrast locally to create a space for the abstract visualization that is as uniformly lighted as possible. In general, in the design of such systems, there needs to be a focus on whether and how a visualization can benefit from the dimensionality of a specific virtuality stage [9, 41].

5.2 Challenges

There are also some challenges when considering realistic lighting information to be included in visualization techniques. Color is an important channel in Visual Analytics for encoding information. The proper perception of colors is already challenging to manage on its own [60]. When considering coherence, color perception additionally depends on the illumination. Optical see-through head-mounted displays (OHMD) suffer from the problem of color-blending – the mixing of the virtual color with the background color [28]. However, the correction of this color blending changes the intended color which makes the mapping in a visualization technique difficult or even impossible. Furthermore, depending on the ambient lighting, current OHMDs offer poor contrast due to their additive light model. When working outdoors, more than 10,000 lux is quickly reached, which leads to an almost complete loss of contrast [17].

6 Conclusions And Future Work

In this position paper we have presented our initial ideas on how to use VC data beyond rendering coherent AR applications and have shown how XVA applications could benefit from this world knowledge. Four categories of transition techniques have been presented which can be generated with the help of knowledge acquired from VC approaches. We believe that the contribution of such data is crucial to allow for less disruptive transitions between real and virtual. Based on available VC data prototypes will have to be created and investigated via user studies.

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