ARES: An Application of Impossible Spaces for Natural Locomotion in VR

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Abstract
Natural locomotion in room-scale virtual reality (VR) is constrained by the user's immediate physical space. To overcome this obstacle, researchers have established the use of the impossible space design mechanic. This game illustrates the applied use of impossible spaces for enhancing the aesthetics of, and presence within, a room-scale VR game. This is done by creating impossible spaces with a gaming narrative intent. First, locomotion and impossible spaces in VR are surveyed; second, a VR game called *Ares* is put forth as a prototype; and third, a user study is briefly explored.

Author Keywords
Virtual Reality; Virtual Locomotion; Interaction Design; Virtual Environments; Architecture; Game Design

ACM Classification Keywords
I.3.7 [Computer Graphics]: 3D Graphics and Realism–Virtual Reality;

Introduction
In VR, users' ability to move naturally in a large-scale virtual environment (VE) is limited by the confines of the physical space. Commercial VR can provide up to approximately 4 meters by 3 meters of tracking area. Constrained by the size of the physical space, navigation in VEs include teleportation, gaze-directed locomotion, and gesture-initiated navigation [1]. While each solution allows users to navigate in a VE beyond

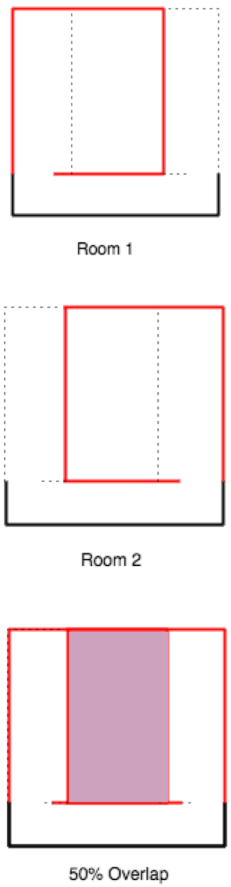

Figure 1: Diagram of 2 rooms that overlap by 50%. The user only sees one room at a time, and the other room is rendered when vision of the first room is blocked.

the perceived physical space, most fall short of maintaining user's sense of presence [3], and can lead to discomfort or motion sickness due to perceptual imbalance of movement control and movement in the VE. One potential solution for achieving natural navigation is the impossible space design mechanic, which supports natural locomotion in room-scale VR by employing overlapping architecture and perceptual illusions [4]. With natural locomotion, users mental model of navigation in the real world approximates that of the virtual world, which may enhance sense of presence within the VE.

We begin by briefly reviewing previous work in VR navigation. Then we explain the design of impossible spaces followed by an explanation of ARES, a VR game that augments the impossible space technique with gaming intent, such as setting and context, to increase" immersion in VR.

Navigation in VR

Several solutions for navigation in VR currently exist. They range from utilizing a super-natural approach such as teleportation, to an engineering approach such as building a physical space that matches the VE, or to using a physical joystick. While these and other solutions have thoroughly explored virtual locomotion, they compromise navigation fidelity for ease of use and technical feasibility. More complex approaches, such as the walking in place (WIP) technique, approach natural locomotion but still remain far from natural and break presence in the virtual world. The work of [4], however, enables natural locomotion in VR by compressing large VEs into smaller, more manageable ones. Building upon this previous research through the lens of video game design, we employ the impossible space technique to create a world that responds contextually to users' interactions while naturally navigating the VE. Although reuse of space in VR gaming has been explored such as in *The Void* or *Unseen Diplomacy*, to the authors' knowledge this is the first application specifically of impossible spaces in the VR gaming space.

Impossible Spaces

The impossible spaces design mechanic was developed to enable natural locomotion for navigation in large-scale VEs using room-scale VR technology [4]. By designing virtual spaces that architecturally overlap (Figure 1), designers can effectively compress large interior VEs into smaller, more manageable ones. In Figure 1, we depict two rooms whose geometries overlap by 50%. As the user leaves room 1 via a corridor, room 2 is rendered without the user knowing. Although these rooms are architecturally impossible, users perceive them to be adjacent without overlap. Such spatial architecture enables natural locomotion in VEs larger than the physical tracking space of room scale VR, and empowers VR game designers to build game worlds with real depth and believability.

ARES Game Design

ARES is an interactive VR thriller set within a series of three subterranean caves. Each cave room fills up nearly all of the trackable play space. However, as users move from the first cave to the second, their vision is blocked by cave walls. During this transition, the first cave room is minimized 'behind-the-scenes' by 20%, which effectively creates 20% of new space to be used for transitioning the user out of the first cave. As users enter the second cave room, they perceive it to be adjacent to the room they just came from. A

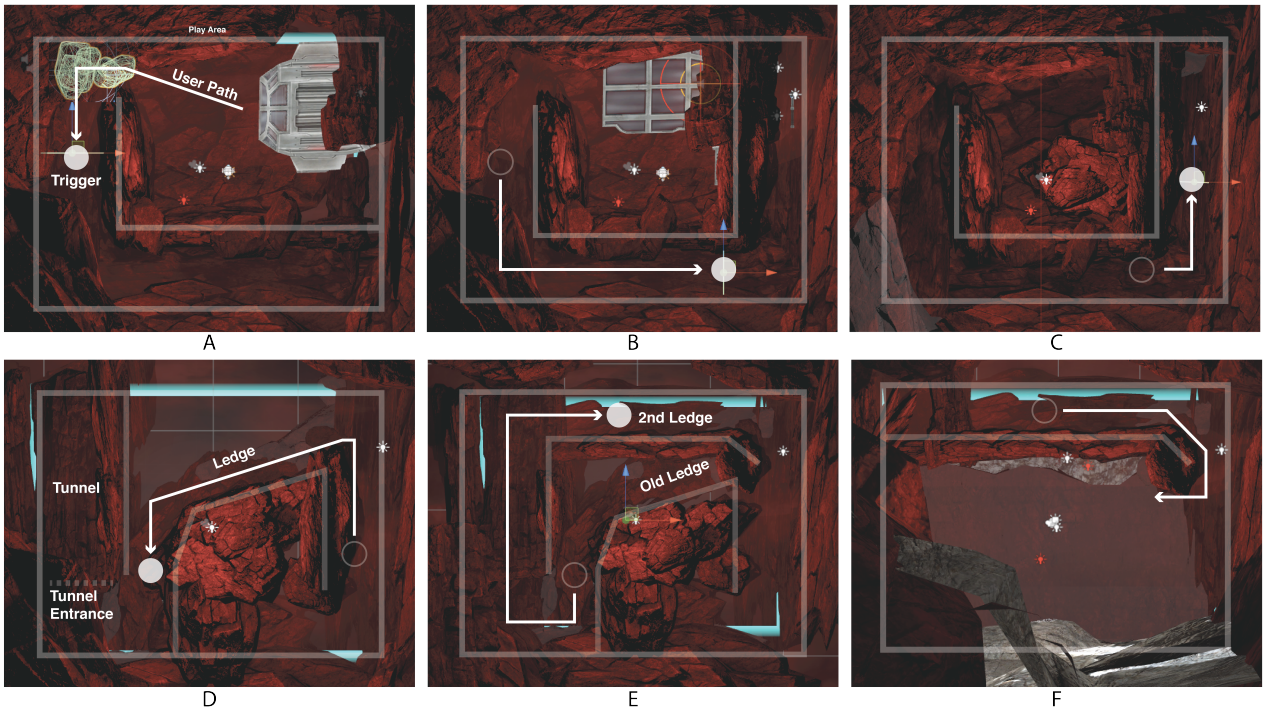

Figure 2: Diagram of the overlapping architectures. Solid circles represent triggers that rendered new spaces. Figures A, D, and F are the 3 different rooms. B, C, and E show narrow corridors and ledges for transitions between rooms.

similar transition occurs from second to third room (Figure 2D to 2F). The narrow transition paths in figure 2B, C, and E were designed to block the vision of the user during rendering of new spaces and perceptually preserves the game's setting (e.g. narrow crevasses in caves).

Game Mechanics

Players are given a pickaxe to break rocks in the first cave, which are textured differently than other, non-breakable cave walls. They grab the pickaxe with virtual hands and receive haptic feedback when they break the rocks. An oxygen meter is shown as a 3D holographic display on their left hand, which reminds players how much oxygen is left before they die. Players lose oxygen every time they crack their spacesuit's helmet by bumping their head into a cave wall. Lastly, players fall to their deaths if they step into a pit or let go of the wall while climbing the cave walls.

User Study

Participants began the study in the first cave room, and were told to find their way out. As they explored the VE, architectural layouts were manipulated as described above according to the impossible space mechanic. After reaching the final room and climbing out of the cave, participants were told to remove the headset. They were then interviewed regarding the believability of the space using questions from [4], and the naturalness of their movement within the VE:

1. *How natural was the mechanism that controlled movement through the VE?*
2. *How proficient in moving around the VE did you feel at the end of the experience?*

None of the participants felt lost during the experience, nor did they notice any unnatural events. Four participants were not able to deduce the impossible space mechanic on their own, however understood its purpose when we explained it. One participant, a heavy gamer and VR developer herself, was able to deduce the mechanic during gameplay. However, when asked about how it affected the experience, she mentioned it did not detract from the thrilling nature of gameplay.

Participants felt that the mechanism for controlling movement in the VE was very natural. Moreover, because of the subterranean setting, participants mentioned that the crawling and shimmying movements immersed them more in the game environment. By the end of the game, all participants felt proficient in moving around the VE, and attributed this to the ability to walk/crawl/shimmy throughout the VE.

Conclusion and Future Work

In ARES, users were able to explore a virtual world larger than the physical play space of 4m x 3m without using presence-breaking navigation techniques. Instead, by employing impossible spaces with a gaming lens, we enabled natural locomotion throughout an end-to-end VR gaming experience. As such, game designers might consider other ways in which natural movement can enhance the VR gaming experience. As this game was a prototype, future work concerns creating full scale games that utilize this framework, and conducting full evaluations on sense of presence.

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