Design and Implementation of Impossible Spaces in VR

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1. Abstract

One of the biggest challenges in virtual reality (VR) is locomotion. The best way to experience VR without cybersickness is through natural walking. However, since virtual worlds are often much larger than the physical space we are in, natural walking in VR is limited by the physical space. A technique called impossible spaces solves this problem by designing virtual environments that overlap, allowing a point in physical space to be mapped to more than one point in virtual space. However, the original implementation of using triggers requires manual setup and planning. In this project, we propose a new implementation technique using stencil buffers to render only the visible rooms. This new technique allows for a simple drag-and-drop approach for fast level design and makes designing a variety of impossible spaces easier. Additionally, we have developed several sample environment layouts to demonstrate the usage of this technique.

2. Background

- The impossible spaces technique uses overlapping layouts to make virtual rooms larger than would otherwise be possible.
- The middle wall in Figure 1 is more toward the right when the user is in the left room. The effect is reversed when the user is in the right room. A study found that such rooms could reach about 55% overlap before being perceived by users [1].

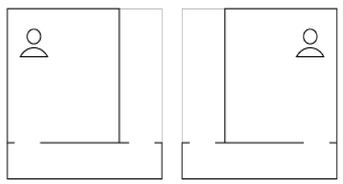

Figure 1. The location of the middle wall changes depending on which room the user occupies.

- Impossible spaces are typically implemented by swapping layouts outside of the user's view. The environment in Figure 1 might be triggered to swap when the user walks halfway down the hallway.
- However, designing layouts and triggers that create seamless transitions can be difficult, especially when the user can see into both rooms at the same time.
- Impossible spaces fall under the category of research called redirection, which is a collection of techniques that reorient or reposition the user to expand access to the virtual environment. Such techniques can be classified as either overt if the user can perceive the redirection or subtle if they cannot [2].
- Prior research in impossible spaces has focused on subtle redirection, meaning there is plenty of room for exploration into the design of more overt spaces.

3. Stencil Buffer Implementation

- The stencil buffer is a per-pixel buffer that only renders objects on a specified stencil layer.
- The stencil layer can be changed on a per-pixel basis using a stencil mask, which can be thought of as a window to a different layer. If the cameral looks through a stencil mask, it will change the reference value for anything behind it. For example, the circles in Figure 2 are not rendered unless viewed through the stencil mask.
- The stencil buffer implementation of the impossible spaces technique works by rendering only the room that the user is currently in, as well as adjacent rooms through stencil masks in the doorways. When the user walks through a doorway, the stencil layer switches seamlessly to the next room.
- This implementation offers a drag-and-drop approach to level design and gives designers flexibility to easily create expansive networks of overlapping rooms (Figure 3).

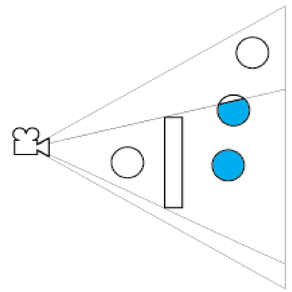

Figure 2. The rectangle is a stencil mask, and the circles are objects that are only visible through the mask.

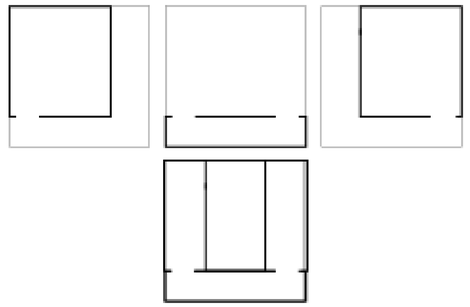

Figure 3. The top three boxes represent the individual rooms from the layout in Figure 1. The bottom box represents the how the rooms overlap in the editor. The lighter lines represent the outline of the walkable area.

4. Layouts

Many new layouts are easy to design and develop with this new implementation. Figure 4 shows a layout similar to that of Figure 1, except the series of overlapping hallways and rooms guide the user in a circular path. This allows an efficient reuse of space because each virtual room can occupy much of the physical space. Furthermore, the personal experience of those who have tried this design also indicates that the overlap is subtle. However, proper experiments need to be conducted before anything can be said about the user experience.

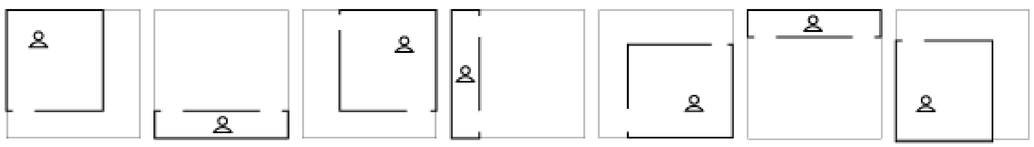

Figure 4. The rooms and hallways overlap each other, but only what is visible to the user from their current room is rendered. The lighter lines represent the outline of the walkable area.

One common scenario in games is exploring rooms along a long hallway. This is difficult when using natural locomotion in virtual reality because the user will quickly reach the physical boundary when walking in a straight line. The layout in Figure 5 simulates an infinite hallway when the user passes through a series of three rooms, and then a repeat of the first room. The user is redirected to the start of the hallway after passing through the rooms and can continue down the hallway to the next set of rooms.

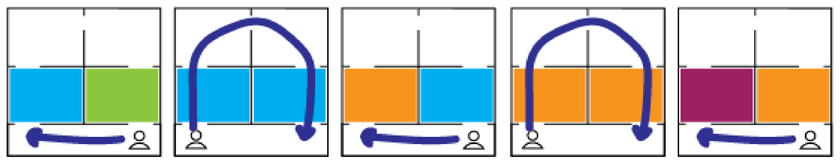

Figure 5. The user walks down the hallway and enters the blue room. Then they walk through two other rooms and return to a copy of the blue room. Finally, they exit the blue room and return to the starting point of the hallway. The process is repeated to simulated an infinite hallway.

5. Conclusion

The impossible spaces redirection technique has been a promising development with many possible applications. With this new stencil buffer implementation, many of the practical downsides of designing impossible spaces like carefully placing imperceptible triggers and layout changes are negated. This implementation allows designers to create complex overlapping environments with ease.

Additionally, several layouts were proposed along with their potential use cases, such as a rotating sequence of rooms and hallways (Figure 4) and an infinite hallway (Figure 5). These layouts might serve the virtual reality community when developing virtual environments for a variety of applications.

6. Future Work

Only personal testing was conducted on the layout designs. Further study and experimentation is required before it can be determined if they are subtle enough as to not be noticed.

Future work might include designing more layouts for more use cases, as wells as testing each one's perceptibility under different conditions through experiments. For example, a study could be conducted to determine if users could detect the duplicated room in the infinite hallway layout (Figure 4).

References

[1] E. A. Suma, Z. Lipps, S. Finkelstein, D. M. Krum and M. Bolas, "Impossible Spaces: Maximizing Natural Walking in Virtual Environments with Self-Overlapping Architecture," in IEEE Transactions on Visualization and Computer Graphics, vol. 18, no. 4, pp. 555-564, April 2012, doi: 10.1109/TVCG.2012.47.
[2] E. A. Suma, G. Bruder, F. Steinicke, D. M. Krum and M. Bolas, "A taxonomy for deploying redirection techniques in immersive virtual environments," 2012 IEEE Virtual Reality Workshops (VRW), 2012, pp. 43-46, doi: 10.1109/VR.2012.6180877.