# Spatial Chef: A Spatial Transforming VR Game with Full Body Interaction


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**Figure 1: Spatial Chef: A Spatial Transforming VR Game with Full Body Interaction**


## ABSTRACT

How can we play with space? We present *Spatial Chef*, a spatial cooking game that focuses on interacting with space itself, shifting away from the conventional object interaction of virtual reality (VR) games. This allows players to generate and transform the virtual environment (VE) around them directly. To capture the ambiguity of space, we created a game interface with full-body movement based on the player's perception of spatial interaction. This was evaluated as easy and intuitive, providing clues for the spatial interaction design. Our user study reveals that manipulating virtual space can lead to unique experiences: Being both a player and an absolute and Experiencing realized fantasy. This suggests the potential of interacting with space as an engaging gameplay mechanic. *Spatial Chef* proposes turning the VE, typically treated as a passive backdrop, into an active medium that responds to the player's intentions, creating a fun and novel experience.


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## CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Gestural input**; • **Software and its engineering** → **Interactive games**; • **Computing methodologies** → **Virtual reality**.

## KEYWORDS

Virtual Reality, Game Design, Spatial Interaction, Virtual Environment

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## 1 INTRODUCTION

Recently, as the virtual reality (VR) game market has gained popularity in that it can turn imagination into reality, various creative interactions have been attempted. However, typical VR games focus on object transformation and control. Although space is an important factor in VR for immersion and presence [13], it is often treated as just a backdrop, leaving spatial interactions underutilized. In this paper, we introduce *Spatial Chef*, a game that explores how to play with space in VR. We devise interactions for natural manipulation of the virtual environment (VE), shifting the player's attention from object to space. Ultimately, we investigate what experiences spatial interactive games evoke in players and how that could expand and be applied.

# 2 RELATED WORK

## 2.1 Non-VR games with spatial interaction

The concept of using interaction with space as a core game mechanic is not entirely new to the non-VR game field. Several PC and mobile games that play through spatial transformation are well-known and have been recorded as innovative and unique. The Portal Series [17, 18] creates portals connecting different spaces to solve puzzles, while Miegakure [15] uses a four-dimensional space. Superliminal [8] uses non-Euclidean space and hyperbolic geometry. However, Miegakure and Superliminal only utilize visual effects that arise from engagement through navigation, without directly interacting with space. Moreover, non-VR games can be challenging to provide an active spatial experience since the screen essentially blocks the player from the game space. We improve the player's engagement by enabling direct interaction with the game space within the virtual environment.

## 2.2 VR researches with spatial interaction

Spatial interaction in virtual reality has been steadily explored in recent years. Space-warping interactions for precise object grabbing [5] or distant selection [3, 11] have been mainly explored, as well as interactions with portals and proxies [7, 9, 14]. However, other than the incidental use of space to interact with objects, the purpose of interacting with space itself has received little attention. Examples of more active use of spatial interaction in VR for user experience can be found in From Sensable to Sensible Spaces [4] and Lucid Loop [6]. However, in these cases, the spatial interaction relies on passive input from a biosensor, making it difficult to reflect the player's intention directly. We focus on spatial interaction as a primary purpose rather than just a means, and make it a core game mechanism that directly reflects the player's intention, encouraging a more active and immersive spatial interaction game experience.

# 3 INTERFACE INNOVATION

As stated above, we concentrated on space-related questions in VR games. How should games be designed to play with space in VR more actively? How do we naturally interact with an abstract concept of space? We wanted to see what experiences would be shaped by a space-focused VR game aside from object interaction.

This study devises a VR game interface that allows players to focus on the space and presents a concept that more actively utilizes the space as a game medium. This goes beyond previous attempts, which primarily used the virtual environment space as a backdrop for passive visual effects, and transforms the space into an exciting place where the user's intent is directly reflected and audio-visual feedback occurs.

We provide a simple and engaging spatial interaction by mapping spatial manipulation, which can be difficult because it is wider than the object, to simple movement based on the player's spatial mental model. We capture how space can be used to play an active role in a VR game and the unique feeling it gives the player.

# 4 GAME DESIGN

*Spatial Chef* is a VR action game that directly transforms and generates the surrounding space in a VR environment with body movement. The game's motif begins with the German word *Spielraum*, my own playground space where I can do whatever I want. Inspired by this, we developed a game concept allowing players to interact with the space itself.

We define space as the virtual environment (VE) and cover a large range of interactions with the room surrounding the player in the game. We come up with the concept of a cooking game to borrow the fact that various dishes can come out of the same recipe according to one's taste. All spatial changes in our game are irreversible, as dishes once cooked cannot be undone. The player is given a special order in the game: Today's cooking ingredient is a space. The player has to transform the dusty attic space to their taste. Be a Special Chef as a Spatial Chef!

## 4.1 Space-Oriented Game Phase Design

Our game is designed to naturally divert the player's attention from object to space. The game is played in three phases to motivate and create fun in interacting with the space, as shown in figure 2.

*4.1.1 Preparation phase for shifting focus and motivation.* As the player chooses materials and music for the room-scale space, the player's attention is smoothly shifted from the object to the space. It also activates the desire for customization, prompting players to transform the space actively to their taste in the next step.

*4.1.2 Cooking phase for spatial interaction.* This is the stage where players can use their bodies to transform the surrounding room-scale space. Players can slice a room and stretch it sideways, back and forth, or make the entire room inflate or shrink. To keep players focused on their interaction with space, all objects in the game are limited to transforming with the room rather than moving independently.

*4.1.3 Serving phase for enhancing the fun.* This stage reinforces the fun of space interaction by retracing the players' movement in space and showing their creation as a reward. The finished dish (transformed space) is served in miniature with a recipe based on the player's movements. The recipe includes the cooking time according to the song the player initially selected, the cooking difficulty according to the number of interactions, and the taste according to the shape of the transformed space. This enriches the interaction with the space by transforming it within the space and then viewing it as a whole from the outside and recapitulating the movement.

## 4.2 Spatial Interaction Design

To amplify the pleasure of creating a personal space by overcoming a narrow room, an interaction that the player actively utilizes the whole body was necessary. A formative study was conducted to observe how players interacted and perceived near and far spaces in order to design game interaction. It was performed with 5 participants (4 females and 1 male). The participants viewed moving illustrations of near and distant spatial transformations projected on screens. They then came up with possible actions leading to

**Preparation Phase** **Cooking Phase** **Serving Phase**


**Figure 2: Game phases designed to arouse motivation and interest in spatial interaction**

those changes by freely moving their bodies (Bodystoming [12]). At the same time, researchers used a Wizard of Oz [19] approach to deform the graphics on the wall in response to their movements. Participants were asked to think out loud during the interaction, and their intent was investigated through a semi-structured interview afterward.

Insights obtained through thematic analysis of interview scripts and observed participants' behavior during the study reveal the following spatial interaction rules. (1) Near interaction: players attempted to transform the near space by dragging or pulling directly, which evokes a metaphor for a physical object. Players anticipate that the space will change linearly in response to their movement. (2) Distant interaction: players expect an exponential transformation to far space will occur immediately when performing a specific action, thinking of unrealistic abilities such as psychic powers.

Based on these player perceptions of distant and near spatial transformations, we designed gestures and rules for spatial interaction of the game (Figure 4). In *Arm Swing to Slice* and *Inflate and Shrink*, an immediate change occurs according to the specific action. In *Grab and Drag*, a linear change occurs according to the movement like a physical object.

*Arm Swing to Slice.* Slice the virtual space by making a quick arm movement similar to swinging a knife, while simultaneously pressing the trigger button on the controller. If a player swings their arm quickly toward the wall, it will be cut in that direction. The cut walls flinch for a moment, tempting the player to move them.

*Grab and Drag.* The grabbing interaction is designed to mimic the action of holding something with a fist. To grab and drag the sliced wall, the player must simultaneously press and hold the trigger and grip buttons on the controller. Once these buttons are released, the shape and position of the wall are fixed.

*Inflate and Shrink.* To initiate inflating and shrinking, the player must press both grip buttons and simultaneously open or close their arms faster than a threshold. Head position is also measured to detect changes in postural height. Stretching out the whole body inflates the space, and contracting the body shrinks the space.

## 4.3 Technical Details

We devised techniques to maintain the structural and visual coherence of the space as the player transforms it in order to preserve the experience of manipulating a space within a space.

Structural continuity is achieved by constructing a new mesh between the deformed meshes. In our game, an invisible slicing plane is used to divide the wall that it collides with into two parts based on the direction of its normal, i.e., the normal-facing side is considered an upper part, while the opposite is a lower part. To ensure object continuity, an in-between mesh is generated at the point of slicing to connect the upper and lower parts, even if one

**Near Interaction** **Distant Interaction**

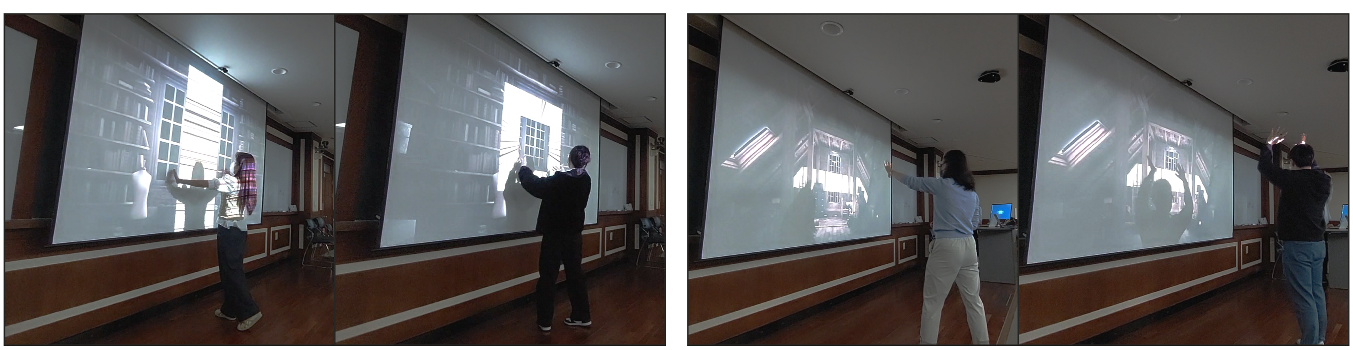

**Figure 3: A formative study to investigate players' perception of spatial interaction depend on the distance**

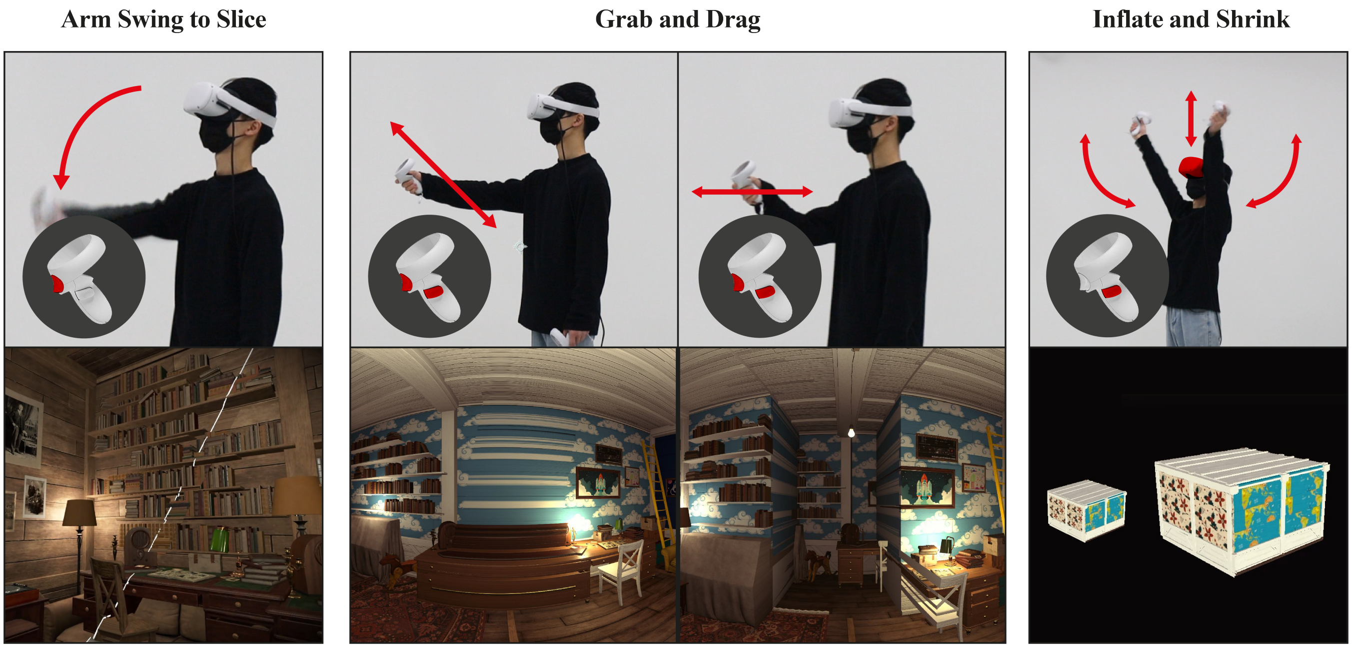


**Figure 4: Interaction design and controller input**

of the sliced parts is moved away from another by the controller. To achieve this, we identify the intersection points on both the upper and lower parts that are traversed by the slicing plane, determine their order, and generate the in-between mesh in closed triangles form. This ensures that the geometry of the object is displayed seamlessly, preserving its connectivity even when its spatial structure is modified.

To maintain the visual continuity of space, we have developed a technique to preserve the environment's original color scheme while providing an additional layer of visual appeal to the manipulated sections. This is achieved by storing and copying the UV coordinates of the intersection points to the corresponding ones on the intermediate mesh. This results in a colorful stripe pattern on the intermediate mesh, as shown in figure 1.

# 5 EVALUATION

## 5.1 Participants

We conducted a user study to investigate the impact of including space as a medium in the VR game *Spatial Chef* on player experience. We targeted adults with previous VR experience and no severe VR sickness, and recruited 11 participants (5 females, 6 males, mean age=25.18, SD=2.75).

## 5.2 Procedure

To begin, participants provided informed consent for the study, including filming and recording. Wearing the VR equipment, they then watched a 360-degree video introducing the game's concept and practiced game operations to establish a mental model. After becoming familiar with the operation, they played the game and freely deformed the virtual environment to their taste. For safety, we used Oculus room scale boundaries in a 3m*2m space where participants can move freely. After the time limit, in the outro, participants were able to check a miniature of the transformed space with a recipe recapping their movements. An online Google Forms survey and a semi-structured interview about the game experience were conducted post-experiment.

## 5.3 Measurement

A quantitative survey was conducted to determine the game's overall performance. The System Usability Scale (SUS) [2] was investigated to confirm its usability as a spatial transformation and generation interface. The Slater-Usoh-Steed Presence scale [16] and the subscales 'Interest/Enjoyment' of the Intrinsic Motivation Inventory (IMI) [10] examined the presence and enjoyment of the VR game, respectively. Through an online survey, participants scored each question on a 5-point(SUS) or 7-point Likert scale(IMI, Slater-Usoh-Steed). In addition, semi-structured interviews on interactions and game experiences were designed to investigate what experiences our game evokes in players.

# 6 RESULTS

## 6.1 Quantitative Evaluation

*Usability.* We evaluated the usability of this game as an interface transforming space according to the player's taste. The SUS score was analyzed by mapping with adjectives referring to the 7-point scale [1]. Two Poor, seven OK, one Good, and one Best imageable were obtained. Participants generally accepted the usability of this game, stating that it was useful for focusing on the space and transforming it to their liking. Further questioning revealed the reason for the low score. The occasion that the direction of the arm swing and where space is sliced were not precisely aligned caused frustration. We infer that we can improve the usability of this game by overcoming technical limitations and increasing the targeting accuracy.

*Interest and Presence.* We analyzed 10 responses excluding outliers for interest. Generally, participants were interested in our game and enjoyed it. (Interest mean score = 5.33, SD=0.82). To investigate the experience of manipulating a space within a space, we ensured that the VR presence, a prerequisite for it, was well implemented. We analyzed 11 responses for presence. Presence is calculated by counting the number of responses marked above 6 on a 7-point scale. Participants generally experienced a sense of 'being in a place (presence)' within the VR space. The mean presence count is 3.45 (SD=2.42), and the mean presence score is 5.10 (SD=1.46).

## 6.2 Experience of Space-foucsed Game

From the interview data analyzed through thematic analysis, we confirmed that the game Spatial Chef interacting with the space elicited the following common experiences from players.

**Novel and Intuitive Spatial Manipulation.** Participants rated the experience of interacting with the space as novel and exciting. *"Normally, VR games focus on objects, but it was refreshing to interact with the space itself by stretching and contracting it"* Although spatial manipulation was an unfamiliar concept, they explained, *"It was easy and intuitive in that it was possible to control a space of ambiguous concept through realistic body movements."* The arm swing for slicing was chosen as the most natural manipulation by five participants. This was because the perception of action corresponded well with the audio-visual feedback from the immediate spatial change.

**Being Both a Player and an Absolute.** The experience of manipulating the space in which the participants were contained created a unique experience that makes them feel like absolute beings with absolute power while also strengthening their presence as players by being aware of the entire surrounding space. *"Space is a larger concept than objects. So I had a strong sense of being in the VR space because I was aware of everything around me rather than just the small objects... At the same time, I felt like I had absolute power because I could bend space with my gestures alone."*

**Realized Unrealistic Fantasy Stimulating Creativity.** Viewing the transformed space during the game, participants reacted as follows. *"Look! I'm in Interstellar right now." "It reminds me of Harry Potter. It's fun to see unexpected graphics that seem to be in the real world."* Participants presented creative spatial transformation results to suit their tastes, associating fantasy imaginations. In particular, the more the room was transformed, the more abstract the room itself became, encouraging their creativity.

# 7 DISCUSSION

In this paper, we explore the use of space in VR games, which has received little attention. We will discuss how to design and expand the space-focused game enabling players to transform the environment directly.

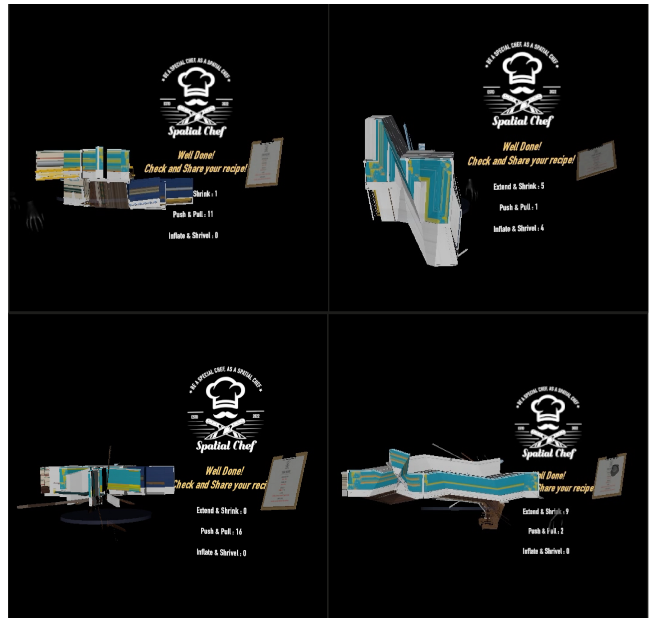


**Figure 5: Creative spatial transformation results according to the player's taste**

We found that what the player associates with (physical objects or magic powers) varies depending on the interaction distance in space. The spatial operation based on this was evaluated as intuitive. This implies that manipulating the virtual environment can be ambiguous, but that ambiguity can be effectively managed by designing actions to match player perceptions. Also, the user study showed precise targeting should be taken into account for better usability, even in large-space interactions.

Interviews reveal that our space-focused games have given players a one-of-a-kind experience. Being a player and an absolute is a unique experience not found in non-VR games or passive spatial interactions. Our game utilizes space as a canvas to realize fantasies and enable various creative plays, giving the clues that more spatial interactions in VR games make players more active and immersion. The response that *"the focus area spread to the surrounding space and increased the VR presence"* compared to conventional object manipulation, suggests the potential of spatial interaction to enhance realism in VR. This approach can be applied to puzzle and adventure genres to allow players to explore virtual worlds with greater immersion and presence. Manipulating virtual space to solve puzzles enables a differentiated game that leverages the unique capabilities of VR, where the boundaries of what is possible are greatly expanded. This introduces a larger canvas, the virtual environment, to the game, opening the door for more diverse and interactive games. In particular, there is room to maximize unreality with spatial interaction in VR games, which inherently sacrifice realism and vivid tactility, allowing for unique positioning in the gaming industry.

## 7.1 Limitations and Future Work

While user studies provide a proof of concept for our space-focused game, a more rigorous study can be conducted with a larger sample size and an object-focused interaction as a control condition to obtain a more accurate assessment. The interview insight that presence is felt more strongly in spatial interaction can also be strengthened through quantitative research comparing object interaction situations.

Since our game only used the Oculus Head-Mounted Display (HMD) and controllers without additional equipment, the game interaction was composed of actions distinguished by head and hand data values. We also used a controller rather than hand tracking to easily track a wide range of hand positions. Future work could expand spatial interaction with more natural and richer body movements by adding hand tracking or full-body capture equipment.

# 8 CONCLUSION

*Spatial Chef* is designed to break away from traditional object interaction VR games by emphasizing space and allowing active interaction with it. We investigated players' perceptions when transforming near and far spaces to capture the abstract concept of spatial manipulation. Based on that, we designed game operations so players could easily control the space with their movements. The interface's usability was generally rated as appropriate for players to focus on and transform the space to their liking. Directly imprinting body movements into the VR space could provide players with a fun and unique experience. This shows that a virtual environment that used to play a passive role like a backdrop has a high potential to become an exciting place for direct interaction with players and audio-visual feedback.

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