

# IllumiRoom: Peripheral Projected Illusions for Interactive Experiences

Brett R. Jones<sup>1,2</sup>

Hrvoje Benko<sup>1</sup>

Eyal Ofek<sup>1</sup>

Andrew D. Wilson<sup>1</sup>

<sup>1</sup>Microsoft Research  
Redmond, WA

{benko, eyalofek, awilson}@microsoft.com

<sup>2</sup>University of Illinois at Urbana-Champaign  
Urbana, IL

brjones2@illinois.edu

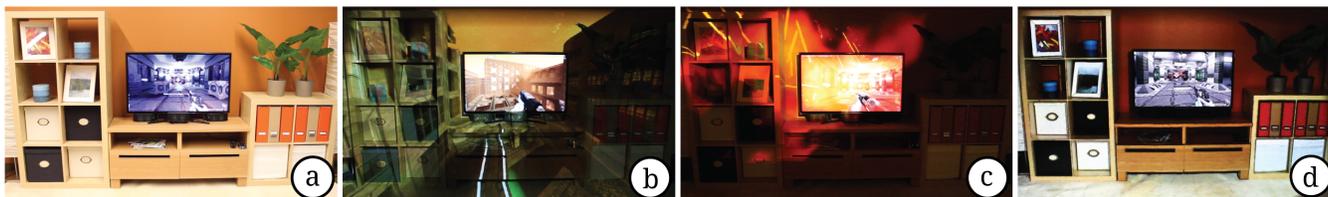


Figure 1. *IllumiRoom* is a proof-of-concept system that augments the physical environment surrounding a television to enhance interactive experiences. We explore the design space of projected visualizations which can negate, include or augment the surrounding physical environment. (a) With a 3D scan of the physical environment we can (b) directly extend the FOV of the game, (c) selectively render scene elements, (d) augment the appearance of the physical environment (here as a cartoon). All of the images in this paper are un-edited; showing the real-time, working prototype.

## ABSTRACT

*IllumiRoom* is a proof-of-concept system that augments the area surrounding a television with projected visualizations to enhance traditional gaming experiences. We investigate how projected visualizations in the periphery can negate, include, or augment the existing physical environment and complement the content displayed on the television screen. Peripheral projected illusions can change the appearance of the room, induce apparent motion, extend the field of view, and enable entirely new physical gaming experiences. Our system is entirely self-calibrating and is designed to work in any room. We present a detailed exploration of the design space of peripheral projected illusions and we demonstrate ways to trigger and drive such illusions from gaming content. We also contribute specific feedback from two groups of target users (10 gamers and 15 game designers); providing insights for enhancing game experiences through peripheral projected illusions.

## Author Keywords

Spatial augmented reality; projection mapping; gaming; immersion; apparent motion; augmented reality.

## ACM Classification Keywords

H.5.1. Multimedia Information Systems: Artificial, augmented, and virtual realities

## INTRODUCTION

The television remains the focal point of living room entertainment today. While visual and audio quality has improved over the years, the content we watch (e.g., games, movies, TV shows) remains boxed in the frame of the display and thus restricted by the physical size of the screen. Also, the experience is limited to an entirely virtual world trapped inside the television, ignoring the user's surrounding physical environment.

In this paper, we propose a novel approach to enhance the viewing experience and blur the boundary between the on-screen content and the surrounding room. We extend the visual experience outside of the television screen, using a projector that covers a wide area of the surrounding physical environment. Similar to Focus+Context displays [3], the television provides a traditional, high-resolution gaming experience and the projector provides low-resolution information for the user's peripheral vision. In contrast to previous work in Focus+Context (F+C) displays, we do not assume that the space surrounding the high-resolution display is a flat, white projection screen. Instead, we capture the appearance and geometry of the surrounding room (e.g., furniture, carpet, wallpaper) and use that information to create novel, interactive visual experiences.

In particular, our work investigates how projected visualizations in the periphery can negate, include or augment the physical environment, and thus enhance the content displayed on the television screen. We call such visualizations *peripheral projected illusions*. To investigate these illusions, we implemented a proof-of-concept system, called *IllumiRoom*, which is capable of augmenting the environment around traditional game content. *IllumiRoom* can change the appearance of the room, induce apparent motion, extend the field of view (FOV), and enable entirely new virtual-

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

CHI 2013, April 27–May 2, 2013, Paris, France.

Copyright © 2013 ACM 978-1-4503-1899-0/13/04...\$15.00.

physical gaming experiences. Our system is self-calibrating and designed to work in any room. The concept could be developed into a next generation game console with game content designed from the ground up, or it could be an ‘addon’ for existing consoles with gamers writing scripts to ‘mod’ their favorite games.

While our explorations are performed in the context of interactive games, the same or similar illusions could be used to enhance movies and television content.

This paper makes the following contributions:

- Implementation and description of the proof-of-concept *IllumiRoom* system for real-time generation of peripheral projected illusions
- Implementation of 11 illusions that demonstrate the important dimensions of the design space
- Analysis of the design space of peripheral projected illusions
- Discussion and implementation of methods to drive illusions from new and existing content
- Feedback from 10 casual gamers and 15 expert game designers over two separate evaluations; showing the most promising dimensions of the design space

## MOTIVATING SCENARIO

To illustrate the idea behind the *IllumiRoom* system, imagine sitting down in your living room to play a video game on your television. When the game starts, the room magically transforms to look like a cartoon, matching the shading in the video game. The colors of the room become supersaturated and cartoon edges appear on your bookshelves. You come across an enemy in the game, and suddenly a streaking bullet flies towards your character and then out of the television. The enemy throws a grenade towards you. The grenade rolls out of the television, bounces off your coffee table and explodes in your living room, throwing shrapnel across your bookshelf. The entire living room appears to shake as you take damage from the explosion. This is just one of many interaction scenarios made possible with the peripheral projected illusions described in this paper.

## RELATED WORK

Our work draws on previous research in Spatial Augmented Reality, artistic installations with ‘projection mapping’, and HCI research on peripheral displays.

### Spatial Augmented Reality

Spatial Augmented Reality (SAR) is the concept of merging the physical and virtual worlds through video projection [8]. Shader Lamps first developed the idea of augmenting the colors of physical objects with video projection; appropriating everyday physical objects as displays [24]. A number of projects have since demonstrated the use of projectors to augment workspace environments [20,23,30].

Several SAR projects have enabled gaming experiences involving physical objects, such as wooden blocks, which can be arranged by users to create a game [15,30]. Two re-

cent examples [4,30] supported real-time physics-based interactions between virtual objects and physical objects.

We also draw on previous work in radiometric compensation, a process that compensates for the original color and geometry of display surfaces [24]. A number of projects have demonstrated turning a curtain or a building facade into an almost ideal projection surface (e.g. [5,6]). Additionally, virtual images can be overlaid onto physical paintings [5,11] and the contrast of a printed image can be increased by superimposing projected content [7].

Most similar to our work, ‘Cartoon Dioramas in Motion’ [25] demonstrated effects projected onto a small, white toy car diorama. Effects included non-photorealistic shading, apparent motion through camera movement and virtual lighting on the car. Inspired by this approach, we explore a larger design space including effects designed to work with a complex, textured living room. We also consider effects that complement the content on the television.

### Projection Mapping

Our illusions are also inspired by projection-based art installations, known within the art community as ‘projection mapping’ or ‘video mapping’ [18,21]. These installations are frequently used to make building facades come to life, as in ‘Son et lumière’ shows. Artists create amazing effects by rendering a video that is specific to the scene and projector location. In contrast, *IllumiRoom* generates real-time, interactive illusions that automatically adapt to any room, any television and any game.

### Display Research

The characteristics of a display can have a large impact on user performance, especially while gaming. A larger display has a wider field of view, can cause the user to feel more immersed and more present in the experience, and is more likely to induce simulator sickness [14,28].

Unfortunately, large displays can be expensive. To balance the costs of a high-resolution, larger display with the benefits of a wider field of view, Baudisch et al. proposed Focus+Context displays. Focus+Context displays have a high-resolution computer monitor (focus) surrounded by a lower resolution projection screen (context). This configuration takes advantage of the lower optical resolution in peripheral vision [13]. We refer the reader to [9] for a more comprehensive review of Focus+Context techniques.

The Philips Ambilight television is an example of a commercially successful Focus+Context display. The Ambilight TV has a series of color LED strips surrounding its edges. The color of the LEDs is dynamically changed to match the television content. In a follow-up research project, Philips created a prototype with multiple LED strips located around the room that change colors to adapt to gaming or movies [29]. Our system advances this idea to high-resolution projected content which is dynamically adapted to the appearance and geometry of the room.

A few previous projects have explored automatically extending video beyond the television frame for Focus+Context displays. The Infinity-By-Nine project [19] displayed extrapolated video content on three projector screens surrounding a television, in a small CAVE [10] setup. Aides et al. described a system that creates an ultra-wide foveated video from a normal input video sequence [1].

As in these previous works, the *IllumiRoom* system can be used for panoramic movies and television, and could be extended to use extrapolated content from standard video sources. Rather than relying on separate projection screens, *IllumiRoom* adapts the projections to the user's existing living room, and demonstrates a large range of possible peripheral projected illusions.

### DISPLAYING IN THE PERIPHERY

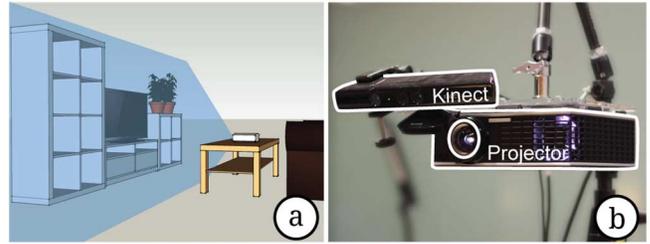
The configuration of a small, high-resolution display within a large, surrounding projection is consistent with the setup of human visual system. Compared to the center of gaze, peripheral vision is highly sensitive to motion, but is relatively poor at distinguishing color and shape [27]. This is due to the lower density of receptors and the changing distribution of receptor types outside the fovea. Optical flow in peripheral vision is thought to play an important role in the perception of motion [12]. Peripheral vision also enables the early detection of objects of particular relevance (e.g. predators) before they come into full view.

In *IllumiRoom*, the smaller display serves the high-resolution capability of the fovea, while the projector serves the low-resolution, motion sensitive periphery. As peripheral vision is insensitive to color and highly sensitive to motion, many of the illusions are tailored to peripheral vision. For instance, abstract patterns can be used to induce optical flow and give an impression of motion.

The stimulation of peripheral vision could alternatively be addressed by a single, very large display, a F+C screen [3] or a CAVE setup [10]. While these are great approaches for training and simulation, they are not suited for deployment in typical living rooms. *IllumiRoom* does not require installing expensive projection screens, nor changing anything about the existing living room. Furthermore, *IllumiRoom* leverages the existing physical environment to create unique virtual-physical game experiences.

### ILLUMIROOM SYSTEM

Our vision for a fully developed *IllumiRoom* system includes an ultra-wide field of view device sitting on the user's coffee table, projecting over a large area surrounding the television (see Figure 2a). The device would be connected wirelessly to a next generation gaming console as a secondary display. The ultra-wide field of view could be obtained with an ultra-short throw projector, or by coupling a standard projector with a spherical/parabolic mirror (as the peripheral content does not need a uniform pixel aspect ratio). The room geometry could be acquired with a depth sensor or a structured light scan (which would require only a web camera, similar to the setups in [6,15]).



**Figure 2. (a) Our vision for a productized *IllumiRoom* system includes an ultra-wide field of view device that sits on a coffee table and projects content in the area surrounding the television. (b) Our current proof-of-concept prototype uses an off-the-shelf projector and a Kinect sensor.**

Our current proof-of-concept prototype uses a commodity wide field of view projector (InFocus IN126ST) and a Microsoft Kinect for Windows sensor (see Figure 2b). The prototype is limited by the field of view of the Kinect and projector ( $\sim 57^\circ$  horizontal FOV). Therefore, the system is mounted above and behind the user's head, as they are seated on a couch in front of the television.

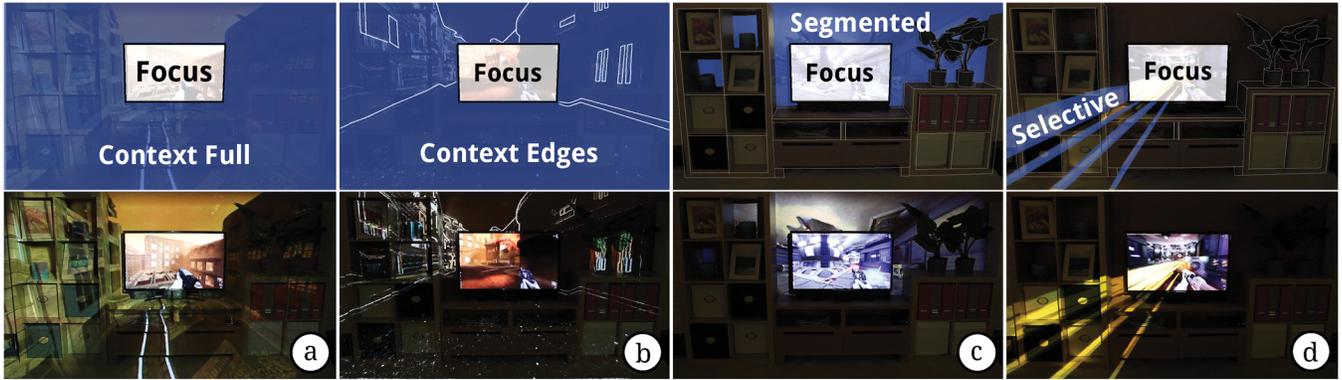
The Kinect sensor captures the color and geometry of the scene, and the system renders the illusions using the acquired depth map. Careful calibration of the system is required in order for the illusions to tightly match the on-screen content and the physical environment. The calibration of the *IllumiRoom* system is fully automatic, determining the relative pose of the projector to the depth sensor and the position of the television in the projector image. Therefore, setup only requires that the projector and depth camera are placed such that they cover the area surrounding the TV.

The automatic calibration projects Gray code sequences [2] to establish dense correspondences between the projector and the Kinect's color camera. Using the default parameters for the Kinect, we transform these correspondences into 3D points. We then solve for the intrinsic and extrinsic parameters of the projector. As there is no depth data for specular surfaces such as that of shiny, black televisions, we recover the position of the TV using a 2D homography, with virtual markers displayed in each corner of the screen. It is important to note that the calibration need only happen once. Thus the Kinect camera could be used to calibrate the projector and then returned to the TV stand for gaming.

The acquired living room geometry is used during calibration and to drive illusions that respond to living room furniture in a physically realistic manner (similar to the ideas in [4,30]). *IllumiRoom* could easily be extended to continuously capture the geometry, enabling *ad hoc* changes to the living room such as moving furniture and people.

### Radiometric Compensation

*IllumiRoom* projects on the existing living room furniture, and therefore cannot rely on the presence of a white, flat projection surface. Using radiometric compensation [5,7,24] the projected light may be modulated to achieve a desired color, given knowledge of the existing surface color and geometry. However, this process is limited by the brightness, dynamic range and color primaries of the projector, as



**Figure 3. Projecting wider field of view game content around the TV can increase immersion. (a) *F+C Full*: The full game content is projected with radiometric compensation onto the surrounding furniture. (b) *F+C Edges*: A high-contrast version where only the edges in the game content are projected. (c) *F+C Segmented*: Game content is projected only onto the flat, rear wall. (d) *F+C Selective*: Selective game content (e.g. bullets) bleed out of the TV.**

well as with the existing surface color, material, and geometry. Accordingly, many desired surface colors are unachievable. For example, a solid red object in our physical environment cannot be made to appear green or blue.

Therefore, all of the illusions use the fact that they occur in peripheral vision. Illusions that may not seem realistic on close examination may be quite effective in the user’s peripheral vision. Most illusions do not attempt to accurately reproduce a scene, but aim to introduce motion in the periphery. Also, subtly modifying the existing surface color may be more effective than replacing the color entirely.

Illusions that modify the surface color and not the apparent geometry of the room are independent of viewing position, and thus can be viewed by multiple users from any position within the room. Illusions that add to or modify the geometry of the room are inherently dependent on viewing position and are most effective when viewed from a fixed point within the room. Generally, as the room’s furniture becomes more complex, effects which virtually modify the geometry are more sensitive to viewing position.

### ILLUMIROOM ILLUSIONS

We envision the *IllumiRoom* system supporting a great variety of peripheral projected illusions, limited only by the imagination of game designers. We have prototyped illusions that we believe represent the primary dimensions of the design space (discussed in the next section). This represents an initial survey of the design space and is not exhaustive. We outline the techniques used to create the illusions, and describe the illusions that were implemented. The illusions are best understood by demonstration (see the accompanying video).

We present the illusions as distinct points in the design space. However, the illusions can be combined in the *IllumiRoom* system. While some illusions are mutually exclusive (*F+C Full* & *F+C Edges*), almost all illusions can be combined.

#### Focus+Context

The most obvious way to increase the user’s sense of immersion is to extend the content from the television screen

out into the room, replacing the physical reality with the game’s reality. We call this *Focus+Context Full* (*F+C Full*) (see Figure 3a). This is essentially the Focus+Context approach [3], but using a non-flat, non-white projection surface, with radiometric compensation. As stated above, the ability to compensate for the existing surface color is limited, and so this effect relies on the fact that the user will directly attend to the television screen rather than the periphery.

The next illusion, *Focus+Context Edges* (*F+C Edges*), provides a maximum contrast representation of the peripheral content by displaying black-and-white edge information (Figure 3b). This illusion is more robust to ambient light in the room, and increases peripheral optical flow.

*Focus+Context Segmented* (*F+C Seg*) extends the game only onto the rear wall surrounding the television (Figure 3c). While the furniture in the room may not be ideal for projection, most televisions are at least partially surrounded by a flat, light colored wall which provides an ideal, view-independent projection surface. This rear wall could be found by a recursive RANSAC plane fitting procedure [22], seeded with the location of the television. Our prototype currently relies on a manually-specified image mask identifying the rear wall.

While the previous illusions bleed all game information into the physical environment, there are times when a more subtle approach may be appropriate. For example, when watching a horror movie, an atmosphere of immersion and suspense is created by the absence of the villain, and then their sudden appearance. When all information is present all the time, there is no opportunity for suspense or surprise. With *Focus+Context Selective* (*F+C Sel*) only certain game elements escape the television (Figure 3d). For instance, a first-person shooter might bleed only weapons fire or explosions out of the television. Or, markers representing other characters or key items in the game may be selectively displayed, thus increasing their emphasis.

These illusions increase immersion, induce apparent motion, and provide additional information about the game content.

The *Focus+Context* illusions all require access to the video game’s rendering process.

### Peripheral Flow

If we do not have access to the rendering process, apparent motion may still be induced through peripheral visual flow, as long as we have information about the motion of the game’s camera. In *Grid* (Figure 4a), an infinite grid moves with the motion in the game. When the user moves or looks left or right, the grid moves in the opposite direction. When the user moves forwards or backwards, the grid zooms in or out.

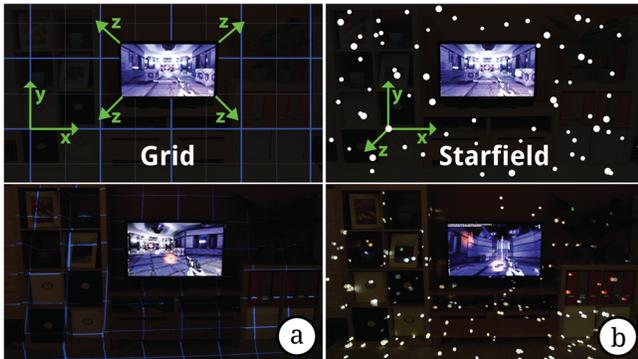


Figure 4. Apparent motion may be induced without access to game rendering by displaying abstract peripheral visual flow. (a) An infinite *Grid* moves with the game’s camera. (b) A 3D *Starfield* of spheres moves with the game’s camera.

Similarly, *Starfield* (Figure 4b) creates peripheral flow by moving 3D points to match the movement of the game’s camera. Points are randomly generated in the virtual space between the TV and the user, according to the position and orientation of the game’s camera.

### Color Augmentation

The physical environment may be augmented to match the theme or mood of the game. For instance, room colors may be super-saturated to resemble a cartoon look by simply projecting the color of the surface back onto itself [7], and then drawing silhouette edges black (Figure 5). Similarly colors may be desaturated to create a black-and-white, “film



Figure 5. *Appearance*: The appearance of the physical environment may be augmented (a), to match the theme of the game. (b) Cartoon super-saturated colors and silhouette edges (c) Black-and-white (de-saturated) colors.

noir” look. We leave more complex texture replacement techniques (i.e., procedural texturing) for future work.

### Texture Displacement

Imagine an explosion in a video game or film that is so powerful that it shakes your entire room. *IllumiRoom* can use projected light to modify the appearance of objects in the room, making them appear to move or change size, or distort in more extreme ways. Due to the projector’s limited ability to compensate for surface color, these illusions are most effective if the displacements are small and short-lived. *Radial Wobble* (Figure 6) distorts the apparent room geometry in a ‘force field’ ripple effect. The illusion displaces the original surface texture in an expanding, radial sinusoidal wave.



Figure 6. *Radial Wobble*: To create a ‘force field’ ripple effect, the physical surface texture is displaced with a radial expanding sinusoidal pattern.

### Lighting

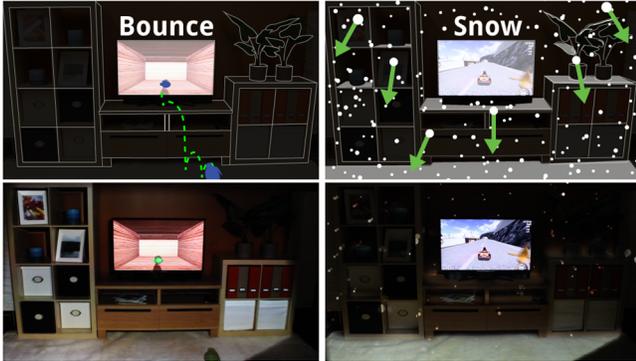
With full control over the illumination, the lighting in the physical environment may be altered [24,25]. Room lighting can change based on the mood or theme in the game. For example, the look of a scene set in space might be achieved by illuminating with point light sources and harsh shadows. The *Lighting* effect attempts to match the lighting conditions of the physical environment with the virtual environment (Figure 7). Our prototype implements soft shadows and a single point-light source, matching the closest point-light source in the game.



Figure 7. *Lighting*: The lighting and shadows of the physical environment are matched to lighting in the virtual environment.

## Physical Interactions

In *Focus+Context Selective* elements from the game (e.g., bullets) break the screen barrier and fly into the physical environment; however, there are no physical interactions with the environment. *Bounce* envisions an element in the game leaving the virtual environment and interacting with physical reality. In our prototype, a grenade rolls out of the television, and then bounces and rolls around the physical environment according to a physics simulation using the room geometry (Figure 8).



**Figure 8.** Virtual objects can realistically interact with physical objects. (a) In *Bounce* a grenade rolls out of the TV and bounces around the living room. (b) In *Snow*, falling snow moves according to the user’s movement in the game and interacts with the physical environment.

In *Snow*, falling snow interacts with the physical environment, briefly collecting on surfaces in the room. Similar to *Starfield*, the snow moves according to the movement of the user in the virtual environment, allowing the user to walk or drive through snow (Figure 8). Our prototype simulates the accumulation of snow by turning surfaces with an upward facing normal gradually white.

## DESIGN SPACE

The range of possible peripheral projected illusions is as great as the range of visual effects in video games or film. In order to better understand the full range of illusions, we identify the primary dimensions of the design space. Illusions are defined by three primary factors: the goals of the illusion, the connection or separation from physical reality and the level of abstraction from the game content.

## Illusion Goals

Peripheral projected illusions can enhance gaming experiences in a variety of ways. All of the proposed illusions attempt to increase the user’s sense of immersion by increasing the FOV and surrounding the user with content. All of the illusions can increase the user’s sense of presence, making the user feel ‘in the game.’ More specifically, the illusions can induce apparent motion, provide additional information and content, create a sense of atmosphere or theme and support entirely new physical-virtual game mechanics. These goals are not mutually exclusive, and a single illusion may support multiple goals (see Figure 9).

## Connection to Reality

*IllumiRoom* enables designers to explore the entire spectrum of the reality-virtuality continuum [17]; by negating, includ-

	Immersion	Presence	Apparent Motion	Theme	Content	Information	Reality	Connection	Reality Distortion
F+C Full	✓	✓	✓		✓				
F+C Edges	✓	✓	✓		✓				
F+C Segmented	✓	✓	✓		✓				
F+C Selective	✓	✓	✓		✓				
Grid	✓	✓	✓						
Starfield	✓	✓	✓						
Appearance	✓	✓		✓			✓		✓
Radial Wobble	✓	✓	✓	✓	✓		✓		✓
Lighting	✓	✓	✓	✓			✓		
Bounce	✓	✓			✓		✓		
Snow	✓	✓	✓				✓		

**Figure 9.** *IllumiRoom* illusions have a variety of goals: increasing immersion and presence, inducing apparent motion, providing additional information or content, creating a sense of atmosphere or theme and supporting entirely new physical-virtual game mechanics.

ing, or augmenting the surrounding physical environment. Designers can negate the physical environment, making the living room disappear; thereby immersing the user in an entirely virtual environment (e.g., *F+C Full*, *F+C Edges*, *Grid*, *Starfield*).

Or the game can be grounded in reality, by including the physical environment and selectively introducing virtual objects into physical reality (e.g., *F+C Seg*, *F+C Sel*, *Bounce*, *Snow*).

Finally, *IllumiRoom* enables a unique middle ground, where the physical surroundings are augmented to match the virtual environment, creating a mixed reality where it is not clear what is real or virtual (e.g., *Appearance*, *Lighting*, *Radial Wobble*).

## Abstraction

The illusions can be dependent or independent of the underlying game content. For instance, if we extend the exact game content outside of the TV, the illusion is entirely dependent on the game content (e.g., *F+C Full*, *F+C Edges*, *F+C Seg*, *F+C Sel*, *Bounce*). However, if we display an abstract visualization, such as a moving grid, then the peripheral illusion is independent of the game content (e.g., *Grid*, *Starfield*, *Snow*, *Appearance*, *Lighting*, and *Radial Wobble*).

## TRIGGERS

The illusions can be connected with game content through a variety of means. Ideally, *IllumiRoom* would be directly integrated into a next generation console and new games would be designed for *IllumiRoom* from the ground up. We envision an API that enables triggering illusions, changing surface appearance, controlling room lighting, inserting objects into the physical environment, etc.

In our prototype, we also demonstrate how to connect existing game content to drive illusions. In order to make the system work with numerous games, the *IllumiRoom* system is a separate component from the game examples, and networking messages are sent to share information. We present a variety of methods for modifying existing content. Figure

	Controller Input	Controller Rumble	Optical Flow	Source (Network Msgs)	Source (Rendering)	Unified (Ideal)
F+C Full					●	●
F+C Edges					●	●
F+C Segmented					●	●
F+C Selective					●	●
Grid	○		●	●		●
Starfield	○		●	●		●
Appearance						●
Radial Wobble	○	○		●		●
Lighting				○		●
Bounce				○		●
Snow	○			○		●

**Figure 10.** Ideally the *IllumiRoom* system is unified with the game content. However, existing game content can be used with the prototype through a variety of input sources. Here we show the different ways of connecting game content to the illusions.

10 enumerates the input sources that can be used for each illusion.

If the source code of the game is available, then the game can be easily modified to trigger effects. In the current prototype, the game sends networking messages to the *IllumiRoom* system in order to toggle illusions on and off. The position and orientation of the player (or often, equivalently, graphics camera) in the virtual world may be sent to drive the *Peripheral Flow* illusions. With access to source-code the game can support *Focus+Context* illusions by conducting a second rendering pass using a wider field of view. In our prototype this information is sent to the *IllumiRoom* system through a texture residing in shared memory.

Source-code is not available for most existing games. Fortunately, many of the illusions can be controlled by other means. For example, the *Peripheral Flow* illusions need only some measurement of the player/camera movement. An approximation can be obtained by real-time image analysis of the rendered game (e.g., optical flow). In our prototype, any game’s image may be captured using a video capture card (DeckLink Intensity Pro), and subsequently analyzed by optical flow techniques to drive the illusions.

A significant amount of game state may be inferred solely from the user’s input through the controller. Given knowledge of the game and the controller mapping, controller input may be mapped directly onto illusions. For instance, if the game is a first-person shooter and the player presses the ‘Right Trigger’ button on the XBox controller, then the player must be shooting. The *Radial Wobble* illusion may then be activated, for example. In our prototype, input from the Xbox controller and vibrotactile output sent to the controller from the game can drive illusions. This works with any game. We envision users scripting and sharing ‘mods’ of their favorite games to work with the *IllumiRoom* system.

For our prototype, games are run on the same PC as the *IllumiRoom* system. GlovePIE<sup>1</sup> intercepts and sends game controller input to the *IllumiRoom* system by networking messages. Vibrotactile output at the controller is captured by using an Xbox controller modified with an Arduino.

## END USER EVALUATION

We evaluated eleven points in the design space of peripheral projected illusions through a user study. We were primarily interested in determining user perceptions along different dimensions of the design space. Just as there is no ‘best visual effect’ for film or video games, we were not expecting to identify a ‘best illusion’. Rather, we sought the strengths and weaknesses of each technique. We were also interested in the user’s overall comfort level during the illusions. Each user interacted with the illusions, answered a Simulator Sickness Questionnaire (SSQ) [16], and performed a card sorting task where they rated and ranked each illusion along a variety of dimensions.

We recruited 10 participants (ages 20-30, 2 female). In order to ensure that participants could focus on the gaming experience and not the control scheme, we required that participants be familiar playing first-person shooter games with an Xbox controller. The user study lasted approximately one hour and participants received \$10 for their participation. Audio and video of the sessions were recorded for the purposes of extracting quotations.

In our experiments, the user sat on a couch 8 ft. from a 40” diagonal television displaying 720p content. A projector was mounted above and slightly behind the user’s head, 11 ft. from the television and 5 ft. above the ground, at a resolution of 1280x800, casting a 130 inch diagonal image (measured within the plane of the television). The television viewing angle was 20° and the projector’s viewing angle was 45°. These distances were chosen to maximize the projected area, within the limits of the working range of the Kinect sensor.

## Game Content

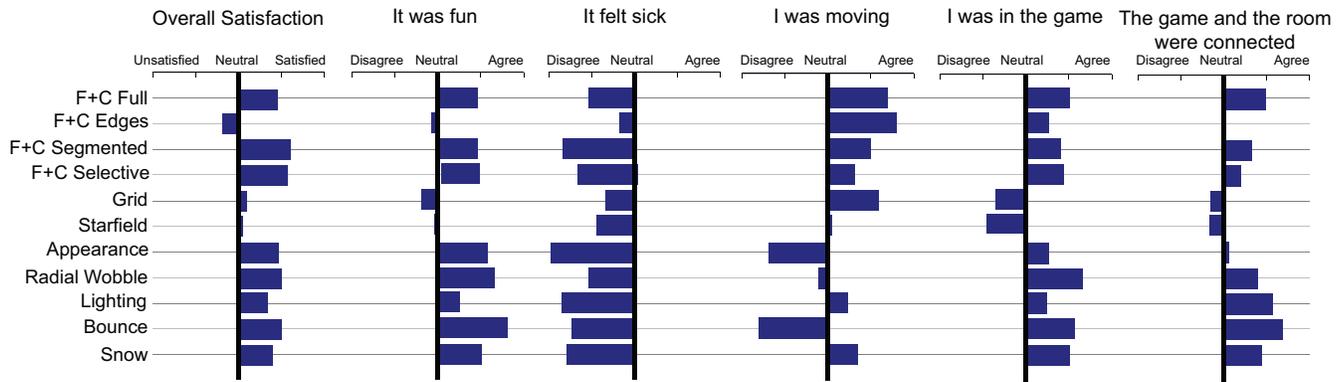
Each participant interacted with eleven illusions paired with matching game content. We paired game content with the illusions in order to maximize the effectiveness of the experience. The majority of the illusions were paired with an open-source first-person shooter (Red Eclipse<sup>2</sup>). This created a rich, interactive experience, enabled by access to source code. The *Snow* illusion was paired with a racing game with a snow level (SuperTuxKart<sup>3</sup>), triggered with controller input. *Lighting* was illustrated by a Unity3D race car example<sup>4</sup>, which uses a few clear light sources. The light positions were sent by network messages. The *Bounce* example was paired with a custom DirectX application in order to perfectly synchronize the content between the physical and virtual worlds. This example was not interactive, but served to demonstrate the basic concept of virtual to physi-

<sup>1</sup> <http://glovepie.org/glovepie.php>

<sup>2</sup> [www.redeclipse.net](http://www.redeclipse.net)

<sup>3</sup> <http://supertuxkart.sourceforge.net>

<sup>4</sup> <http://unity3d.com/support/resources/tutorials/car-tutorial>



**Figure 11. Mean rating for each illusion evaluated in the user study. Participants rated ‘overall satisfaction’ and responded to five questions on a five point Likert scale from ‘strongly disagree’ to ‘strongly agree’.**

cal interactions for users. See the accompanying video for the exact content.

### Procedure

Participants interacted with the eleven illusions with paired video game content in a randomized order. Participants were first introduced to each game without any peripheral projected illusions so that they could learn the control scheme and game objectives. Then, the illusion was revealed and gameplay continued. Immediately following the last illusion, participants filled out a Simulator Sickness Questionnaire (SSQ) evaluating their overall comfort level.

Participants then engaged in a card sorting task, where they rated the illusions on various dimensions. Cards with a picture representing each illusion were placed on a coffee table in front of the user to act as a visual reminder of the illusion. The participants rated the ‘overall satisfaction’ of the illusion on a 5 point Likert scale, and then ranked its ‘overall satisfaction’ (without ties). This procedure was designed to spur careful critique and comparisons, not to identify a ‘best illusion.’ Participants then rated the illusions on a 5 point Likert scale in response to the following prompts: “It was fun”, “I felt sick”, “I felt like I was moving”, “I felt like I was in the game world”, and “The game and the physical world felt like separate spaces.” As this task was completed after viewing all illusions, this enabled the users to mentally compare and contrast the illusions. Users did not express any concern regarding their ability to recollect the illusions.

### Results & Feedback

Participants responded very positively to the illusions and the concept of *IllumiRoom*. As expected, there was not one ‘winning’ illusion, but a diverse set of illusions that have strengths on different dimensions of the design space. For a summary of participant responses see Figure 11.

The results from the SSQ give a coarse indication of potential issues with simulator sickness. The mean value of Total SSQ (14.96), was within normal ranges for playing stereoscopic video games [26] or interacting with immersive simulators [16]. To keep the user study a reasonable length we did not compare SSQ scores across illusions. Future work could explicitly compare individual SSQ scores.

Participants found the *Focus+Context* techniques some of the most useful illusions for game play, because they naturally provide additional gaming information. Simply by extending the field of view of the game, these illusions increase the user’s sense of motion and presence (“I was in the game”). For instance, one user commented that *F+C Selective* was “very useful for finding items, it kinda lets you see just pieces of the game that are important to know around you, and do spatial orientation.” However, the *F+C* illusions can also make the user overwhelmed or more prone to sickness. For instance, one user commented that with *F+C Full*, “There was just a lot going on. To see everything going on around you it was like really cool but especially in as fast paced a game as that, it was just too much happening at once.” *F+C Edges* only made that problem worse, by emphasizing high contrast edges; thereby receiving the lowest satisfaction scores. The *F+C Selective* and *F+C Segmented* illusions seem to represent a middle ground between immersion, adding content information and balancing user comfort. As one user said about *F+C Selective*, “Out of all of these that would be the most useful and immersive without being distracting.”

Of the *Peripheral Flow* illusions, *Grid* seemed to be more successful at imparting a sense of apparent motion; possibly due to the more coherent, 2D nature of the visual flow that it created. One user commented about *Starfield*, “I like the idea of being able to feel your motion in the game, but the random placement of points made it less consistent.” Users were split as to whether the *Peripheral Flow* illusions were more or less distracting than the *F+C* illusions. Multiple users commented that they had a sense of motion, but missed the contextual information of the *F+C* illusions.

*Appearance* worked well at creating a sense of atmosphere for the game. As one user put it “The appearance is awesome. Like that could just be an effect in someone’s living room all the time. That is just super cool.” However, the effect by itself was deemed not as interesting as it would be if it were combined with other effects. One user stated “If you are going to project something, you might as well project something that is directly relevant to the game.”

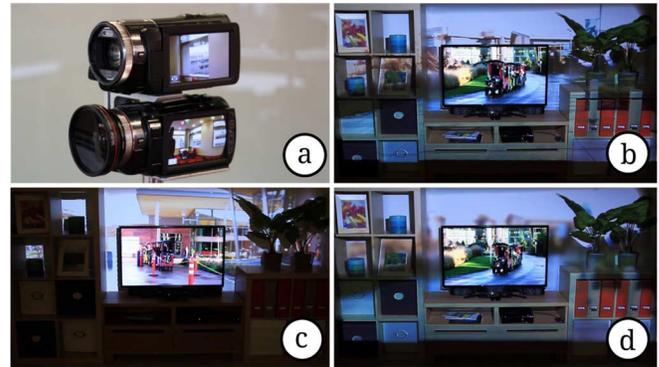
*Radial Wobble* was another ‘magical’ effect, that “kinda made you feel like you are physically doing something in [the game].” However, some users said the effect was off-putting, because “all your stuff is shaking in the real world.” In the evaluation, *Radial Wobble* was triggered in the first-person shooter every time a weapon was fired. As one user stated, “It just seemed like one that you should save for really impactful moments. So I just wouldn’t want it all the time.”

Participants generally liked the play between the physical and virtual worlds in the *Bounce*, *Snow* and *Lighting* illusions. For example, *Lighting* served to create a better sense of immersion and presence for some users “I think more so than any of the others, that one made me feel like I was in the game world.” For the *Bounce* illusion, due to the rough nature of the paired DirectX sample application users had to imagine what it would be like to incorporate this effect into a real game. Multiple users referenced the grenade indicator in Infinity Ward’s Call of Duty, “Most of the time I don’t see the grenades at all...They always kill me, so that was a good one.” The *Snow* illusion created a sense of atmosphere and movement for users; however most users did not notice the physical interactions with the geometry. This is because the snow quickly ‘melted’ after impact. One user commented that they “really wanted it to pile up more. I found it to be melting and if it was piling up it would be an indication of how long I was playing and that would be cool.” However, these illusions (particularly *Lighting*) easily revealed even the smallest mismatch between the game world and the real world, which hampered the illusions for the participants. One user commented that a better use for *Lighting* would be in illustrating the difference in illumination when the player moves between indoors and outdoors in an open world game (e.g., Grand Theft Auto).

### GAME DESIGNER FEEDBACK

In addition to gamers, we also elicited informal feedback about our illusions from game designers (N=15). From the previous user study, we grasped how gamers would react to the illusions, but we wanted to see what content creators thought about the design space. We showed the illusions to three groups, each composed of five game designers or game artists. Each participant had more than 5 years of experience in the game industry.

While individual game designers had different preferences, we extracted the commonalities amongst designers. Generally, the game designers thought that *F+C Full* was impressive at first, but “would probably not hold up to the long term play.” They thought the most promising illusions were ones that altered the mood (*Appearance*), altered the players sense of reality (*Radial Wobble*), or ones that selectively showed game content without becoming overwhelming (*F+C Selective*, *F+C Segmented*, *Bounce*). They expressed concern over illusions that need a tightly, fine-tuned connection with the game (*Lighting*); as they were worried about destroying the illusion for the user if the illusion was not perfectly matched to the game content. Therefore, they saw the merits of *Snow* and *Starfield*, which have much



**Figure 12.** *IllumiRoom* can also be used for panoramic video. (a) A custom dual camera rig for capturing F+C Video (a). The panoramic video content can be displayed as (b) *F+C Full*, (c) *F+C Segmented*. (d) Peripheral content can be deemphasized by blurring (shown with *F+C Full*).

looser connections with the source content. They all suggested games where *IllumiRoom* could be applied (e.g., Forza, Skyrim, Halo, Portal) and enthusiastically suggested that they would like to have a setup like this at home.

### BEYOND GAMING

All our examples so far have focused on computer games; however, *IllumiRoom* can also be used to enhance the viewing experience of film and television. In such applications, the user is not in direct interactive control of the experience, but the dual nature of the content can create some interesting cinematic effects. For example, imagine watching a sporting event (e.g., football game) where the ‘focus’ video is tightly held on the players capturing their actions, while the ‘surround’ video is immersing the viewer with live panoramic views of the stands and the fans at the game. Or imagine a music video where the focus and surround video show different footage, but mimic the camera motion (e.g., pan with exactly the same speed and direction).

To begin experimenting with such video experiences, we built a custom dual camera rig, with a narrow FOV ‘focus’ camera and a wide FOV ‘surround’ camera (Figure 12). This panoramic content can be displayed around the television using *F+C Full* or *F+C Segmented* (with radiometric compensation). Additionally, it can be blurred to decrease the emphasis on the peripheral content. Future video content could be filmed with such a rig, or existing video content could be extrapolated (e.g. [1,19]). Our existing experience with recording and watching such dual feed videos in *IllumiRoom* leads us to believe that a whole new set of cinematic effects could be produced by creatively combining the two video feeds.

### CONCLUSION AND FUTURE WORK

In this paper we presented a proof-of-concept system for augmenting the physical environment surrounding a television to create a more magical gaming experience. We presented eleven peripheral projected illusions that demonstrate the variety of the design space. We then elicited feedback from gamers and game designers about the peripheral projected illusions along dimensions of the design space. While we did not formally compare the experience of the

*IllumiRoom* system with a standard TV setup, the very positive feedback of both user groups indicates that there is great promise in the approach.

While we explored eleven points in the design space, there are many peripheral projected illusions left to be explored. We only scratched the surface of what is possible with a shared physics representation between the virtual and physical environments in *Bounce*. It is not clear what it means if a grenade falls out of a game and explodes in your living room; particularly, if the virtual camera is moving around and the physical environment is static. Furthermore, as some illusions distort reality, future work should explore how far users are willing to push their concept of reality, in their own living room.

Another promising direction is to further explore illusions specifically for video content (e.g. TV shows or full length feature films). Authoring such content is a challenge, but it could enable unique viewing experiences. Can a grenade from the latest Bond film explode in your living room? How would such content be authored? It would be important to investigate how the movie director should deal with the fixed nature of a film and the randomness imbued by the system adapting to the user's living room.

Additionally, our methods for connecting content and illusions are not exhaustive. It should be possible to use other cues (e.g., audio) to trigger illusions. For instance, a loud explosion in a film could trigger a *Radial Wobble* illusion. Simple techniques such as these could enable users to 'mod' existing films and games, and share the scripts. Future work could explore this design process from a standpoint of collaborative design or crowd-sourcing.

Finally, before the *IllumiRoom* system can be in every living room, the final form factor, cost and computational requirements of the system must be determined. While there are many unanswered questions regarding peripheral projected illusions, we hope we have demonstrated that they are worth answering.

## REFERENCES

1. Aides, A., Avraham, T., and Schechner, Y.Y. Multiscale Ultrawide Foveated Video Extrapolation. *IEEE ICCP*, (2011).
2. Battle, J., Mouaddib, E., and Salvi, J. Recent progress in coded structured light as a technique to solve the correspondence problem: a survey. *Pattern recognition* 31, 7 (1998), 963–982.
3. Baudisch, P., Good, N., and Stewart, P. Focus Plus Context Screens: Combining Display Technology with Visualization Techniques. *ACM UIST*, (2001).
4. Benko, H., Jota, R., and Wilson, A. MirageTable : Freehand Interaction on a Projected Augmented Reality Tabletop. *ACM CHI*, (2012).
5. Bimber, O., Coriand, F., Kleppe, A., Bruns, E., Zollmann, S., and Langlotz, T. Superimposing pictorial artwork with projected imagery. *IEEE Multimedia* 12, 1 (2005), 16–26.
6. Bimber, O., Emmerling, A., and Klemmer, T. Embedded entertainment with smart projectors. *IEEE Computer* 38, 1 (2005), 16–26.
7. Bimber, O. and Iwai, D. Superimposing dynamic range. *ACM Trans. on Graphics* 27, 5 (2008).
8. Bimber, O. and Raskar, R. *Spatial augmented reality: Merging real and virtual worlds*. AK Peters Ltd, 2005.
9. Cockburn, A., Karlson, A., and Bederson, B.B. A review of overview+detail, zooming, and focus+context interfaces. *ACM Computing Surveys* 41, 1 (2008), 1–31.
10. Cruz-Neira, C., Sandin, D.J., and Defanti, T.A. Surround-Screen Projection-Based Virtual Reality : The Design and Implementation of the CAVE. *SIGGRAPH*, (1993).
11. Flagg, M. and Rehg, J.M. Projector-Guided Painting. *ACM UIST*, (2006).
12. Gibson, J.J. *The Perception of the Visual World*. Boston: Houghton Mifflin, 1950.
13. Henderson, J. Human gaze control during real-world scene perception. *Trends in Cognitive Sciences* 7, 11 (2003).
14. Hou, J., Nam, Y., Peng, W., and Lee, K.M. Effects of screen size, viewing angle, and players' immersion tendencies on game experience. *Computers in Human Behavior* 28, 2 (2012), 617–623.
15. Jones, B., Sodhi, R., Campbell, R., Garnett, G., and Bailey, B.P. Build Your World and Play In It: Interacting with Surface Particles on Complex Objects. *IEEE ISMAR*, (2010).
16. Kennedy, R.S., Lane, N.E., Kevin, S., and Lilienthal, M.G. Simulator Sickness Questionnaire : An Enhanced Method for Quantifying Simulator Sickness. *Aviation Psychology* 3, 3 (1993), 203–220.
17. Milgram, P., Takemura, H., Utsumi, A., and Kishino, F. Augmented Reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies* 2351, (1994).
18. Mine, M., Rose, D., Yang, B., Jeroen van Baar, and Grundhöfer, A. Projection-Based Augmented Reality in Disney Theme Parks. *IEEE Computer* 45, 7 (2012), 32–40.
19. Novy, D. and Jr., V.M.B. Infinity-by-nine. <http://obm.media.mit.edu/>, (2012).
20. Pinhanez, C. The Everywhere Displays Projector: A Device to Create Ubiquitous Graphical Interfaces. *ACM UbiComp*, (2001).
21. Projection Mapping Central. [www.projection-mapping.org](http://www.projection-mapping.org).
22. Quirk, P., Johnson, T., Skarbez, R., Towles, H., Gyarfas, F., and Fuchs, H. RANSAC-Assisted Display Model Reconstruction for Projective Display. *IEEE VR*, (2006).
23. Raskar, R., Welch, G., Cutts, M., Lake, A., Stessin, L., and Fuchs, H. The Office of the Future: A Unified Approach to Image-Based Modeling and Spatially Immersive Displays. *ACM SIGGRAPH*, (1998).
24. Raskar, R., Welch, G., Low, K.L.K., and Bandyopadhyay, D. Shader lamps: Animating real objects with image-based illumination. *Eurographics Workshop on Rendering Techniques*, (2001), 89.
25. Raskar, R., Ziegler, R., and Willwacher, T. Cartoon dioramas in motion. *ACM NPAR*, (2002), 7.
26. Schild, J., Laviola, J.J., and Masuch, M. Understanding User Experience in Stereoscopic 3D Games. *ACM CHI*, (2012).
27. Sekular, R. and Blake, R. *Perception, 2nd Edition*. 1990.
28. Tan, D.S., Gergle, D., Scupelli, P., and Pausch, R. With similar visual angles, larger displays improve spatial performance. *ACM CHI*, (2003).
29. Weffers-Albu, a., De Waele, S., Hoogenstraaten, W., and Kwisthout, C. Immersive TV Viewing with Advanced Ambilight. *IEEE ICCE*, (2011), 753–754.
30. Wilson, A., Benko, H., Izadi, S., and Hilliges, O. Steerable Augmented Reality with the Beamatron. *ACM UIST*, (2012).