Arcaid: Addressing Situation Awareness and Simulator Sickness in a Virtual Reality Pac-Man Game

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Abstract
This paper describes the challenges of converting the classic Pac-Man arcade game into a virtual reality game. *Arcaid* provides players with the tools to maintain sufficient situation awareness in an environment where, unlike the classic game, they do not have full view of the game state. We also illustrate methods that can be used to reduce a player's simulation sickness by providing visual focal points for players and designing user interface elements that do not disrupt immersion.

Author Keywords
Game Design; Virtual Reality; Situational Awareness; Simulation Sickness

ACM Classification Keywords
K.8.0. [Personal Computing]: General - Games

Introduction
Virtual reality (VR) gives players and game designers new ways to interact with video games. VR enhances immersion while allowing players to physically interact with their environment, for example using head movements to change point of view. *Arcaid* reimagines the classic arcade game *Pac-Man,* where VR allows

players to experience the game in the first-person. Players play as Pac-Man, navigating him through a maze of narrow corridors. VR controls allow players to use physical head movements to look down hallways for pellets while evading pursuing ghosts.

Most traditional arcade cabinet games are designed so that players have full knowledge of the game state at all times. *Pac-Man* [1], for example, displays the location of power ups, enemies, and the player in the environment from a top-down perspective. In contrast, in VR, a player can see only what is within their first-person field of view. *Arcaid* illustrates techniques for improving situation awareness in a VR environment; specifically, information stations are distributed throughout the maze and power-pellets temporarily lower walls to reveal information. Our goal in this design was to give players enough information to make decisions while retaining the game's challenge.

Low latency and frame rate [5] along with visual feedback not matching physical movements [2] can result in feelings of vertigo, nausea, and eye strain [3] not experienced in traditional arcade games. In *Arcaid,* we adopt a variety of emerging techniques to reduce the effects of simulation sickness on players. Through testing we found that using a reticule that followed the player's gaze helped to alleviate feelings of dizziness and nausea. Additionally, user interface elements such as menus occupy a static location in world space so they do not interfere with a player's ability to look around the scene.

Related Work

There has been to our knowledge only one earlier attempt to port the Pac-man game to VR. In 1996, *Arcadian Virtual Reality* developed a VR version of *Pac-Man* titled *Pac-Man VR* using their arcade system, the SU3000. This original title was designed for arcades and focused on multiplayer gameplay in a specially designed maze. In this version of the game, the entire game state is visible at all times because the walls are low enough to see over. This design helped suggest the lowered walls of our power-up abilities.

Our support for situation awareness is informed by Endsley's classic paper, in which he details a model for understanding how a user of a software system forms situational awareness [4]. Users must not only have a good understanding of the system's current state, but the user must also have access to enough information to understand future states in light of their own goals. Chang et al. have explored how situation awareness can be supported in digital games, through a timelines visualization of game state and history [7].

LaViola has performed research into specific sources of simulation sickness, showing that using flashing or bright textures in an environment where they are displayed close to the visual plane can cause eye strain and feelings of nausea [2]. As we shall see, this informed the design of textures in Pac-Man Arcaid.

Over the last year, considerable experience has been reported by game developers in how to develop games for VR, prompted by development for the newly available Oculus Rift and HTC Vive headsets [6]. The addition of user interaction elements like targeting reticules as well as better designed menus has been shown to reduce the effects of simulation sickness in games like *Lucky's Tale* and *Mirror's Edge.*

Pac-Man and *Arcaid*

Arcaid is a first-person adaptation of the classic arcade game *Pac-Man*. The player navigates a maze full of yellow pellets. To clear the level, players move through the maze and collect all of the pellets. In addition, players can compete for high scores by defeating ghosts quickly and finding bonus fruit.

In the maze, there are four ghosts that kill the player on contact. Ghosts have behaviour patterns that vary from hunting the player to patrolling the maze.

In addition to the regular pellets, there are a small number of power pellets that are larger than the others and pulse slightly. These pellets, when collected,

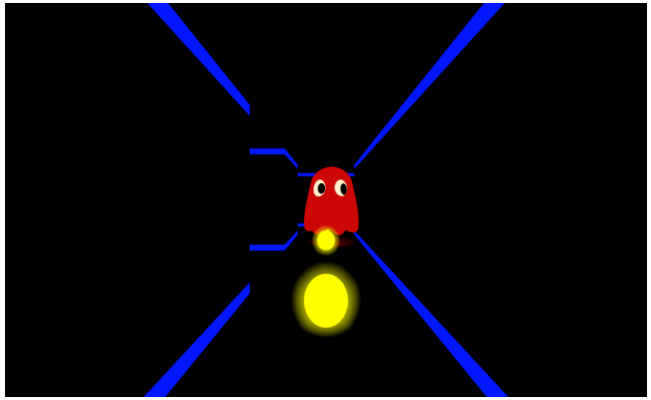

Figure 1. A ghost chasing the player through the maze

change the ghosts to a dark blue colour and cause them to move away from the player. If the player touches a blue ghost, it turns into a pair of floating eyes and returns to the center of the maze. Additionally, power pellets reduce the height of the maze walls, making it possible for the player to see the entire maze and the location of all ghosts.

Situation Awareness

Kolasinski defines situation awareness as "a state of knowledge capturing a user's perception of the elements in the environment, an understanding of their meaning, and an understanding of their predicted status in the near future" [4]. In classic *Pac-Man,* situation awareness is directly supported, as the player sees the entire level via a top-down map and can see how the ghosts move. In contrast, in VR's first-person view, only a small portion of the level is visible to the player. *Arcaid* enhance players' situation awareness through *map stations*, *spatial sound* and *lowering walls*.

Map Stations

In VR, options for user interface elements are limited. If an object like a mini-map is constantly in the player's peripheral vision, it can be distracting and can cause eye strain and simulation sickness [2]. Therefore, these objects need to occupy a static location so that players can look away from them. Furthermore, giving players constant access to a full map of the game state made the game too similar to traditional *Pac-Man.*

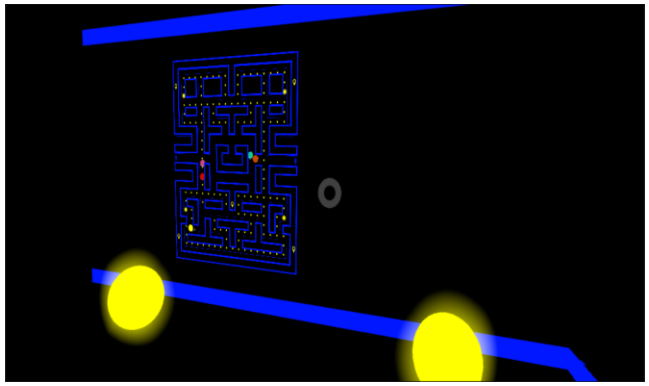

Figure 2. An Example of a map station

There are several map stations in the level that show the location of the player, pellets, and ghosts. Players can glance quickly at a map station while passing by. They are placed in commonly reached areas of the map, including the corners, the center, and the midpoints of the outer walls. Therefore, if a player is feeling lost, they will not need to travel too far to regain their bearings. Additionally, because the maps are stationary, players are forced to quickly establish where they need to go next and move on so that pursuing ghosts do not catch up to them.

Spatial Sound

When a ghost is approaching, players are given clues to where they are through the use of spatial sound. Whenever a ghost gets within a threshold distance of the player, a sound begins to play and gets louder depending on how close the ghost is. The sound is localized via a stereo headset, indicating the ghost's location relative to the player. Thus, even if the ghost is out of sight and there are no map stations nearby, the player can plan their next turn to avoid the threat.

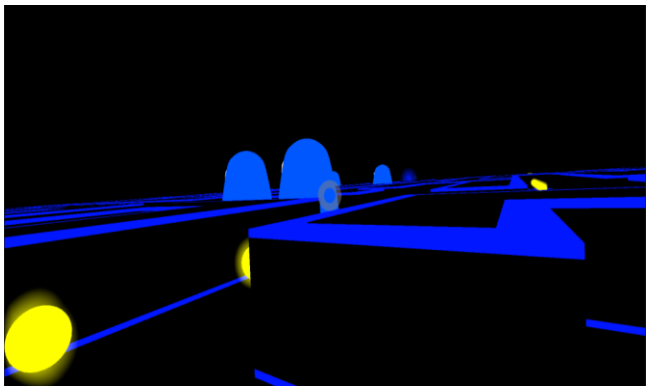

Figure 3. After collecting a power pellet the walls are lowered

Lowering Walls

Various wall heights were tested in development of *Arcaid*. When the walls were set too low, players could see the entire maze, eliminating much of the challenge. However, high walls of the maze made it too difficult for players to locate ghosts, reducing the effectiveness of the power pellet. In the final game, when players pick up a power pellet, the walls are reduced to half height while the pellet's effect persists. Players have the situational awareness to be able to capitalize on the increased power and maximize their score.

Simulator Sickness

Simulator sickness is caused by a disconnection between the vestibular system, which provides information on the head's orientation in space, and the visual system [2]. When there is a perceived disparity between the two systems, the body can react with feelings of vertigo and nausea. We designed the placement of UI elements and added a targeting reticule to reduce the effects of simulator sickness.

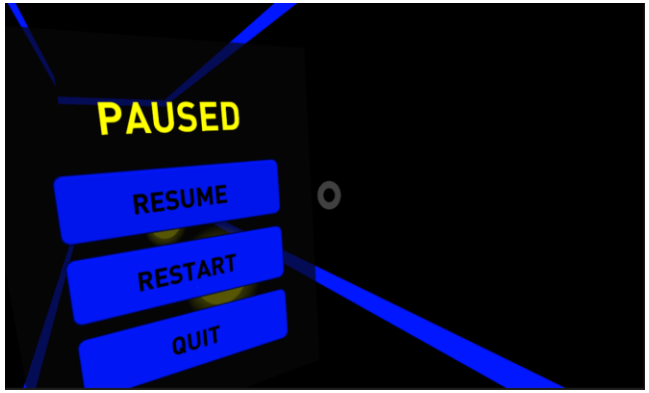

Figure 4. Pause Menu stays stationary while player looks around

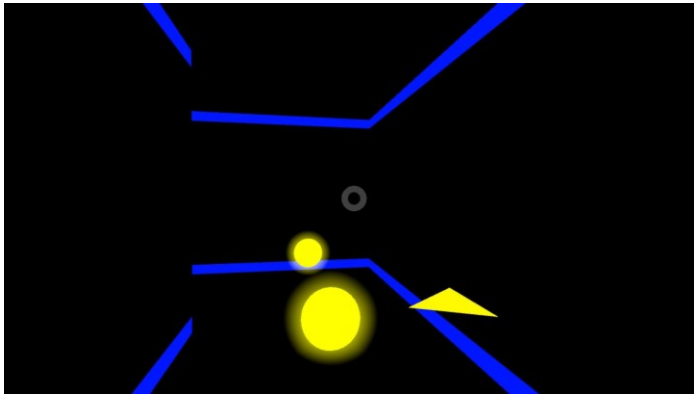

Figure 5. The targeting reticule (white) follows the player's gaze while the yellow triangle (yellow) shows body orientation.

Placement of User Interface Elements
In traditional first person shooters, it is common to prevent the player from looking around while the game is paused. However, in VR taking control of the camera away from players can cause simulation sickness [5]. To avoid this, even if the game is paused the player should be free to look around. Additionally, pause menus should remain stationary so that the player can look away as having a menu occupy the visual plane constantly can lead to eye strain [2]. Having the menu be independent of the player's gaze allows the user use their focus as an input method, highlighting the option they want to select.

Targeting Reticule
In fast-paced first-person shooter games, players can struggle to find a point in the scene to focus on, exacerbating simulator sickness [6]. To combat this, *Mirror's Edge* implemented a small reticule in the middle of the screen for players to focus their gaze. In *Arcaid,* we adopted a similar strategy and we use a reticule that follows the player camera. Player testing showed this to reduce the symptoms of simulator sickness among players. Additionally, we use a second indicator to show the orientation of the player's body to reduce disorientation while glancing around.

Implementation

Arcaid was built using the Unity 3D game engine and the C# programming language. We used the existing Oculus SDK to interface with the Oculus Rift headset. The SDK includes an in-game camera that matches the movements of the headset using the accelerometer in the headset and the tracking camera that views changes in position.

We used the Oculus Rift DK2 headset to display the environment in stereoscopic vision. This version supports positional tracking of the headset as well as detecting where the player is looking.

Experience

In order to measure the effectiveness of our implementation, we invited players to several play-testing sessions. These sessions involved between five and ten participants playing over the course of an evening. In the first play testing session, few aids were given to players to assist with simulation sickness or situation awareness. UI elements such as the targeting reticule and map stations were not present. This early version was received negatively, as players often felt lost and in most cases quickly felt sick. In subsequent sessions, we included the targeting reticule. This version was received more positively showing greatly reduced feelings of simulator sickness.

Through playtesting it was determined that of the implemented methods, map stations were the most effective in giving an overview of the game state. However, in future iterations other methods of giving situation awareness will be tested. One particular problem that players face is locating the last remaining pellets when the level has been nearly completed. One method of solving this would be to add a visual indicator pointing to these last remaining pellets.

During playtesting sessions, the amount of time between players collecting pellets was tracked. Lengthy times where players navigate the maze without collecting pellets indicate that the player does not have enough information to find the next pellet. With the introduction of map stations, we found that the amount of time between pellet collection was greatly reduced, as players were able see their location. In future iterations, we will additionally track the length of time players spend at map stations to determine both the effectiveness of the stations in establish situation awareness, as well as determining how much time is required at the map station. Anecdotal feedback from testing has indicated that the map stations aid in situation awareness; this quantitative information will allow precise evaluation of their effectiveness.

Arcaid was showcased at a local creative computing showcase where it was tested by approximately 50 attendees. We observed that most players followed two distinct stages in play. When there were many pellets in the maze, they followed corridors in straight lines, and made little use of the VR head tracking to look side-to-side. At this stage, players largely relied on sound cues to detect and avoid ghosts, and did not reference the map. However, once pellets became scarce, players spent much more time looking around while moving, and quickly glanced at map stations as they passed them. They also used the head tracking to glance down hallways as they passed, checking for ghosts as well as pellets.

Players reported feeling immersed during play. Numerous players had startled physical reactions when a ghost surprised them, jumping and attempting to physically move away in their chair. After each play session, we asked players what genre of game they would associate *Arcaid* with, and we were surprised that approximately 25% of testers stated that they found elements of horror games in *Arcaid*. Four testers at the showcase reported feelings of motion sickness; however, they reported that the severity was low. The four players who reported motion sickness had been playing for longer periods of time than average, attempting to complete the maze multiple times. This was an improvement over earlier versions of the game where players often felt sick early in a play session.

References

1. Atari. Pac-Man Atari 2600 Instructions Archive
2. Joseph LaViola. A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin* (2000), 47-56.
3. Mica Endsley. Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 1995, 32-64.
4. Eugenia Kolasinski. Simulator Sickness in Virtual Environments.
5. Oculus. Oculus Rift Best Practices. https://developer.oculus.com/documentation/intro-vr/latest/concepts/bp_intro/
6. Ben Lewis-Evans. How to minimize simulation sickness in your VR games. http://www.gamasutra.com/view/news/252735/Video_How_to_minimize_simulation_sickness_in_your_VR_games.php
7. Betty Chang, Stacey Scott, Mark Hancock. Supporting Situation Awareness in Collaborative Tabletop Systems with Automation. *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces*, 2014, 185-194.