Interactive Dome Experiences: Designing AstroSurf

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ABSTRACT

Dome and display technology have evolved to the point that designing interactive dome experiences no longer requires expertise with dome technology. In particular, the DomeLab provides an interface for designers to work with popular game development technology, such as Unity. Without the technologic concerns of developing the domes themselves, research can shift focus towards designing games and novel experiences for them. This raises new questions: "what kind of interactive experiences can domes support?" and "how can these experiences be designed for?" Through the design and evaluation of AstroSurf, a game designed for the DomeLab, this paper contributes three themes: co-location in the dome context, interacting with dome interfaces, and designing for exhibition. These themes present an argument for designing 'enveloping experiences' for domes and identify domes as a unique immersive environment supporting drop-in play, converged multiplayer interactions around the pole, and blended physical-virtual play.

CCS Concepts

•**Applied computing** → **Computer games;** •**Human-centered computing** → *Human computer interaction (HCI);*

Keywords

dome; fulldome; game design; interactive experience; co-located; social play; immersion; play; games; public games

1. INTRODUCTION

Large installation displays and interface technologies are increasing in popularity, showing potential for new interactive experiences, collaboration, increased immersion, and more. One particularly prominent variant is the fulldome projection room. These domes are display platforms including a hemisphere which its inside surface is fully projected onto. These domes are mounted above a walkable surface area that can encapsulate multiple people in an encircled space. There has been significant work towards understanding domes, both from a technologic perspective, such as overcoming the difficulties in developing effective domes, as well as their application, where there are potential uses in planetarium, film, museum applications, and data visualization. More recently, the potential for domes as interfaces in interactive applications, such as in games, is being explored. Technology has sufficiently matured to shift focus toward creatively exploiting the technology. This raises the questions, what kind of interactive experiences can domes support? and how can these experiences be designed for? And furthermore, how can games be designed to utilize domes? This paper contributes towards these questions using a research-through-design approach, including the design and evaluation of a novel game, AstroSurf. This game was designed as one of the first games for the University of New South Wales (UNSW) National Institute for Experimental Arts' DomeLab [14], where it was exhibited as part of the RMIT Design & Play exhibition.

This paper firstly provides context of the game, AstroSurf, including its design goals and an overview of its development. This provides insights for others seeking to design games and interactive experiences for domes using technology, such as the Unity game engine [30]. Next, we provide insights derived from the design process as well as player observation and engagement in the exhibition setting. These insights fall into three themes relevant to the project: colocation in a dome, dome interaction, designing for exhibition settings. The findings are presented to support designing interactive experiences and games for domes, and in particular, highlight some of the distinct interactive properties of domes. These include general dome properties such as drop-in play and blended physical-virtual play, as well as dome specific properties that must be designed for, such as converged multiplayer interactions around the pole.

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2. RELATED WORK

Dome projections have seen a growth in application through the rise in application of digital technology incorporated into planetariums; as of 2012 there are more than 700 digital dome theatres in operation in the world [26]. This growth and an emergence of portable, more recent lower-cost dome projections that use off the shelf technologies e.g. DomeLab [14], allow for less specialized applications in dome projections and content than traditionally shown within a planetarium.

While there has been a diversification of dome content into non-astronomy-based entertainment and education contexts (e.g. [18, 6]), dome studies predominantly focus on three areas of interest: 1. Education applications [19, 27] emphasize the closed, sensory experience of the dome environment as a unique learning environment which enhances educational content projected. 2. The sensory experience of the dome: A frequent point of focus in dome studies, for example, Shnall et al. [26] argue the unique traits of dome environments provide an immersive experience to viewers, not to dissimilar to virtual reality devices. 3. The technical challenges in dome projection: Bourke [4], Lantz [17] and Gaitatzes et al. [11] discuss the unique technical challenges in operating and creating content for dome projections, and Melenbrink and King [21] discuss 3D technical workflow for a fulldome interface.

Despite the growth in dome use and proliferation of more cost-effective dome projections, there has been little application of interactive content for dome environments, or studies that focus on the unique design challenges in creating this content that utilizes the dome's experiential properties.

Li et al. [20] indicate the potential applications of their theatre-sized dome design, which incorporates multi-sensory motion seats, hand held controllers with pointer functions, and stereoscopic 3D rendering for interactive edutainment and immersive training. Tredinnick and Richens [29] outline the potential benefits for multi-user interactive experiences in dome environments for users to "immerse themselves in the tangible and intangible heritage of a site" [29, p. 1], through a 360 degree view via low-cost dome technology. The study focuses on the technical challenges in creating accessible and cost-effective interactive experiences for multiple users in the dome. For application and use as an educational experience, accessibility and ease of use for a general audience, young and old are noted as requirements for the design. A gesture-based interface utilizing markers and infrared (IR) controllers are proposed as a viable alternative for multi-user interaction to more complex off-the-shelf game controllers such as the Nintendo Wiimote or Xbox Kinect. Few other examples of interactive dome content include commercial project Earth Patrol by Fulldome.Pro [10]. Created specifically for dome use, Earth Patrol adapts the light-gun shooter format common to arcades to the dome projection.

The emergence of multi-user large-scale interactive user interfaces such as QUT's multi-screened Cube, present alternative understandings as to how social, collaborative, and co-located user experiences may be designed. Examples include the 'physics playroom' a multi-user sandbox that allows users to collaboratively construct and destroy creations and playfully experiment across a virtual environment, within the large-scale interface [25]. Spatially immersive display (SID) the CAVE exemplifies the immersive experiential properties of large scale projections [7]. The spatial configuration of the CAVE physically surrounds the viewer and allows for group viewing within the projection environment. The CAVE presents unique opportunities for interaction between users and the display interface and highlights the strengths of immersive panoramic viewing as a shared, co-located experience [16].

Increasingly within game design and HCI fields, social factors have become a major point of focus as part of the interactive, played experience. This includes topics such as spatial presence [23], proxemics (the interpersonal distance between players [22]), physicality [9], co-experience [1], and stimulating social engagement through interaction design values [2]. Multi-user interfaces such as the QUT Cube [24], the CAVE [7] and iGameFloor [13] present opportunities to rethink and further our understanding in light of these advances; to consider how these larger-scale user interfaces are shared, how social theories such as proxemics can inform immersive multi-user co-located environments. The dome provides a particular vantage to inform our understanding of these factors. The dome is both an audio-visual technology and social environment de-emphasizing face-to-face social interaction, that offers a unique set of values and constraints for the design of interactive experiences.

Core aspects of the dome projection such as the expanded field of view, an enhanced sense of depth and closed environment are frequently highlighted as major factors in creating a sense of immersion (by Schnall et al. [26]). Furthermore, spatial factors that include the physical properties of the room, angular viewing of the projection, and group viewing opportunities are additional influential factors that may shape an immersive user experience within a projection environment [16]. The benefits of the shared viewing experience are often highlighted in educational and data visualization contexts [27, 29, 16]. However little has been discussed as to how both may be applied to, or enhance interactive experiences through design-focused design experimentation and discussion.

3. EXHIBITION DESIGN & RESEARCH

AstroSurf was designed as an original playful interactive dome experience for UNSW's DomeLab [14] to be exhibited as part of the DomeLab Arcade at the RMIT University Design & Play Exhibition. This exhibition was coordinated by the Centre for Game Design Research (CGDR) and the Digital Ethnography Research Centre (DERC). This section provides context for this process of design, exhibition, and study from which insights in the paper are drawn from. This research adopted a research-through-design approach [34] for the purpose of contributing propositions and insights from the design thinking occurring during and after the design process. This research approach allowed for the exploration of domes for interactive experiences through the process of game design where there are limited prior works to investigate. This paper makes a contribution towards the design audience, where there is limited research on interactive dome experiences. This investigation was driven with both design motivations listed in the section below and the aforementioned research questions.

The project spanned over three months, starting with two months of ideation, early asset preparation and conceptualisation, and planning. This was followed with four weeks of production. The game was produced with the Unity game engine [30] using DomeLab scaffolding assets developed by Paul Bourke to bridge the engine's display output to a format compatible with the dome. During production, the project was revised continuously in iterations [33] counting 148 Git source control repository commits, some of which inform our findings. The first 2 weeks of iteration drew on playtesting in a simulated environment amongst the designers and colleagues, which is discussed in the development section. This was due to the limitations of testing on the DomeLab, which was in the process of being installed or used by others. The last two weeks of design overlapped with the exhibition, informing iterations with in-the-wild player observation and feedback.

The DomeLab arcade was a permanent event during the exhibition, running from April 30 to May 14 in 2016. AstroSurf was one of five games and interactive experiences exhibited as part of the arcade. The games were periodically changed by exhibitors to cycle through the library or in response to changing audiences as some games required specific player amounts, making them ill-suited for single participants or larger groups. During the exhibition, exhibitors took the dual role as design researchers, allowing for player observation in an in-the-wild exhibition setting, as well as ad-hoc discussions initiated by players. Notes were taken after exhibiting, motivated to inform iteration of the design. Discussions with players were unstructured, allowing for players to highlight salient points of interest from their perspective. Exhibiting of the game included a total of 30 hours between two exhibitors during the two-week exhibition and included the observation of over 100 players. This environment provided a source of unexpected insights by evaluating emergent properties of the game. To contextualise the subsequent findings in this paper, the next sections outline the DomeLab, AstroSurf, and camera-to-display mapping for projection with Unity.

3.1 DomeLab Overview

The DomeLab [14], as seen in exhibition in Figure 1 is a high fidelity, low cost, ultra-high (4K) resolution portable dome installation developed of UNSW's National Institute for Experimental Arts. The dome has been designed as a mobile system, allowing it to be moved to different institutions for research and exhibition. It has been designed to support both pre-rendered and interactive content. It features a diameter of 6m, covering a space large enough for a dozen players to fit underneath it comfortably. Eight projectors drive the display, powered by an NVIDIA graphics card set up to drive 8 outputs over a mosaic display output setup. Each of the projectors are arranged with an overlap. This overlap is balanced with a vignette image filter providing a shadow around the borders of the display output based on calibration data. NVIDIA's Mosaic output provides a single graphics context to render out to, making the 8 projectors this setup outputs to present themselves as a single display adapter.

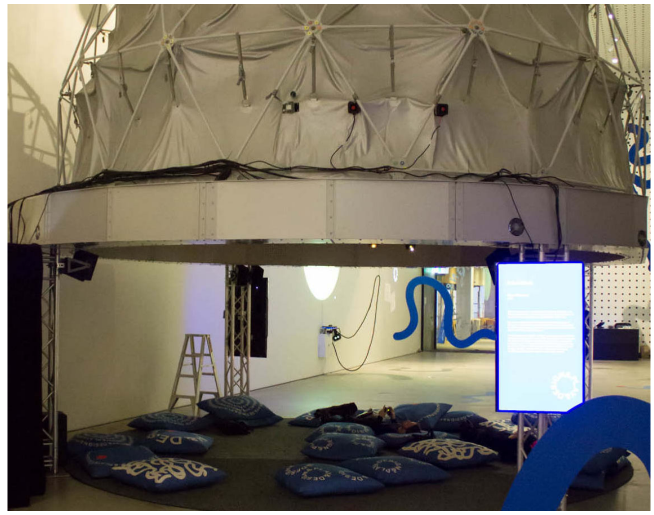

Figure 1: The DomeLab in RMIT's Design Hub.

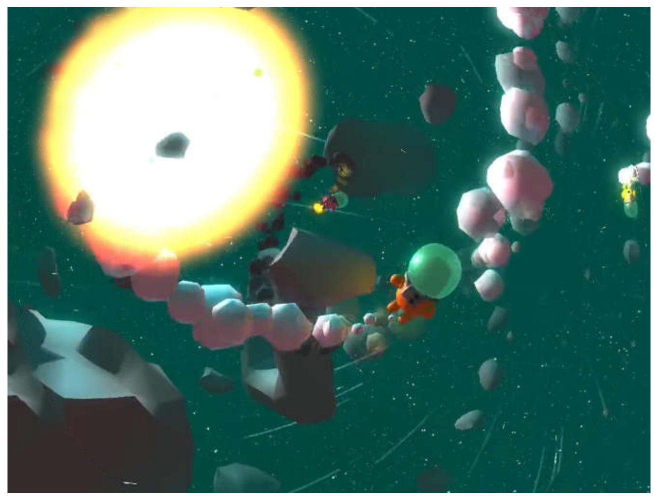

Figure 2: A fisheye rendering of AstroSurf gameplay footage. Three players are jetpacking around asteroids. The purple player is near destruction.

3.2 AstroSurf Overview

AstroSurf[1 2], as seen in Figure 2, is a playful multiplayer game designed from the ground up for UNSW's DomeLab. The game can be played by 1 to 4 players using wireless Xbox 360 controllers connected to a desktop computer driving the dome. The game operates in a loop time of 6:30 synchronized with backing music. Players take the role of astronauts who can freely fly around in space. Players do not win or lose, but rather they can master the control of their astronaut in space or simply enjoy themselves in the space environment.

Players use the Xbox 360 game controllers to control each of their characters. The astronauts leave a salient particle trail from their jetpacks as they turn, tumble, and accelerate through space. Players can choose to dance with a trail similar to rhythmic gymnastics, survive their destruction by avoiding collisions, intentionally destroy themselves for the explosion and its impact on the asteroid field and other players. Additionally, asteroid rings regularly reveal themselves which if the players can navigate through, they are given a rainbow particle trial for five seconds, an increase in top speed, and their health is restored.

3.3 Designing for Spherical Play in AstroSurf

AstroSurf was initially conceptualised as, and inspired by, the endless runner [12] genre, also known as an infinite runner, and is exemplified in many titles, such as Kiloo's Subway Surfers [15]. The endless runner genre is defined by the continuous movement of the player, of which the players have no control over. Common design aspects of this include limited player control such as simple gestures and has been popularised for mobile devices. Adapting this genre

[1]Video of AstroSurf gameplay by Yo Szczepanska is available on YouTube with interactive 360 degree view: https://www.youtube.com/watch?v=BQstsSh0Md0

[2]A 360 degree interactive viewer is available on Theta: https://theta360.com/s/eiJy3ETGCFH4U7X3ZnlgxZUMS

to the dome platform was promising as it provided a simple game accessible to a broad audience, but more importantly, employed persistent camera movement allowing for an experience of being immersed in endless space as opposed to the physical reality of confined space in the installation. The designed use of motion in endless runners is particularly useful for domes as it does not provide players the ability to manipulation the camera, either directly or indirectly. This is important as AstroSurf was designed as a multiplayer game, and the control of cameras in the environment would be unduly disorienting for other players and also limit the feasibility of designing an experience through camera animation.

3.3.1 The Dome Carnival Experience

Camera animation was considered a pivotal component of AstroSurf's design. Inspiration was drawn from the Gravitron amusement ride [32], also known as the Starship 3000. This popular amusement ride mounts players against the inside wall of a ring which is then rotated at high speeds to create a centripetal force, creating a sense of exhilaration for amusement riders. The Gravitron can further augment the experience on the ride by tilting the rotating. The movement on the ride is accelerated at a low rate, so although the riders may experience high centripetal forces, they are not subjected to jerks and instead smooth acceleration curves. These features were included in the design of the camera assemblage to create the 'Dome Carnival Experience', however, the maximum angular velocity and rate of acceleration was significantly reduced to provide a playable interface and create a space-like feel. The dome carnival experience system allowed for designers to craft a custom sequence which was used to design an experience synchronized in timing and magnitude with the music. This carnival experience design allowed for utilisation of the spherical nature of the dome, where players might be drawn to encircle the dome and spin around to indulge in the full panoramic display. Pitch was constrained within 30 degrees in either direction from origin to avoid disorientation, by "flipping the world upside down". Similarly, a moon is visible in the skybox to provide a constant frame of reference and is never put out of view.

3.3.2 Endless Asteroid Evasion

The principal system employed to create an endless runner experience was the asteroid system. In the scene asteroids are continuously spawning in. These asteroids are designed into waves entailing different densities and compositions of five different asteroid prefabs, each with different sizes, models, and weights. The asteroid waves are hand crafted and synchronized with the sections in the music (e.g. verse, chorus). The asteroid waves are used to create moments of danger, claustrophobia, such as when the larger asteroids and asteroid volumes are employed, void, such as when minimal asteroids are employed in a vast empty space, and playfulness, such as when special ring asteroids are timed with positive crescendos in the music, a moment that creates a temporary rainbow particle trail in the characters and increased movement speed. These waves are designed to reinforce, and be reinforced by, the dome carnival experience. The asteroid field and virtual play space is in contained in a rectangular prism with a fixed location. The asteroids move, along with a particle system in the same direction, creating an illusion of nearly infinite depth similar to the endless runner genre. A sense of progression in the seamlessly looping play sequences through these asteroids and backing sound piece.

3.3.3 Accessible and Inclusive Playful Designs

Considering the exhibition context, such as diverse set of potential players and people attending for non-game items on display, the game was designed for a casual appeal. This was marked by two design values. Firstly, AstroSurf was designed to emphasise playfulness over gamefulness, or to draw on Caillois' continuum on play [5], it was designed to exhibit paidic play. Secondly, gamefeel [28] was strongly considered, both to create a sense of strong proprioceptive connection with the dome, and towards the end of casual design, provide an audiovisual experience connected to procedural animation and player interaction. Towards the end of playfulness, outcomes were omitted from the game and formal structures were limited to the physical limitations of the virtual world, i.e. they were not playing by explicit rules. Avoiding this goal oriented structures would have also introduced difficulties, such as requiring players to wait for the start of a game, or require them to commit to a session of play until the outcome. This would have been difficult in the exhibition setting and could have created a barrier for inexperienced players. Instead, driven by playfulness, the game was designed to support players finding their own intrinsic motivations in freeplay, either to survive or self-destruct, avoid obstacles or not, and otherwise conduct themselves as they saw fit. In a loose sense, this playfulness was designed around the concept of rhythmic gymnastics with ribbons. The player gets taken on a walk through space. During this walk they can choose to move around like a space-dancer with a trail of particles behind them.

3.4 Developing Enveloping Dome Scenes

The design of AstroSurf was motivated to create an experience that took advantage of the spherical and immersive potential of the dome. Previous examples, such as Earth Patrol, created a single focal point shared between players during play. In such designs with only one focal point, players only interact with a sub-section of the dome display.This diminished its utilization of the spherical qualities of the dome display. In order to overcome this, there the game needed the possibility of more than one focal point in order to allow for a dynamism between players, their physical situatedness, and these focal points. Conventional single frustum camera setups in games would not meet our needs. They would generate a flat surface that would not take advantage of 3D environment of the dome. While such a design could be adapted to be compatible with the dome, they would introduce new difficulties. For example, they would create unacceptable levels of distortion around the equator of the dome and lend themselves to 2D-constrained virtual space. In order to meet these needs, we would need a camera setup specifically designed for the dome.

3.4.1 Render Stage 1: The Virtual Scene

To address the need for a camera setup tailored for domes, AstroSurf employed a four-camera assemblage based on Paul Bourke's design as part of a three-stage render process developed for the DomeLab. In the first stage of the render process, four cameras render out to textures. In the second stages, these surfaces are curved into a fisheye warped mesh to adjust them for the sphere. In the final stage, the spherical projection is adapted for the particular projector arrangement of the DomeLab. As seen in Figure 3, the cameras used in the first stage capture four views, perpendicular to each and other facing outward from a shared origin with each a 90 degree field of view. Their arrangement can be likened to the inside of a cube. Two 'sides' of the cube are wholly discarded as the dome is a hemisphere. In the next step, each of these textures is used in a fisheye pass. This camera assemblage afforded unlimited rotation on any axis while creating an intuitive mapping from virtual to projected space.

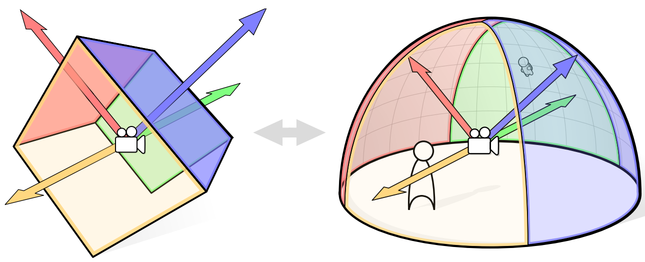

Figure 3: Frustum setup of four perspective 90° FOV cameras. Camera output passes two more render stages before reaching the dome's surface.

3.4.2 Render Stage 2: Fisheye Distortion

In the second stage, the textures generated from the first stage are each mapped onto a mesh. This can be seen in Figure 4, where each colour is a different mesh and different source texture, following the colour coding in Figure 3. This stage inevitably introduced distortion to the scene in order to map it to a curved surface. During this stage, an orthographic camera targets the fisheye circle, renders out to another render texture.

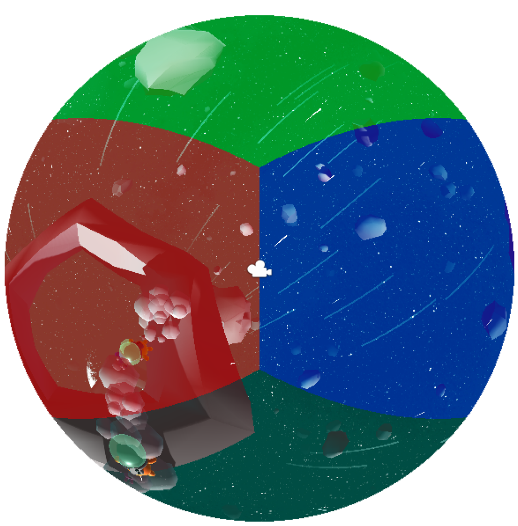

Figure 4: The frustum setup render textures are mapped to four curved meshes and subsequently rendered (visible) to a fisheye render texture using an orthographic projection.

3.4.3 Render Stage 3: Projector Mapping

In the final render stage, when deploying for the dome environment, a final render pass is made. This time the cameras render to display output instead of to render textures. An unusually wide 16:5 orthographic projection is used to capture 8 quads, as seen in Figure 5. Each quad is UV mapped to a subset of the fisheye render from stage 2. Each quad will be dissected to a separate video output at the driver level, using NVIDIA's Mosaic multi-display setup. This allows one display adapter to drive 8 displays which is more than possible in conventional display adapters. Alternatively, Unity's recently developed multi-display output could be used to target each of the 8 displays, but this can introduce issues of display output ordering, making it difficult to get each output to go to the appropriate projector. The NVIDIA Mosaic setup allows the whole scene to render as one display, simplifying the development and setup process.

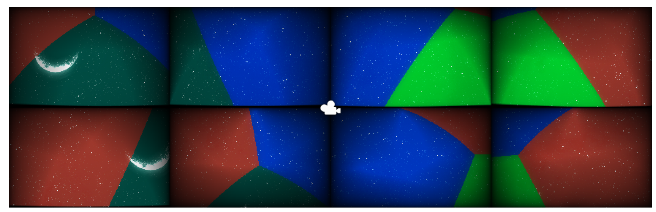

Figure 5: Each of the UV mapped quads dissect the a portion of the fisheye render texture to provide video for each of the 8 projectors.

3.4.4 Simulating the Dome Environment

Developing for the DomeLab introduced an interesting difficulty. The dome environment was not only technically different to a development environment, but markedly experientially different, in particular with concerns to space and bodily orientation. Conventionally, game development provides simulated devices that provide often sufficiently analogous experiences. For example, console development, while taking place on a computer, can typically simulate the destination environment with the use of specific hardware such as game controllers. However, when developing for the Dome, it was not possible to always use the physical dome environment for testing or conventionally simulate the experience.

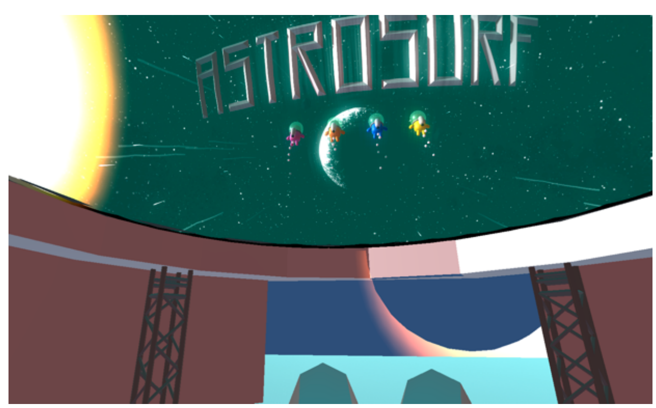

Figure 6: AstroSurf in the simulated environment

To overcome this difficulty, we play-tested within a virtual dome environment. This process entailed UV mapping the output from render stage 2 to a virtual DomeLab, seen in Figure 6 . A first person controller, mapped to mouse and keyboard, was used to simulate the player (as in body). The first person camera would output to the test computer's monitor as a conventional first game. Game controllers were used, as in the dome environment, to control the player's avatar (as in the astronaut). This generally required one person to "play" the player and other players to play the avatars.

Further developing on this technique, we explored virtual reality (Oculus Rift DK1) for the first person controller, but this introduced additional performance bottlenecks and prevented multiplayer testing. This simulation environment was effective at capturing the spatial context and user's control over viewing perspectives. Unfortunately, this technique was not useful for simulating other aspects in the located and co-located environment of the dome, such as physically moving around, lying down, sense of physical closeness with other players, and other social aspects.

4. THEMES FOR DESIGNING FOR DOMES

Through the design and evaluation of AstroSurf several insights emerged. These insights were constrained to those that affected game and interactive experience design for domes, although these insights may have extended utility outside of designing for domes and this has been identified where possible. The insights have been coded into three primary themes relating to intersection between dome design and: co-location, interface including interaction and display, and exhibition settings.

4.1 Co-location in the Dome Environment

4.1.1 Lying down and standing up

Lying down emerged as an unexpected phenomenon during the exhibition. The game was designed in anticipation of standing players. As part of this, the projection arrangement was designed to prioritize activity over the equatorial edge, which is discussed in the following section on dome interaction. This would allow players to engage with the dome without inducing excessive strain on their necks by raising their heads to view the pole of the projector. During the exhibition, large floor pillows were provided for the dome. This afforded lying down and playing, however, this was against the design's intent, but provided a point of contrast in understanding dome interaction. Players who opted to lie down were unable to readily turn around. This constrained their viewing perspective to one orientation within the 360° dome. Consequently, this required greater skill in navigating their astronaut into their visible subsection and cognitive skill, in empathising with the avatar's forward vector from irregular angles, instead of being able to adjust both bodily orientation. This in effect both worked against the intention of utilizing player perspective as an interactive component of the navigating the projected virtual space by constraining players' ability to change their perspective, but conversely highlighted the significance of perspective as different players would have easier or more difficult times in navigating different scenarios from different orientations within the dome. A sense of spatial presence [23] is afforded by the dome. This presence is evoked with interactions within the physical context, such as bodily movement, and relative orientation of the body within the dome. These physical factors extend are major points of influence in the player's game experience, highlighting orientation and perception beyond a theatre projection or large-scale monitor that may be easily viewed from one angle.

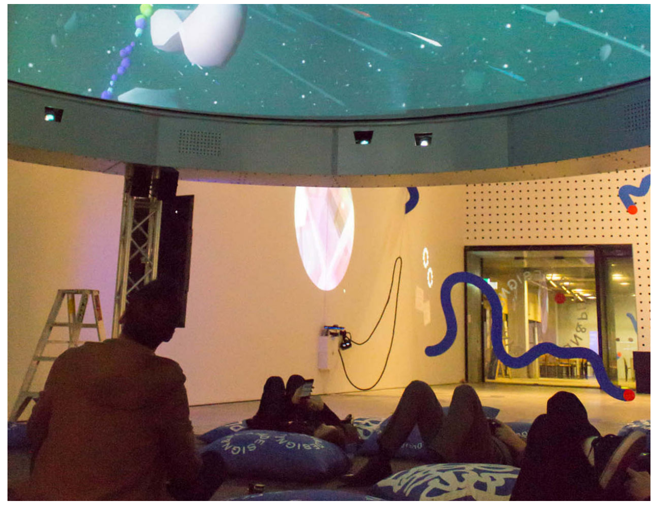

Figure 7: Players lying down, enjoying the atmosphere and intimacy under the dome.

4.1.2 The closed space under the dome

During the exhibition the DomeLab was positioned in the middle of a long and well-lit room. Usually the dome would be curtained off, but for safety reasons it was not for this event. Despite this, playing under the dome created a strong sense of enclosure and disconnect from the rest of the environment. The space clearly delineated being in, or out, of the dome, and the enclosure of the dome afforded playing and spectatorship only from within this space. If part of a group were to play, there was a sense of gravity in drawing in the entirety of them. Close proximity and shared interpersonal space were notable factors in enhancing the sensory experience. Particularly, the title was able to evoke a degree of proxemics play through the strategy of challenging players' cultural norm [22] of not interacting with strangers in public settings. The atmosphere, notably lighting, sound, and the visibility of the game, all created a space that felt disconnected from the rest of the exhibition, and contributed to a sense of being in space, disconnected from the world. Furthermore, families, groups of schoolchildren, and pairs of players would pull pillows together into clusters to form a more intimate yet sense of space under the dome. Conversely, complete strangers would find their avatars and themselves juxtaposed with new strangers. Combined with the atmosphere, theme, and dynamism of the camera controller, there was a sense of sharing the ride with strangers, creating a kind of carnival "co-experience", as outlined by Battarbee [1].

4.2 Interacting with Dome Interfaces

Domes are spherical and provide a larger physical environment. These present opportunities for designing games that take advantage of physical situatedness. This shifts part of the game's design into the physical environment that play occurs in, whereas screen based game design typically focusses on the virtual environment. As part of this physical design, elements of the body in play become salient, such as player orientation, player positioning, and the physical relationship between players. One of the primary elements, player perspectives, in particular whether they are oriented toward the pole (standing at the edge looking inward) or toward the edge (standing at the pole looking outward), as summarised in Table 1, which we will unpack in this section.

Table 1: Player Orientation vs. Interactive Qualities

	Towards Pole	**Towards Edge**
Body Language	Juxtaposed	Side by Side
Perspective	Overlapping	Mostly differing
Proximity	Distant	Close
Locus of Play	Virtual	Physical
Experience	Cinematic	Enveloping

4.2.1 Enveloping & Cinematic Experiences

Domes can offer enveloping or cinematic experiences. In enveloping experiences, players feel surrounded by the dome and disconnected from outside environments. The spherical design of the dome reinforces this experience and can be utilised by designing for changing player perspectives, with weight given to the equator. Players standing beneath the pole looking at the equator can see only a subset of the dome. When combined with proprioceptive feedback, such as sound design and other players, players can be made aware of game events that they cannot see. This can heighten their sense of being surrounded as they turn to look for these events. This re-orientation of players and heightens the impact of depth and panoramic viewing and is supported without seams in the viewing space, such as corners in a CAVE, or height boundaries, such in 360 panoramic displays. Designers seeking to maximise the enveloping dome experience should consider supporting fluid movement in the dome environment and include game mechanics that evoke player reorientation. AstroSurf achieved this by rotating the camera assemblage, players reoriented themselves within the dome, as they followed their avatar. Through this, players sense of the enveloping nature of the dome is highlighted. This effect was more strongly achieved through rotation as opposed to translating the camera assemblage and as this was possible and sensible in the dome, due to its spherical nature, it suggests that this particular dynamic enveloping experience is only possible in domes.

Contrasting the enveloping experience, when players look toward the pole they are able to see the majority of the dome at once. This evoked a more cinematic experience. When players and spectators look toward the pole, in particular if they are lying down, they are able to see most, if not all, of the dome. This creates a diminished need to move or reorient within the dome environment in order to view different perspectives. As such, the cinematic experience might better suit an environment where players lie down and are less able to move around. When looking at the pole, what is visible to players might be perceived as flatter, or without depth and their bodily sense of being enveloped by the dome is also diminished. Games being designed for a more cinematic experience should consider perspective agnosticism. This means that the game is intelligible and playable regardless of perspective. Due to the lack of perceptible depth, a game played within 2D space and with axial input mapping, such as the 1962 classic Spacewar, might be an ideal format as it is perspective agnostic. Specifically, input can be mapped to rotation and local thrusting. Otherwise, fixed perspective designs would require players orienting in a particular way, such as in a theatre or cinema. This constrains other perspectives, consequently giving primacy to a subsection of the dome. This would create a focal point, likely around the pole of the dome, and undermine the advantages of the hemispherical panorama. However, perspective dependent designs would be a simpler adaptation when porting games designed for conventional display technology.

4.2.2 Orientations for Multiplayer Experiences

For standing players, only part of the dome is visible at a given orientation. This can be useful in providing a way to seamlessly sub-divide play space, as an alternative to conventional techniques such as split-screen. Furthermore, the dome distinctly allows for convergence of multiple perspectives around the pole, as seen on in Figure 8, that can be seamlessly shifted and re-divided toward the equator. If players' focuses are divided players can operate in different virtual space. Conversely, their perspectives can overlap, increasing their multiplayer agency and interaction in the virtual space. Players might be focused on their orientation with respect to the dome, but this will also affect their interpersonal body language.

The differing interpersonal stances can be used to foster experiences that maximise either cooperation (side by side) or competition (juxtaposition). This could be particularly exploited in games that include physical or exertion interactions within the dome. Furthermore, overlapping viewing perspectives may be useful in reinforcing competition by placing players' avatars in shared virtual space where they can interact. Likewise, differing perspectives could be used to present players information asymmetry problems, where they cooperate to resolve them by each viewing differing subsections of the dome. In the case of any designs aiming to use the body, there is an interesting compatibility for players that are positioned near the pole. These players are firstly in closer physical proximity, allowing them to physically interact, and additionally are inclined to be more aware of their bodily environment, as they are looking toward the edge. This shifting spatial awareness towards physical space better supports physical interaction.

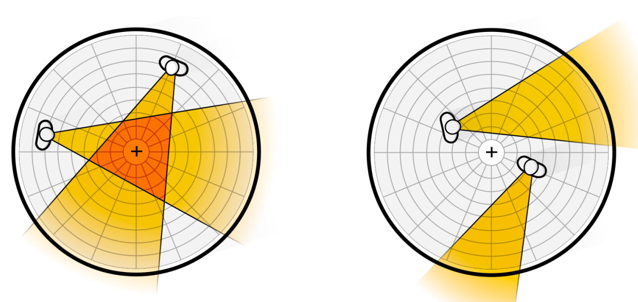

Figure 8: Differing perspectives can create distinct interpersonal dynamics.

4.2.3 Immersion in Dome Games

According to Wiebel and Wissmath immersion can be considered in two main constructs in terms of games, spatial presence and flow [31]. Spatial presence in a dome environment can be be realised in two ways. When players focus on the activity on the dome, they can immerse themselves in the virtual world and develop a virtual spatial presence. This is the typical sense of being "in the game". However, the dome, being a physical environment, can generate a physical-spatial presence within the dome environment.

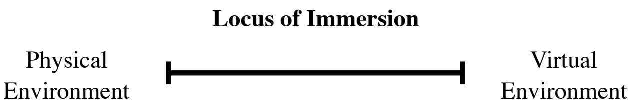

Figure 9: Domes provide physical and virtual interactive contexts for immersion that compete for the player's sense of spatial presence.

These two senses of spatial presence can be seen as exclusive to, and competing with, one another, as plotted on a continuum in Figure 9. Depending on how the game is played, the locus this spatial presence will shift. For example, players lying down or otherwise less engaged with their physical environment shift that locus toward the virtual environment and controlling their avatar. Players engaging with physical and social play within the co-located environment shift their locus of immersion towards the physical environment. Flow, described as immersion in the task of playing the game [31], is a mental state that transcends the context of play. This suggests that flow can persist through shifting a locus of spatial presence.

4.2.4 Relative Input Controls

One of the sources of both joy and frustration was the input mapping for the player controller. The controls allow for players to rotate their yaw, pitch, and roll, while thrusting along their local up vector. This is analogous to the classic Lunar Lander game, but extended to three dimensions. As the game in the dome needed to support multiple and indeterminate player perspectives, it was not possible for certain techniques to improve playability using techniques employed in non-dome games, such as mapping controller input to movement vectors instead of rotation, such as seen in platformer games such as Super Mario. These conventional games benefit from a fixed and known player-interface orientation. For example, with a monitor it can be expected what is 'up' and what is 'forward'. During the design process, two alternative dome-controller-interfacing techniques were devised. The first technique is seen in Figure 10.

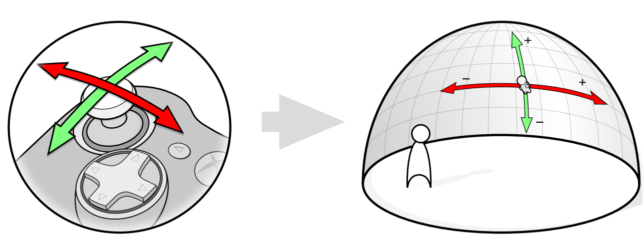

Figure 10: Constraining playable space to the 2D surface of the dome allows for intuitive controls.

This input technique was discarded for AstroSurf because it effectively constrained playable space to a 2D plane that wrapped around the dome. Consequently, this diminished the interactive aspects of depth in the game. Another technique, seen in Figure 11 would allow for this intuitive platformer input mapping. This technique would require input sensing that was able to detect players viewing orientation, such as by tracking their eyes. By using their viewing perspective as a forward vector, input could be mapped similarly to as if they were playing on a monitor. This solution, however required hardware unavailable to the platform and outside of the scope of this project, but could be utilised in future dome interface designs.

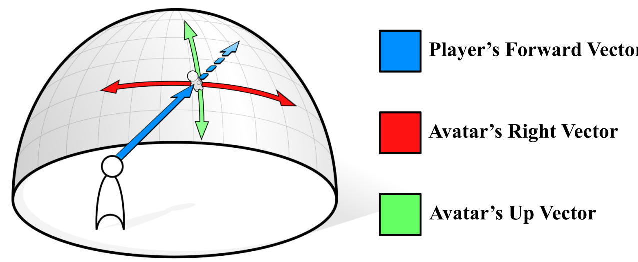

Figure 11: If the player's viewing perspective is known, it can be used as the forward vector to create intuitive platformer controls.

4.3 Designing for Exhibition

Dome platforms tend to be larger than conventional gaming platforms, such as PCs, consoles, and even other nonconventional game installations. As a side effect of this, they are infrequently, if ever, moved. Fortunately, AstroSurf was able to be designed and deployed on one of the few portable domes, UNSW's DomeLab. However, even then the operation of moving, re-building, and re-calibrating the dome was significant. As part of this, designers should consider the contexts in which domes will be accessible to an audience. In the case of AstroSurf for the DomeLab, this meant availability during a design exhibition at a University. Furthermore, the endless cycling structure and lack of competitive structures within the game's design supports 'interruptibility' [3]; multiple players and spectators may switch in and out of play without interrupting the experience. In addition the game may be kept running when exhibited, even when not played, allowing for potential players or an audience to step in at any time. While most domes may be permanent installations, such designs can still consider public or semipublic, and multi-user or multi-player interaction.

4.3.1 Design for an Audio-Visual Experience

Despite the intention of exploring play in AstroSurf to understand the interactive possibilities of domes, the noninteractive audio-visual components of design were still a leading parameter in design. Domes are capable of encapsulating many participants, but it may not be possible to have all of the participants as active players due to technical and design reasons. Furthermore, in an exhibition setting participants might not be interested in playing games, but still engaging with what's on exhibition to some other capacity. Consequently, drawing on the fundamental strengths of the dome can help create a spectacle, whether media, play, or performance. In AstroSurf an energetic backing track was composed to contribute to this 'carnival' experience detailed in the previous section. By creating wonder and full-scene activity, casual audiences were still able to appreciate the experience in a non-interactive way, drawing on the immersive qualities of the dome space outlined by Schnall et al. [26]. During the exhibition families and larger groups, frequently up to a dozen, came through the exhibition. AstroSurf provided an environment where parents could sit down and enjoy watching their children play before taking a turn and other players stayed to for times up to 30 minutes to view the game, even when they would not rotate into play. For some players, AstroSurf was a dynamic stargazing experience, enjoying some of the thrill of an amusement ride.

4.3.2 Domes for Short Plays: Drop-in/Drop-out

AstroSurf worked effectively in the exhibition environment by supporting drop-in/drop-out play. The dome supported the drop-in experience by allowing for players to physically move into the dome environment during play, without disrupting other players such as by blocking their visibility of the dome. This would not be possible with physically enclosing environments. With respect to the game, it was designed to a 6-minute loop without keeping score and allowed for up to 4 players. This provided an experiential or playful motivation to the game as opposed to motivations of competition or mastery. This is similar to Bekker et al's principle of 'open-ended play' [2] which was noted as useful for stimulating social interaction and engagement during play. Furthermore, the powerful audio-visual experienced created an experience that non-players could enjoy, including spectators and zero-player runs.

4.3.3 Consider Usability and Motion Sickness

When designing for a broad audience, designers should consider the usability and accessibility of their game. In initial consideration of AstroSurf, strain on players' necks while standing and looking up along with usability of controls were concerns. During early deployment and exhibition of the game, a few other concerns arose. The nature of the projection and the inability to curtain off the dome created a high-dynamic-range between the lighting inside the dome and that outside. This generally reduced the visibility of low-contrast imagery. For players this was not generally a problem, however the scene and skybox were modified to maximise contrast. Furthermore, overall design of the scene included a limitation of objects to reduce clutter and allow players to better follow the action. This did increase the difficulty of photography, but that was outside of the domain concern for the project. In addition to this, at least one player experienced some kind of vertigo or motion sickness. This suggests that the immersive environments of domes might face some of the embodiment and proprioceptive dissonance as seen in virtual reality interfaces [8] and other interactive immersive spaces [7], however we were unable to isolate the underlying cause. This may have been caused by the rotation of the entire camera assemblage to create the carnival experience detailed in the earlier section.

5. CONCLUSIONS

This paper investigated a novel dome game called AstroSurf. This investigation was guided by the questions "what kind of interactive experiences can domes support?" and "how can these experiences be designed for?" Domes can support an 'enveloping' interactive experience where players feel contained within and surrounded by the dome. This experience is supported by evoking proprioceptive reaction to the spherical display during play. Specifically, game events in the surrounding environment that can be heard, but not seen, can evoke bodily reorientation and a sense of being surrounded. Bodily elements in play can be further supported by utilising the physical context of the dome. For example, when designing for multiple players, the dome can provide a physical environment for physical and social play. Additionally, unlike physically bounded environments, the dome supports drop-in/drop-out play, without undermining the immersive experience, as players can physically enter and exit the dome during play, without interrupting its operation. This makes the dome ideal for public settings where a 360° enveloping experience is desired.

In order to support this enveloping experience, the camera frustums and interactive space need to be designed appropriately. This paper details a camera assemblage that supports spherical operation, including three-axis rotation. Designers should consider 360° playable virtual space and creating multiple dynamic focal points in order to evoke shifting bodily perspectives. Designed perpetual and dynamic rotation of the camera assemblage, such as in the game's 'carnival experience', can further reinforce an enveloping experience. In multiplayer contexts, these shifting focal points can be utilised to create overlapping perspectives, or shared virtual spaces, at the dome's pole and shift players' towards juxtaposition or alternative interpersonal stances. Designing interaction for domes, especially with multiple players, can be difficult. To address this, the paper explores three potential input schemes with Xbox controllers, ultimately employing a mapping to manipulate the avatar's local space. Finally, play in domes can operate in both physical and virtual spaces. Designers should consider how play interacts between these two spaces, such as by considering shifts in the locus of play.

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