# Redirection Masking Strategies: Understanding the Implementation and Application of Redirection Techniques in Research and Practice

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**Abstract**

Redirection techniques aim to enlarge the available physical space to freely explore virtual environments using natural locomotion. Various techniques have been introduced that reposition or reorient the user by manipulating the senses or the surrounding geometry of the environment. We introduce redirection masking strategies: the layers in between the redirection technique and the player, aiming to ease the user into the manipulation or to make it imperceptible. In this work, we provide a framework regarding the usage of the masking strategies and review their mechanics and implementations from the data extracted from both research, commercial VR games and technical prototypes. Furthermore, a reworked classification of redirection techniques is included, which aims to resolve the ambiguity of terminology within the research domain.

## 1 Introduction

Locomotion is the physical or virtual traversal of oneself through an environment. In physical environments, people move from one point to another in space using gait (the manner of walking). This is harder to achieve in virtual environments due to physical tracking space limitations and the fact that these can be considerably larger than where the user is physically situated. Numerous solutions have been proposed to overcome this issue, from digital locomotion techniques in virtual reality, such as joystick movement or simple teleportation features in most VR devices, to the development of treadmills, a solution more expensive than others but it does enable freedom of movement. Natural walking increases the sense of presence (Usoh et al., 1999) compared to other locomotion techniques, as it generates the same proprioceptive and vestibular cues as walking in the real world.

Various researchers have introduced other methods to facilitate the exploration of larger virtual environments using natural walking in smaller physical spaces called redirection techniques. These alleviate the space problem of natural movement by subtly or overtly repositioning the user's location within the environment or by reorienting the mapping between their virtual and physical paths during the experience. Within the literature, there is no clear definition of what redirection techniques entail, but all agree on the same goal: allowing users to walk freely within a virtual environment. In our case, we globally define redirection techniques as a collection of approaches enabling users to explore a larger virtual environment than space restrictions within the physical environment allow for. Hence, we use the broader definition (redirection techniques) than the commonly used 'Redirected Walking', as we include other techniques not mainly applied to the player's movements. A more appropriate terminology would be welcome, but currently, this is the most accepted definition within the research domain.

Examples of various techniques ranging from imperceptibly altering the environment's geometry (Suma et al., 2011; Suma, Lipps, Finkelstein, Krum, & Bolas, 2012; Vasylevska, Kaufmann, Bolas, & Suma, 2013) to manipulating rotations and translation movements of the user during movement (Razzaque, Kohn, & Whitton, 2001; Williams et al., 2006) have been used extensively within the research domain. Additionally, many other methods enable natural walking within a limited physical space without actively manipulating the user's motion or surroundings. For example, virtual elevators or escalators reposition the player virtually whilst standing still, or seemingly impenetrable objects inhibit the user from walking in a particular direction within the virtual environment. Therefore, our interpretation of the 'Redirection Technique' includes various other techniques that differ from the current convention. Which include, but are not limited to, the manipulation of movement or other exploits.

Furthermore, researchers started to include virtual objects within their experiments to mask some redirection techniques which influence the player's movements (T. C. Peck, Whitton, & Fuchs, 2008; Cools & Simeone, 2019; Chen & Fuchs, 2017; Rewkowski, Rungta, Whitton, & Lin, 2019). Visual or auditory objects can be used to mask subtle changes in orientation or alterations to the geometry of the virtual environment, but many more are still to be discovered. Therefore, if redirection techniques such as rotational gains, translational gains or impossible spaces are the actual manipulations, then masking strategies are the facilitators who operate between the manipulation and the player, easing them into the alteration and making it completely undetectable. In other words, while being part of the same entity, redirection techniques seek to fulfil a particular goal or aim regarding how the user should be enabled to explore the virtual environment freely. The Masking Strategies have a more supportive role, they are the building blocks of how the redirection technique achieves its objective of enabling free exploration by masking the exploit.

However, there are some problems within the research domain. Firstly, the overall definition of the term redirection is ambiguous and varies between research articles. Secondly, the proliferation of new techniques to implement redirection results in new labels being introduced into the literature on an ongoing basis, making it difficult to distinguish the differences between the individual techniques. Thirdly, it is essential to relate redirection techniques contextually to specific virtual environments or narrative settings (e.g., real-world game environments). In contrast, most experiments were conducted in basic experimental environments that lack ecological validity.

Aside from the introduction of new terminology within research, some researchers have attempted to provide structure to the field of redirection techniques. One study by Suma et al. (2012) aimed to categorise redirection techniques according to their geometric flexibility against the likelihood of detection by the user. Subsequently, various researchers have given a rundown of specific redirection techniques (Nilsson et al., 2018; Vasylevska & Kaufmann, 2017a). In our previous work (Vries & Putten, 2022), we introduced the concept of redirection masking strategies. Here we created a preliminary framework which explored the various methods available. However, while we assumed that more strategies were available, we mainly delved into the 'Attention Diversion' masking strategy due to the limited scope of the research.

In this work, we will extend our redirection masking strategy framework based on the analysis of ‘encounters’. These are moments within an experiment or experience where the player comes in contact with a redirection technique and a masking strategy within a specific environmental or narrative context. These encounters have been extracted from 35 research papers and 9 commercial VR games and technical prototypes.

Secondly, we will provide a reworked classification of the redirection techniques based on how they aim to enlarge the virtual exploration space and enable natural walking. This classification is based on definitions and characteristics from the literature. It includes techniques we could deem as a masking strategy using our perspective regarding redirection techniques and the introduction of our framework. When these techniques and their masking strategies are implemented and applied correctly, their insights could benefit researchers and developers in creating engaging experiments or experiences.

The remainder of this paper is structured as follows. Section 2 briefly reviews key concepts and related work on frameworks and definitions of redirection techniques and masking strategies. Secondly, in section 3, we delve into our research approach and elaborate upon our preliminary framework, where we go into more detail on the available individual masking strategies. After this, in section 4, the data collection and extended framework are elaborated upon, including a reworked categorisation of the redirection techniques presented in section 5. Finally, the thesis ends with a discussion and conclusion (section 6 and section 7).

# 2 Related Work

This section will give an overview of a selection of redirection techniques, providing insight into their definitions and how they are categorised. This summary of techniques is included in this paper to give some context on the inner workings of common approaches. It could be possible that some listings are defined as a redirection technique in this section but will be referred to as a masking strategy in later sections. This is because the techniques were introduced by authors who could have different points of view about what a redirection technique is. Therefore, this section will act as a baseline for the different categorisation schemes and definitions regarding the technique upon which we built our framework. Subsection 2.1 will outline the discussions regarding the categorisation of redirection techniques within the literature. Subsection 2.2 will briefly elaborate on the most prominent techniques, which are later reclassified in section 5.

## 2.1 Categorisation of Redirection Techniques

Many researchers have attempted to categorise redirection techniques, but within the research domain, there is an ambiguity regarding the definition of a redirection technique. Research by Suma et al. (2012) introduced a taxonomy of redirection techniques based on how the technique was applied within the virtual experience and the likelihood of it being noticed by the users. According to the study, redirection techniques aim to reposition or reorient the player during the experience, and the method could be overt or subtle. The manipulation would be visible to the user with overt techniques, whereas subtle techniques aim to remain imperceptible. Within the study, the researcher refers to redirection techniques as: “a promising approach that relaxes the space requirements of natural walking by manipulating the user’s route in the virtual environment, causing the real-world path to remain within the boundaries of the physical workspace”.

Another work does not refer to ‘redirection techniques’ as the chosen umbrella term for the manipulations, exploits or other methods. Instead, they refer to ‘spatial compression methods’ that enlarge the walkable virtual space (Vasylevska & Kaufmann, 2017a). Within the work, they introduce four types of spatial compression methods: basic reorientation, sense manipulation, rendering manipulation and 3D scene manipulation. The first method involves basic approaches that stop the users at the boundaries of the tracking space and prompt the user to reorient or reposition within the physical space manually. Secondly, sense manipulations involve one class of techniques called redirected walking, a self-proclaimed classification commonly used for redirection techniques that apply gains to the user's movement. Thirdly, rendering manipulations apply manipulations directly to the rendered output of the VR experience. Finally, scene manipulations only involve the manipulation of the surrounding environment and geometry, such as the impossible spaces redirection technique.

Within the research of Nilsson et al. (2018), they categorise the manipulation techniques under two sections and another definition. Firstly, redirected walking techniques that manipulate the mapping between the physical and virtual movement of the user, steering them away from the boundaries of the tracking space and other obstacles. And secondly, redirected walking techniques that alter the architectural properties of the VE (virtual environment). However, apart from the classification, their definition of redirection techniques is that they: "manipulate the physical transformations of the user's movement within the VE so that motion is no longer mapped 1:1, or they manipulate the physical characteristics, e.g., the architecture, of the VE". Regardless, the authors mention redirection techniques as the main method of allowing users to freely explore a large virtual environment. However, the authors make the distinction between walking and non-walking (or relocation techniques) techniques and refer mostly to walking techniques (thus, 'Redirected Walking').

Interestingly, we can see from these examples that the interpretation of redirection techniques differs between the articles, which all have different contexts and focal points: one focusing primarily on techniques which include walking as the dominant locomotion mode and others utilising and defining techniques as spatial compression methods. Fortunately, there is a consensus regarding the aim of redirection techniques: enhancing the physical space using approaches which enable the user to walk within the virtual environment naturally. The following subsection will elaborate on a variety of redirection techniques.

## 2.2 Overview of Redirection Technique definitions according to literature

A selection of 11 prominent redirection techniques from the literature is available in Table 1. The initial publication of the redirection technique and the author's original definition are emphasised. While the selection has been characterised as a redirection technique by its original resources, we might classify it as a masking strategy instead during this research or omit the item as a redirection technique or masking strategy entirely.

Redirection techniques clustered within the 'Redirected Walking' classification are rotational, translational, curvature and bending gains (see Figure 1). Rotational gains impose an addition on the yaw rotation within the virtual scene or the camera. Head orientation (or head pose) can be specified by three angles: yaw, pitch, and roll. Rotational gains could be applied to each of these three angles. Still, prior research only includes the yaw rotation, the most manipulated rotation for redirected walking (Steinicke et al., 2010). Translational gains take the positional information of the user while traversing in the virtual environment and inject a manipulation when the system detects a change in the user's real-world position. This technique actively scales the translational movement of the user up or down. This allows the exploration of considerably large virtual environments within a constrained physical environment. Curvature gains create the illusion of walking in a straight path within the virtual environment while walking in a curved path in the real world due to compensating for undetectable offsets within the perceptual system. With bending gains, the

| Redirection technique | Author | Definition |
|---|---|---|
| Rotational Gain | (Razzaque et al., 2001) | *"... works by interactively rotating the virtual scene about the user, such that the user is made to continually walk towards the farthest 'wall' of the tracker area. The user does not notice this rotation because the algorithm exploits the limitations of human perceptual mechanisms for sensing position, orientation and movement."* |
| Translational Gain | (Williams et al., 2006) | *"One way to increase the amount of space explored is to change the translational gain of the system, so that one step forward in the physical environment carries one several steps forward in the virtual."* |
| Distractor | (T. C. Peck et al., 2008) | *"Our method introduces the concept of a distractor. an object, sound, or combination of object and sound in the VE (Virtual Environment) that the user focuses on while the VE rotates, reducing perception of the rotation and, thus, reducing the likelihood of a break in presence."* |
| Curvature Gain | (Steinicke, Bruder, Jerald, Frenz, & Lappe, 2010) | *"Instead of multiplying gains with translations or rotations, offsets can be added to real-world movements ... If the injected manipulations are reasonably small, the user will unknowingly compensate for these offsets resulting in walking a curve."* |
| Change Blindness | (Suma et al., 2011) | *"... redirects the user's walking path through subtle manipulation to the geometry of the virtual environment model. Since building architecture does not spontaneously change in the real world, we believe that users will unconsciously assume that the architectural layout of the virtual world is fixed."* |
| Impossible Spaces | (Suma et al., 2012) | *"Impossible virtual environments contain geometry that violates the rules of Euclidean space, and therefore cannot exist physically in reality. While there are many potential ways in which virtual content may transgress physical laws, for the purposes of maximizing effective walking space, we focus on one specific type of Euclidean violation: self-overlapping architecture"* |
| Bending Gain | (Langbehn, Lubos, Bruder, & Steinicke, 2017) | *"Bending gains are similar to curvature gains, as they combine walking and rotations, but are applied to curved paths instead of straight paths. In a similar way, this kind of redirection can be achieved by combining curvature and rotation gains. However, the definition of bending gains is useful in cases where the curvature of the virtual path is known ..."* |
| Deterrent | (T. C. Peck, Fuchs, & Whitton, 2011) | *"... we introduce a new technique, deterrents—objects in the virtual environment that people stay away from or do not to cross."* |
| Inattentional Blindness | (Joshi & Poullis, 2019) | *"In our work, we leverage Saccades to refresh the foveal zone render and therefore redirect the user multiple times per minute during blinks."* |

Table 1: Various Redirection Technique Definitions from Literature

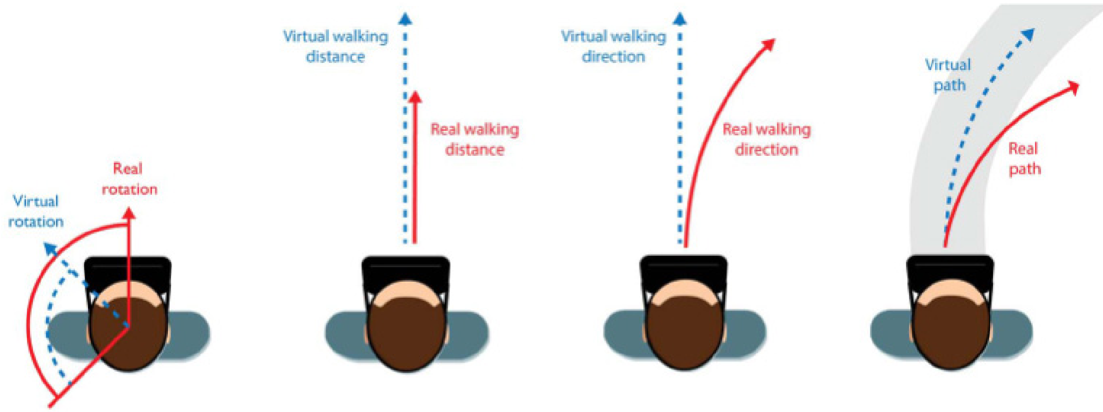


Figure 1: Overview of the various Redirected Walking Techniques (Nilsson et al., 2018)

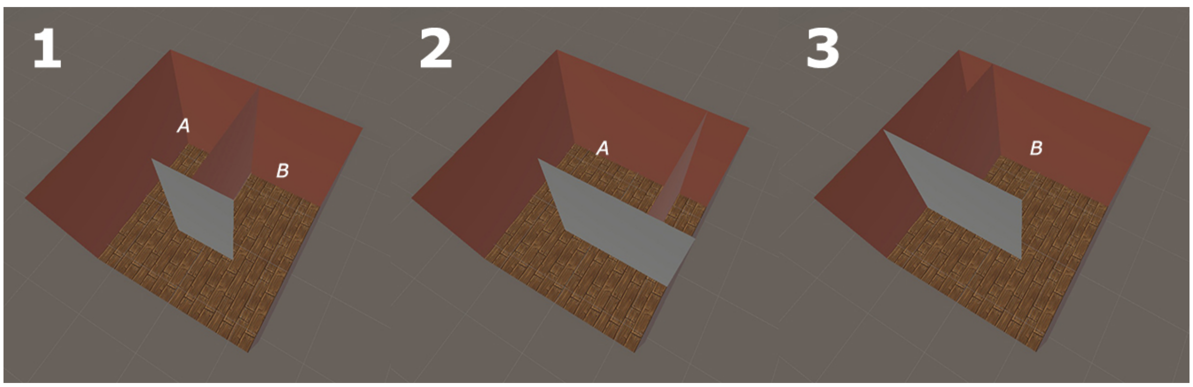


Figure 2: A simple use case of Impossible Spaces: In state 1, room A and B are the same size; in state 2, room A overlaps room B and in state 3 room B overlaps room A.

virtual and the physical paths are curved instead of perceiving the virtual path as straight. The users are guided on a physical path with a different curvature than the path they are walking on within the virtual environment (Langbehn et al., 2017). Bending gains are estimated by comparing the user's position and orientation in the environment to the user's position and orientation in the physical world.

While other manipulation methods apply alterations to the user's movements, non-Euclidean spaces are environments that do not follow the fourth property of Metric Space: that all right angles are equal to one another. By breaking this property, larger virtual environments can fit into the same limited physical space. These techniques utilise the human perceptual ineptitude of detecting these spaces defying the laws of physics. Due to this, researchers and designers can create virtual environments that overlap in physical space, hence the terminology 'Impossible Spaces' or 'Self-overlapping architecture'. Using this knowledge, Suma et al. (2012) implemented non-Euclidean geometry within their experiment to reduce the severity of the restrictions imposed by limited physical space. "Impossible Spaces" maximises the size of the virtual environment that can be explored with natural locomotion. Such spaces use self-overlapping architectural layouts, compressing comparatively large interior environments into smaller physical spaces (see Figure 2).

The distractor technique is introduced in the work of Peck et al. (2008). These virtual objects

Figure 3: The leftmost illustration depicts an early distractor object in the form of a butterfly (T. C. Peck et al., 2008). The rightmost illustration represents a deterrent object as horizontal bars (T. C. Peck et al., 2011).

combined with redirection techniques imperceptibly apply gains to the user's movement. By implementing moving objects within the virtual environment, the user's attention gets diverted from the manipulated environment around them. Initially, distractors were deemed to aid in the discreet rotation of the virtual environment when they realistically fit the environment and the narrative of the experience. They should be implemented to naturally distract the user in the virtual environment by employing fluid, easy-to-follow motions. Contemporary examples have incorporated support for other sensory modalities, including audio, touch, or a complex combination of multiple interactions. One experiment by (Rewkowski et al., 2019) used auditory triggers to distract users in complex scenarios such as crossing a street and avoiding obstacles. Additionally, (T. C. Peck et al., 2011) introduced the deterrent technique. Objects within the virtual environment that users would actively avoid when encountered guide the user away from the physical boundary. Within the work, they visualised the deterrent as bars blocking a passage (see Figure 3).

Change Blindness redirection is a technique that applies slight, undetectable alterations to the virtual environment outside of the user's field of view (Simons, 2000). One of the first applications of change blindness within a virtual environment was by Suma et al. (2011), where participants explored a virtual apartment much larger than the available physical space. Upon entering a room, the door would flip 90 degrees, allowing the participant to walk around the apartment. Another example is inattentional blindness, the inability to detect an unexpected item within the visual field. In a famous experiment (Simons & Chabris, 1999), participants were instructed to watch a basketball match and count how many times the ball was passed around. However, after some time in the match, a person dressed as a gorilla would walk around the playing field for approximately 5 seconds. Remarkably, results showed that nearly half of the participants didn't see the gorilla appear in the video.

## 3 Research Approach

This section describes the general research approach, in which we give a brief overview of the methods and contributions. Furthermore, the preliminary theoretical framework will be elaborated upon, including the following addition to the field: the introduction of redirection masking strategies.

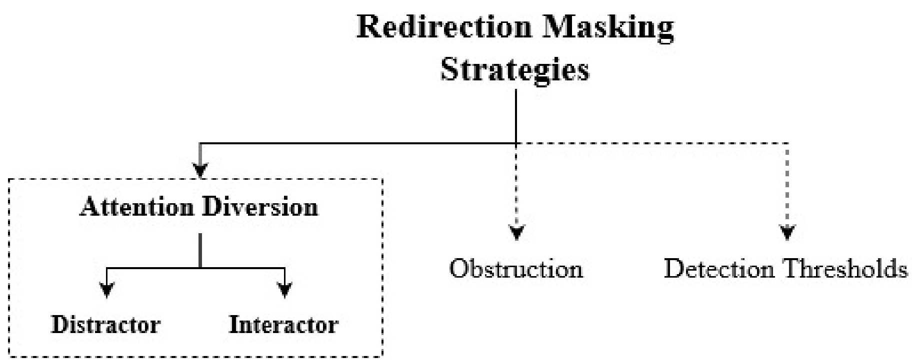


Figure 4: Overview of the preliminary framework (Vries & Putten, 2022)

## 3.1 General Research Overview

In our prior research (Vries & Putten, 2022), a general understanding of the usage and implementation of redirection masking strategies was created: a method used to reduce the redirection technique's noticeability and ease the player into the manipulation, exploit or other methods. The framework was constructed by conducting a literature survey of 11 papers and extracting the encounters. However, this work was based on a small segment of academic research and included limited redirection techniques, as the focus was on the 'Attention Diversion' masking strategy. This work aims to analyse VR experiences or experiments from academia and industry that incorporate redirection techniques into their applications. Encounters from these experiences will be extracted where the user comes in contact with a redirection technique, including a masking strategy.

After collection, inductive thematic analysis will be used to form the base of the improved framework. A continuous evolutionary process will be utilised to implement alterations and additions to the resulting framework. Iterative versions of the framework will not be generated as the process is naturally fluid; each addition or change will be added instantly. By analysing the extracted implementations of redirection techniques from both papers and VR games or prototypes, we will create themes using mind-mapping methods that aid in creating the masking strategies. Further elaboration on the collection process will be provided in section 5.

Secondarily, our contribution includes a new classification of redirection techniques based on data from academic and commercial sources. This will aid in understanding the differences in implementation as we categorise how these techniques aim to enable the free exploration of a virtual environment using natural walking. Our prior work from the collected encounters will be extended to include additional masking strategies to the "family tree". We assume that previously unknown masking strategies will be uncovered as the preliminary framework and knowledge of redirection techniques is primarily based on academic literature. We expect that the inclusion of data sources from commercial VR experiences (from industry or other platforms) will result in the extension of our framework. Furthermore, we assume that the analysis of the academic and commercial experiences and experiments will provide knowledge on the applied use and implementation of the redirection techniques in combination with the masking strategies and provide instructions on correctly incorporating the techniques to developers and academics.

## 3.2 Preliminary Framework

Masking strategies are the layers between the player and the redirection technique that ease the user into the manipulation or make it entirely undetectable. We believe most redirection techniques

Figure 5: A preliminary experiment testing the effectivity of the Interactor objects, based on the Change Blindness Redirection experiment (Suma et al., 2011)

that subtly manipulate the user's perception or alter the virtual surroundings must include a masking strategy. The masking itself could be an object, part of the environment or even physiological aspects of the human visual system, such as blinks and saccades or exploits in multisensory interactions. In essence, the masking strategies are a part of the redirection technique in how it tries to enlarge the available space for the user to explore. While mostly incorporated within the redirection technique or even defined as a technique by itself, most masking strategies were undetected and unmentioned within contemporary literature.

Therefore, after discovery, the strategy was dissected from the technique, creating a new understanding and categorisation of utilising redirection in experiments and experiences. During the exploration and formation of the framework, it was found that several secondary additions could be applied to the implementation of the masking strategies to significantly increase the efficiency of masking the redirection technique; these include the integration within the overall narrative of the experience or experiment and the incongruency of the masking object and the aesthetics of the environment. However, the main goal of this work is to identify, elaborate on and categorise the masking strategies and their corresponding redirection techniques. A detailed description will be given in section 6 of this work.

One previous notion of redirection masking in literature was the work by Ciumedean et al. (2020). They describe the idea as *"Approaches belonging to this category decrease noticeability by creating or awaiting opportune moments where perspective and environment manipulations can be subtly introduced."*. While this definition is an essential goal of redirection masking, it merely is a subcategory of the overall framework, in this case, the 'Attention Diversion' strategy, one of the many available. As seen in Figure 4, the preliminary strategies that were identified in our previous work (Vries & Putten, 2022) are masking by attention diversion, masking by obstruction and masking by detection thresholds. First and foremost, the main goal of the attention diversion masking strategy is to divert the user's attention away from the occurrence of the redirection technique by using distractor and interactor objects. Distractors are virtual objects with visual, auditory, olfactory properties or even a fusion of the former. While these objects are often used for various redirection techniques, their main goal is to decrease the noticeability of the redirection technique by creating or awaiting opportune moments within the virtual environment.

Interactors are visual objects that attract the user's attention by facilitating interactivity. While sharing some characteristics with the distractor by containing visual and auditory properties, they differentiate themselves by not being a momentary encounter and not being dependent on the element of surprise. They engage users in interactions that are often integrated within the narrative of the experience itself, such as solving a puzzle to open the door to the next section of the environment. Therefore, their main goal is to decrease the noticeability of redirection techniques by diverting the user's attention to the task or interaction.

Another strategy to mask redirection techniques is obstruction, which blocks the user's field of view using environmental geometry. While obscured, an imperceptible alteration to the virtual environment is made; this is often the case with self-overlapping architecture or Impossible Spaces. Thirdly, using specific detection thresholds for the subtle application of, e.g., rotational, and translational gains has been a popular choice within the scientific community. This is due to the psychophysical conflict where a person's vision overrules the information of other senses, such as proprioception and the vestibular system. When these conflicts are small enough, slight alterations to the user's movement can be made while remaining undetected.

In the previous work, only the 'Attention Diversion' masking strategy was thoroughly elaborated on. After completing our previous work, several other masking strategies were explored, which will be incorporated into this work. Furthermore, this preliminary framework will be extended in the following sections.

# 4 Data Collection

Within this section, firstly, the process of the empirical analysis will be elaborated upon. These include the procedures used and the corresponding criteria to select the resources and the extraction of encounters from the collected resources and the process thereof. In total, 36 papers and 9 VR games and prototypes have been collected, available in the footnote. However, 4 of the 36 papers did not necessarily include an active redirection technique. Still, they contained potential inspiration for a masking strategy that could be incorporated into an experiment or experience that included a redirection technique. 85 encounters have been extracted from the collected resources, from which 66 originated from papers and 19 from commercial VR games or prototypes. [1] These sources will serve as inspiration for the development of the extended framework. Additionally, the difficulties encountered when extracting the encounter data from these resources will be briefly covered. Section 5 covers the analysis of the acquired data and the implications that emerged; from this, the basis of our extended framework was formed.

## 4.1 Resource Collection from Literature and Industry

Before finding appropriate resources for the extraction, a selection criterion for literature and (commercial) VR experiences or prototypes needs to be defined. A sample of candidate papers was collected using broadly specified criteria in the enumeration below to discover related works using literature mapping tools such as Research Rabbit or Connected Papers. Much of the literature, which included some form of a redirection technique, was mostly papers introducing a new technique, an extension of an earlier technique or a comparison between techniques without a compelling experiment to be included in the research. Therefore, our selection criteria for the collection of literature and VR experiences or prototypes included the following:

1. Encounters within papers, commercial games or prototypes include a redirection technique and a masking method used to 'cover' or 'facilitate' the redirection technique.

[1] Data available by using the following link: https://bit.ly/3owne5N

2. The main goal of the redirection technique is to enable natural walking within a constrained physical environment.

3. Encounters are integrated into the nature of the VR experience (aesthetically or embedded within the narrative) or tested in isolation.

The selection criteria were created with the following in mind. First and foremost, the primary criterion was the paper or game using a redirection technique with a corresponding masking strategy. Secondly, the used technique must facilitate natural walking in a constrained physical environment by any means possible, passive techniques such as deterrents could therefore be included in the dataset. Thirdly, some resources were primarily meta-reviews or extensions of other techniques and didn't include novel experiments or experiences but were merely technical demonstrations. Therefore, the third criterion was implemented to increase the novelty within the data pool. As a disclaimer, some papers in the analysis included potential examples of a redirection technique or masking strategy. Here, no implementations are available, but they could be used as inspiration for developing the extension of the family tree or could serve as a foundation for developing other redirection techniques and masking strategies.

## 4.2 Encounter Data

Masking strategies in experiments and games are often divided during the experience. In our earlier work, these segments were referred to as redirection encounters or spatial-temporal segments of the VR experience where players encounter a redirection technique embedded with a masking strategy. These masking objects were stated as often being incorporated within the environment and narrative to improve the feeling of presence during the VR experience (Vries & Putten, 2022). To extract an encounter, one must analyse the experience or experiment itself and find the 'encounters': the moment the player comes into contact with a redirection technique. Theoretically, that event would be noted down and instantly would be ready for analysis. However, extracting the papers and games each required specialised steps that could only be used for their respective medium. Since the textual resources, video footage, or actual virtual reality gameplay, differed from each other significantly.

Often the textual sources included an elaboration on the inner workings of the encounters: gaining insight into the flow of the experience and how the participant would encounter the redirection technique. The textural source is often supported with visual imagery. The redirection techniques and their connected masking strategy would be visualised within the resource itself, enough to get a clear sense of the inner workings of the used technique and how the masking strategy impacted its imperceptibility. Some of the collected research articles were contributions to conferences, which often meant that the article's contents were elaborated on in a short video that would be used as a preliminary presentation during (or before, as a means to skim the participants) the conference. Here, they would briefly explain the experiment's setup and give an overview of the elements used within the experience, giving a better overall view of the implementations and surrounding narrative (if applicable) as the authors go through the experience step-by-step. In a best-case scenario, the paper's authors would include a link to a video demonstrating the experience fully. However, occurrences of this scenario were minimal, where some resources included partial footage of the experiment itself, often exhibiting the encounters.

While extracting the encounters from the collected resources, there were some difficulties to resolve before its acquisition. Examples include the extraction of encounters from textual data, primarily present within the literature. The written format does not support visual media, such as videos or demos of the experiments, apart from including visualisation in the form of figures. This made it difficult to estimate the contents of the encounters, how they were implemented within the experiment, if the objects could be observed visually or were merely auditory triggers, and whether these objects had the same aesthetics as the surrounding environment or were included within the overall narrative of the experience.

The collection process of (commercial) Virtual Reality experiences and prototypes varied greatly from the papers. Whereas literature resources had more textual elaborations on redirection techniques, the experiences and prototypes presented more visual media, such as videos and imagery. However, the emphasis was mainly on the gameplay and environment for promotional reasons, not necessarily on showcasing the integrated redirection techniques and their inner workings, apart from some examples that made the utilisation of the techniques their main selling point (e.g., Tea for God and Unseen Diplomacy (Ciupińsk, 2019; Pixels, 2016)). As the VR games and prototypes were accessible on separate VR systems and only two were available at our disposal (Oculus Quest 2 and HTC Vive), there was a guarantee that some of those games and prototypes could not be tested due to system limitations. As a proxy of substitution to playing these VR games and collecting the encounters from first-hand experience, it was necessary to employ a proxy. Fortunately, on multiple social media video-sharing platforms, a plethora of content on people playing the game or prototype from start to finish was available. Thus, it enabled the extraction of the encounters from the content itself.

After the preliminary process of extracting the encounters and after the dissection of their corresponding implementations and design was completed, it was used to validate our assumptions made in section 3. This concerned the allocation of masking strategies to the respective redirection technique used in the encounter. After this process, the second round began, which analysed the encounter 'edge cases' that were not befitting the characteristics of the formulated masking strategies. Here, another round of reassessment was necessary to redefine and reformulate the previous speculations in an evolutionary process. Consequently, a third round was required when a new trend emerged regarding unallocated masking strategies to redirection techniques. This meant an alteration to the existing framework was made or a new addition to the redirection masking 'family tree' was provided. Take note that these rounds took place ubiquitously and included multiple iterations.

# 5 Results

Within this section, the results extracted from the data analysis from the previous section 4 are elaborated upon, their impact on the reclassification of the redirection techniques, and the additions and alterations made to our preliminary framework regarding the masking strategies. During the analysis, we have created a redefinition of redirection techniques in Figure 9 based on the encounters. Here we reclassify redirection techniques from literature and practice (VR games) according to how they enable the free exploration of a virtual environment using natural walking and using our perspective of what a redirection technique entails. Be advised that this classification differs from the summary in section 2. These items were defined as a redirection technique by their original author but could be considered a masking strategy using our framework. Furthermore, we have thematically clustered some redirection techniques from the encounter data and concluded that these could have more fitting labels. Therefore, we introduced 'Stationary Locomotion', 'Transformational Locomotion' and 'Rotational Task' as additional redirection techniques (more information in subsection 5.2). Secondly, we have extended our framework with the following masking strategies: Occlusion, Viscerallity, Vection and Psychophysical Detection Thresholds. A broad overview of the extended framework can be observed in Figure 10. In-depth elaboration on both can be found in

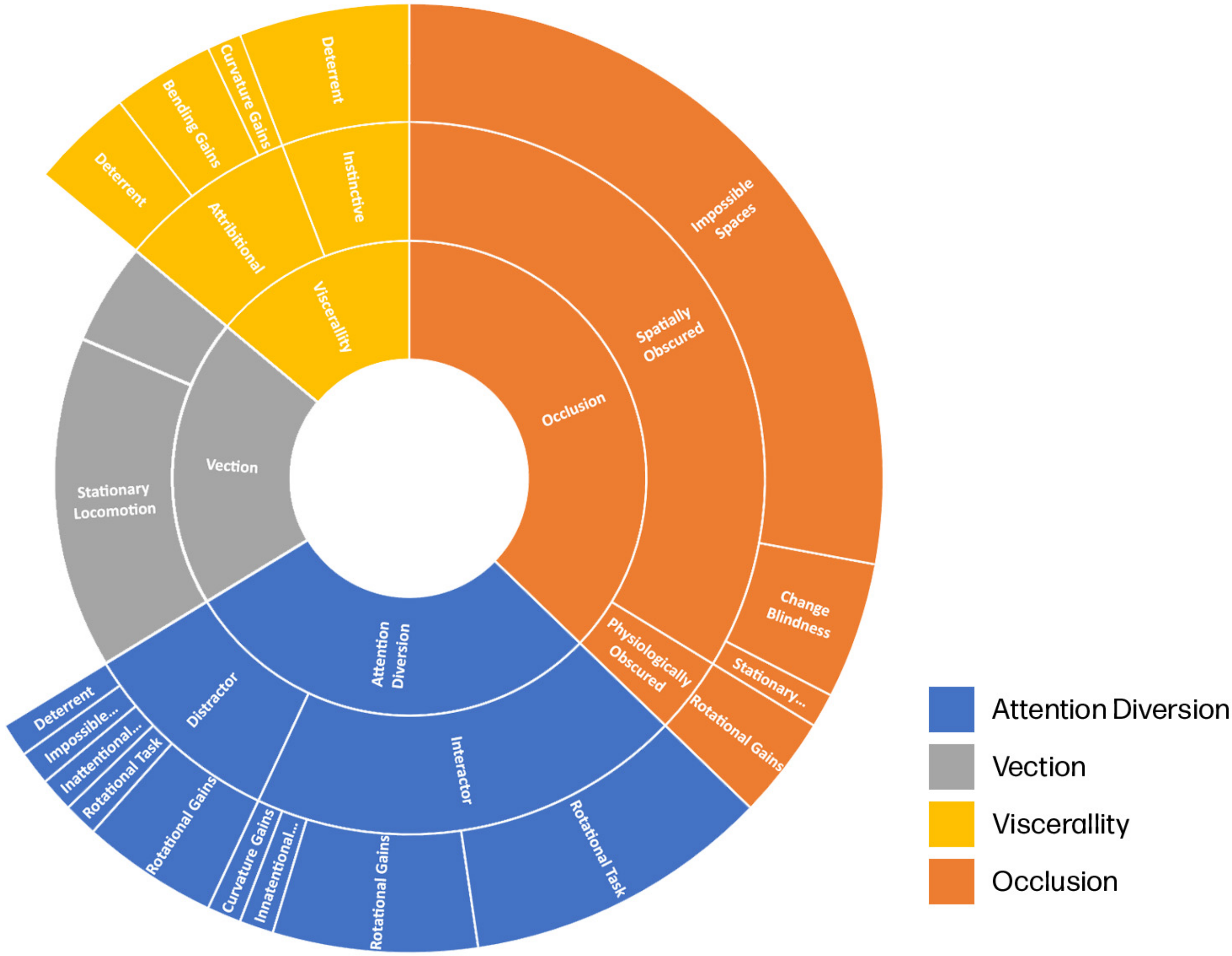


Figure 6: Redirection Techniques per Masking Strategy

the subsections below.

## 5.1 Relating Redirection Techniques to Masking Strategies

In Figure 6, we observe the relationship between the technique and masking strategies. Here the redirection techniques used for each masking strategy are visualised. There is a slight preference for Occlusion with 31 encounters utilising this strategy, Attention diversion in second place with 25 encounters, followed by Vection with 17 encounters and Viscerallity with 12 encounters. Interestingly, when the data is filtered from their source (see Figure 7), it was observed that the game encounters favoured the Vection masking strategy (10 encounters) and only included Attention Diversion and Occlusion as the other utilised masking strategies. The paper encounters preferred the Attention Diversion (23 encounters) masking strategy, with Occlusion as the second favourite with 24 encounters. Secondly, in Figure 8, the total frequency count of the used redirection techniques within the encounter data set was observed. Impossible spaces (24 encounters) were the most frequently used redirection technique. Stationary Locomotion (14 encounters), Rotational Gains (13 encounters) and Rotational Tasks (10 encounters) were the runners-up.

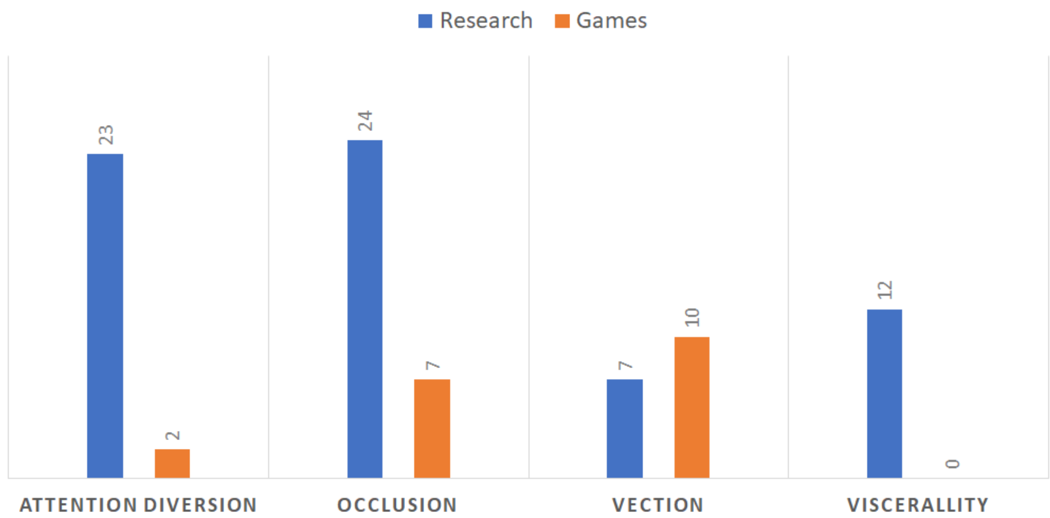


Figure 7: Masking Strategy encounters frequency difference between research and games

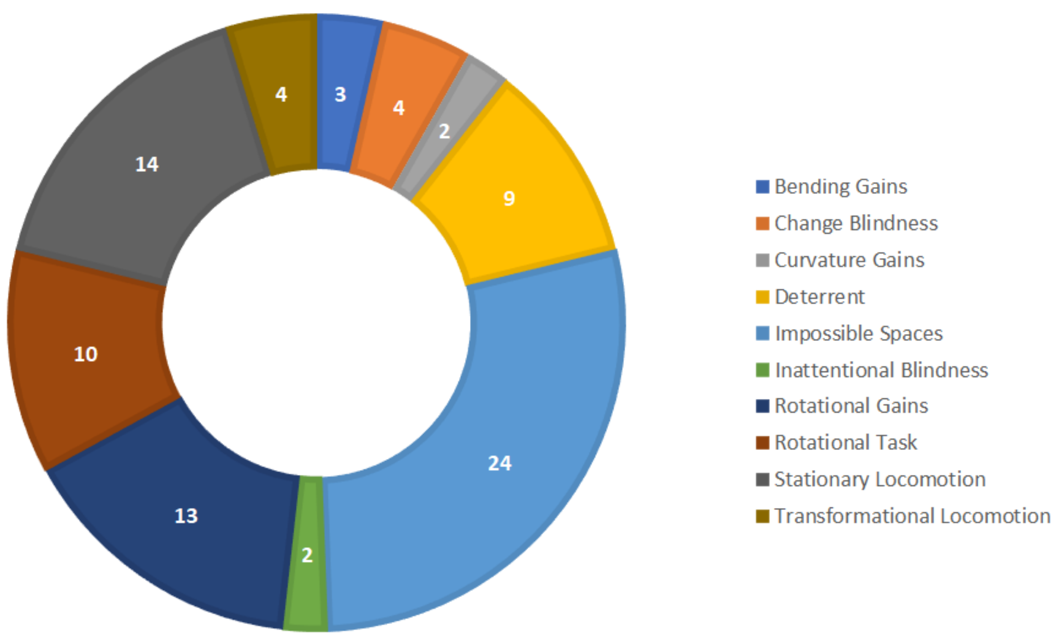


Figure 8: Redirection Technique frequency count from the encounters

Table 2: Classification of redirection techniques including their definitions

| Classification | Definition |
|---|---|
| Gain Application | Techniques that raise or lower the user's movement and/or rotation during movement. |
| Non-Euclidean Geometry | Techniques that utilise our inability to notice "severe" violations of Euclidean Geometric space. |
| Perceptual Exploit | Techniques that actively utilise the exploits of human perception. |
| Vection Exploit | Techniques that create illusions of self-motion within a virtual environment or transform (partial) physical motion into virtual translation. |
| Visceral Exploit | Techniques that utilise virtual objects that influence user behaviour due to previously learned experiences or biases. |

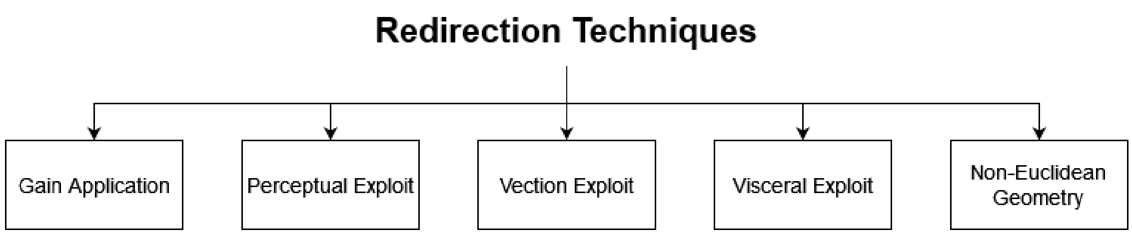


Figure 9: Reworked classification of redirection techniques

## 5.2 Classification of Redirection Techniques

After analysis of the collected encounters, we have created an overarching classification of the various redirection techniques. The classification is a superset of grouped redirection techniques that share similar aims and methods of how the techniques aim to enable the exploration of virtual environments using natural locomotion. One could observe a similarity with the definitions provided in section 2. However, this classification is based on our perspective of what a redirection technique entails and includes techniques not yet identified by the research domain. While the redirection technique and masking strategy are essentially part of the same entity, we found it necessary to elaborate on each part as they differ in function. As a reminder, we consider the redirection technique the method or 'aim' of how it enables natural walking in a constrained environment. The masking strategy is the facilitator of the method, easing the player into the exploit or alteration or making the method completely imperceptible. A visual depiction and definition of the classification scheme can be observed in Figure 9 and Table 3.

### 5.2.1 Elaboration on the Classification Scheme

Redirection techniques under the 'Gain Application' classification aim to increase or decrease the user's movement, resulting in the reorientation towards an accessible part of the physical space. While the translation, rotational, curvature and bending gains have been used in literature for a while, a fifth technique is included in this classification. This is the rotational task technique, where the user is actively involved in an interaction task. Examples include the work of Paulmann et al. (2021), where the user needs to complete a task using several interactions. During the interaction, the user must clear a passage of obstructing planks. By frequently placing the planks at a designated zone behind the user, the interaction forced multiple head rotations, injecting a rotational gain into the user's movement each time.

The 'Perceptual Exploit' classification involves techniques that aim to utilise perceptual phenomena such as change blindness or intentional blindness and more physical occurrences, such as eye blinks or saccades, to enlarge the available walkable areas by altering the geometric structure of the virtual environment or reorienting the player towards an open space in the physical area.

Techniques within the 'Vection Exploit' classification aim to increase the size of the virtual environment by using objects that virtually transport the player while remaining (partially) immobile. The user remains physically stationary while virtually being transported throughout the environment. Examples include vertical transportation using virtual platforms and elevators and transportation in multiple directions, e.g., a rollercoaster cart or other vehicles. Within the encounter data, we have labelled these encounters as Stationary Locomotion and Transformational Locomotion. The former label refers to techniques that reposition the player virtually while remaining immobile, the latter refers to techniques that transform (partial) user movement into another form of movement within the virtual environment.

The 'Visceral Exploit' classification aims to enable free exploration by unconsciously redirecting the player's path within the virtual. This could be achieved by including seemingly dangerous and humongous 3D avatars blocking an entrance within the virtual environment or using innate human fears such as heights and the fear of darkness.

Finally, the 'Non-Euclidean Geometry' classification aims to enlarge the virtual environments by utilising our inability to notice violations of Euclidean geometric space and is often collectively referred to as 'Impossible Spaces', a technique introduced by Suma et al. (2012). Techniques under this classification manifest in many forms within the academic literature, commercial VR games and technical prototypes. These forms include portals, mazes, and the classic overlap. Portals redirect users by teleporting them to another location when stepped through; mazes use alternating intertwining corridors; and the classic overlap uses overlapping rooms connected using a transitional corridor. The next section will cover the masking strategies often combined with the classes described within this passage.

## 5.3 Redirection Masking Strategies

This section describes the various masking strategies, their inner workings, and their theoretical background. While these are essentially part of redirection techniques, they facilitate the goal of the redirection technique by easing the user into the manipulation, causing the alterations to feel more natural or rendering the technique's method completely undetectable.

### 5.3.1 Attention Diversion

This masking strategy was introduced in our previous work (Vries & Putten, 2022) and aims to divert the user's attention away from the resulting alteration of the redirection technique. Technique

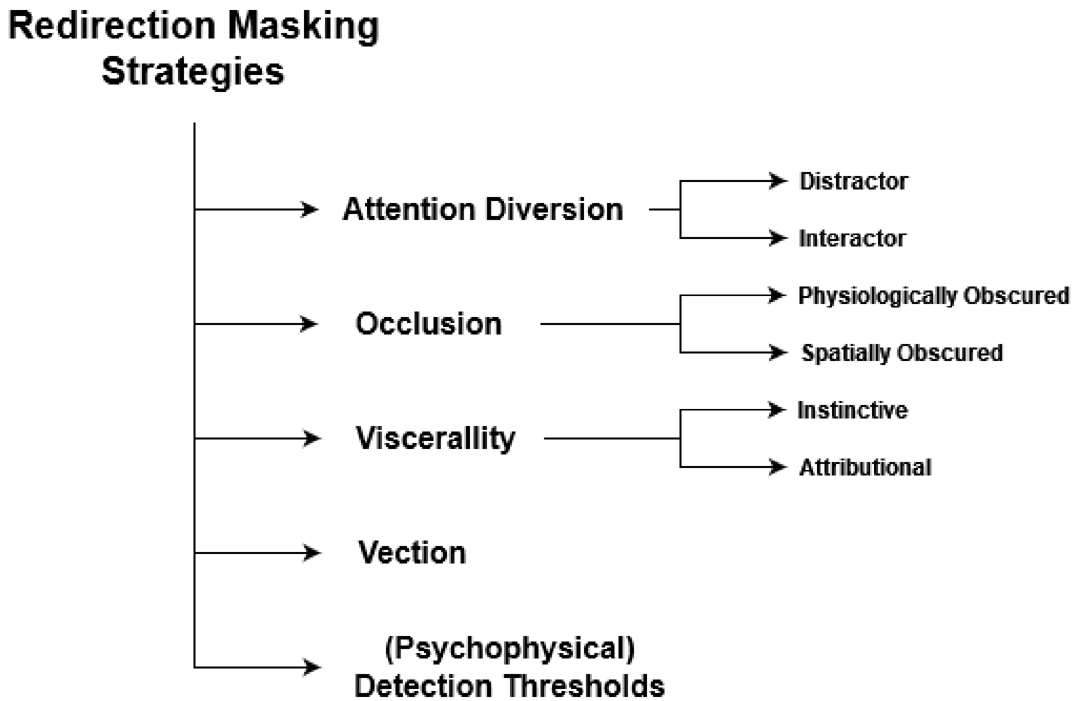


Figure 10: Overview of the redirection masking strategies

Table 3: Overview and Definition of the available Masking Strategies

| Classification | Definition |
|---|---|
| Attention Diversion | Objects that aim to divert the user's attention away from the redirection technique's method. |
| Occlusion | Utilising or exploiting the visual system to occlude the exploit from the player's sight. |
| Viscerallity | Utilising the player's unconscious assumptions or biases towards certain situations, objects, or material properties to influence the user's behaviour, guiding them towards a certain path. |
| Vection | Using illusion(s) of self-motion to mask the virtual repositioning by seemingly "natural" moving virtual objects. |
| Psychophysical Detection Thresholds | Altering the player's movement within the psychophysical magnitude to mask the redirection. |

classifications mostly used with this masking strategy are 'Gain Application', but edge cases include 'non-Euclidean Geometry', 'Perceptual Exploit' and 'Visceral Exploit'. Within the research domain, masking is achieved by implementing distractors and interactions (a thorough description of these objects can be found in section 3.2). Distractors are ephemeral virtual objects with primarily auditory, visual, or olfactory properties: they attempt to catch the user's attention by surprise. Additionally, Interactors are visual objects that can be interacted with, instead of distracting the user momentarily. During the interaction, the player's attention is focused on the actions themselves, resulting in the masking of the redirection technique's method. Therefore, the resulting definition for the attention diversion masking strategy is as follows (Vries & Putten, 2022):

*Objects that aim to divert the user's attention away from the redirection technique's method*

One relevant field to examine when understanding the inner workings of attention diversion is how magicians successfully perform street performances. In the work of Macknik et al. (2008), one of the many techniques magicians utilise includes misdirection. Misdirection aims to draw the attention away from the method or secret behind the illusionary effect towards what the spectator factually perceives. Both can be applied covertly or overtly, where the former involves methods that redirect the actual gaze of the spectator. The latter redirects the spectator while they could be looking directly at the illusionary secret while remaining undetected due to the diversion of their attention.

According to Kuhn et al. (2008), physical misdirection refers to controlling the person's attention using specific stimulus properties. The aim is to capture the attention by generating areas of high interest while the secret is carried out in an area of low interest. Various effective techniques could be utilised to achieve this, including properties such as novelty, movement, and saliency of the distractor object. In the case of the interactor, the attention is naturally diverted to the task at hand. Creating mentally or physically demanding tasks could therefore decrease the detectability of the redirection technique (Coelho, Steinicke, & Langbehn, 2022). Some examples from the encounter data set that employed redirection techniques such as change blindness (Suma et al., 2011; Hwang, Kwon, Cho, Jeon, & Lee, 2022) could be considered attention diversion strategies, as they require the user to look at specific objects or perform a certain search task. However, the implementation does not utilise distractors or interactors at all. Secondly, no active attempts are made to divert the user's attention during the experiences. Instead, the manipulations are applied outside the user's field of view. Therefore, these have been categorised under the Occlusion masking strategy.

Furthermore, in one case where inattentional blindness is used within the experiment, both an interactor in the form of shooting a green alien and physiological obstructions such as saccades and eye blinks are used (Joshi & Poullis, 2019). In one case, gains were applied while the user was actively guided in a curved path by a physical prop (Matsumoto et al., 2019). While the player was engaging with the physical interactor, the perceived path the player took was seemingly straight. Finally, an edge case utilised a distractor object in the form of a graphical user display displaying the layout of the virtual environment. The player's position would be visible on the mini-map (Auda, Gruenefeld, & Schneegass, 2022). Still, it would display an overlap amount which is incorrect but believable (the mini-map shows a Euclidean layout, whereas the actual environment is non-Euclidean).

### 5.3.2 Occlusion

The occlusion strategy involves all methods that mask exploits by letting the occurrence happen outside the user's field of view, e.g., by using obstructing geometry or triggering it behind the player or by natural events of the visual system such as blinks, saccades, or micro-saccades. Therefore, the sub-strategies are 'Physiologically Obscured' and 'Spatially Obscured'. Technique classifications used with this masking strategy, according to our encounter analysis, are 'non-Euclidean Geometry' and 'Perceptual Exploit'. But edge cases include 'Vection Exploit' and 'Gain Application'. Therefore, the definition of the Occlusion masking strategy is as follows:

*Utilising or exploiting the visual system to occlude the exploit from the player's sight.*

#### 5.3.2.1 Physiologically Obscured

Within this segment of the Occlusion masking strategy, the alteration is not occluded by external forces such as the environment's geometry, obstructing objects, or other virtual entities. Instead, this part of the Occlusion masking strategy utilises the naturally occurring phenomena of the visual system, such as eye blinks, saccades, and other eye functions. Therefore, this segment is defined as:

*Obscuring sight using suppressions of the visual system to mask the exploit.*

Blinking can be categorised into two types: voluntary and involuntary. Voluntary blinks are made consciously, often as a means of communication or social interaction. On the other hand, involuntary blinks happen without conscious control and can be caused by various factors (Fitzakerley, 2015). Conversely, saccades are rapid eye movements that occur when fixation points are changed. They are a normal part of viewing and happen several times per second. Nonetheless, voluntary and involuntary blinking, saccades and other visual suppressions cause functional blindness for up to 10% to 15% of our waking hours (Johns, Crowley, Chapman, Tucker, & Hocking, 2009).

One research utilises the moment of blindness due to eye blinks to add rotational gains to the virtual environment inexplicably (Langbehn, Steinicke, Lappe, Welch, & Bruder, 2018). Preliminary research by Dennison et al. (2016) observed an increase in eye blinks when wearing a VR head-mounted display due to increased visual stress and fatigue in VR. They utilised this phenomenon to increase the rotational gain to be applied to the user's movement, as a reduced amount could be injected normally. Another work utilised another function of the visual system called saccadic suppression (Sun et al., 2018). This suppression of perception occurs at each point during the saccadic eye motion, leaving a person temporarily blind (Burr, Morrone, & Ross, 1994). They detected these suppressions using eye-tracking and added imperceptible rotation gains to the player's rotation. Both examples were the only implementations of this masking strategy in our data set.

#### 5.3.2.2 Spatially Obscured

This segment of the Occlusion masking strategy is relatively self-explanatory. When utilising this strategy, the surrounding geometry of the virtual environment is used to block the user's vision or the occurrence of the exploit is placed out of the user's field of view. For example, with non-Euclidean geometry techniques, one often uses a transitional corridor between overlapping spaces. The corridor ensures that the overlapping wall segment is never visible to the player, thus remaining imperceptible. Additionally, other techniques adjust the surrounding geometry behind the player when distracted or involved in a task. In this case, the definition is:

*Activating the exploit outside the player's field of view or by utilising environmental geometry.*

According to previous research on change blindness (not the redirection technique) in visual perception, various processing strategies are utilised to handle conflicting visual information (Simons,

Figure 11: Two examples using the Vection Masking Strategy: The leftmost illustration (instinctive) depicts the player standing on a tall building (Toast, 2017); The rightmost depicts (attributional) a dirt road in a forest (Langbehn et al., 2017).

2000). These strategies include relying on first impressions of the environment, overwriting initial mental representation, and combining conflicting features. When subtly changing a feature of the surrounding virtual environment, these remain unnoticed due to the first impression overruling the conflict. Furthermore, Research by Bruce et al. (1996) indicates that when a person's visual field is obscured during a scene change, it is challenging to notice a change after their vision is restored. In this case, the manipulation often occurs behind the user or is obstructed using environmental geometry.

A second example is the use of the transitional corridor within impossible spaces (Suma et al., 2012). Here, the author argued whether the violations of Euclidean geometry that did not interfere with the navigation of a 2D environment would transfer to a 3D environment within Virtual Reality. Using a transitional corridor between the overlapping rooms, the user is not visually aware of the change as its geometry blocks it. In both cases, the player's assumption that the architectural layout of the virtual environment will remain static due to real-world examples is also prevalent. Most examples within our dataset that utilised this masking strategy were techniques that employed non-Euclidean geometry. Other encounters included change blindness redirection and another case where stationary locomotion was used within the experience.

### 5.3.3 Viscerallity

This masking strategy is more obscure than the other strategies and could be viewed as both a redirection technique and a masking strategy when considering the various implementations from the encounter data. While based on a few literary resources and mostly referred to as suggestions for future work in their original work, we still considered this masking strategy worth mentioning due to its potential. This strategy utilises virtual objects that invoke a visceral response within the user to alter their movement and behaviour unnoticeably. In our case, viscerality uses instinctive reactions or behaviour towards a certain situation or object. For example, imagine standing on a frozen lake nearing open water; when approaching an open area within the lake, multiple cracks start forming around you, evoking a reaction that alters your current behaviour and movement. Technique classifications used with this masking strategy are 'non-Euclidean Geometry' and

'Perceptual Exploit'. The definition of the Viscerallity masking strategy is as follows:

*Utilising the player's unconscious assumptions or biases towards certain situations, objects, or material properties to influence the user's behaviour, guiding them towards a certain path.*

Most redirection techniques utilising this masking strategy are initially a supportive factor for another technique. The object would hinder the movement towards a particular region of the virtual environment, thus deterring the user from moving within the boundaries of the physical playing space.

#### 5.3.3.1 Instinctive

This segment of the Viscerallity masking strategy utilises our instinctive fears to influence the user's behaviour and could be used to mask redirection. It involves using some of our natural fear of the dark, predators, heights, and harm. The definition of this section is as follows:

*Exploiting instinctive fears or utilising imminent dangers to influence the user's behaviour, guiding them towards a certain path.*

While these fears are not prevalent for everyone, combined in a VR experience with a related narrative and aesthetics, the masking object representing the fear or danger could be very effective in manipulating the user's path as it could mimic the perils of real-life situations. For example, the successful VR game "Richie's Plank Experience" (Toast, 2017) has been developed solely to impose the fear of heights upon its players. Within the experience, the player walks down a plank on a tall building, looking down at the streets and other buildings below (which some people could consider frightening). Many examples within our encounter data have been found that utilise this strategy. One research utilised lighting to envelop certain regions of the virtual environment in darkness, taking advantage of people's tendency not to enter a dark and unknown area (Yu et al., 2018). This was combined with rotational gains to enable the player to enter other areas of the virtual environment without colliding with the boundaries of the physical space. Many experiments and experiences that utilised non-Euclidean geometry included wide varieties of this masking strategy, from dangerous lasers trying to exterminate the player to narrow ledges on a high tower overlooking a landscape far away or areas in which a crouching movement was necessary due to a low ceiling (Pixels, 2016; Paulmann et al., 2021). Developers and researchers can be creative when using this masking strategy to create endearing situations resembling real-life dangers. However, when incorporated correctly in the overall narrative of the experience and the aesthetics of the environment, we assume the effectivity is significantly increased.

#### 5.3.3.2 Attributional

Attributional masking objects include our unconscious assumption of objects and their material properties. Experiences encountered during a lifetime provide information about particular objects and their materials. For example, diving in water causes wetness, solid walls are impenetrable, and when walking into a forest, the tendency is to follow the existing path not to get lost. While this masking strategy includes some close resemblances from the previous one (Instinctive Viscerallity), the main difference is the focus on surrounding objects and materials instead of the context of the situation itself. The definition of this section is as follows:

*Using an object's material properties and scale to guide the user's movement or behaviour.*

One research introduced a phenomenon called 'adherent behaviour': "the set of actions indicating that participants adhered to the visual stimuli, behaving as it would be typically expected under analogous conditions in the real world" (Simeone, Mavridou, & Powell, 2017). The research aimed to determine whether people would exhibit the same behaviour when naturally walking in a virtual environment as in a physical one. Some examples of the experiments included a forest environment that could be explored freely. A virtual path resembling a dirt road was also situated within the environment, one which wasn't required to be followed by the player. However, all participants (N=4) unconsciously followed the path throughout the experiment. Other examples included a water pond in the middle of the virtual environment that most participants actively avoided to evade the risk of getting wet.

Another scenario replaced the water with ice; in this experiment, a fraction of the participants walked around the ice. This was due to the participants not recognising the icy material and thinking it was stone. Finally, additions of seemingly impenetrable objects (e.g., walls and boulders) manipulated the walking path of the participants, making their route longer. The main outcome of the research was that it was important to use virtual materials and textures that closely resemble their 'real-life' counterparts. Secondly, seemingly impenetrable objects must be free of interaction affordances so as not to break the suspense of disbelief. However, these are not ground truths as cultures and individuals significantly differ in behaviour, but the research provides a foundation to be built upon. Examples within the dataset included the usage of visible and subtle pathways, which included multiple impassible objects directing the user towards a specific path. Secondly, impenetrable objects were also used within the encounters—one example utilised bars before an entry to inhibit the user's movement towards this direction.

### 5.3.4 Vection

This masking strategy has been used in commercial VR games for quite a while. Here, objects are utilised in the virtual environment to transport the player around the scene. One could argue that gradually repositioning the player around the environment imposes a sense of movement within the experience. This instils an illusion of locomotion in the player during the virtual transportation, creating a feeling of naturalness while remaining immobile or when performing partial movement. When utilised correctly, it can significantly increase the perceived size of the virtual environment remaining mostly immobile within the physical space. Technique classifications used with this masking strategy only included the 'Vection Exploit' type. The definition of this section is as follows:

> *Using illusion(s) of self-motion to mask the virtual repositioning by seemingly "natural" moving virtual objects.*

The illusion of self-motion, or vection, is the feeling of moving in space while physically remaining still. The train illusion is a famous and often-used literary example to explain the effect. This example's popularity is due to its relatability with most people who travel. While seated in one train and observing the movement of the neighbouring train, one can experience the feeling of movement in the former train. The illusion of self-motion can be induced and experienced in numerous physical and virtual situations, using 2D and even 3D displays such as VR head-mounted displays.

This masking strategy is generally utilised in commercial VR games and technical prototypes to reposition the player throughout the virtual environment while remaining immobile. It has been observed that this masking strategy can be implemented with their corresponding redirection techniques: Stationary Locomotion and Transformational Locomotion. Transformational Locomotion

Figure 12: Two examples utilising the Vection masking strategy: The leftmost illustration implemented the stationary locomotion technique using moving platforms (Johansen, 2021); The rightmost illustration uses transformational locomotion to enable the user to scale walls using interactions while remaining mostly immobile (Crytek, 2021).

could utilise the Vection masking strategy as a virtual object resembling a climbable surface, such as an interactable ladder or rope. During the interaction, the player is repositioned gradually within the virtual environment while engaging in partial movements (using a climbing motion with the controllers while the feet don't move) (Paulmann et al., 2021). An example of the Stationary Locomotion technique enables the player to traverse the environment without actively moving around in physical reality, and this is enabled by using the illusion of self-motion. Examples within the dataset included various implementations: moving platforms and elevators, which translated the player horizontally, vertically, and even rotationally. Vehicle objects transported the player along a visualised track, and interactive objects enabled active transportation, such as ladders, ropes and even garlands (e.g., (Johansen, 2021; Ciupińsk, 2019; Wetzold, 2014)).

We have observed that the viscerallity masking strategy often accompanied these examples by utilising heights and dangerous materials such as lava to prevent the player from moving off the platform and breaking the suspense of disbelief. The effect of the repositioning would be enhanced when the player traverses a large section within the virtual environment. When using this masking strategy correctly, one could theoretically have a 100% overlap with vertical rooms when using an elevator or platform moving vertically, as they would be placed on top of each other vertically.

### 5.3.5 Psychophysical Detection Thresholds

This masking strategy has been used in the research domain since the term 'redirected walking' was coined. This strategy mostly masks the 'Gain Application' classification techniques, which often involve the injection of gain in the user's movement without using additional or external masking objects. In this case, the human perceptual system is masking the injection itself. Psychophysical Detection Thresholds could be the most used strategy within the research domain. The definition of this masking strategy is as follows:

*Altering the player's movement within the psychophysical magnitude to mask the redirection.*

The inner workings of this masking strategy are based on the mismatch between vision, vestibular sensations, and proprioception (Dichgans & Brandt, 1978). In certain situations, such as the train example in the previous section, the external motion could be perceived as self-motion when applying multiple rotations to the virtual environment due to vision overruling the vestibular and proprioceptive senses. This finding has been utilised in one of the first occurrences where rotational gains were applied, coined as 'redirected walking'. The research (Razzaque et al., 2001) detected that players unconsciously compensate for the slight mismatches during walking. Therefore, he created the notion of guiding the players along physical paths that differ from those they perceive in virtual reality. The user will not perceive these mismatches when small enough, and various works (Steinicke et al., 2010; Bruder, Steinicke, Hinrichs, & Lappe, 2009; Jerald, Peck, Steinicke, & Whitton, 2008) have experimented with finding the threshold before the user starts noticing these mismatches. More recent research also started experimenting with other sensory modalities, such as audio or even the combination of visual-audio stimuli (Serafin, Nilsson, Sikstrom, De Goetzen, & Nordahl, 2013; Meyer, Nogalski, & Fohl, 2016). This masking strategy is often the baseline for redirection techniques from the 'Gain Application' classification and is often combined with other masking strategies.

# 6 Discussion

In this section, we conduct a reflective analysis of the research process, framework, and results presented in this article. We acknowledge the limitations encountered during data collection and analysis and discuss their implications. Finally, we outline potential avenues for future research, highlighting the areas that warrant further exploration and development.

## 6.1 Research Process

While we had done foundational work on our framework within our previous research (Vries & Putten, 2022), the impact of additional papers and the inclusion of VR games from the industry altered the initial framework drastically. As many more resources became available, so did the disparity of the encounters we collected and, thus, the structure of our framework. Due to this continuous evolutionary process, the current classification and masking strategies could change after new redirection techniques are developed within academics and the industry in the near future. In that sense, the framework itself is essentially an evolutionary entity. Additional encounters become available for future analysis as more experiments and experiences are being developed using this work as a reference sheet. Furthermore, our current method of extracting the encounters from the original resources could be made more efficient in the future since the process took quite some time. This was because of the differences between the resources' medium; one resource could be textual, and another a video or image. However, due to the divergent nature of the original resources, a uniform method would be hard to develop, as each type would require separate procedures.

## 6.2 Framework and Results

The purpose of this framework could be defined as being a reference sheet to develop experiences and experiments utilising redirection techniques aimed to be made imperceptibly or more natural. At the same time, there currently are no guides or best practices for implementing the techniques and their connected strategies, as more experimentation would be needed using this framework. However, researchers and developers could keep this work as a reference sheet when designing experiments or experiences, and in turn, their results could be integrated into this work for further improvement of the framework. Regarding the results of this work, the contemporary resources we've collected that include redirection techniques are often combined with narrative themes and are integrated into the aesthetics of virtual objects and environments. In contrast, early research within the domain isolated the redirection techniques in basic virtual environments to fully explore the underlying principles and processes of the redirection techniques themselves.

Furthermore, note that the masking strategies within this work are not merely aimed at decreasing the detectability of the manipulation. When visually integrated within the overall aesthetics, contextually fitting the narrative of the experience, or when the interaction tasks are thoughtfully blended into the former topics, the effect on presence could be exponentially increased. When using virtual objects, or even auditory stimuli, they should be connected to the other aspects of the experience, as thematic congruency will boost the suspense of disbelief. As a contradiction to the previous statement, when the virtual objects do not fit into the visual theme of the surroundings, they must fit the overall narrative instead. For example, when the experience narrative takes the player into an 'Alice in Wonderland-esque adventure', one could expect to find some virtual objects standing out from the rest: deserts containing snowmen or trees made of candy.

Additionally, one could find some exciting implementations and designs when observing the encounter data. It has been noted that some games that utilised techniques of the non-Euclidean geometry classification would include additional objects of the Viscerallity masking strategy, such as shooting lasers or other dangerous objects that the player needed to avoid. The games included novel implementations within the transitional corridor often used with Impossible Spaces: e.g., crawling spaces or narrow ledges looking down from a vast height.

## 6.3 Limitations and Future Work

Regarding the limitations of our framework and the results, we would like to note that we mainly included redirection techniques designed to be imperceptible or categorised as Subtle techniques according to the taxonomy of Suma (2012). Overt techniques that openly share their exploit or method with the user were omitted from the research as we assumed they wouldn't include a masking strategy, as they didn't need to mask the method.

Interestingly, some encounters originally defined as a redirection technique could instead be defined as a masking strategy. Techniques such as inattentional blindness and change blindness used various perceptual phenomena which masked the alteration made to the surrounding virtual environment. Additionally, some masking strategies, such as Viscerallity, could be defined as a redirection technique or a masking strategy, depending on the context they are used in. For example, a laser embedded into the transitional corridor of a technique utilising non-Euclidean geometry could be considered a masking strategy, as its purpose is to mask the adjacent overlapping rooms. In contrast, a path surrounded by lava, or an abyss actively influences the user's movement and could be defined as a redirection technique. Finally, one could argue that the essence of detection thresholds is the mismatch between vision and proprioceptive-vestibular senses and thus could be part of the Vection masking strategy. A sense of self-motion is evoked during the slight manipulations of the virtual environment during rotations in the early applications of rotational gains, whereas contemporary applications mainly rotate the user's movement.

In future work, with the imminent development and introduction of novel redirection techniques, momentary updates of the framework are needed based on the encounter analysis of these new works. These will result in the creation of additional elements within the framework, which in turn aid in developing more novel techniques and strategies. Additionally, we would like to create experiments and experiences utilising redirection techniques with this framework as a reference for designing and developing the encounters. With these experiments, another possibility arises to measure the impact of the congruency of the masking object concerning its connection with the environmental design and overall narrative. This could result in a crucial addition to the domain as techniques could be more tightly coupled within the context, resulting in more immersive experiences. Finally, recurring encounters of 'Gain Application' reorientation techniques, even when imperceptible, could diminish the experience for the player and eventually alleviate the suspense of disbelief (T. Peck, Fuchs, & Whitton, 2012). While we have found no further evidence that this applies to other technique classifications, we assume that combining and utilising various redirection techniques and masking strategies could keep the VR experience novel. Therefore, we suggest that developers and researchers create innovative implementations of redirection techniques and their corresponding masking strategies.

# 7 Conclusion

Within this work, the current state of the research domain regarding the utilisation of redirection techniques was reviewed. Secondly, we have differentiated between a redirection technique and a masking strategy, which are part of the same entity. The technique exploits or modifies a facet of the user's experience within the virtual environment. The masking strategy facilitates the technique by masking the method for the user, making it imperceptible or easing the user into the manipulation.

The extracted encounters were spatial-temporal moments when the player comes in contact with a redirection technique from contemporary research and commercial VR games or technical prototypes. Based on the analysis of the encounter data, the preliminary framework regarding the available masking strategies was extended, their inner workings were elaborated upon, and a reformed classification of the redirection techniques was supplied. When utilising and combining the masking strategies with the redirection techniques, one could create novel and engaging experiences for both academic research and industry.

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