

Walking in Two Directions at Once

Locomotion Techniques in Virtual Environments

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Abstract

Walking constitutes a fundamental method for traversing virtual environments, i.e. pressing buttons as an abstracted way to move around such as in videogames. With the second advent of virtual reality devices, virtual walking has gained traction and is gradually becoming a more embodied experience. The ability of virtual reality hardware systems to rudimentarily track the human body allows us to explore a virtual space by physically walking through it. *Room-Scaling* creates a direct mapping between our bodily movements in the physical room and our corresponding virtual movements. Another technique called *Redirected Walking* takes virtual walking a step further by disengaging the physical from the virtual space – theoretically – providing the opportunity to virtual walk infinitely in a finite physical space. Based on my research with virtual reality developers, I explore the ideas behind different locomotion styles such as *Teleportation* and *Redirected Walking* and the ways developers use and trick our perception to create believable virtual walking and locomotion methods.

Keywords: Locomotion, Virtual Reality, Merleau-Ponty, Perception, Redirected Walking

In avatar-based applications and video games, users and players manipulate their representation in the three-dimensional virtual environment to walk through digital worlds. Developers of Virtual Reality (VR) software use this “fictional and vicarious embodiment” (Klevjer 2006, 9) as well but the strength of VR hardware and software lies in a direct, immediate or natural embodiment (Klevjer 2006). These two forms of embodiment in virtual environments can be found throughout Game Studies literature (e.g. Calleja 2011, McMahan 2003, Murray 1997, Waggon 2009). Looking at VR applications and the algorithms, ideas, mechanics, and hardware solutions they employ to let users move through virtual environments, transform walking into an increasingly embodied endeavour.

Following this natural embodiment in which “the body is the interface” (Klevjer 2006, 196), I am turning to the phenomenological considerations by French philosopher Maurice Merleau-Ponty. Adding to my insights from interviews with VR developers during my empirical research, Merleau-Ponty provides helpful ideas and concepts to understand and broaden the ways users perceive and experience walking through virtual environments in VR. With this paper, I aim at providing a different perspective on the implementations and workings of walking techniques in VR in order to open up a discussion about the influence of VR on the user’s embodiment, their ways of perceiving, and their experience of walking as a bodily technique (Mauss 1975; Schüttpelz 2010).

Merleau-Ponty (1958, 1964) identifies the body as the point of origin for experiencing the world, which is accomplished through intentional bodily movements. Intentional, because you move in adjustment to the world that you perceive. The bodily movement carries and generates meaning in the world that you perceive. Additionally, to Merleau-Ponty, experience means the perception of the world through the body or, more precisely, the *body schema* through which you *inhabit* space rather than just *being in* it. This is due to the body’s intentional and meaningful relation to its surroundings. Transferred to the virtual environments and immediate embodiment of VR, the benefit of Merleau-Ponty’s views lie in the possibility to describe and analyse walking and locomotion tech-

niques in particular and VR in general in regard to why users are able to walk around virtual environments without any obvious problems of clashing perceptual inputs. Merleau-Ponty's connection between perception and experience allows for an explanation of how VR can exert (some) control over the paramount reality by utilising perceptual mechanisms and shifting the user's experience to the virtual environment. Perception is more than you experience, as "it is the background from which all acts stand out" (Merleau-Ponty 1958, xi).

To illustrate how VR hardware and software can use the user's perception to override her experience of the paramount reality, I give you a brief example of a demonstration I was given during the 2018 IEEE (Institute of Electrical and Electronics Engineers) VR conference in Reutlingen, Germany. Eike Langbehn from the Human-Computer Interaction research group at the University of Hamburg walked me through their implementation of a technique called *bending gains*. Wearing a HTC Vive VR-headset, I found myself inside a spaceship. I had to pick up a holographic representation of the Earth that was linked to a physical prop, which I could pick up with my hands. As part of the demonstration I had to carry the hologram to another room on the spaceship. Since my spatial movements were tracked by the headset's tracking system, the steps I took around the conference room got transferred to the virtual environment, which let me walk through an arc-shaped corridor to the other room naturally.

In my experience of this demonstration, I walked quite a bit through the virtual spaceship environment, but as Langbehn (2018) explained to me, this was just due to their bending gain technique. While I was walking along the arc-shaped corridor on the spaceship, adjusting my steps in relation to the walls of the spaceship, the program turned the corridor around me ever so slightly to redirect my walking path. Consequently, I walked on a tighter arc in the conference room than I experienced in the virtual environment, yet I did not perceive that my physical body turned in a different way than I experienced. Overall, I was not aware of this redirection taking place. The implemented technique of bending gains counts towards a more comprehensive technology called *redirected walking* (Razzaque 2005) and allows developers to take advantage of the user's perception in order to overcome the limitations of the physi-

cal world within the virtual environment. The goal of this technology lies the decoupling of the user's path in the physical from her path in the virtual environment to ultimately be able to traverse infinite virtual environments within the finite confines of a living room by letting users walk in two directions at once.

By connecting technological insights with Merleau-Ponty's Phenomenology of perception and experience, this paper explores not only the benefits and shortcomings of this link but a possibility to talk and think about the technological measures used in VR hardware and software and their implications on users (Hansen 2006; Rammert 1993).

Before I dive a little bit deeper into how redirected walking works, I will examine other locomotion techniques more commonly used in VR applications to provide a wider frame of reference. At present redirected walking mostly exists in the academic and research areas of VR development, whereas the other methods, i.e. *room-scale walking* and *teleportation*, are already common in commercially available applications.

Decoupled from the Body: Indirect Locomotion

With the term *indirect locomotion techniques*, I refer to instances in which the movement of the physical body does not correspond to the movement of the virtual body. These ways of moving are mainly known from traversing screen-based virtual environments, like computer or console video games. However, indirect locomotion techniques exist within VR as well. Rather than being in the vein of *prosthetic telepresence* as Rune Klevjer (2012) describes it, in VR, these locomotion techniques are embodied experiences and thus pose different problems to users and developers. As an example of such an indirect locomotion technique, I will turn to teleportation in virtual environments. While the essential concept of teleportation is well known through science-fiction media, none can know what teleportation might feel like. This familiarity with the concept in combination with a lack of experiential knowledge gives developers some freedom in implementing different ways of teleporting in immersive virtual environments. Nevertheless, all of them are indirect locomotion techniques, which means that you do not have to move your body while your avatar teleports. From a user interaction point of view, you simply point the controller to

your desired destination in the virtual environment and then press or let go of a button and you would somehow appear at the selected destination.

As many of the developers I talked to explained, teleportation is not as easily implemented as the sequence of pointing, confirming, teleporting. If done like this, users get disoriented and motion sick, an effect most commonly known from being on a moving ship. In VR, two phenomena are commonly responsible for inducing motion sickness: First, the brain adopting the virtual environment as the primary source of perceptual information with which it correlates other sensory information; and second, the dominance of the visual perceptive system that favours the lack of distance between the eyes and the displays. Thus, the information sent by the inner ear – one contributor to the sense of movement – clashes with the visual stimuli the brain processes during teleportation in virtual environments. Developers figured out that the speed of the teleportation transition is important to avoid motion sickness and disorientation. One quick and easy solution for the transition itself is fading to a black screen and then back to the destination. A more sophisticated approach folds the virtual space between your origin and destination, coalesces them into the same point in space before moving you to your destined location and unfolding the environment behind you. To come up with those workarounds, developers need at least a basic understanding of biophysical processes related to perception which they then adjust and refine in trial-and-error approaches.

Perception and Experience: Merleau-Ponty and VR

I chose to discuss teleportation, although it is a locomotion technique that has nothing to do with the bodily experience of walking, because it makes the step from screen-based virtual environments to immersive virtual worlds with embodied interactions less demanding. With this brief example of how teleportation can work and which problems it poses to developers, I want to establish a connection between the ideas of Merleau-Ponty and VR. He conceives perception as “a whole already pregnant with an irreducible meaning, not sensations with gaps between them” (Merleau-Ponty 1958, 25). Although VR covers only two albeit the most important senses, visual and auditory, it delivers – together with a feeling of

embodiment of the avatar in the virtual environment – a whole sensation rather than singular ones with gaps. David R. Cerbone (2008) calls this prioritisation of the whole over its parts the *integrity of perception*. And even though VR has yet to reach its aim to incorporate every sense as proclaimed early on by Ivan Sutherland (1965), it already conveys an *integrity of perception* that allows you to experience the virtual world you perceive.

Following Merleau-Ponty, I argue that such an experience of the virtual world is achieved through your body schema and its motility. Your bodily movements in the virtual world are as intentional as they are in the physical world, which means that the virtual world must allow for meaningful and intentional movements. While a lot hinges on the design of the virtual worlds, VR systems trace your head and hand movements to provide a spatial awareness and embodiment of your avatar. Although teleportation does not enable users to walk around the virtual environment, it still calls on the body schema to deliver a “finely coordinated ensemble of motions intentionally organized in advance” (Morris 2008, 116). Moving your head around, raising your arm, pointing to a certain place, activating and confirming your teleportation destination, are all intentional movements that only work in conjunction with the experience and perception of the virtual world.

As stated by the developers I talked to, they cannot just implement anything that comes to their minds as it might not feel natural to the user. *Natural* or *coherent* means that the experience of events should not be perceived as unexpected. In teleportation, if you raise your arm to select your destination, your virtual arm should move in the same way with the same speed, otherwise your experience of the virtual world feels off. The naturalness, coherence and predictability of the virtual world elicits *presence* or the subjective feeling of *being there* in users (Slater 2003). The concept of presence links to Merleau-Ponty’s view of the body as “the vehicle of being in the world” (Merleau-Ponty 1958, 94). Thus, your experience of the world that you perceive needs to work in unison with your body schema. Therefore, VR developers deploy tricks to achieve this unity, such as fading to black or folding the virtual space, in the example of teleportation.

Walking in Sync: Direct Locomotion

Direct locomotion techniques, unlike indirect techniques, let you and your avatar move in unison. One step in the physical world is one step in the virtual world. Additionally, there is no discrepancy between the perceptual intake of the eyes and the sensory information of the inner ear. Since this direct mapping of physical and virtual worlds does not leave much room for variation, there is basically only one locomotion technique, so-called room-scaling.

Room-scaling is mainly achieved through the hardware set-up of a VR system and its underlying software rather than through additional tricks employed by developers. Utilising optical tracking systems with submillimetre precision, the bodily movements of the user's head and hands are traced and digitised spatially. This allows tracking systems to create an immediate connection between you and your virtual avatar.

Thus, these tracking techniques provide the possibility for meaningful and intentional bodily movement in the virtual world. Being able to move around the virtual world in the same way you move around the physical world heightens your feeling of presence and your being in the world. Room-scale walking is still and even more so than teleportation in line with the *integrity of perception*, since the virtual world is what you perceive and what informs your motility. Developers create these meaningful virtual worlds for you to walk around in and experience, thus shifting your body schema to the virtual world.

Directly Mapping the physical and virtual spaces highlights certain issues for developers. A prevalent issue comes with the varying sizes and shapes of tracked spaces. Since it proves difficult to build scalable virtual worlds that would adjust to different physical spaces, room-scaling demands a specific size and shape of tracked physical space. Academic researchers address these limitations by experimenting with *translational gains*, meaning they elongate or shorten the stride length of your step in the virtual world (Zhang et al. 2018). Basically, one metre in the physical world could be translated to one and a half metres in the virtual world – without you noticing.

What is happening with translational gains can be described as a decoupling of the virtual and physical spaces. Your avatar moves in a different way from your body, yet unnoticeable. Developers are

figuring out thresholds that allow this manipulation to stay unnoticeable from being perceived, mainly by your proprioceptive sense. Providing you with the position your arms and legs are in without any visual cues, proprioception generates a spatial body awareness and hence delivers essential cues for walking. This divide between the avatar's and the body's movements might influence the feeling of presence, embodiment and the integrity of perception, but if the translation gains stay within the unnoticeable thresholds the user is unaware of the differences in movements. Looking at Merleau-Ponty's triarchy of perception, experience and body, the part of perception seems to be split for VR environments. The user still perceives and experiences the virtual world as coherent and with its integrity of perception, but at the same time her body's proprioceptive sense perceives something slightly different. Due to the dominance of the visual perception, the user is not aware of this slight difference in movement between the physical and the virtual world.

Walking in Two Spaces: Redirected Walking

Langbehn and his colleagues (2018) use bending gains to let the user walk a tighter arc on her physical path than the one she experiences. In the same way, translation gains work within a certain threshold. Developers achieve this redirection by ever so slightly and unperceivably turning the virtual environment around the user's avatar while she is in motion. Utilising this rotation constitutes a fundamental method of redirected walking implementations. Redirected walking is a direct locomotion technique like room-scaling. However, it decouples the user's bodily motions in the physical space from her motions in the virtual environment, similarly to teleportation. In the following, I will discuss the workings and effects developers put into redirected walking to deliver a seamless experience.

In his doctoral thesis, Razzaque (2005) lays down the foundation for redirected walking. Fundamentally, it takes advantage of limitations of how users perceive certain sensations to let them walk on a path in the physical world that is different from its virtual counterpart. To take an extreme and unfeasible example: when the user walks to the right in the virtual world, redirected walking would make her turn left in the physical world, without her experiencing any form of dissonance. With Merleau-Ponty's understanding of

perception, changing one or more sensations that the user *perceives* although she does not consciously *experience* them is not in line with the integrity of perception.

To convey a better idea of what the limitations of perception entail, I will briefly explain two methods redirected walking deploys to move beyond limitations of the physical space. Razzaque takes research that deals with self-motion perception as the starting point for redirected walking. Self-motion perception means that you take cues from the eyes, ears, skin, inner ears, and kinaesthetic senses to determine if you are moving or not. Explaining the concepts of *optical flow* as a visual self-motion perception and on the *proprioceptive sense* helps illustrating how redirected walking operates.

To explain optical flow, imagine boarding a train. If you are on a train standing still at the station, you typically see another train at the platform next to yours through the window. Now, the train you are looking at starts moving. It may take you a moment to figure out that, in fact, it is not your train that started moving but the other one. The train's movement created the effect of optical flow on your retina. This means that the brain traces features of the images the eyes capture to determine movement, but in the case of the trains it could not deduce which train started moving. This shows that you cannot rely solely on visual perception to determine self-motion and that you can induce the feeling of self-motion through visual stimuli by creating optical flow as well.

Looking at redirected walking, creating and maintaining optical flow provides the footing for the redirection techniques to work. The brain perceives self-motion through visual cues from the virtual world, which are in line with other cues, because the user is walking. Since the brain is distracted by the optical flow, the user will not register the slight but rapid rotations of the virtual world. Developers use those rotations to adjust the user's trajectory through the physical world without her being able to perceive them consciously.

Another fundamental effect that goes hand in hand with optical flow stems from the podokinetic system which is part of the proprioceptive or kinaesthetic perception system. This system relies on receptors in muscles, joints, and tendons to provide a spatial sense of the body as well as on tactile sensors in your skin. Thus, the po-

dokinetic system knows the orientation and position of the feet and legs and gives you the ability to sense and be in control of walking (Razzaque 2005, 53).

This provokes the following question: How can redirected walking work, if the user is always aware of the position of her feet?

When you are supposed to walk in a straight line without any external point of reference or being blindfolded, you tend to drift to the left or right and – given enough space – would walk in a circle. While VR shows many points of reference, it can use them to redirect the user's path in the physical world by rotating the virtual world around her using optical flow, employing translational and rotational gains, and utilising other perceptual effects and perceptual limitations. Thus, redirected walking provides the possibility to infinitely walk through a virtual world in a finite physical space.

Divided Body and Split Perception

Theoretically one could argue that – to follow Merleau-Ponty's terminology – your perception, experience, and body schema shift to the virtual environment and leave it at that. As I have shown with my examples above, more happens when you are using VR and step into a virtual environment. Unrelated to the locomotion technique, your experience shifts towards your virtual avatar or body schema through which you inhabit the virtual environment. Your intentional bodily movements are then made in adjustment to your virtual surroundings, which you perceive. All of this leaves behind your physical body of which you are increasingly unaware of and opens up the possibility of unintentional bodily movement, such as walking on a tighter arc or a longer distance. In taking advantage of this shift of experience to the virtual environment, developers employ tricks to your perception in order to influence your physical body and induce unintentional bodily movements.

With a body divided between a virtual and the physical world and a perception split between conscious, experiential and unconscious inputs, VR, its developers, and its researchers explore rather novel ways of what can be done with and to our body by the means of our perception and senses. With Merleau-Ponty's body-centric phenomenology, it is possible to better describe what happens to our perception and body when stepping into a virtual environment mediated by VR. Being able to distinguish between what is

perceived and what is experienced helps a lot but ultimately reaches its limitations as to what can be grasped with Merleau-Ponty's phenomenological insights. Rather than ending this paper with critical statements, which might be outside my expertise, I want to pose two lines of inquiry that arose from my theoretical exploration of VR and Merleau-Ponty: With our thresholds for certain perceptual inputs that are used by developers to manifest a split perception and induce unintentional movements, the integrity of perception is not destroyed but, at the same time, does not feel intact either. Since our experience seems to be either in the paramount reality or in the virtual reality, could an exploration of the integrity of experience rather than perception be more fruitful to talk about? Especially, since our experience of any environment links our body schema to our intentional bodily movements and uses parts of our perception as a vehicle to do so.

Another illuminating line of inquiry originates from the idea that developers inscribe ideas (Rammert 1993) and conceptualisation of the human perceptual systems into VR hardware and software. Aside from the important question of how this is primed by a certain cultural background, an illuminating issue poses itself in the influence these assumptions and ideas have on users and developers alike. Does VR have the power to change the ways we see and think about certain topics and ask different questions due to the experience VR facilitates?

In conclusion, my exploration of VR locomotion techniques through the lens of Merleau-Ponty yielded valuable insights into how we can talk about less obvious aspects of VR. Additionally, it showed that VR as a medium and as a technology becomes more and more powerful and allows for different and novel experiences and practices, which need to be explored further and – in terms of walking through virtual environments – might lead to similar spatialising properties and experiences as Michel De Certeau (1984) describes in his 1984 work *The practice of everyday life*.

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