

Embodying Self in Virtual Worlds

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Players project their intentions, expressions and movements into virtual worlds. A dominant reference point for this projection is their avatar. We explore the transfer of a player's own body movements onto their virtual self, drawing on cognitive science's common coding theory as a model for understanding their self-recognition. This chapter presents the results of two sets of self-recognition experiments that investigated the connections between player and virtual avatar. In the first set of experiments, we investigated self-recognition of movement in different levels of abstraction between players and their avatars. The second set of experiments made use of an embodied interface for virtual character control that was designed based on common coding principles. The results demonstrate that this interface is effective in personalising a player's avatar and could be used to unlock higher cognitive effects compared to other interfaces.

1 Introduction

Virtual worlds have become personal and social spaces into which players project their intentions, expressions and movements. In many cases, players are presented with an avatar that acts both as a projection plane and access point into the virtual world. Players customise their avatars in terms of appearance, clothes and accessories, and then control their movements in real time through the use of a control interface, such as a keyboard, joystick or gamepad. Although widely used, these conventional interfaces provide a limited degree of engagement, because the finite number of response options on the interfaces force the use of a set of standardised mappings between the player's response and resulting movements of their avatar. As a result, these interfaces restrict the player's ability to generate a range of different and, importantly, personalised movements and expressions in the virtual space. Since all movements by characters in the virtual space are the same regardless of who is controlling them, virtual identity is based primarily on appearance, naming conventions, and patterns of communication, not on movement patterns or animations. In the real world however, identity is a combination of all of these things, because movement profiles are unique to each person. Our work explores the way players identify with the avatar, specifically in relation to movement.

Despite the standardised nature of character movements in virtual worlds, players develop close connections with their avatars, often treating them as extensions of their own selves. Virtual worlds have thus increasingly become part of our socialisation and personal growth, through playful learning, social interactions, even physical exercise and rehabilitation. Our work seeks to strengthen the connection between player and avatar, by giving personalised movements to virtual avatars through tangible and embodied interfaces. The work is driven by recent experimental evidence from neuroscience and psychology showing that execution, perception and imagination of movements share a common coding in the brain. One implication of this common coding system is that it would allow people to recognise their own movements when they are presented as abstract representations, and also to coordinate with these movements better, compared to standardised movements. This theoretical model can help us to better understand the role played by the motor system in our interactions with computational media, specifically with virtual characters that embody our own movements. It can thus enable us to bring the virtual self closer to the physical world self, and perhaps also allow changes in the virtual self to be more quickly transferred back to the physical world self.

In this chapter, we present the results of two sets of experiments that investigated the connections between player and virtual avatar. In the first set of experiments, we hypothesised that players would identify and coordinate better with characters that encode their own movements. This was tested by

tracking movement perception in different levels of abstraction between players and their avatars. The results show that participants can recognise their own movements even in abstracted presentations, and even when they do not see their own movements, but just the movements of a puppet they controlled. The second set of experiments made use of a custom full-body puppet interface for virtual character control that was designed based on common coding principles. The results show that this interface is effective in personalising an avatar. We believe this embodied control could be used to unlock higher cognitive effects compared to other interfaces. In the following sections, we examine the differing ways in which we identify ourselves in the physical vs. virtual worlds, and the way in which existing interfaces support character control in the virtual space.

2 Identifying self in the virtual and physical worlds

In the physical world, a large amount of information is conveyed through our movements. Studies in social psychology have shown that after watching ‘thin slices’ of video (up to 50 seconds) of two people interacting, participants can predict the relations between the two people (friend/lover, like/dislike), their sexual orientation, and even the state of a marriage. Participants cannot do this if the videos are presented as a sequence of static pictures (Ambady, Bernieri, & Richeson, 2000). This indicates that the judgements are based on movement information. Ideomotor or common coding theory explains this effect, as it suggests that when we perceive and imagine actions, our motor system is activated implicitly (Prinz, 1992; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 2005). In other words, seeing someone walk will activate some of the same parts of our brain that are activated when we walk ourselves. This simulation of the actions of others may be the basis of our ability to project ourselves into different character roles, empathise with others, and make judgements about internal states of other people. Whether the actions are performed by another human being or by an avatar in a virtual world, we understand the actions of others through our own body memory reservoir, which is leveraged to predict actions and movements in the world. This understanding of the way we identify ourselves, and with other people, is not incorporated into current designs of virtual characters. In the virtual world, identity is primarily based on the appearance of the avatar, from body type and hair, to clothes and accessories.

2.1 Identifying self in the virtual world

Early on, academic analyses acknowledged the effect of “presence” as a key design constraint for the emerging virtual environment (Minsky, 1980). Definitions of presence, how it might be measured, its causes and effects vary, as the research addressing this question is based on a range of perspectives (e.g., Slater, 1999; Witmer & Singer, 1998). Defining presence is further complicated with the field of virtual environments spreading from virtual reality to collaborative virtual worlds to video games and augmented reality. Each of these fields has its own technical and perceptual conditions to create and test levels of presence. The quality of the visualisation, individual player’s physical condition, responsiveness of the system, and many other elements can affect presence. In the area of video games, the feeling of “being there” is based on a “perceptual illusion of non-mediation” (Lombard & Ditton, 1997) and can be divided into two main categories: a physical category (i.e. the sense of being physically located somewhere) and a social category (i.e. the sense of being together with someone) (IJsselsteijn, de Ridder, Freeman, & Avons, 2000). Both are relevant for self-projection into a virtual world.

In video games, the illusion of a “physical” personal presence is connected to the notion of a “transformation” of the player through the game (Murray, 1997). Transformation is caused by interaction with a usually goal-driven virtual environment. Video games engage players by letting them take on a role with a given purpose inside these virtual worlds (Laurel, 1991). The games stage players into a conflict and let them act out parts of this conflict as embedded in the game’s universe. The role is enacted by the player through the activity of play (Huizinga, 1950). The player’s involvement usually operates on multiple levels: engagement with a task, identification with a character, comprehension of a narrative, projection and

performance of activity are among the many parallel tasks and activities undertaken by a player involved in a game. A heightened level of involvement can evoke a state of “flow” in the player (Csikszentmihalyi, 1991) wherein s/he is so immersed in the virtual activity that s/he loses track of the physical space and time. The immersion can become so dominant that it not only relates to, but sometimes overpowers and replaces, awareness of one’s surroundings and conditions. One of the activities in a virtual world that supports high engagement is the connection between a player and the projected self in the game world. This was initially discussed by Turkle (1984, 1996) for characters in text-driven environments. In more advanced 3D worlds, the range of expression is less descriptive and more representational as it includes more details on appearance, movement, and animation from subtle facial reactions to full body moves. These can allow for more effective projections of players into characters (Bailenson, Blascovich, & Guadagno, 2008). The resulting player-avatar connection has been extensively discussed as a dynamic relationship that shapes narrative construction (Ryan, 2004) and serves as a measure of enjoyment of virtual worlds (Hefner, Klimmt, & Vorderer, 2007). Finding oneself in a virtual world, and the acceptance of the virtual world as such, are thus interconnected. As Wertheim (2000) states: “Despite its lack of physicality, cyberspace is a real place. *I am there*—whatever this statement may ultimately turn out to mean” (p. 229). “Being there” (*I am there*) and the reality of the virtual universe (“cyberspace is a real space”) are interdependent. There is a strong correlation between players’ acceptance of a virtual game world, their role within it, and the level of self-projection into the game. As we accept a virtual there, we inherit a virtual “I” and vice versa. The virtual world that Wertheim still approaches as a novelty has increasingly become accepted as cultural fact. It is not uncommon to find images of virtual avatars such as Nintendo’s Miis or one’s Second Life avatar as visual representatives for real people on facebook or other social media. Gamer tags serve as connecting links online, and customization of characters becomes more and more intricate, as video games become part of the cultural realities we live in. As the gap between real and virtual is shrinking, the step into a virtual self is becoming easier.

Social presence and its role for self-recognition in an avatar is particularly relevant for multi-player games, but also shapes our behaviour in single-player environments. Blascovich (2002) asked how perception of human representations influence social behaviour in virtual environments, and concluded that it hinges on a model of “interpersonal self-relevance” which itself depends on a sense of self in these environments. They highlight the realism of the virtual character as essential to evoke this sense of self. Parts of this realism are the expressive means of that avatar, the texturing, level of detail, and behaviour. In later work, they tested this sense of self in virtual representations of customised avatars whose features resembled those of test participants, and this evoked more personal interactions (Bailenson, Blascovich, & Guadagno, 2008). This behaviour change, in what is termed “parasocial” behaviour, highlight the relevance of a sense of self in our interaction in virtual worlds at large. Communication patterns in digital environments are directly connected to an identification of oneself as situated in these worlds. As we play a game, we accept the virtual roles it offers, which may appeal to usually suppressed parts of our identity. This is why these virtual representations can often be used to unlock hidden and suppressed aspects of our inner self. They allow us to question gender (Stone, 1998) or race (Kolko, Nakamura, & Rodman, 2000) in a safe and playful – virtual – setting.

Virtual environments offer important access points for understanding how the self emerges in the physical world and how we identify selves. But how the mediated virtual environment and the physical player’s body interaction affect the perception of one’s self continues to produce new research problems. Among them is the question of whether the self-representation should be optimised to suit an ideal image or to realistically reflect the physical features of the player. While players seem to be attracted to more interaction with characters reflecting their own features (Bailenson, Blascovich, & Guadagno, 2008), others have shown that an ideal self image is more appealing to players (Jin, 2010). Another question is whether seeing one’s avatar body when interacting with the game system affects self-projection and what qualities in that avatar body’s visualisation are important to enhance self-projection (Mohler, Creem-Regehr, Thompson, & Buelthoff, 2010). This chapter focuses more specifically on the recognition of one’s self through movement, which is an important aspect of our sense of self in the physical world.

2.2 Identifying self in the physical world: the role of movements

One of the key sources of information that we use to identify selves in the physical world is the relative and absolute motion of bodies and body parts during the execution of goal-directed movements. Some initial evidence for the important role of biological motion in identification of the self comes from a long series of psychophysical studies showing that subtle changes in the motions of the most abstract representations of people, such as point-light displays, can be used to identify characteristics of individuals (e.g., gender or weight) and even their emotional states (e.g., happy/sad or nervous/relaxed) (see Troje, 2008). Much of the research on the perception of motion has been driven by a developing approach to cognition that is broadly termed “embodied cognition”. Proponents of the embodied cognition approach hold that there is an intricate relationship between the body and cognitive operations, such that cognitive processes are influenced by the body’s current and future action state, and action planning and control are modulated by cognitive processes. In this way, the mental state of the individual (e.g., their mood) shapes the actions of the individual and, likewise, the actions of the individual (e.g., pulling their hands towards them vs. pushing their hands away) can bias or alter the mental states and perceptions of the individual.

One of the key mechanisms thought to underlie our ability to perceive and recognize actions (and associated mental states) is a neural coding system in which the representations of actions and the perceptual consequences of those actions are tightly bound in a common code (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997). The main implication of this common coding system for behaviour is that the common codes allow for a bidirectional pathway between responses and their after-effects such that the activation of an after-effect code evokes the response code that would bring about the effect and vice versa. For example, the desire to slow a car down (the after-effect) activates the neural codes for the action that will cause the foot to press the brake pedal (the action) and, likewise, the activation of the plan to press the brake pedal will allow one to predict that the car will slow down. This is the ideomotor effect, where the intention/planning of a movement automatically activates its associated motor action, and executing an action will allow making predictions about future states, and thereby help perceive them. In a more computer-based interaction, the need to generate the letter “F” on the computer screen activates the neural codes that would cause the typist to flex the left index finger and, in the opposite direction, activating the motor plan to press the “F” key can evoke the image of the letter on the screen. In both physical and virtual world interactions, these action/after-effect bindings are developed through extensive practice during which the actor learns to associate a specific action with a specific after-effect. Not surprisingly, the greater the practice, the tighter the association or bind between action and the sensory consequences of the action.

Although the common coding model was developed to provide a reasonable account of action selection and the prediction of the consequences, it is now thought these common codes can also be the foundation for action perception and recognition. Specifically, it is thought that one is able to perceive and recognise action patterns because the perception of biological motion and/or the perceptual consequences of an action in the environment automatically activates the representation of the response via the common action/after-effect code. One important source of evidence supporting the role of common codes in action perceptions is derived from study by Casile and Giese (2006) who observed that the participants’ ability to recognise an unusual walking pattern improved after they had learned to perform that unusual walking pattern. Consistent with the results of the study by Casile and Giese, a series of studies has revealed that people are generally better able to identify their own walking patterns than those of their friends (e.g. Beardsworth & Buckner, 1981; Jokisch, Daum, & Troje, 2006) - though this own-action recognition advantage is not universally observed (see Cutting & Kozlowski, 1977). More recent work from Knoblich and colleagues (2006) has expanded this general self-identification finding to a wider array of tasks such as patterned clapping and writing. Presumably this enhanced ability to recognise our own actions is the result of the massive amounts of experience we have had generating our own actions and experiencing the perceptual consequences of those actions. In the framework of the common coding/ideomotor theory, this ability to efficiently identify our own movement patterns, even in extremely abstract and information poor representations such as point-light displays, is based on highly developed action/after-effect codes and/or more intricate coupling between specific and detailed action and effect codes. That is, because we have such extensive experience with our movements and their effects on the environment (i.e., in contrast to the

relatively little experience we have watching other people's movements and their after-effects), we have highly developed and accurate common codes. These highly accurate common codes then enable us to identify our own movement patterns/after-effect better than the movement patterns/after effects of other people.

Of particular relevance to the purpose of the present chapter, these common action/after-effect representations are thought to support a series of other cognitive processes. Specifically, it has been suggested that the activated common codes may be accessed by a variety of other cognitive systems for a number of other purposes, including agency, intention understanding, and empathy. In support of the broader use of common codes, Sato and Yasuda (2005) have shown that there was more agency confusion (i.e. participants were less accurate in determining whether they or another person was responsible for generating a specific after-effect) when the time between response and effect generation increased. In addition, Sato and Yasuda observed a decrease in the sense of self-agency when the after-effect that was presented following the response was different from the one that has previously been established through learning. These decreases in the sense of self-agency were thought to occur because of the discordance between the timing and characteristics of the predicted (learned) after-effect associated with the response and the actual characteristics of the after-effect generated on that specific instance. That is, because there was a difference between the timing and characteristics of the learned after-effect and the actual generated after-effect, the participant was less certain as to whether they or someone else generated the after-effect. Thus, moving these findings into the context of translating an actor's movements into the virtual world, it is likely that: (1) the actor will only feel true "ownership" (agency) of the avatar's movements with the arbitrary relationship between button presses and actions after a period of training; and, (2) a sense of agency will be tighter and more efficiently established if the actors own actions are more accurately transferred onto the avatar.

In sum, action and after-effect representations are tightly bound in a common coding system. The critical implication of this common coding system for the present purpose is that an actor's ability to identify with and feel a sense of control (agency) over the actions of their characters in the virtual world may be largely dependent on the discordance (or lack thereof) between the actor's own movement patterns and those of the avatar. This suggestion is based on the combined findings that: (1) people are better at identifying themselves than other people from the motion of abstract representations of bodies; and (2) people feel a greater sense of self-agency over after-effects that more closely match the after-effects that they have learned to associate with their own actions. Thus, it follows that, since we have a lifetime of experience with our actions and the perceptual consequences of those actions, an actor's sense of agency and identity with an avatar should be greater when HCI designers can more accurately and efficiently translate the actions of the actor in the real world to the avatar in the virtual world. This is not to suggest that a sense of self-agency and identity with the avatar cannot be developed when the avatar's movements are enabled via a relatively arbitrary matching of button and joystick presses (for a common coding explanation of this identity, see Chandrasekharan, Mazalek, Nitsche, Chen, & Ranjan, 2010). Certainly, the requisite associations can be established through a period of learning. Our contention here is that this sense of self-agency and identity will be more efficiently and accurately established when the movements of the actor in the physical world are more faithfully translated to those of the avatar. With this end in mind, our group has been developing a novel interface to facilitate the transfer of one's self to an avatar. We outline the stages of development and testing of this identity interface in the following sections.

3 Interacting with the virtual self: interfaces for controlling avatars

For the most part, interfaces for controlling virtual characters, whether for games or film and television production, have been either extremely simple or extremely complex. In the case of game controllers, gamepads and joysticks have been focused on changing the two-dimensional location of objects, and when they are adapted to controlling movements of characters in expressive ways, especially in 3D space, it leads to overly complicated button combinations and unintuitive mappings. Interfaces like The Character Shop's

Waldo® devices¹ designed for animating the movements of 3D characters often require multiple people, do not work in real time, require intense amounts of post production, and are prohibitively expensive for use in the home. We look at conventional and embodied interfaces, which have provided a starting point for our work on designing a simple, low-cost, real-time, full-body puppet interface for mapping a person's own body movements to a virtual character.

3.1 Conventional interfaces

Most games use a gamepad, a joystick, or a keyboard and mouse to control a virtual character. Over the course of the evolution of games and controllers, interactions for controlling game characters have for the most part become standardised. For example, walking forward is often mapped to the "W" key on a keyboard, or to the forward movement of the left joystick on a PlayStation®3 or Xbox® controller. Character control in games most often involves controlling the 2D (or sometimes 3D) position of an avatar. Seldom does a player have the ability to fluidly and precisely control the gestures of their avatar. When games do provide this ability, the mapping of the character movements to the button presses either becomes overly complex, using awkward combinations of buttons to achieve a particular arm position or facial expression, or assigns a large array of buttons or commands to access pre-rendered animations of the movement.

The result of these unintuitive mappings is that game players usually control a character's position and not his particular body movement. This limitation in character control is also a legacy of game design. Simple controllers and limited processing power led early games to involve moving 2D shapes around on the screen. The progression from *Ms. Pac Man*² to *Donkey Kong*³ to *Super Mario Bros.*⁴ to the most recent adventure games like *Uncharted: Drake's Fortune*⁵ illustrates the carry over of this design feature, in which the primary form of gameplay is to figure out where a character needs to go and how to get them there. These types of games require no more than the ability to trigger certain sets of actions, like walk, run, jump, climb and combinations thereof, in order to be playable. This means that game designers can map animations for these movements to different buttons, define specific behaviours that can be triggered in different contexts, and focus on making levels that are fun given these constraints. Another reason for limiting the control of character movement in games is the relative simplicity of conventional interfaces compared with the range of motions encompassed by the body. This is a problem of a discrepancy between the manipulator and the manipulation task (Jacob & Sibert, 1992). Jacob and Sibert have shown that a device that controls the same number of values as required by a manipulation task works better than one that controls fewer. However, when the tasks become sufficiently complex as to be expressive, the number of values that need to be controlled becomes unmanageable with a conventional controller. For example, in

¹ The Character Shop's Waldo® devices are telemetric input devices used for controlling multiple axes of movement on virtual characters or animatronics. They are designed to meet different criteria depending on the character they control. They use different kinds of sensors to capture movements, and are typically made of plastic and metal joints, and leather and nylon strapping. Specific types include the Facial Waldo®, the Body Waldo®, and the Warrior Waldo®

² *Ms. Pac Man* was originally published by Midway in 1981. The player moves a circle with a mouth around a 2D maze, visible on screen all at once, in order to eat dots while avoiding ghosts.

³ *Donkey Kong* was published by Nintendo in 1981. The player controls jump man, who must avoid barrels thrown by a giant ape named Donkey Kong, as well as other obstacles, and climb to the top of a structure to save a girl from the ape.

⁴ *Super Mario Bros.* was released by Nintendo in 1983. The player controls Mario, who must avoid obstacles as he moves through a series of side-scrolling levels on an adventure to rescue a princess from Bowser, an evil lizard-like king.

⁵ *Uncharted: Drake's Fortune*, from Sony Computer Entertainment 2007, follows treasure hunter Nathan Drake, as he jumps, climbs, dodges and shoots his way through the jungle in search of the lost treasure of El Dorado.

the PlayStation®3 video game, *Little Big Planet*⁶, various combinations of left and right joysticks, shoulder buttons and the d-pad control either the arms and hips, or facial expressions, and while the expressiveness of the character is much better than in most games, the complicated control scheme makes it hard for players to use the expressivity for communication.

3.2 Embodied interfaces

Whether designed to move past limitations of standard controllers, or simply created as a novelty to increase sales, different types of controllers have been developed for both gameplay and expressive control of virtual characters. The recent surge of interest in embodied interaction brought about by the Nintendo Wii™ overshadows a long history of embodied controllers for both games and film and television production.

The Wii™ remote (or Wiimote) is the first in the most recent iteration of embodied game controllers, and while it does encourage players to physically perform the same actions that they want their avatars to perform, the mapping between controller and character is still heavily abstracted and oversimplified. For example, in the tennis game that is packaged with the system, swinging the Wiimote like a tennis racket triggers a set of actions for the game character, which includes running to the place where the ball will be hit and swinging either forehand or backhand depending on which makes the most sense in the game world. Furthermore, the system does not require the motion to be very much like the swing of a real tennis racket at all. Players can sit on their sofa and play Wii™ Tennis with a very minimal flick of the wrist, which can often lead to better results in the game. The Wii™ is also not the first time Nintendo has experimented with embodied interfaces. The Power Glove, developed by Mattel in the 1990s, mapped standard game interactions onto rotations of the wrist and grasping actions. The Power Glove was the least accurate but also the lowest cost of many glove-based interfaces developed in the 1980s and 1990s (see Sturman and Zeltzer, 1994). Another notable example that was used for virtual character control is the DataGlove, which was developed by VPL Research for controlling virtual reality environments. In the early 1990s, Dave Sturman used the VPL DataGlove to explore a “whole-hand” method for controlling a digital character as part of his doctoral research at the Massachusetts Institute of Technology (Sturman & Zeltzer, 1993). He defined “whole-hand input” as the full and direct use of the hand’s capabilities for the control of computer-mediated tasks, and used the term independent of any specific application or interface device.

Embodied interfaces for expressive character control are often used in television and film production. One example of these is The Character Shop’s Waldo® devices, which are telemetric input devices worn by puppeteers and used to control puppets and animatronics. In the late 1980s, a Waldo®-controlled digital puppet, Waldo C. Graphic, appeared in *The Jim Henson Hour* (Walters, 1989). Puppeteers used Waldos® to control the digital puppet’s position, orientation, and jaw movements. A simplified representation of the character showed in real time on a screen along with physical puppets. The data was later cleaned and used to add a more complex version of the character into the video. The Sesame Street segment, “Elmo’s World” uses a similar approach to perform virtual and real characters together in real time. The Henson Company’s most recent digital puppetry system, implemented in the production of *Sid the Science Kid*, requires two puppeteers, one for body movements and one for facial expressions. In this case, the performance of the puppeteers is credited with making the actions of the characters “organic and fun – it never drops into math” (Henson, 2009). Another technique for animating digital puppets is the Dinosaur Input Device (DID) created by Stan Winston Studio and Industrial Light and Magic for *Jurassic Park*. The DID is a miniature dinosaur which the animators use to set the keyframes used by the film’s animation system (Shay & Duncan, 1993). Digital Image Design Inc. implemented a similar system with its Monkey Input Device,

⁶ *Little Big Planet*, published by Sony Computer Entertainment Europe, allows the player to control Sackboy, a doll-like character, through a series of worlds collecting stickers and other objects that can then be used to build new, custom levels, which can be shared over the PlayStation® Network with other players around the world. Many levels can only be solved collaboratively, either through collocated or remote multiplayer gameplay. The game provides players with different ways to interact with each other during multiplayer scenarios.

an 18" tall monkey skeleton equipped with 38 separate sensors to determine location, orientation, and body position (Esposito, Paley, & Ong, 1995). For transferring human motion onto virtual human characters, producers often opt for motion capture systems, which require the performers to wear suits covered in balls or spots of paint that are tracked by a computer-vision system. Motion capture requires the use of multiple cameras and large spaces. These systems are expensive and require a significant amount of work in post production, which makes them impractical for use in games and virtual worlds and unattainable for most other home based applications like online role-playing or machinima production.

Recently, interfaces that can make the expressiveness and control offered by professional puppetry and motion capture systems more widely accessible are beginning to appear, especially in academic research environments. These fall under growing areas of research such as tangible and embodied interaction, which seek to provide more seamless ways of bridging the physical and digital worlds than is possible with conventional interfaces (Ishii & Ullmer, 1997; Dourish, 2001). Notable examples of research that focus on the control of character in 3D virtual space include the work of Johnson and colleagues on sympathetic interfaces (1999). Their system called *Swamped!* made use of a plush chicken to control a chicken character in a story that took place in a 3D virtual world. In a similar vein, the *ActiMates Barney* plush doll had sensors in its hands, feet, and eyes and could act as a playmate for children either standalone or when connected to a television or computer (Strommen, 1998). Our own past research has involved hand puppets tracked by computer vision (Hunt, Moore, West, & Nitsche, 2006) and a tangible marionette that controls characters in the Unreal game engine in real time (Mazalek & Nitsche, 2007). These projects served as early tests for our current work which uses common coding principles as a basis for designing interfaces that can map a user's own body movements to a 3D virtual character in real-time.

4 Identifying with self in virtual worlds: a common coding approach

As new interfaces such as those described above provide more embodied forms of interaction with the virtual space, it becomes increasingly important for human computer interaction designers to consider fundamental aspects of the interaction between perceptual, cognitive and motor processes. The common coding model discussed above links perception, action and imagination of movement, and can help us better understand the cognitive connection we make with our virtual selves. Moreover, this model can help us determine, as interface and game designers, what level of movement abstraction between our physical and virtual self can still maintain self-recognition, and thus support (movement-based) identification with our virtual avatars. For example, can we still recognise our own movement if it is presented in a visually abstracted or proportionately standardised form, such as a point-light walker or generic virtual avatar? And does self-recognition also hold if the movements of this point-light walker or generic avatar are made using a control interface, such as a puppet?

The answers to these questions require careful experimentation, which can provide a starting point for the design of control interfaces that translate a player's own body movements to their avatar. It is also worth noting that in order to support effective movement translation to a virtual avatar, the control interface needs to provide the ability to map a high level of granularity in action in the physical world onto a high level of granularity in action in the virtual world. The use of canned animations in the game engine triggered by button presses, joystick movements or the flick of a Wiimote is thus not an option for common-coding based interaction design.

In order to understand what level of movement abstraction can still support movement-based self-identification with our virtual selves, we conducted an experiment that tracked different levels of movement perception abstraction between players and their avatars (Mazalek et al., 2009). Based on the results from this experiment, we designed a full-body puppet controller for translating a player's own movement to a virtual avatar.

4.1 *Self-recognition of abstracted movements*

The self-recognition study consisted of two types of experiments to assess the hypothesis that a person can identify their own movement even when the movement is visually abstracted, and even when the movement is made using a controller like a puppet. The first type looked at whether a person can recognise his or her own body movement, and the second type looked at whether a person can recognise his or her movement of a puppet. The first type built on previous work that has shown that when a person sees an abstract representation of their movements, they are able to recognise those movements as their own (Beardsworth & Buckner, 1981; Cutting & Kozlowski, 1977; Knoblich & Flach, 2001; Knoblich & Prinz, 2001). The second type allowed us to determine whether people are able to recognise their movements in abstract representations of the movements of objects that they control. The results suggest that we can recognise movements of characters whose movements derive in second order from our own body memories, and this recognition is based on us projecting our own movements into the movement of the character. This indicates that people could potentially recognise themselves in a virtual character that is controlled by a tangible user interface, which encodes their own movements and also translates these movements to the character.

[Figure 1. Walk and jump movement tracking with LED straps attached to: participant body (1a & 1b) and both puppet and participant bodies (2a & 2b).]

In the first set of experiments, we tested whether people can identify their own body movement (walking and jumping) when it is represented abstractly with either normal proportions or standardised proportions. The second set of experiments looked at whether people can recognise their movements of a puppet (making it walk or jump) when: 1) they can see abstractions of themselves moving the puppet, and 2) when they can only see abstractions of the puppet's movement. In each case, we placed LEDs on the participant, or on the participant and the puppet, as shown in Figure 1, and recorded five videos of each movement. In postproduction, we altered the contrast and saturation of the videos to get point-light images as shown in Figure 2.

[Figure 2. Video stills of visually abstracted walk and jump movements for: participant body (1a & 1b), participant body with puppet (2a & 2b), and puppet only (2c & 2d).]

Participants returned after ten or more days to take a set of recognition tests. We tested a total of 20 participants with 5 males and 5 females for each type of experiment. In the first type (body movement), participants were shown 70 pairs of videos for each case, normal and standardised proportions, and asked to choose which video showed their own movements. The videos appeared side-by-side and participants pressed 'Q' to select the video on the left and 'P' to select the video on the right. The trials were counterbalanced by showing half of the participants videos with normal proportions first, and the other half videos with standardised proportions first. In the second type of experiment (puppet movement), participants saw 60 pairs of videos for each case, puppeteer with puppet and puppet only. The subjects were again counterbalanced, half of them seeing the puppeteer with puppet videos first, and the other half seeing the puppet only videos first. Participants were asked to select, by pressing 'P' or 'Q', the video that showed their movements of the puppet.

Figure 3. The average percentage of correct results for all tests across all four study trials. The recognition of body movements is higher than the recognition of puppet movements, but both are significantly better than chance.

The results showed that participants were able to recognise their movements at a high level in all cases. Figure 3 shows the mean and standard deviations of positive identifications for the four test cases. Since previous studies have shown that people are able to identify the gender of point-light walkers (Cutting & Kozlowski, 1977), we compared the results for same-gendered video pairs and different-gendered video pairs and observed no significant difference in the results. This indicates that the self-identification effect is

based on a simulation of movements and not on a logic-based elimination process. While the results are better for body movement cases than puppet cases, the puppet results are still significantly better than chance (50% correct) which indicates that people do translate themselves to the puppet and project themselves into characters whose movements derive from their own.

4.2 Full-body puppet controller design

The results of our self-recognition study using abstracted body and puppet movements indicate that it should be possible to design a control interface that can effectively translate a person's own body movements to a virtual avatar in a way that supports (movement-based) self-identification. Our goal was to design an interface that could map the real body movements of the puppeteer, and thus broaden the expressiveness offered as compared to existing embodied game controllers, while remaining simple to use as compared to conventional interfaces. We also required the interface to be self-contained and in a price range that would make it accessible to everyday game players, which is not the case for existing motion capture or puppetry approaches that are used in professional film and television production.

With these goals in mind, we began with a review of existing approaches to puppetry as inspiration for our own design. In order to support a player's identification with the puppet, our design required a balance of direct contact and level of expression in the puppet. However, the puppet also needed to be accessible to non-professional puppeteers. Figure 4 shows the trade-offs between the ease-of-use and the level of expressiveness and articulation of a puppet. Our interface design combines construction techniques of both full-body puppets and stick puppets, to achieve a good mix between ease-of-use and expressiveness. We focused on full-body puppets, since they conform to our body's configuration and allow expressions that are similar to body movements. At the same time, stick puppets enable direct control of the limbs and are easy to use for even novice puppeteers. Combining these approaches to create a hybrid puppet allowed us to achieve the appropriate balance between ease-of-use and expressiveness that can support a faithful transfer of the player's body movements to the virtual avatar, while retaining the abstraction of a control device in between the player and their virtual self.

[Figure 4. Our review of different puppetry approaches found an inverse correlation between the ease of use and the expressiveness and articulation of the puppet.]

Our puppetry system consists of two main components: the physical puppet and the 3D engine. The physical interface shown in Figure 5 consists of 10 joints with a total of 16 degrees of freedom. The puppet's feet attach to the player's legs just above the knees, and the puppet's body hangs chest high from the player's shoulders. The player grasps the puppet's forearms. This configuration allows the player and puppet to move as one and provides enough information back to the 3D interface to allow for expressive movements. The puppet's bones are made of pieces of wood that are connected at the joints with potentiometers. Joints that rotate in two directions consist of two potentiometers oriented perpendicularly to one another, and each rotates independently. The potentiometers connect to a microcontroller through a multiplexer, which allows us to send 16 analogue signals to a single analogue input on the microcontroller. The microcontroller constructs a serial message out of the numeric data it receives from the potentiometers and sends the message to a computer via a Bluetooth connection. On the computer, an application receives the serial messages and converts them into OSC (Open Sound Control) messages, which are sent to and interpreted by our 3D engine.

The 3D engine is an open-source, OpenGL-based, machinima tool called Moviesandbox (MSB) developed by Friedrich Kirschner. It stores information about scenes and characters in XML files and translates OSC messages into joint rotations using forward kinematics. Our entire system functions in real-time. There is no need for postproduction. Anyone can use it, and with a relatively new laptop, the system can be implemented for a few hundred dollars.

[Figure 5. Embodied puppet interface with 10 joints for the knees, hips, waist, shoulders, elbows and neck (left) and player interacting with the puppet (right).]

5 Giving your self to your avatar: puppet controller study

To assess whether our full-body puppet controller supports effective translation of the player's own movements to a virtual avatar, we conducted an experiment similar to our earlier point-light walker self-recognition study, but this time using the puppet and virtual avatar (Mazalek et al., 2010). There were two sets of experiments. The first set looked at whether people can recognise their own walking movements: normal walk, walking with their hands on their hips, and walking with their arms out to the side. The second set of experiments studied whether people can recognise themselves performing standing actions: drinking, tossing a ball from hand to hand, and doing the twist. In each set of experiments, participants wore our puppet interface and performed each action five times. Figure 6 shows the virtual avatar performing each of the movements. We recorded the movements in the 3D engine, and had the participants return one week later to take recognition tests. During the recognition tests, participants saw pairs of videos and were asked to choose which video showed their movements. In both sets of experiments, walking actions and standing actions, participants saw 99 pairs of videos divided evenly between the three types of actions, 33 pairs for each action.

[Figure 6. Stills of the 3D avatar in the walking movements (walk (1a), hip-walk (1b), arm-out-walk (1e)) and in the standing movements (drink (2a), toss (2b), twist (2c)).]

The results showed that in all cases people were able to identify their own movements significantly better than chance. Figure 7 shows the percentage of correct identifications for each movement. The high standard deviations indicate significant individual differences, an effect that we observed in our previous study and that has shown up in other studies in the literature. Again, since people can recognize gender from movements, we compared the results between same-gendered video pairs and different-gendered video pairs. If participants used gender-based cues and logic to recognize their video (e.g., I am male, one of the videos is of a female, therefore the other video is of me), the performance on different-gendered video pairs would be better when compared to the same-gendered video pairs. Since no pattern or significant difference appears in the results between the two sets, we conclude that the identification is based on a simulation of the movements seen on the screen, and is not a cue-and-logic-based recognition. These experiments show that people project themselves into abstract representations of movements that are based on their own and that providing interfaces that accomplish this representation is an effective way to increase identification with virtual characters. Future experiments will examine the extensions of this effect, which might include enhancing players' body memories through augmenting the movements of a character to which they identify strongly or enhancing mental abilities that are linked to body movement such as mental rotation.

[Figure 7. The average percentage of correct results across all six study trials.]

6 Discussion and implications

The two experiments show that people can recognise their own movements in a virtual character, when these actions are translated using embodied interfaces. Combined with experiments in common coding showing the higher coordination with own actions (Knoblich & Sebanz, 2006), and the thin slice experiments showing judgement accuracy of others from social psychology (Ambady, Bernieri, & Richeson, 2000), this transfer of one's own movements to a character suggests that our puppet interface would enable virtual interactions very similar to those possible in the actual world. Particularly, people

interacting in games would be able to judge others' internal states. Also, reflecting on the movements of their virtual characters in relation to others' would give players more insight into their own biases and preferences.

Further, the transfer of one's own movements to a character would enable better immersion in the virtual world, and better coordination with movements of the character. This better coordination could be leveraged for applications such as motor recovery therapy. As an illustrative instance, a stroke survivor with significant gaming experience recently used the puppet interface to play a game in our lab. In the post-game interview, she commented: "I just felt like we were one and the same person. Cause I felt like that was me." Contrasting the puppet with the Wii™ remote, she said: "I'm just handling a piece of machinery, but with the puppet. ... It would be like it was my friend." This qualitative difference in her experience suggests that transferring her own movements brought the character's movements closer to her actual experience, thus bringing the character closer to her self. Given the tight feedback loop between execution and perception of movements suggested by common coding, we believe it would be possible to generate movements in the character that would help her recover her lost movements.

More generally, we think the connection between self and virtual avatar enabled by the puppet interface creates a channel that could eventually be used to transfer novel movements executed by the character on screen back to the player, via the common coding between perception of movements and imagination/execution of movements. This could in turn be used to create opportunities for players to shape and grow their own identities in virtual worlds, as well as their notion of self in the real world. This has a range of potential applications, particularly in the development of social skills through role-playing and increased empathy, as well as in areas such as medical rehabilitation for patients with movement disorders, and also possibly disorders of volition such as schizophrenia, where the common coding system is considered to be damaged (Firth, 2006). It has been shown that an increased self-presence can positively affect the educational impact of digital environments (Annetta, Folta, & Klesath, 2010), improve exercise behaviour (Fox & Bailenson, 2009) as support neurocognitive rehabilitation (Panic, 2010), among other effects.

From a research perspective, we have found that combining game design with cognitive theory and experiments is very effective and fruitful, and a very promising avenue for systematically exploring the real and virtual self and their interactions. Others have recognised this synergy, and there are some recent studies that combine the two approaches. For instance, there is some recent work examining the social conditions of both cognitive experiments and game systems (see Jin & Park, 2009) and (Blascovich, 2002). However, the two disciplines – game design and cognitive science – cannot simply be forced onto each other as the narratives and methodologies of the two disciplines differ considerably. For example, the game industry regularly uses an overload of sensory input to keep a player stimulated, whereas cognitive scientists are usually more interested in single actions and conditions and isolating their effects. Similarly, game engines are often tweaked to ever-increasing levels of complexity, making them unsuitable for therapeutic purposes. Both sides have to reach a middle ground and develop truly shared approaches (Grau Tost, Campeny, Moya, & Ruiz, 2010). For this, closer collaborations between game designers and cognitive scientists are clearly required, and we hope our work contributes to the coming together of these two research traditions.

7 Conclusion

The research presented in this chapter illustrates ongoing work at the interface between basic science and technology development – applying common coding theory to virtual character control through tangible interfaces. It is part of our larger and ongoing project investigating how tangible user interfaces and virtual characters can augment a user's body memory gradually, by exploiting the common coding and self-recognition effect. We presented our implementation of a tangible puppet interface and 3D virtual environment, which are tailored to optimise the mapping between player and virtual avatar. Using this interface, players were able to recognise their own movements when presented alongside others' movements, even though they did not observe their movements being transferred to the avatar, and the recognition occurred after a week of the transfer. We have, thus, demonstrated that our puppet interface

design supports players' recognition of themselves in a 3D virtual character. Based on these results, we are conducting a new set of experiments to examine whether controlling the avatar using our puppet interface leads to better cognitive performance of the player, in comparison to other interfaces (such as game controllers and keyboards). Building on that research trajectory, future experiments will examine whether perceiving a "personalised" video game character executing novel body movements can change how a player uses his body to make artistic expressions and unlock new creative potential that will further the evolution of one's self.

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