

PILOT: Unlocking Body Memories for Creativity: Controlling virtual characters with tangible interfaces to augment expression and cognition

0. Results from Prior NSF Support

Not applicable.

1. Introduction

"Creativity is piercing the mundane to find the marvelous." –Bill Moyers

"A puppet is a thought in your hands." –Robert More

Creativity can be understood in analogous ways across both arts and sciences. A central component of artistic creativity is the ability to generate many different expressions. Scientific creativity involves the ability to generate various novel solutions to problems. This means a possible way to augment creativity in both arts and science is to seek to increase our ability to generate many expressions and solutions.

A rapidly expanding research stream in cognitive science suggests that imagination and action share a common coding in the brain. Known as ideomotor theory, this work suggests, that when humans perceive and imagine actions, our motor system is activated implicitly. Simplified, the model argues that we understand somebody else's movements and actions through our own body memory. The preferences and biases of our own movements guide how we perceive and imagine movements. This is particularly true of artistic expressions involving movement (such as dancing, acting and drawing), and scientific and engineering problem solving involving movement (such as mental rotation of molecular structures and gear systems).

A common instance of this 'simulation' process is familiar to cinema goers: while watching an actor or car moving along a precipice, viewers move their arms and legs or displace body weight to one side or another, based on what they would like to see happening in the scene. Similar effects are seen in sports fans and novice video game players. Such 'simulation' of others' actions underlie our ability to project ourselves into different character roles as well. More precisely: we use our own body memories to understand the other's role. Whether the actions are performed by an animated cartoon character in a virtual world or a real human being we understand the actions of others through our own body memory reservoir. Our body memory is 'leveraged' to predict the actions and movements in the world.

Reenacting other people's actions using our own motor system also allows us to make predictions about the movements and objects involved. For example, we can guess an object is heavy from the way a person lifts it. It has been shown that people with compromised ability to activate their body, such as deafferented individuals, cannot make such predictions [Bosbach 2005]. While our body memories support understanding and predicting movements and actions, it also acts as a cognitive bottleneck, through which our creative output as well as our imaginative comprehension is filtered. Because body memories shape both our understanding and our range of expression, they also form the restrictions for our expression and action possibilities. Because our artistic and scientific creativity works through body memories, it is also limited by the body memories that we have acquired.

The proposed project seeks to overcome this bottleneck, by extending body memories using virtual environments and tangible interfaces. It is a collaborative research effort that seeks to utilize, categorize, and ultimately expand an interactor's existent body memory through tangible interfaces and virtual environments. Building on the ideomotor (common coding) theory, our approach makes use of emerging tangible interaction technologies, and uses them to control characters inside real-time 3D virtual environments. We use the mapping of body memories through novel interfaces onto virtual characters and the mental connection of a player with the virtual character under control to ultimately expand an interactor's vocabulary of body memories. Our pilot project proposes to test the following hypotheses that relate creativity to body memory:

Hypothesis 1: One way to expand the solution or expression space and enhance creativity in the scientific and artistic domains is to broaden a person's body memories.

Hypothesis 2: Video game characters that encode our body movements through tangible user interfaces can be used to broaden the body memories of the player.

Our approach is highly interdisciplinary. Based on our ongoing individual research in cognitive science, virtual environments and human-computer interaction, we argue that digital media offer unique flexibility and functionality to support this research into the mapping and reshaping of body memory. In the following section, we provide an overview of background research and related work to support our approach. Sections 3 and 4 outline the proposed hypotheses and research approach, and section 5 explains how we plan to experimentally test our hypotheses. Section 6 describes our implementation plan, including our research team with international collaborators, our coordination plan and research timeline. Finally, section 7 discusses the broader impacts of this work.

2. Background

The research proposed here builds on three separate fields of research: cognitive science, virtual environments, and tangible user interfaces. The ideomotor approach from cognitive sciences provides the theoretical basis for developing technological tools for enhancing human creativity. This cognitive model links perception, action and imagination, and can help us better understand how to employ our body memories in creative endeavors that make use of computational media. To this end, the combination of tangible interfaces with virtual environments can provide a link between physical actions and the digital space that builds on the ideomotor approach. While virtual spaces and real-time game engines can provide a digital space into which a user can project their expressions and solutions, tangible interfaces can provide a physical form factor that naturally maps onto a high level of granularity in action within the virtual world. In this section, we provide an overview of the state of the art in these three related areas of research and discuss the way in which they drive and support the proposed project.

2.1 The Ideomotor Approach

The central insight emerging from the ideomotor approach is a body-based 'resonance' – the body acts in a way similar to a tuning fork, replicating all movements it detects. However, all the replicated movements are not overtly executed: most of this replication stays covert, as the overt movement is inhibited. To illustrate, going round and round can make you dizzy, but equally, watching something go round and round can also make you dizzy. This is because observing a movement leads to an implicit replication of the movement by the body. Such replication generates a representation of the movement in body coordinates, which can play a role in cognition and imagination. The ideomotor view argues for a common coding in the brain that connects an organism's movement (motor activation), its observation of movements (perceptual activation), and imagination of movements (simulation). This common coding allows any one of these movements (perception, action, imagination) to generate the other two movements ([Brass 2005, Prinz 2005]; also see [Decety 2002, Hommel 2001]). Recent work has extended this common coding to language processing, showing that there is motor activation while imagining words encoding movements, and processing sentences involving movements [Barsalou 1999, Bergen 2004, Wilson 2007, Holt 2006]. Finally, it has also been shown that this common coding leads to a common task representation when two people execute a task together. This is because perceiving another's actions activates one's own action system, leading to an intermingling of perception and action across people. We briefly review evidence for different types of common coding below.

Perception-Action common coding

When participants execute an action A (say tapping fingers on a flat surface), while watching a non-congruent action on a screen (say an object moving in a direction perpendicular to the tapping), the speed of action A slows down, compared to the condition when the participant is watching a congruent action on screen [Brass 2002]. This effect also occurs when only the terminal posture of the non-congruent action, a static signal, is presented on screen, and is stronger for movements involving human hands, compared to movements involving mechanical hands. A similar effect of perception has been

shown for unattended movements as well, where movement trajectories of participants veer away or towards the location of a non-attended movement on the screen [Welsh 2004]. The effect occurs even for unconscious movements. When participants are asked to move their eye (saccade) to look at a target, and the target is changed suddenly at the peak velocity of the eye, the movement of the eye shifts in response to the movement (forwards, backwards) of the target, even though the participants do not report seeing the shift in the target [Gaveau 2003]. Observing an action primes the very muscles needed to perform the same action [Fadiga 1995, Fadiga 2002].

Supporting this behavioral data is a range of neuroimaging experiments that show that action areas are activated when participants passively watch actions on screen ([Brass 2005] provides a good review). Expert performers of a dance form (such as ballet and capoeira) when watching video clips of the dances in which they are experts, show strong activation in premotor, parietal and posterior STS regions, compared to when watching other dance forms. Non-dancer control participants do not show this effect. Similar motor activation has been shown for expert piano players watching piano playing [Brass 2005]. When we observe goal-related behaviors executed by others (with effectors as different as mouth, hand, and foot) the same cortical sectors are activated as when we perform the same actions [Gallese 2002]. We do not overtly reproduce the observed action, but our motor system acts as if we were executing the same action we are observing. The neuronal populations that support this blurring of first person and third person views have been termed “mirror neurons” (see [Hurley 2005] for a review). In contrast, motor areas are not activated when humans watch actions not part of our repertoire (such as barking).

The mirror neuron system is better activated when watching one's own actions. For instance when dancers watch videos of their own dance and piano players watch their own piano playing. [Knoblich 2006] reports experiments that show that people can recognize their own clapping from a set of recordings of clapping, and pianists can pick out their own rendition of a piece from a set of recordings of the same piece. People can also recognize their own handwriting when it is traced by a moving dot of light. Extending this effect to others, watching a person throw a dart, people can predict where the dart will land more accurately when they have watched a video of themselves throwing the dart.

Imagination-Action common coding

We will use mental rotation work to illustrate this case, though the effect has been shown in many other areas (see [Nersessian 2008] forthcoming for a review). While imagining a mental rotation, if participants move their hands or feet in a direction non-compatible to the mental rotation, their performance suffers [Wohlschlagler 2001]. Planning another action can interfere with mental rotation [Wohlschlagler 2001], and also generate tiny involuntary movements even when subjects are trying to stay still [Cohen 2007]. Wexler et al. [Wexler 1998] show that unseen motor rotation in the Cooper-Shepard mental rotation task leads to faster reaction times and fewer errors when the motor rotation is compatible with the mental rotation than when they are incompatible. Wexler et al. also report that in some cases motor rotation made complex mental rotations easier. Also, speeding up the motor rotation speeded up the mental rotation, while slowing the motor action slowed down the mental one.

When sharpshooters imagine shooting a gun, their entire body behaves as if they are actually shooting a gun [Barsalou 1999]. Similarly, imagining performing a movement helps athletes perform the actual movement better [Jeannerod 1997]. The time to mentally execute actions closely corresponds to the time it takes to actually perform them [Decety 2002, Jeannerod 2006], and responses beyond voluntary control (such as heart and respiratory rates) are activated by imagining actions, to an extent proportional to that of actually performing the action. Closer to the current project, links between imagination and action have been found by experiments investigating mechanical reasoning, such as how people imagine the behavior of pulleys, gears etc. (see [Hegarty 2004] for review). In related work, children who learn fractions by actually executing movements on blocks have been shown to learn the fraction concepts better than others who do not perform such movements [Martin 2005]. It has also been shown that some complex mental rotations automatically generate involuntary hand movements [Chandrasekharan 2006, Chandrasekharan 2007a]. Imaging experiments support these behavioral results, and show that premotor areas are activated while participants do mental rotation [Vingerhoets 2002].

Perception-Action-Imagination common coding

Evidence of the perception-action-imagination coding comes from the way the motor system is used while generating dynamic information from static images such as system drawings [Hegarty 2004], and vice versa. Common instances of this generation include: judging the sense of speed of a vehicle from its tire-marks (or judging tire-marks given speed), judging the sense of force from impact marks (or judging impact marks, given force), sense of movement speed from photos of action (say soccer), sense of movement derived from drawings, cartoons, sculptures etc. Experimental evidence for the use of the motor system in this process comes from work on a relation known as the Two-Thirds Power law for end-point movements such as drawings and writings. The law relates the curvature of a drawing trajectory with the tangential velocity of the movement that created the drawing/writing. The human visual system deals more effectively with stimuli that follows this law than with stimuli that do not. When the curvature-velocity relationship does not comply with the power law, participants misjudge the geometric and kinematic properties of dynamic two-dimensional point-displays [Viviani 1989, Viviani 1992]. Also, the accuracy of visuo-manual and oculomotor 2D tracking depends on the extent to which the target's movement complies with the power law. This relation allows humans to judge the speed in which something was drawn, using curvature information, and vice versa (judge curvature given speed). This capacity is presumably what we use when we judge speed from tire marks. The prediction can also work the other way, where given a dynamic trace, we can imagine and predict the static sample that comes next. In one experiment, dynamic traces of handwriting samples were shown to participants. They were then shown some samples of written letters (such as l, h etc.), and asked to judge which letter came next to the shown trace. Participants could identify the letter following the trace more accurately [Kandel 2000] when the trace followed the Two-Thirds power law, i.e. the angular momentum of writing was related to curvature in a way laid out by the law. Accuracy went down significantly for traces that did not follow this relation. [Viviani 2002] argues that the power law relation is a common feature of biological motion. Movements that violate this relation are usually classified by observers as non-biological.

Common coding across individuals

There is emerging evidence that action-perception common coding stretches across individuals in shared tasks. A series of studies, where two participants performed reaction time tasks alongside each other, have shown that each actor's performance was influenced by the other's task [Sebanz 2005, Welsh Forthcoming]; for reviews see [Knoblich 2006, Sebanz 2005]. Such sharing, supported by the mirror neuron system, emerges even when such sharing leads to a decline in one's own performance.

2.2 Virtual Environments

Virtual Environments have become accessible spaces in the media form of the video game. Players can navigate these game worlds and perform specialized interactions in them. Very often, players are presented with an avatar as a projection plane and access point to the virtual world. The interactions of this avatar are defined by the game designer and implemented by animators and coders. This poses a strict regulation of avatar control that can only be overcome when players become coders themselves and modify or hack the game code. Even if players perform a kind of 'emergent play' [Salen 2003] and use the available interactive vocabulary in innovative ways not foreseen by the designer, they still depend on the limitations of the animation system until they reach the level of the animator or coder themselves.

On the other hand, the value of the avatar and its performance for the player has been recognized (from [Turkle 1996] to [Isbister 2006]). Players create an emotional and cognitive connection to their characters. A wide-spread paradigm is that of the player as actor with the avatar as a representation of the performance in the virtual world (for different approaches see e.g. [Laurel 1991] vs. [Mateas 2002]). This is actively encouraged by many video games that allow customization of the character in terms of body appearance, clothes, and accessories. Players closely connect to their carefully crafted and controlled alter egos. One part of this connection is the projection of the player's body onto the virtual one. Players can be situated in the virtual world [Dourish 2001]. Critics have argued for an age where we 'become posthuman' [Hayles 1999] while others see it as an opportunity for personal growth [Turkle 1996].

In any case, the close mental connections between physical player body and virtual avatar have been utilized in numerous virtual training applications, from treatment of the fear of flying [Rothbaum 2006] to

treatment of post-traumatic stress disorder in the wake of the 9/11 attacks [Difede 2002] to military combat simulations. Playing video games has been shown to improve attention, spatial ability and mental rotation [Feng 2007, Green 2003]. Manipulating virtual objects improves subsequent mental rotation and recognition of such objects [Wexler 2005]. Recently virtual reality was even used to generate out-of-body experiences in the lab [Ehrsson 2007, Lenggenhager 2007]. However, the detailed mechanisms of *how* this projection operates and *how* immersion in the virtual world works are not entirely clear. There are various suggestions to explain and measure player's presence ([Slater 1999] vs. [Witmer 1998]) and models to define and track immersion ([Lombard 1997, Heeter 1992], or Game Studies' references to Csikszentmihalyi's principle of 'flow' [Csikszentmihalyi 1991]) but although we know that this connection is operative and at times highly effective we cannot precisely tell why or how much.

Game Studies is well aware of the cognitive effects in video games, but struggles with a definite and clear approach or theory. Cognitive effects have been discussed in a range of contexts such as spatial navigation, effect of violence in games, and educational value, among others. But explanations of how the effects are evoked are at times too simplistic (see e.g. [Koster 2005]). Tests deal with the cognitive skills that a game world might increase or decrease in the player. These setups do not include the players themselves as creative factors. Effects are investigated purely from the game onto the player.

The technology of game engines is still a limiting factor for the expressive freedom of the player. Game engines are optimized for performance. One consequence is the use of pre-defined sets of animations that are by and large inaccessible to the average player. Engines can blend between different animations and create hierarchies between them but even most advanced titles such as the Unreal 3 engine still base their animations on pre-captured motion capture data. At the same time, the flexibility and complexity increases: the number of bones and the animation details grow exponentially, procedural animation can be blended into the canned animation data [Perlin 2002], physics can be applied to the skeleton. The expressive quality of animation systems improves dramatically but the conceptual underpinnings of pre-canned animation are still dominating. This excludes player-generated animations.

Virtual environments and video games have a fast growing history with cognitive sciences, yet we do know little about the underlying connections and mechanics. Games have become media for our process of socialization and feature highly advanced animation and control technologies. Yet, they still follow outdated paradigms as they block out any creative control of the player onto the de facto animation system of the avatar.

2.3 Tangible User Interfaces

When players move through a virtual environment, they need to use some kind of control device or interface that will allow them to project their intentions and expressions into the virtual space. For the most part, current game systems make use of a number of generic controllers for this purpose, such as keyboards, mice, joysticks and gamepads. These are generally two-axis pointing devices and arrays of buttons or on/off switches that provide low-bandwidth single-channel streams of information. However complex characters have many degrees of freedom to control. This is not easily done with input devices that provide at most two degrees of freedom, since it requires a high level of abstraction between the control device and the virtual object that is being controlled.

Jacob and Sibert describe this as a mismatch between the perceptual structures of the manipulator and the perceptual structure of the manipulation task [Jacob 1992]. They have demonstrated that for tasks that require manipulating several integrally related quantities (e.g. a 3D position), a device that naturally generates the same number of integrally related values as required by the task (e.g. a Polhemus tracker) is better than a 2D positioning device (e.g. a mouse). Since a high level abstraction limits the player's ability to precisely control their character across all its degrees of freedom, it also restricts their freedom to generate different movements and expressions in the virtual space. For example, if 'walking forward' in the virtual space is accessed by pressing the 'w' key on a standard keyboard, then the player will not be able to easily access a range of walking expressions for their virtual character.

Given the limited form factor of existing human-computer interfaces, application designers and researchers have been exploring new ways to better integrate the physical and digital spaces in which we exist. These efforts have resulted in emerging areas of digital interaction research, such as the field of tangible user interfaces or tangible interaction. Tangible user interfaces (often referred to as TUIs) aim to

extend our means of input and output into the digital space beyond a primarily audiovisual mode, to interactions that can make better use of the natural skills that humans have with their hands [Ishii 1997, Ullmer 2001]. This approach involves coupling digital information with physical artifacts that can act as both controls and representations for the underlying systems they embody. In the case of TUIs, there is typically an explicit interface that must be manipulated by one or more people at a time. These interfaces take advantage of our manual dexterity and capitalize on the well-understood affordances and metaphors of the physical objects we use in our daily lives.

The field of tangible user interface research can provide approaches for solving the question of how to map player expressions into the virtual space in two ways:

1. Tangible user interfaces can provide a high level of granularity across many degrees of freedom in the physical world.
2. Tangible user interfaces can be designed in a physical form that naturally maps onto a high level of granularity in the virtual world.

To a certain extent, related approaches are already in use in professional production companies, which have increasingly turned to various forms of puppetry and body or motion tracking in order to inject life into 3D character animation. Putting a performer in direct control of a character like in puppetry, or capturing body motion for real-time or post-processed application to an animated character, can translate the nuances of natural motion to computer characters, which can greatly increase their expressive potential. For example, The Character Shop's trademark Waldo devices are telemetric input devices for controlling puppets (such as Jim Henson's Muppets) and animatronics that are designed to fit a puppeteer or performer's body. Waldos allow puppeteers or performers to control multiple axes of movement on a virtual character at once, and are a great improvement over older lever-based systems that required a team of operators to control all the different parts of a single puppet. A big limitation of motion capture and puppetry systems is the fact that they typically require significant clean-up of sensor data during the post processing stage, and their high price point precludes their use in the consumer space. As a result, it is not feasible to make use of these systems for enhancing the creativity and expressive potential of everyday game players – yet.

In the interaction research realm, a number of efforts have centered on new physical interfaces for character control and animation. For example, the Monkey Input Device is an 18" tall monkey skeleton that was equipped with sensors at its joints in order to provide 32 degrees of freedom from head to toe for real-time character manipulation [Esposito 1995]. At the University of Toronto, researchers have explored using Measurand's ShapeTape, a fiber optic-based 3D bend and twist sensor, to facilitate direct manipulation of curves and surfaces in 3D [Balakrishnan 1999]. At Carnegie Mellon University's Entertainment Technology Center, researchers have made use of puppeteering techniques based on a variety of input devices (joysticks, MIDI controllers) to manipulate virtual characters in a 3D environment in real-time [Virpet Theater]. Additionally, our own past and ongoing research here at Georgia Tech has used paper hand puppets tracked by computer vision [Hunt 2006] and tangible marionettes equipped with accelerometers [Mazalek 2007] to control characters in the Unreal game engine.

To our knowledge none of the work on tangible interfaces for virtual character control has applied ideomotor theory to enhance the user's ability to generate artistic expressions or scientific solutions in virtual space. As such, we believe our project provides a unique interdisciplinary approach towards the design of systems that can help to enhance the user's potential for expression and problem-solving.

3. Hypotheses

To summarize, the above background review introduced three different but related idea streams.

1. Perception, action and imagination of movements have a common coding in the brain. This leads to:
 - a) processing other movements by 'simulating' our own stored movements, and
 - b) lack of movement or stored movements hindering the processing and imagination of novel movements.

2. Video games present a virtual action space that help augment cognition, imagination and action. But this augmenting process is:
 - a) in need of more precise experimental analysis, and
 - b) is based on characters with non-fluid movements, which cannot be adapted for players to suit their own movements.
3. Tangible user interfaces are increasingly being used to provide more fluid and individualized movements to virtual characters. But these interfaces thus far:
 - a) do not exploit what we know about common coding, and
 - b) are not directed towards augmenting cognition and imagination.

We bring these three idea streams together, to generate two central hypotheses.

Hypothesis 1: One way to broaden the solution/expression space and enhance creativity in the scientific and artistic domains is to broaden a person's body memories, to incorporate novel movements.

This hypothesis is based on empirical evidence reviewed above, showing that 1) imagination of movements shares a common coding with execution of movements, and 2) not being able to execute some movements hinder the imagination of the same movements. This suggests being able to execute novel movements should support imagining novel movements.

Hypothesis 2: Video game characters that encode our own body movements through tangible user interfaces, and subsequent modifications of the movement repertoire of these characters, can be used to broaden body memories of the player.

This hypothesis is based on two sets of empirical evidence reviewed above. One shows that playing video games, which involves executing novel actions virtually, leads to better imagination and execution of movements [Difede 2002, Feng 2007, Green 2003, Rothbaum 2006, Wexler 2005]. This suggests that video games provide a good medium to introduce novel movements to a person's repertoire of stored body memory. The other set of evidence shows that people use their own body movements to understand and process other movements. This suggests that encoding a person's own movements into a video game character would improve chances of her adding novel movements to her repertoire of movements. Indicative evidence for this comes from the recent work on generating out-of-body experiences in the lab [Ehrsson 2007, Lenggenhager 2007].

Characters can become personal entities specific to the individual user [Taylor 2006]. We argue that this cognitive connection between virtual character and interactor is not necessarily a one-way relationship from the player onto the character, but that it can also be used as an effect from the virtual world onto the physical body of the player. As they learn the movements of their characters, players do this on the basis of their own existent body memory and sensorimotor vocabulary. Although they cannot apply the necessary physical movements onto the character, they still use the abstraction of these movement patterns to operate the avatar. A lot of this effect is lost in translation when standardized interfaces force input into pre-defined shapes and canned performances. That is why we will develop less restricted and more open tangible user interfaces for the character control. Every player will generate unique animations for the individual character. We believe this will have a number of important effects as follows (and illustrated in Figure 1):

1. When you avoid the streamlining of player input and instead allow interactors to affect the virtual character freely through tangible interfaces, the projection of body memory stays intact.
2. A developing relationship between the player and the virtual character allows us to use the mapping of the physical body onto the virtual character in both ways. When players "read" their personal characters and their animations, they will continue to apply their own body memories on which these animations are based.
3. We can change the virtual character's animations during this projection and teach the player a new sensorimotor pattern.

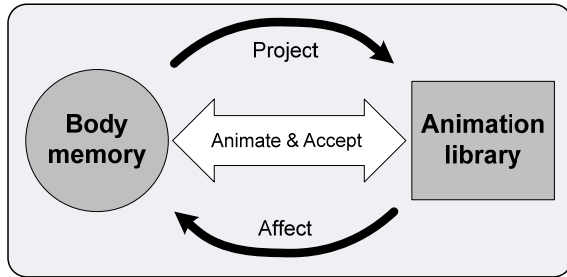


Figure 1: We believe that users can not only project their sensorimotor patterns onto virtual characters through tangible user interfaces, but can also expand their own body memories by perceiving other people's movement patterns in their virtual characters.

4. Proposed Approach

In order to test our hypotheses, we envision creating a system that will map user actions with tangible interfaces onto characters in a real-time virtual environment. The system will be used to test the hypotheses described above in two sets of experiments, conducted at the end of each project year. The experimental design is described in section 5, and the implementation plan and timeline for the research are outlined in section 6.

Our approach uses iterative design principles. The exact form of the tangible interfaces, the design of the 3D content, and the technical implementation of both the physical and virtual components will be developed in an iterative manner. We plan to progressively refine the components of the system through user testing in our labs, leading towards a set of experiments that test our hypotheses at the end of each project year. However, in order to give reviewers a sense of how such a system would work, we present an overview of how the different parts of the system might look, along with example scenarios of use.

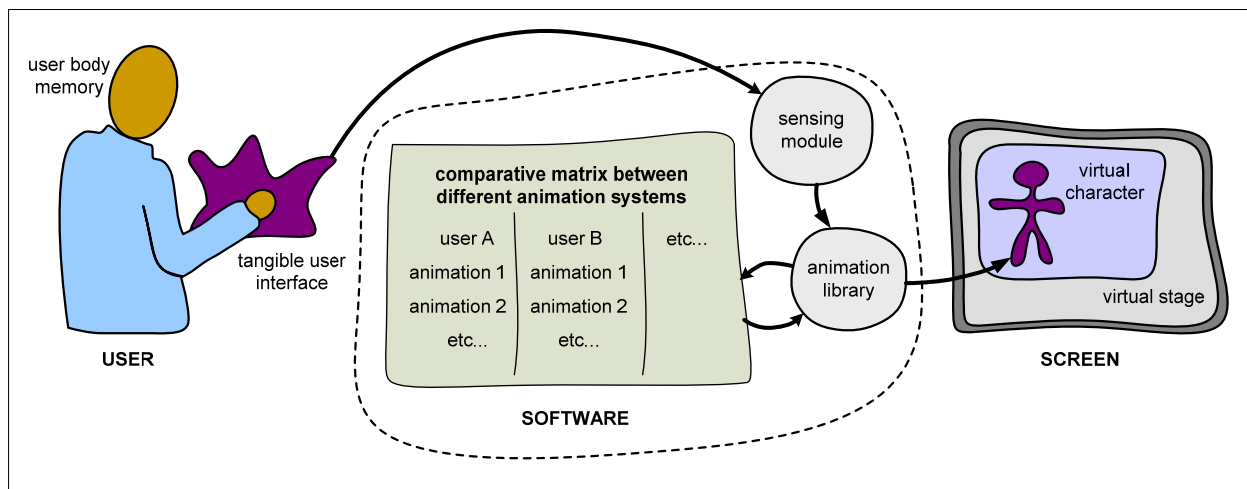


Figure 2: Illustrates the three main parts of proposed system while the player navigates the unaltered puppet. User interactions with tangible interface prototypes are interpreted and filtered through the matrix of sensorimotor-to-behavior mappings in order to provide real-time character control in the virtual environment.

4.1 Proposed System

The proposed system consists of three main components, illustrated in Figure 2:

1. A virtual stage on which the character avatars controlled by the user can be animated. While the design and development of the 3D content will be determined over time, at this stage we anticipate using a real-time game engine to render and control the 3D characters. Two possible scenarios are outlined in section 4.2.

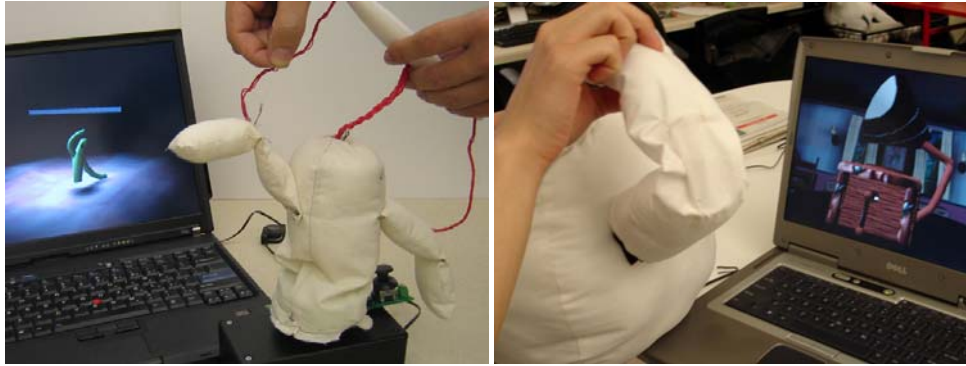


Figure 3: On the left, a cactus-shaped marionette controls a cactus character in a real-time 3D game engine. On the right, the uniball puppet with one limb attached controls an animated phonograph in the 3D game engine.

2. Tangible interfaces that can control virtual characters in a way that reflects the movements of the user. The exact form factor of these interfaces remains to be determined during the design and development stages of the research. They might take the form of marionettes, like the puppet from our TUI3D research [Mazalek 2007], shown in Figure 3 (left). They could also take more abstract forms, like the TUI3D uniball puppet shown in Figure 3 (right). In this case, the physical puppet is a large plush ball that is reconfigurable. Users can plug in limbs at different locations on its surface, enabling it to easily map to different kinds of virtual characters (e.g. human vs. dog). We plan to experiment with these and other possible interfaces (e.g. gloves, wands, squeezables etc.) to find the most appropriate physical form for interaction. We plan to undertake an iterative design process, from design and prototyping through user testing, and expect it will take several cycles to refine the interface for use in the lab experiments that will test our hypotheses.

Additionally, software will be developed to read and interpret sensor data from the tangible interfaces and transmit it to the virtual space to provide real-time character control. We anticipate using Java to develop the software for the system. Through the creation of tangible puppets that can project the movements of the user onto virtual avatars, we enable game characters to take on an entirely customized range of expressions. This is an important change from the dominant commercial approach, in which game character control only makes use of canned animations.

3. By examining the fine granularity of user interactions with our system, we can develop a matrix of differing animations for different users. We plan to analyze this matrix in order to find behavioral clusters, and suggest groupings and focal points that can lead to a method of categorization. Using this categorization of traits, we can then begin to add opposed animations from the matrix to a player's character. In other words, the player's movements with the tangible interface would result in animations based on another user's motor biases rather than the player's own (see Figure 4). These animations will be added in a performance-like setting in the virtual world. Finally, we can evaluate whether the changed avatar animations can affect a user's own body memory and allow them to project themselves in different ways, according to motor biases that are not their own. This evaluation will be based on the set of experiments described in section 5.

4.2 Example Scenarios

The following scenarios illustrate two possible implementations of the proposed system based on user tasks in two example application domains: puppeteering and problem-solving.

Puppet Theater Scenario: Create and animate a basic puppet in a given dramatic scenario, engage the player in the situation, and expand movement patterns through modifications of the character.

- a. The player develops a virtual puppet character in reference to an existing dramatic scene. They use a puppeteering interface as a TUI controller to map their movement patterns onto the puppet. The system categorizes these inputs and animation patterns while the player trains the puppet.
- b. Using their puppet, players perform a role in a dramatic scene on a virtual stage. We hope to use this setting to increase the player's connection to the puppet and increase the cognitive engagement via the dramatized situation. Players should be involved in and activated by the scenario. By now, the

system has collected all available information from the player regarding their animation method and we can re-categorize the matrix.

- c. Players are asked to repeat the performance, but this time the system interferes with the performance. It adds animation patterns from other “opposed” players onto the puppet. While that happens, the player has to continue the performance and thus is forced to comprehend, accept, and use the new animation that their character delivers (see Figure 4). This step is only available in digital media that allow such a change in the functionality of the puppet without completely breaking the control scheme. It opens up new questions of control and puppeteer-puppet relationships and taps into a rich field of cognitive mapping and performance.
- d. Evaluation involves dual tests of scientific realization (mental rotation) and artistic projection (movement interpretation) to test for changes in user’s body memory (described in section 5).

Working Person Scenario: Engage the player in a basic work-task situation that has to be mastered through control of the virtual character.

- a. Confront the player with a set task in the virtual world and let them develop the necessary movements for the virtual character to address this challenge. We expect each player to find a personalized animation sequence. The system will track the input and resulting animations.
- b. The interactor has to perform the solution to the task, but encounters a change in the animation behavior of the character. This change is driven by the new matrix formed from results in step (a).
- c. Evaluation. 1) Artistic: confront two groups of interactors with a new virtual task, one after the experience with the “alien” animation in step (b), one without. Track their response to the new challenge and see whether the changed animation system might have improved their ability to creatively engage in unscripted challenges. 2) Scientific: test the interactors' cognitive engagements through a basic test of reaching and grasping or mental rotation.

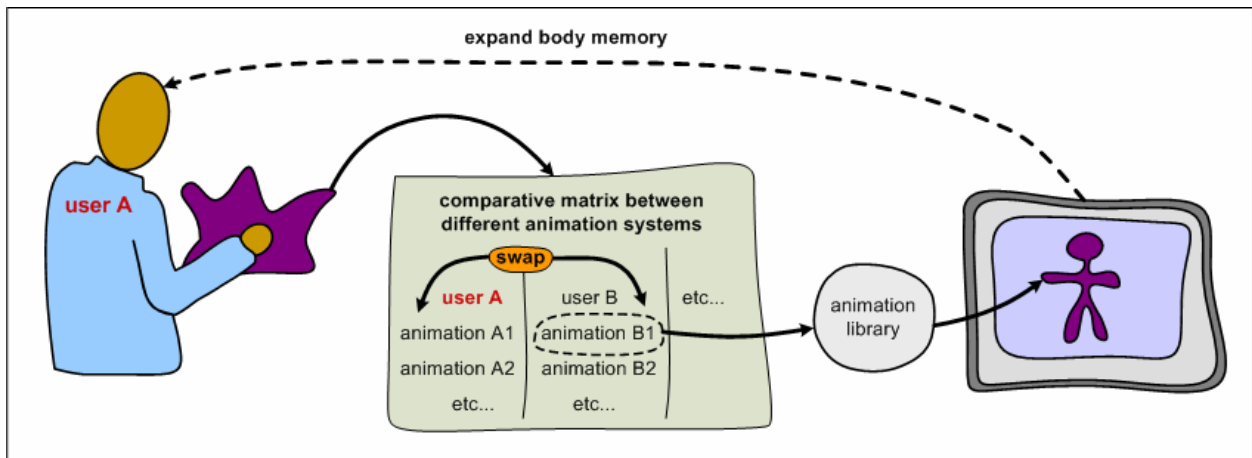


Figure 4: We hope to expand a user's body memory by swapping their character animations with those generated by another user's inherent motor biases.

5. Evaluation

Once we have developed the system for transferring a user’s own movements to a character, and the ability to swap movements incrementally between characters, we will evaluate how the swapping influences players’ ability to generate and process novel movements. We will use two domains (artistic, scientific) to test the hypothesis that novel movements in personalized virtual characters would lead to improvements in imagined movements in players. The following sections describe the experiments to evaluate whether the swapping of movements in virtual space leads to improvement in imagination.

5.1 Scientific Domain

Nersessian ([Nersessian 2008], In Press) brings together results from two sources, a range of empirical experiments examining scientific cognition and historical records of scientific reasoning, to argue that scientists and engineers solve problems using ‘simulative model-based reasoning’. In this highly influential view, the internal mental models that are manipulated during problem solving in science and engineering consist of movement patterns that access the motor system implicitly. Similar views have been put forward by Hegarty [Hegarty 2004] and others studying scientific cognition.

A central component of such movement-based internal models in science and engineering is the mental rotation of objects and other entities, such as atoms, molecules, DNA, proteins, fluids, gases, gears, motors, air currents, planetary systems, etc. Given this central role, mental rotation can be considered a prototypical movement in internal mental models in science and engineering. Limitations in the ability to do mental rotation would affect scientists and engineers’ ability to imagine novel models and systems. Based on this prototypical nature, we will use mental rotation as our test-bed to evaluate how our system could support scientific creativity. Essentially, if novel movements executed by a player’s character in virtual space lead to her performing some complex mental rotations better, we will consider our system to have potential impact in improving scientific creativity.

Mental rotation has been studied extensively in cognitive science, using a variety of experimental paradigms, so it is a well-understood imaginative operation. Our evaluative experiment, testing mental rotation ability in participants before and after using the system, will be designed by our collaborators at the University of Calgary and run at Georgia Tech in consultation with them. The Calgary group has previous experience running mental rotation experiments (see [Chandrasekharan 2006, 2007]), and the stimuli and designs developed for these experiments would be adapted to develop our experiment.

5.2 Artistic Domain

Experiments in this domain will draw on action perception studies using thin slices of video and light-point walkers. Participants watching thin slices of video (50 seconds) of two people interacting, can predict the sexual orientation of the people in the video (gay, straight), the relation between the two people (friend, mate, neutral), the relation between a teacher and student (likes, dislikes) and even the state of a marriage (happy, unhappy, breaking). However, if the videos are presented as a sequence of static pictures, participants cannot make this prediction [Ambady 2000], suggesting that the prediction is made from movement cues. People can make similar judgments from still more abstract stimuli such as light-point walkers (created by affixing small lights to an actor’s body and filming him/her moving in the dark), which provides only movement cues. Participants can predict the gender of the actor, emotions portrayed by the actor, identity of familiar individuals, and even personality traits [Cutting 1977, Kozlowski 1977]. Even facial expressions, which imply elastic transformations, can be perceived from the movements of a few point lights [Bassili 1978].

Common coding theory suggests that such predictions about others’ internal states, based on skeletal stimuli, are generated by triggering simulations of others’ body states using our own motor system. This implicit activation of body memories by minimal stimuli is widely exploited by artists to generate novel experiences in the audience, particularly in art forms involving explicit movement, such as dance, theatre and film. Our second experiment, evaluating how novel movements generated by virtual characters would contribute to players’ artistic creativity, will focus on this ability to experience others’ internal states by proxy. Essentially, having access to novel body states should allow players to predict others’ internal states better, thus refining their ability to both experience and generate novel artistic expressions.

The design of this experiment will be based on an ongoing study that examines how people attribute character traits to cartoon characters, such as Calvin and Charlie Brown. Pilot experiments show that when participants are shown pictures of these two characters, and a randomly sorted set of questions about character traits, such as “which of these characters walks back and forth while waiting for a bus” (trait 1), and “which of these characters keeps clothes neatly folded” (trait 2) one set of traits are mapped to Calvin (trait 1), and the others to Charlie (trait 2), more than 95% of the time. This mapping is chosen both by American participants and non-English speaking people, including illiterates, who have never been exposed to Calvin or Charlie comics. [Chandrasekharan 2007b].

We are currently testing the hypothesis that these character attributions are based on participants simulating both the character traits and the movement that created the drawings. This process allows getting a sense of the movement involved in the trait (trait 1 above provides a sense of impatience and quickness, trait 2 patience and slowness) and also the movement (particularly velocity) that generated the drawing (based on the Two-thirds Power law relation; Charlie can be drawn only using a slow stroke, while Calvin requires fast strokes, see section on the Power law above). Participants then link these two parameters, namely the sense of movement from imagined character traits, and the sense of movement from the drawings. Insights gained about movement and character trait attribution from this experiment will be expanded to design an experiment that tests how access to novel movements changes character trait attribution. This experiment will also be designed by our collaborators at the University of Calgary, and run at Georgia Tech in consultation with them.

6. Research Plan

This section presents our research plan, including the specific research activities undertaken, the timeline for the research, the proposed research team, and the coordination plan.

6.1 Research Activities

Preliminary research in the area of cognitive mapping of body memory onto digital media has been under way at Georgia Tech in the collaboration of Mazalek with Chandrasekharan. Both are currently authoring a paper on their initial findings of activations of ideomotoric patterns through new media. Mazalek has also collaborated with Nitsche on the development of Tangible User Interfaces for real-time virtual environments [Mazalek 2007]. The theoretical and practical work done in these projects will directly apply to the here proposed research and inform our work.

The design of the project is based on iterative design principles as they are common in HCI as well as experimental game studies. We do not claim that we have a perfect model from the start, but argue that our project can help us develop a solid foundation for our argument. We will evaluate our work half way through the project to support this iterative design paradigm and find the necessary adjustments to our prototype. The final evaluation aims to close the argument and trace the creative effect of the here activated sensorimotoric patterning.

6.2 Research Timeline

We propose a two-year project plan to accomplish this work, shown in Figure 5.

Year 1 will focus on the first round of iterative design, development and testing of the proposed system for tangible interface control of video game characters. Based on our ongoing research into character attributes described above, we will begin by defining an initial matrix of motor skills to behavioral traits. This mapping will be used to guide our initial design for TUI interactions onto virtual character movements. The first two terms of the year will also involve preliminary exploration of both, the game engine and tangible technologies, which will quickly lead into iterative design, development and testing of the prototype, resulting in a working prototype in the third term of the first year. The first year will conclude with a first round of experiments to test our two hypotheses in both the scientific and artistic domains, as described above, and with the analysis of experimental results.

Year 2 will focus on the refinement of the proposed system based on the results from the first round of experiments. In particular, we will re-evaluate the matrix of motor skills to behavioral traits based on the first round of experiments using the data collected from multiple interactors. We then use the updated matrix to revise the mapping from TUI to virtual characters. We will also use the results of the first experiments to revise and improve the implementation of the TUI prototypes and 3D virtual content. With the refined matrix of mappings, we will begin to change the animations. We will include animations in the virtual character performance, which are alien to the original player / animator and are drawn from our improved matrix. A user's character will be affected by another person's motor biases. With this switch, we will run a second of round experiments to test our hypotheses and test for raised creativity and cognitive impact. We will conclude year 2 with a summative evaluation and write-up of our results.

Year 1			Year 2		
Term 1	Term 2	Term 3	Term 1	Term 2	Term 3
Ideomotor Theory					
define initial motor skills matrix		experiments to test hypotheses	re-evaluate motor skills matrix	experiments to test hypotheses & summative evaluation	
Virtual Environments (VE)					
<ul style="list-style-type: none"> exploration of game engine iterative VE design, development & testing 		deliverable: working prototype	<ul style="list-style-type: none"> assess VE based on results revise & improve implementation 		deliverable: final prototype
Tangible User Interfaces (TUI)					
<ul style="list-style-type: none"> exploration of TUI tech iterative TUI design, development & testing 		deliverable: working prototype	<ul style="list-style-type: none"> assess TUI based on results revise & improve implementation 		deliverable: final prototype
Integration & Assessment					
<ul style="list-style-type: none"> define TUI-VE sensorimotor mapping integration of TUI & VE technologies 		analyze results & preliminary write up	revise TUI-VE mapping & swap identification		analyze & write up results

Figure 5: Research timeline, including activities and deliverables. The first three rows show work to be done in the three core areas of this collaborative research. The fourth row shows the coordination and integration of parts.

6.3 Proposed Research Team

The Principal Investigators of this project are uniquely suited to carry out this work. They have substantial experience working on the design, development and evaluation of tangible user interfaces, as well as the design, use and evaluation of virtual environments and video game technologies. Each has already made significant contributions in both the technical and theoretical aspects of tangible media and video games, both of which are central to the development of the project proposed here.

Alexandra Mazalek brings to this project experience in designing tangible interfaces and physical sensing/display technologies for collaborative interactions across a range of application domains, such as education, multimedia storytelling and game-play. Her multi-user tangible media tables for storytelling have been used in both arts and education contexts, such as the documenting of shared creative experiences in art/craft studio environments [Mazalek 2003] and in collaborative storytelling workshops with children in underserved communities [Mazalek 2002]. She also has a number of collaborations with industry, such as the development of a full-body interaction storytelling environment with Turner Broadcasting [Samanci 2007], and the development of a home media table platform with Samsung Electronics [Mazalek 2006]. Together with Dr. Chandrasekharan, she has been developing an application to investigate and exploit ideomotor effects. Additionally, her work with Dr. Nitsche has focused on the creation of a suite of tangible interface tools for controlling real-time 3D environments [Mazalek 2007].

Dr. Mazalek is currently co-PI on an NSF grant titled “Physical and Digital Design for Fluid Collaboration” (IIS-0705569, 09/01/2007 through 08/30/2010, total budget \$898,955.00). The grant focuses on developing a set of design guidelines, principles and evaluation methodology that will indicate how to successfully blend the physical and digital design of workspaces to better support fluid collaboration. Mazalek only recently joined the faculty after completing her doctoral work at the Massachusetts Institute of Technology Media Lab in 2005, and hence has only a short history of NSF grants.

Michael Nitsche’s expertise is in the functionality, and presentation of virtual 3D worlds. His current research focuses on procedural game environments [Nitsche 2006] and expressive means available in those worlds [Nitsche 2004, Richens 2005, Nitsche Forthcoming]. His upcoming book at MIT Press (2008) summarizes these interests. At the core of this research, Nitsche aims to increase the expressive

range available in virtual spaces – not only for the game system but also for the participating player. That is why he collaborates with Dr. Mazalek on the use of Tangible User Interfaces in real-time worlds, as well as with Dr. McIntyre and Dr. Bolter on the question of performance in mixed media and multi-player environments. Dr. Nitsche's work is driven by a combination of theory/analysis and practical experimentation. His collaborations include work on educational virtual spaces (Centre for Applied Research in Educational Technologies, UK, and West Herts College, UK) as well as with commercial game developers (Funatics/THQ, Sony Computer Entertainment Europe, and Electronic Arts), and artistic institutions (National Film and Television School, UK, and the American Film Institute).

Dr. Nitsche's work is mainly funded by industry. Since 2005 he has been supported continuously by Turner Broadcasting in his work on Machinima and procedural game spaces. He recently became Co-PI on a network related game project (with Dr. Murray and Dr. Pearce) funded by COX Communications. Nitsche joined the faculty at Georgia Tech in the summer of 2004 after a Postdoctoral research position (funded by Informatix, JP) and a Ph.D. at the Department of Architecture at the University of Cambridge, UK. He started the Machinima at Tech initiative in 2005, founded the Digital World and Image Group in 2006, and was promoted to Associate Director of the Experimental Game Lab in 2007.

Additionally, we will collaborate with researchers at the Faculty of Kinesiology at the University of Calgary, Canada, and include letters of support from Dr. Welsh and Dr. Chandrasekharan, who lend expertise in the area of ideomotor theory, motor control, motor learning, mirror neurons and attention. Dr. Welsh brings to the project many years of experience in designing and running behavioral experiments, and a deep understanding of motor control, motor learning and attention. He holds a number of grants, including the prestigious NSERC grant and the Alberta Ingenuity Grant. Dr. Chandrasekharan brings to the project experience in ideomotor theory, mental rotation and social perception. He has worked closely with Dr. Nancy Nersessian at Georgiatech, investigating cognition and creativity in science and engineering.

6.4 Coordination Plan

This project will be lead by two senior personnel: Dr. Mazalek, Assistant Professor and director of the Synaesthetic Media Lab at the GVU Center at Georgia Tech will be the project's lead PI and manager. Dr. Nitsche, Assistant Professor and associated director of the Experimental Game Lab in Georgia Tech's School of Literature, Communication and Culture, will serve as co-PI.

Mazalek's research responsibilities will be on the tangible side, and will include leading the iterative design, development and user testing of the tangible interfaces prototypes for virtual character control. Nitsche's responsibilities will be on the virtual game space side, and will include leading the game engine programming and 3D content design. Mazalek and Nitsche will coordinate running experiments to test the two hypotheses outlined above at Georgia Tech.

The coordination of the senior personnel and students working on the project will be greatly aided by the fact that Mazalek and Nitsche have been collaborating together for more than one year. Currently, they jointly lead a research project studio called TUI 3D (Tangible User Interfaces for Real-Time 3D Virtual Environments), and their research group meets on a weekly basis at the GVU Center. Mazalek and Nitsche plan to hold regular weekly meetings together with their students in order to coordinate the project, share status reports, and set project milestones. Their research lab spaces will be used for developing, testing and deploying hardware prototypes, for 3D content design and game engine programming, and to conduct experiments.

Additionally, the project has external collaborators at the University of Calgary's Faculty of Kinesiology: Dr. Welsh, Assistant Professor, and Dr. Chandrasekharan, Postdoctoral Fellow. Chandrasekharan worked at Georgia Tech before joining the Calgary lab, and has two ongoing research projects with Mazalek. The contribution of the Calgary group will be background research in Ideomotor Theory, described above, and the design of experiments to test the hypotheses using the tangible/digital tools developed at Georgia Tech. The experiments will be conducted at Georgia Tech in consultation with the Calgary collaborators. In order to facilitate collaboration, we plan to share email distribution lists and a project Wiki website. We also plan to meet with these collaborators via IP-based videoconferencing (using iChat or Skype) on a monthly basis. We will also meet face-to-face at least once in each project year at Georgia Tech during the time that the experiments will be conducted.

7. Broader Impacts

This description only provides a broad sketch of the possible impact of this project. Since the project seeks to engineer a fundamental human attribute, the very way in which humans generate solutions and expressions, its impact would be much wider than we can anticipate.

On science: The project would contribute to a better understanding of the cognitive mechanisms underlying creativity, and also motor learning and action perception. It would also help in understanding and extending the cognitive possibilities of video games and interactive media, and their use in improving education in science, technology and engineering.

On society: The project addresses a basic communication skill, the ability to project oneself into another person. Thus, our system could improve the basic communication principles in digital media. It will question existing paradigms in online worlds and video games and offer a new perspective. We ultimately investigate how these experiences expand the cognitive horizons of players and might improve social networks – virtual ones as well as “real” ones. This might be of importance, for example in conflict scenarios where opposing parties cannot find a shared ground to communicate with each other. Future work might look into the question of body and empathy and how our mapping model might improve that. Once movement patterns become ‘swappable’, it would be possible to share entire personalities online by sharing whole-body movement patterns. This could lead to more refined understanding and empathy for others.

At the same time, our findings might be of importance in the development of medical applications that teach patients certain movements again after some loss of their body memory. Games have been used in the convalescence process of patients, but our model would possibly provide a finer tuned matrix for such a controlled re-training.

On technology: Different types of applications could be developed based on this work. One example involves exploring and exploiting the hypothesized link between character attribution and movement speed. If our experiments show that there is a systematic link between some of the movement parameters of a person and the character traits others attribute to her, then it would be possible to develop template combos of movements that generate specific character impressions in viewers, which would be immensely useful in developing life-like animations and video games and animation features.

Another related application involves developing an algorithm that isolates and accentuates movement features that humans perceive as biological. Work in the ideomotor approach suggests that movements that follow the two-thirds power law are perceived and processed as biological motion, while movements that don't follow this pattern are considered non-biological. As far as we are aware, this feature of movement perception is not taken into account while developing video game characters.

The mingling of actions across individuals in joint tasks could also be exploited to develop more interactive multiplayer environments. Amongst others, this could have applications in areas of distributive and collaborative command and control. For instance, if actions executed by player A's character, such as jumping a hurdle, are always covertly simulated by player B, then it would be easier for player B to execute a continuation of that action, such as jumping a higher hurdle. By taking such simulations of other players into account, events could be designed that ‘carry forward’ one player's actions by the other player, thus aiding in shared problem-solving tasks.

8. Dissemination

In addition to the usual dissemination through publication and conference presentations, we intend to make our research and results available via a project website. In particular, we plan to post both the instructions and software tools we develop for using tangible interfaces to control 3D virtual environments freely available online.