Ideomotor design

Using common coding theory to derive novel video game interactions*

Sanjay Chandrasekharan, Alexandra Mazalek, Michael Nitsche, Yanfeng Chen, and Apara Ranjan[a]
Georgia Institute of Technology / [a]University of British Columbia

Recent experiments show video games have a range of positive cognitive effects, such as improvement in attention, spatial cognition and mental rotation, and also overcoming of cognitive disabilities such as fear of flying. Further, game environments are now being used to generate scientific discoveries, and bring about novel phenomenological effects, such as out-of-body experiences. These advances provide interesting interaction design possibilities for video games. However, since the cognitive mechanisms underlying these experimental effects are unknown, it is difficult to systematically derive novel systems and interaction designs based on these results. We review the emerging cognitive mechanism known as common coding (which proposes a common neural representation connecting execution, perception and imagination of movements), and outline how this mechanism could provide an integrated account of the cognitive effects of video games. We then illustrate, using two ongoing projects, how novel video game interaction designs could be derived by extending common coding theory.

Keywords: common coding, digital media, embodied cognition, interaction design, video games, tangible interfaces

1. Introduction

Game environments allow players to be situated in a virtual world and perform specialized interactions. Supporters see such artificial worlds and our interactions in them as providing opportunity for personal growth (Turkle 1996), while critics have argued that such worlds create an age where we "become posthuman" (Hayles 1999: xiv). In support of the first view, even though games developed as a form of entertainment, a rapidly expanding literature shows that games have significant

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positive cognitive effects. Exploiting these positive effects, games are now being used in many training situations, leading up to the notion of "serious games".

In many games, players are presented with an avatar as a projection plane and access point to the virtual world. One central cognitive effect of playing games is the close connection players develop with their avatar. A widespread 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 Laurel 1991; Mateas 2002). Players often develop an emotional and cognitive connection to their characters, and this is actively encouraged by many games that allow customization of the character in terms of body appearance, clothes, and accessories. Often specialized in their virtual abilities, and equipped with items gathered during long playing hours or extensive avatar customization before the game, virtual characters "belong" to their players. They can become manifestations of the player's individual play achievements and unique preferences. Players closely connect to these carefully crafted and controlled alter egos, and the value of the avatar and its performance for the player has been recognized (Turkle 1996; Isbister 2006).

A second set of cognitive effects of games is the improvement of cognitive skills. Playing video games has been shown to improve attention, spatial ability and mental rotation (Green and Bavelier 2003; Feng 2007). Manipulating virtual objects have been reported to improve subsequent mental rotation and recognition of such objects (Wexler and van Boxtel 2005). Games have also been shown to help overcome cognitive limitations, such as fear of flying (Rothbaum et al. 2006) and post-traumatic stress disorder in the wake of the 9/11 attacks (Difede and Hoffman 2002). Such training effects have been exploited to develop many military combat simulations as well.

A third set of cognitive effects involve discovering novel ideas, and generating novel experiences, using games. Such use of games for discovery is fairly new, and the discovery can be either at the personal level (where a person discovers concepts or ideas new to her) or at the community level (where a person discovers concepts/ideas unknown to her whole scientific community). Examples of such "Tinker-Media" applications (Chandrasekharan 2009) supporting discovery include the UVA Virtual Lab, (*virlab.virginia.edu*), where students can rotate and place molecules in different configurations to learn the structure of the DNA (discovery at the personal level), and *FoldIt*, (*http://fold.it/portal/*), where the protein-folding problem is represented as a video game similar to Tetris, and users around the world play the game to find new protein-folding patterns (discovery at the community level). Another instance of the use of games for discovery at the scientific community level is recent work showing how symbols emerge naturally across players in multi-player games (Galantucci 2005). In the realm of discovering new experiences, recently virtual reality was used to generate out-of-body experiences in the lab (Lenggenhager et al. 2007; see also Ehrsson 2007).

Research of game studies as a discipline is well aware of these three types of cognitive effects of video games, but it has struggled with a definite and clear approach or theory to understand these effects. For instance, we know that the close connection between the avatar and the player is operative and at times highly effective. But we cannot precisely tell why this is so, as the detailed mechanisms underlying the player's relation to the character, and how immersion in the virtual world leads to cognitive changes, are not clear. Similarly, we know games improve cognitive skills such as attention and mental rotation, and also support discovery, but what mechanisms underlie these improvements is as yet unknown. Cognitive effects have been discussed in a range of contexts such as spatial navigation, effect of violence in games, and educational value, among others. There are various suggestions to describe and measure a player's presence (Slater 1999; Witmer and Singer 1998) and models to define and track immersion (Lombard and Ditton 1997; Heeter 1992), but mechanistic explanations of how the effects are evoked are too simplistic (Koster 2005).

In this paper, we outline the emerging cognitive mechanism known as common coding, and show how it can provide an integrated account of the three cognitive effects of video games outlined above (connection to avatar, cognitive augmentation, discovery). We then illustrate, using two ongoing projects, how extending results from common coding research could help derive novel video game formats and interfaces. A close analogy would be the exploration of the movement illusion in the 19th century, and how pushing the limits of this perceptual illusion led to the development of the technological and narrative structure of cinema.

The paper has a theoretical focus, and its objectives are twofold. One is to bring together research in common coding relevant to video games, and use this focused review to show how common coding could account for the above outlined cognitive effects of video games. The second objective is to illustrate, using two of our current projects, how common coding theory could be used to derive novel interface and narrative formats for video games. Note that the theoretical account we provide is a very preliminary one, and requires extensive testing before it can be considered as the best explanation for cognitive effects of video games. For the time being, it only provides a tentative and useful framework for designers to think about novel game interactions.

The paper is structured as follows. The second section presents a broad overview of the cognitive mechanism known as common coding. The third section explores how common coding could explain the three cognitive effects of video games outlined above. We then present two projects that build on common coding results. The first project develops a video game system that uses a tangible user interface to transfer a person's own movements to an avatar. In the second project, common coding theory is used to explore how people attribute character traits to drawings. We describe a simple application in combination with a video game, where this mechanism is exploited to develop a new interaction format. We conclude with a proposal for closer cooperation between the common coding and digital media communities.

2. Common coding

Recent work in cognitive science and neuroscience of movement has illuminated a model of cognition where perception, execution, and imagination of movements share a common coding in the brain. Put simplistically, this means that when humans perceive and imagine movements, particularly actions, their motor system is activated implicitly, and therefore the preferences and biases of our own movements guide how we perceive and imagine other movements and actions. The origins of the common coding idea could be traced to the ideomotor principle outlined by William James:

> Every representation of a movement awakens in some degree the actual movement which is its object; and awakens it in a maximum degree whenever it is not kept from doing so by an antagonistic representation present simultaneously in the mind (James 1890: 526).

The ideomotor effect is explained by a common coding in the brain that connects an organism's movement (activation of motor representations), observation of movements (activation of perceptual representations), and imagination of movements (covert activation of motor and perceptual representations). First clearly articulated by Prinz (1992), this common coding allows any one of these movement representations to automatically trigger the other two movement representations (Prinz 2005; Sebanz et al. 2005; see also Decety 2002; Hommel et al. 2001). The central outcome of common coding is a body-based 'resonance' — the body instantly replicates all movements it detects, generating an internal representation that is dynamic and based on body coordinates. This replication generates a dynamic trace, which can play a role in later cognition. All the replicated movements are not overtly executed or responded to. Most stays covert, as the overt movement is inhibited.

A common instance of this replication, or '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. For instance, this effect explains why we are emotionally moved by a dramatic film scene: we simulate the characters' movements using our own system, and thus implicitly recreate their emotional states. Recent work has extended this effect to language and concept processing, showing that there is motor activation while imagining words encoding movements, and processing sentences involving movements (Bergen et al. 2004; Wilson and Gibbs 2007; Holt and Beilock 2006; Barsalou 1999). Motor activation is also implicated in social biases (Dijksterhuis 2005).

The basic argument for common coding is an adaptive one, where organisms are considered to be fundamentally action systems. In this view, sensory and cognitive systems evolved to support action, and they are therefore dynamically coupled to action systems in ways that help organisms act quickly and appropriately. Common coding, and the resultant replication of external movements in body coordinates, provides one form of highly efficient coupling.

In implementation terms, common coding can be thought of as an artificial neural network encoding both action and perception elements, where the activation of one type of element automatically activates the other (associative priming), similar to connectionist implementations of semantic priming (Cree et al. 1999). Imagination of movement, in this view, would be a form of implicit activation of the action network. It has been proposed that such common coding could arise from Hebbian learning (Heyes 2005).[1] Recent modeling work has shown how such common coding could arise purely through agent-environment interactions, when agents move from not using any representations (being purely reactive) to a strategy of using stored structures in the world/head. This common coding can arise from both evolutionary and within-lifetime learning (Chandrasekharan and Stewart 2007: 347–348).[2]

In operational terms, common coding implies that there are interactions between execution, perception and imagination of movement. We review experimental evidence for different types of such interactions below. Most of the behavioral evidence for common coding is based on interference effects, where actions in one modality (say imagination) leads to a difference in reaction time or accuracy in another modality (say execution). This behavioral evidence is supported by neurophysiological experiments, including imaging, TMS and patient studies.

2.1 Perception-action common coding

If common coding holds, perception of movement should interfere with execution of movement. Brass et al. (2002) showed that when participants execute an action A (say tapping fingers on a flat surface), while watching a non-congruent action on a screen (say another person's finger moving in a direction perpendicular to the tapping), the speed of performed action A slows down, compared to the condition when the participant is watching a congruent action on screen. This is because the perceived opposite movement generates a motor response that interferes with the desired tapping pattern. A similar interference effect has been shown for competing movements within an individual — movement trajectories of participants veer away or towards the location of competing non-target objects (Welsh and Elliott 2004). Establishing the common coding hypothesis further is the reverse of the above, where actions influence perception. Blindfolded subjects, after learning a new sequence of movements based just on verbal and haptic feedback (Casile and Giese 2006), visually recognized the learned movements faster, compared to recognition of other movement sequences. Further, recognition performance correlated strongly with the accuracy of the execution during learning.

This effect of learned actions extends to preference judgments. When skilled and novice typists were asked to pick between dyads of letters (such as FV and FJ) the skilled typists preferred dyads that would be typed with less interference (i.e., different fingers), while novices showed no preference. Moreover, a motor task performed in parallel to the dyad preference judgments lowered skilled typists' preference, but only when the motor task involved the specific fingers that would be used to type the dyads (Beilock and Holt 2007). This preference effect has been generalized recently by Topolinski and Strack (2009), who showed that the mere exposure effect (MEE) — where stimuli repeatedly encountered are increasingly liked — is dependent on motor simulations. They showed that chewing gum while evaluating stimuli destroyed mere exposure effects for words, but not for visual characters. However, kneading a ball left both MEEs unaffected. They argue that this effect stems from individuals representing stimuli by covertly simulating the sensorimotor processes that run when the stimuli are perceived or acted on. So people covertly rehearse words while reading them, and this rehearsal leads to an unconscious preference for those words. Chewing disrupts this process, kneading does not.

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 and Heyes 2005 provides a good review). Perceiving an action has been shown to prime the neurons coding for the muscles that perform the same action (Fadiga et al. 1995; Fadiga et al. 2002). 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. When we observe goal-related behaviors executed by others (with effectors as different as the mouth, the hand, or the foot) the same cortical sectors are activated as when we perform the same actions (Gallese et al. 2002). In contrast, motor areas are not activated when humans watch actions not part of human repertoire (such as barking). The neuronal populations that support such blurring of first person and third person views have been termed "mirror neurons" (Fadiga et al. 2000). These neurons were identified using single-neuron studies in monkeys, and a similar system is now considered to exist in humans.

The action replication 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 and Sebanz (2006: 100) report 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.

Two additional neural mechanisms supporting common coding have been reported. Canonical neurons fire both when a monkey grasps an object and also when it observes a 'graspable' object (Oztop et al. 2006), indicating a common coding between action and perception of action affordances (Gibson 1979). Another supporting mechanism is the behavior of visuo-tactile bimodal neurons during tool use. These neurons fire both when a monkey's hand is touched, and also when light is shown near the hand. When the monkey uses a stick to get food, the visual fields of these neurons "extend out", now firing when a light is shown near the end of the stick. This 'extending' occurs only when the stick is actively used, not when it is held passively, indicating that the perceptual "extending out" is driven by common coding with action (Farne et al. 2005; Iriki et al. 1996). This effect has been shown for people as well, including blind-sight patients.

2.2 Imagination-action common coding

We will use mental rotation work to illustrate this case, though the interaction between imagination and action has been shown in many other areas (see Nersessian 2002, 2008 for a review of action-imagination links as they relate to scientific thinking). If imagination and execution of movement shares a common code, imagining a movement should affect the execution of movement. Wohlschlager (2001) showed that while imagining a mental rotation, if participants plan another action, or move their hands or feet in a direction non-compatible to the mental rotation, their performance suffers. This effect is reversed for compatible movements. Unseen motor rotation leads to faster reaction times and fewer errors when the motor rotation is compatible with the mental rotation, and speeding/slowing the compatible motor rotation speeds/slows the mental rotation (Wexler et al. 1998).

Supporting the common code view further, it has been shown that the time to mentally execute actions closely corresponds to the time it takes to actually perform them (Jeannerod 2006; Decety 2002). 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. When sharpshooters imagine shooting a gun, their entire body behaves as if they are actually shooting (Barsalou 1999). Similarly, imagining performing a movement helps athletes perform the actual movement better (Jeannerod 1997).

Links between imagination and action have also been found by experiments investigating mechanical reasoning, such as how people imagine the behavior of pulleys, gears etc. (see Hegarty 2004 for a review). Children who learn fractions by actually executing movements on blocks learn the fraction concepts better than others who do not perform such movements (Martin and Schwartz 2005). Imaging experiments support these behavioral results, and show that premotor areas are activated while participants do mental rotation (Vingerhoets, de Lange, Vandemaele, Deblaere, and Achten 2002).

In the other direction, common coding would suggest that our action possibilities restrict imagination of novel actions and movements. Kosslyn (1994: 347) reports that participants need more time to perform mental rotations when these are physically awkward. People with writer's cramp (focal hand dystonia) take more time to do mental rotation of hand pictures, and people have difficulty mentally rotating manually difficult hand movements, such as right-sided stimuli at 120 degrees and left-sided stimuli at 240 degrees (Fiorio et al. 2006).

According to common coding, we understand another person's actions by re-enacting those actions using our own motor system. An example would be judging the weight of an object by watching how a person lifts a heavy object. Bosbach et al. (2005) recently showed that people with compromised ability to activate their body, such as deafferented individuals, cannot make such predictions, suggesting that the action system is used in such judgments. Thus, while our action possibilities are 'leveraged' to understand and predict movements and actions, our action repertoire also acts as a cognitive bottleneck, through which our creative output and imaginative comprehension is filtered.

2.3 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, see 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 the work on 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 and Stucchi 1989; 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.

Such predictions 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 et al. 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. Based on this and other experiments, 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. "In formulating velocity judgments, humans have access to some implicit knowledge of the motor rule expressed by the Two-thirds Power Law" (ibid.: 419).

2.4 Common coding across individuals

There is emerging evidence that the common code 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 movements (Sebanz et al. 2005; Welsh et al. 2007; for a review see Knoblich and Sebanz 2006). Such sharing, supported by the mirror neuron system, emerges even when such sharing leads to a decline in one's own performance. The common coding hypothesis can thus also account for the ability of two people to coordinate task performance (say in a multi-player game) because perceiving the other's actions activates one's own action system, leading to an intermingling of perception and action across players (Knoblich and Sebanz 2006).

From this brief review, it is clear that there is significant evidence in favor of a common code linking execution, perception, and imagination of movement. The next section applies this theoretical position to the problem of cognitive effects of video games.

3. Applying common coding to video games

How does common coding explain the cognitive effects of video games? As outlined in the introduction, the known cognitive effects of video games can be broadly classified into three.

- A preference effect, where players develop close connections and attachment to their avatars.
- A cognitive augmentation effect, where players overcome fears (as in the case of fear of flying) or cognitive limitations (as in the case of improving attention and mental rotation).
- A discovery effect, where players discover new ways of doing things (as in the case of developing new protein-folding possibilities using the *Foldit* game) or discover new experiences (as in the case of game environments being used to generate out-of-body experiences).

Common coding posits a common neural representation that connects perception, imagination, and execution of movements. This connection allows movements in any one modality (say perception) to activate movements in the other two modalities (imagination/execution). This connection leads to external movements being covertly regenerated by the player's motor system, transferring the movement instantaneously to the player's body coordinates.

Since all actions you perceive/imagine are covertly replicated, players covertly replicate the actions of their avatar, both when they imagine them, and also when they control the avatar, and see their actions executed on screen. This leads to a mere exposure effect as discussed in Section 2.1 (Topolinski and Strack 2009; see also Beilock and Holt 2007), where the simulation of the avatar's movements, in concert with the movements controlling the avatar, leads to the development of an unconscious preference for the avatar. This accounts for the preference effect. Recent work examining the automatic replication of perceived body movements shows that people replicate the actions of an avatar from the perspective of an avatar (Thirioux et al. 2009), and not from their own perspective. It is possible that such perspective taking could also contribute to the player's preference for the avatar.

The cognitive augmentation effect could be explained similarly, by the player covertly replicating the movements of the avatar on the screen. The covert replication of the observed movements could lead to the fine-tuning of the attention and spatial cognition modules involved in these actions, as these modules contribute to the motor system's simulated response as the player navigates the game. In the case where fear of flying was overcome, the VR system allowed the subject to covertly replicate the movements associated with different flight situations, but in a situation when she was not flying. This replication of movements generated a mimicked experience of the actual movements in a situation perceived as safe, which, over time, led to a habituation of her emotional responses, thus toning them down. This is similar to how imagining performing a movement helps athletes perform the actual movement better (Jeannerod 1997).

The improvement in mental rotation can be explained by the fact that mental rotations are closely related to hand rotations in the brain. Playing the game led to finer motor rotations of the hand, and this, in turn, supported more fine-grained mental rotations. It is also possible that game situations, such as shifting camera angles, required the players to do mental rotations to orient their avatar, and these novel rotations also helped in improving mental rotations. The attention effect is more complex, but it could also be accounted by the expanding literature showing close connections between attention and the motor system (for a review, see Welsh et al. 2007; also see Hommel et al. 2001).

The discovery effect, particularly in science and engineering, is explained by a combination of the replication effect and the movements involved in the building process while playing with simulations such as *Foldit* and UVA Virtual Lab. Roughly, models in science and engineering characterize phenomena in terms of movement of bodies or particles. Hence internal models in science and engineering have movement properties that could be understood in terms of motor simulations (see Nersessian 2002, 2008; Hegarty 2004). Building and running external models involve imagining and generating fine-grained movements, which could also be understood in motor simulation terms. Movement, and its instantiation using the motor system, is thus a common element between internal and external models. Covert activation of the motor system is thus a 'lingua franca' that seamlessly connects internal simulations with external movements generated by built models. This common connection allows the states of external models to change internal models directly.

The generation of new concepts from the building process is explained in two steps. First, building a model involves generating new and fine-grained movements in imagination, but in ways limited by the building process. Second, these movements, together with the movements generated by the external model, 'perturbs' existing internal models in a constrained fashion, allowing the internal models to move away from standard movement grooves and generate new patterns. These new patterns lead to new concepts (for details of this model, see Chandrasekharan 2009).

The experiments that generated out-of-body experiences using virtual reality environments and the one showing the emergence of symbols in multi-player games, are also related to common coding, and these effects can be explained by common coding. However these explanations are closely tied to the setup of these experiments, so we will skip them here.

From the above brief description, it can be seen that common coding, by providing a connection between perception, execution, and imagination of movements, suggests an integrated mechanism that can account for most of the cognitive effects of video games.[3] In the following two sub-sections, we outline two projects where we seek to extend some of the common coding results. The projects illustrate how the effort to extend common coding could lead to the development of novel interfaces and interaction formats for video games.

3.1 Self-recognition: A new control and interaction model

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

In this project, we bring together two research threads from the common coding experiments (see Figure 1). The first thread shows that people recognize their own actions better, such as their own clapping from a set of clappings, their own handwriting from many writings traced by a light-point, and their own piano playing from many recordings playing the same piece (for a review, see Knoblich and Sebanz 2006). This own-action effect arises because perception of actions involves activating the motor system (via the mirror neuron network). Since the motor system is trained by our own actions, perceiving our own actions activates our motor system better, and that allows us to identify our own actions better. Extending this result, we hypothesized that a player will identify more closely with a virtual character in a video game if that character encodes the player's own actions.

To examine this hypothesis, we needed to develop a control interface to map users' own actions onto a virtual character in a real-time virtual environment. For this, we have developed a wearable puppet that moves along with the player's

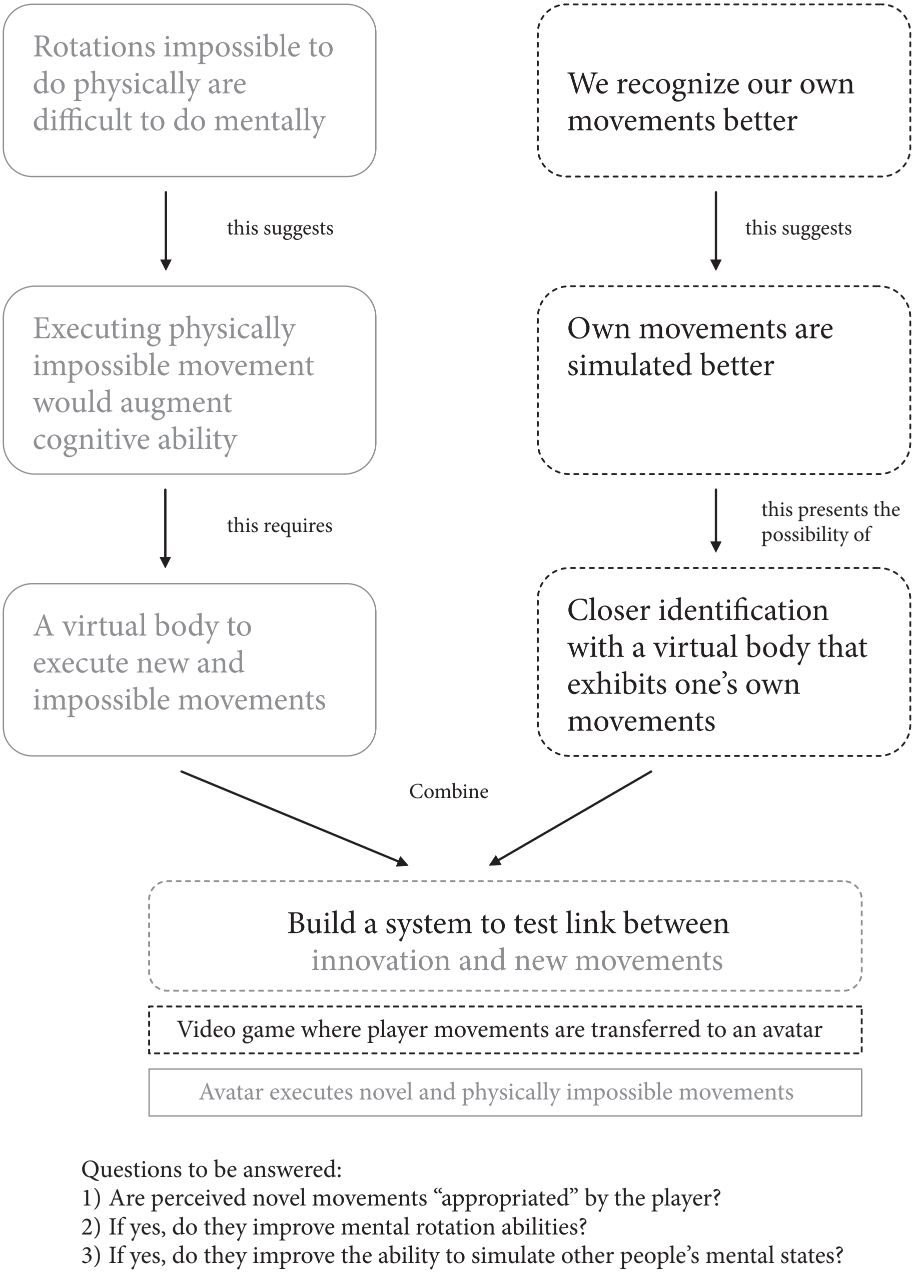

Figure 1. Concept map of the experimental and theoretical background of the project and its objectives.

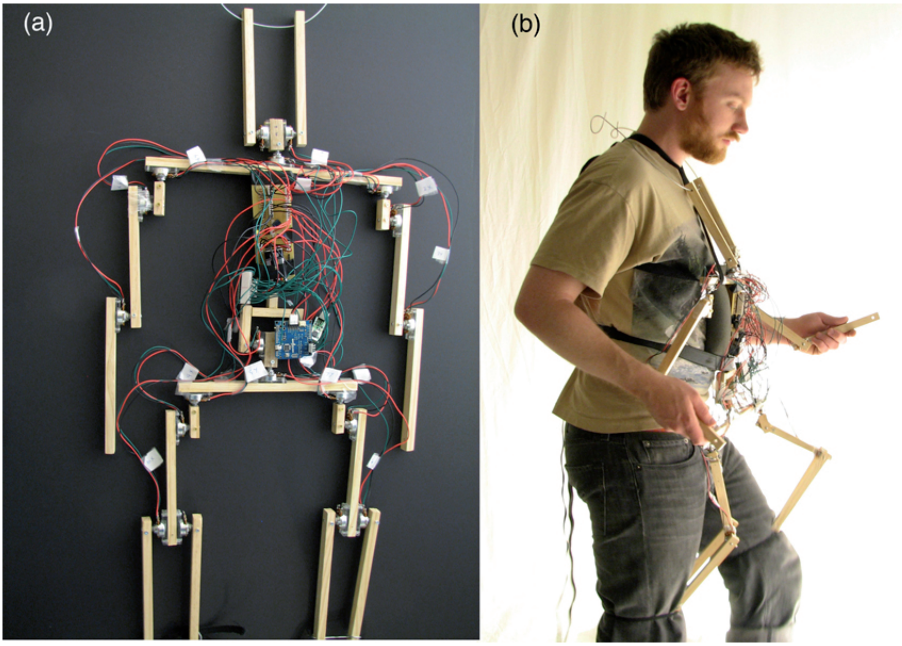

Figure 2. Basic puppet prototype (a); and player interacting with the basic puppet (b).

hands, legs and neck, and the movements of the puppet are transferred to a virtual character (see Figure 2 for an early prototype).

To examine whether people can recognize their own movements when represented in a character, we ran an experiment to see whether players can identify abstract representations that encode their own actions (point-light walkers, created by affixing small lights to an actor's body and filming him/her moving in the dark, see Figure 3), as opposed to other people's actions. The experiments showed that people can recognize their own movements 80% of the time, even when the point-light walkers were presented in altered body sizes, and when the point-light representations showed only a puppet moving, without the person's movements while manipulating the puppet (see Mazalek et al. 2009). We have now shown that this self-recognition effect occurs even when a player's movements are transferred to an avatar using the puppet (Mazalek et al. in press).

The second line of research we exploit involves the link between actions and imagination. Work in common coding shows that losing some motor abilities leads to losing some mental abilities. Examples include lowered ability to do mental rotation by Dystonia patients, and a lack of ability to judge weights by deafferented people (Fiorio et al. 2006; Bosbach et al. 2005). Extending these results, we hypothesized that executing novel movements should improve imagination of novel movements, thus improving players' ability to execute creative cognitive processes

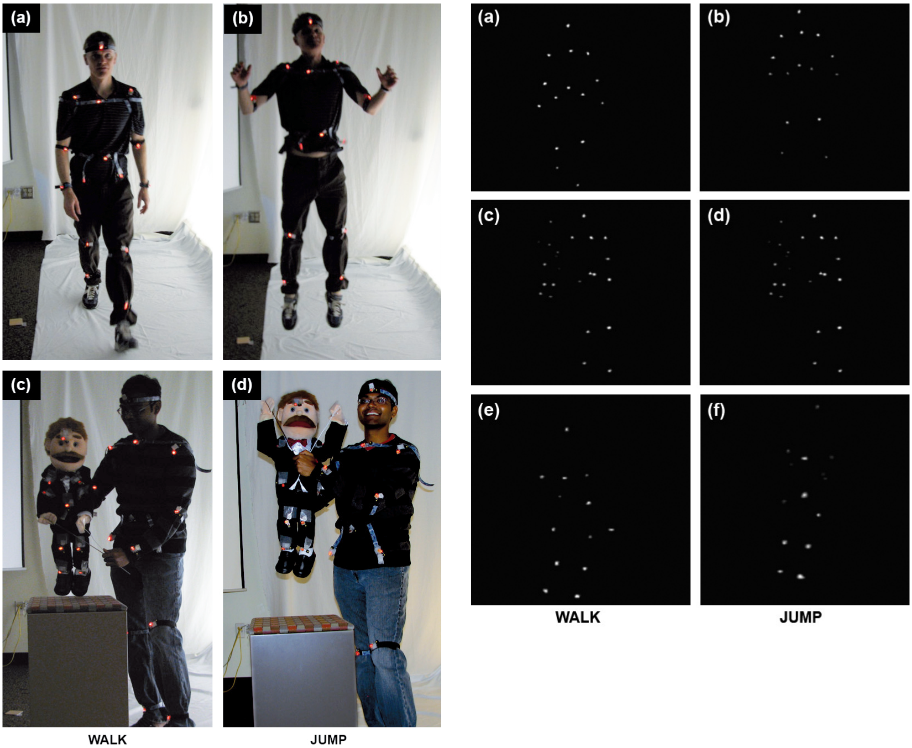

Figure 3. Panel 1 shows 'walk' and 'jump' movement tracking with LED straps attached to: participant body (a and b) and both puppet and participant bodies (c and d). Panel 2 shows video stills of visually abstracted walk and jump movements for: participant body (a and b), participant body with puppet (c and d), and puppet only (e and f).

such as mental rotation. To examine this hypothesis, the "personalized" virtual characters (characters encoding the player's own actions) would need to execute physically impossible movements on screen. However, for the self-recognition effect to work, while executing these physically impossible movements, the puppet-controlled avatar should retain the movement patterns of the user. But the user cannot control the avatar using the puppet when the avatar executes novel movements such as back-flips (as this would require the user also doing back-flips). This is an interesting application challenge, where we need to maintain a fine line between control and no-control, with self-recognition elements of the former situation retained/continued into the latter situation. For this, we have developed a game where the cameras around the avatar rotate slowly, giving the impression of the avatar rotating in space. Objects then appear close to the avatar, and the user's task is to touch these objects using the puppet interface. Our recent results show that playing this game using the puppet leads to better mental rotation performance, compared to playing it using standard game interfaces such as keyboards and game controllers. Insights gained from this experiment would be useful in developing multiplayer games where game objects are shared between players, and also training simulations for distributed systems, such as drones in war zones.

A related effect we are examining is 'morphing' of movements between two players, and how this would affect self-recognition. In this proposed experiment, two participants A and B interact with our experimental system, in two stages. In the first stage, each participant's movements are mapped to the character. After each participant is familiar with their personalized character, comes stage two — each participant tries to coordinate with the animation of a tightrope walker on screen (Thirioux et al. 2009) that encodes their own movements. As participant A does this, her movements in the animation are gradually replaced with person B's movements, and vice versa. We then test to see whether this morphing improves the effect of the participant taking the perspective of the character (i.e., tilting to the same side as the tightrope walker, reported in Thirioux et al. 2009).

These experimental applications are still being developed, but it can be seen from the above description that they all share common coding as a common theoretical base, and were derived using common coding as a starting point. This is true of the next project as well.

3.2 Two-thirds power law: A new approach to character design

In this project, we examine the mechanism people use to attribute character traits to drawings such as a cartoon or animation character. Specifically, we want to see whether people can access the speed at which a cartoon/animation is drawn, and whether people exploit this information while attributing character traits to cartoons or animations. Such access of the movement speeds (involved in the drawing) is achieved by mentally simulating the drawing process, based on the Two-Thirds Power law, discussed in Section 2.3. Based on preliminary results that show that speed values are accessed while making character attributions, we are designing a video game where the natural drawing speed of a player is captured, and correlated with her decision-making patterns in the game.

Part of the background for this work comes from "thin-slice" studies in social psychology, which show that from watching thin slices of video (50 seconds) of two people interacting, participants 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 et al. 2000), showing that the judgments are based on movement information. People can make similar judgments from light-point walkers (see Figure 3), which provides only action cues. Participants can predict the gender of the actor, emotions portrayed by the actor, identity of familiar individuals, and even personality traits (Cutting and Kozlowski 1977; Kozlowski and Cutting 1977). Even facial expressions, which imply elastic transformations, can be perceived from the movements of a few point lights (Bassili 1978). These results have been recently extended (Johnson et al. 2007) to show clearly that people attribute sexual orientation to individuals based on movement cues. As in the case of perceptual judgments tasks reported in Section 2, these social judgments are also considered to be based on motor simulations, driven by perception of others.

We are interested in understanding how people attribute traits to characters in media such as cartoons and animations. The objective is to examine whether motor simulations underlie such judgments, and if yes, how such simulations could be exploited to generate novel modes of expression. For this, we developed a pilot experiment to understand how people attribute character traits to cartoon figures, such as Calvin and Charlie Brown. First, a list of traits was generated (see Table 1), based on character traits of two individuals. One of the individuals, when asked to draw faces and four-leaf clovers on a digital tablet, tended to draw the figures very fast, the other tended to draw them very slow. Some collected traits of these two individuals (randomly mixed with some "possession traits", see Table 1) were submitted to 24 people from different cultural backgrounds, including American, Indian, Chinese, Korean, German and Turkish. They were asked whether the traits/features suggested a person with Fast movements or Slow movements. If the trait/feature did not suggest fast nor slow movements, they were to be classified as Neutral.

From the responses, twelve traits that got the highest fast/slow ratings were selected, and randomly presented to another set of participants as questions along with two pictures, one of Calvin and the other Charlie Brown. For instance, two questions were: "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). The results showed that the traits categorized as Fast by the first group were consistently mapped to Calvin, and the ones categorized as Slow were mapped to Charlie, more than 95% of the time. Surprisingly, this mapping was chosen by American participants, as well as non-English speaking and illiterate participants in India, who have never been exposed to Calvin or Charlie comics (Chandrasekharan and Ranjan 2007).

Given the similar results with illiterates and people not familiar with the characters, we hypothesized that these character attributions are based on participants "simulating", i.e., covertly executing, both the character traits (such simulation of 'situation models' has been shown in language processing, see Glenberg and Kaschak 2002; Johnson-Laird 1983) and the movement that created the drawings.

Table 1. Traits classified as fast/slow/neutral by 24 respondents. The ones used in the drawing study are in bold.

Sorted	Fast	Slow	Neutral
Jumps traffic lights.	21	1	2
Buys things impulsively when shopping.	20	2	2
Prefers to watch action films.	19	2	3
Likes to change jobs, houses, TV channels etc.	18	1	5
Starts pacing up and down while waiting for the bus.	17	1	6
Makes lots of gestures and hand movements while talking.	16	2	6
Goes early for work.	14	4	6
Raises voice in an argument.	12	1	11
Jokes a lot during conversations.	11	2	11
Folds clothes and keeps them neatly in the wardrobe.	2	17	5
Explains things clearly.	1	16	7
Checks doors and windows before going out of the house.	2	15	7
Spends long time in bed.	2	15	7
Likes to do gardening.	1	15	8
Goes for long walks.	2	12	10
Owns a black cat.	1	1	22
Has brown eyes.	1	2	21
Uses a yellow music player.	3	0	21
Wears rings.	3	1	20
Has long palms.	2	3	19
Lives in a big house.	2	3	19
Offers his/her seat to elderly people in a bus.	3	2	19
Has many blue items in wardrobe.	2	5	17
Is tall.	2	5	17

This two-step simulation process would allow 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 2.3 on the Power law). Participants then link these two simulated parameters, namely the sense of movement from the simulated character traits, and the sense of movement from simulating the drawings.

To test this hypothesis more rigorously, we needed to develop sample drawings with accurate velocity values. This required a tool that tracked the tangential velocity of a participant's drawing movement across time, and then regenerated the participant's drawing as animations using the same velocity values. We also wanted to manipulate the speed of the animated drawings, based on values input by the experimenter. This feature was needed for two related reasons. One, to make sure that the attribution of character traits was based on speed, and not on sketch features such as size, shape, squiggles etc. Second, to make sure that the process underlying character attribution is indeed simulation. If a picture (say one drawn at a slow speed) stays constant on the screen, and a light-point moves over it at a different speeds (say much faster than the original drawing speed) common coding theory would predict that there will be interference between two speed simulations, one from the drawing, the other from the light-point. If simulation is indeed the process involved in character attribution, this should lead to different attributions in the light-point condition, compared to the plain picture one. Based on the same logic, the speeds of the animations also needed to be manipulated, to test the simulation hypothesis rigorously.

3.2.1 *BETS: A tool to study and manipulate common coding in media*

To meet these experimental requirements, we developed a combined tracking and media tool in Java, termed BETS (for Behavioral Traits from Sketches, see Figure 4). Based on inputs from a Wacom graphic tablet (Intuos3), the BETS tool implements three separate but related functions: data capturing and storing, sketch analysis, and image/animation export. The first function captures subjects' sketching data and stores it in memory or external storage. The subject sketches using a pressure-sensitive stylus on a graphics tablet, based on predefined samples, instructions or free imagination. A series of coordinates and pressure values associated with a sketch are then stored, along with timestamps — the relative temporal label showing when they are captured — into a data structure called a *drawing*.

Multiple drawings from one subject are displayed together on a thumbnail browser for review, and can be saved to a data file. The data file can then be loaded back to the application for further analysis and processing. Moreover, the application can present additional stimuli to subjects at the time of sketching. Subjects can either see the graphical representation of their sketch, or congruent or conflicting visual/audio stimuli, or a completely blank screen based on the requirements of different experiments.

The second function analyzes the captured sketching data (i.e., time-stamped coordinates and pressure values) in individual drawings to obtain both global characteristics, such as average drawing speed, total time used, and average pressure, as well as detailed local information, such as curvature, speed, and pressure variations. The global characteristic values are displayed as numerical labels. The detailed local values are either displayed in sketches with different colors or in

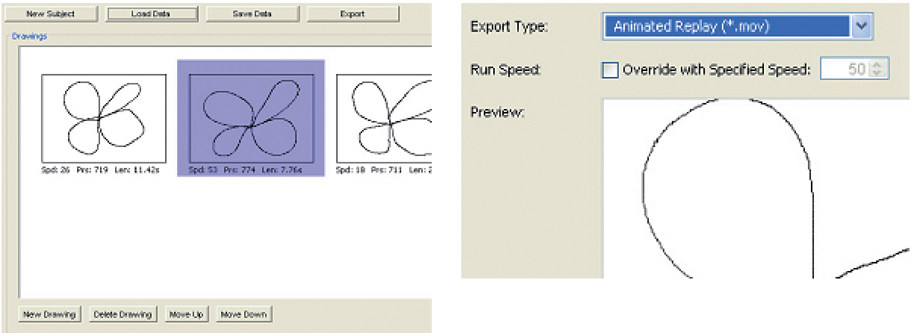

Figure 4. Panel 1 shows the Thumbnail Browser, which displays multiple drawings from one subject, with associated speed, pressure and duration values. Panel 2 shows the export interface that allows sketches to be exported as still images, animated replays of sketching, or light-point replays. Preview is provided before export.

a separate histogram. For example, speed is displayed by varying the colors in a sketch from dark blue (slower) to bright red (faster), while pressure is shown on a separate histogram. In addition, individual drawings can be selected from the thumbnail browser (see Figure 4) and rendered in a separate window using three different representations: still images, sketching animation and light-point animation. The still image, representing the final state of the sketches, visually provides the general quality and curvature detail of the sketch. The sketching animation authentically replays the sketching process, while the light-point animation moves a color dot along a sketch to reflect the moving speed of the stylus (see Figure 4).

The last function exports the graphical representation of drawings to file formats acceptable by other applications, especially web browsers. BETS currently supports exporting drawings in three representations in accord with the on-screen rendering (see Figure 4). Still images are exported in JPEG and animations in QuickTime™ format. Before exporting drawings, users can see previews of the exported files. After examining the preview, users can then specify the export destination and a file name prefix, which will be appended with the text representing global characteristic values of the drawing. By appending those values, users will be able to keep track of the characteristics of the drawing without referring back to BETS. Moreover, in order to allow experimenters to manipulate the speed of the animated drawings, an option has been provided to vary the running speed of the exported animation. This allows testing the simulation hypothesis more rigorously.

3.2.2 *Using speed values in an interactive video game*

The above tool allows developing experiments that explore whether traits one set of people classify as fast/slow tend to be matched to fast/slow drawings by another set of people. If such a correlation emerges, this would provide insight into how people attribute character traits to media such as cartoons and animations. An even more interesting question here is: do people use such speed-based matching while judging other people, and do such judgments really pick out others' behavior? That is, do people who tend to draw fast also behave in a "fast" fashion? Would they be impatient, impulsive etc.? If such a correlation exists, are these correlations picked out and used by others?

To test this, we are using the BETS tool to develop an interactive video game. In the game, players first draw a smiley face and a four-leaf clover using the drawing tool, and their speed values are stored. The player then plays a video game. The game involves judgment situations, such as shoot/not-shoot, fight/not-fight, take risk/no risk etc. The behavior of the player in these judgment situations are then correlated with the speed values of their drawings.

If such a correlation emerges, then we will see whether other people have access to these correlations and use them. This will be done using an experiment similar to the character attribution experiment. First, participants will be shown animations of two drawings, made by person A and B (animations generated by the BETS tool). They will then be shown a random set of decisions made by A and B in the video game, and asked which were made by A and which by B. If people use speed values to make such judgments about others, they would be able to significantly pick out the decisions made by A and B.

As is clear from the above description, this is a different approach to the interaction design for a video game, combining a player's natural (drawing) speeds to her decisions in a game. This application is still under development, but it illustrates how a new mode of interaction emerged from our interest in extending the effects of common coding.

4. Conclusion

We have outlined in broad terms some of the results from the common coding approach to cognition, and how these results could explain three types of cognitive effects of video games. We then presented two experimental applications that are derived by extending common coding results, and how these present new interaction design formats. These applications represent only a small sample of the novel media and interaction possibilities opened up by common coding research. In the other direction, experiments that explore common coding often use computational media such as virtual reality, touch screens, graphic tablets, etc., in novel ways (such as to generate out-of-body experiences), and also extend techniques such as motion capture and movement tracking. We believe close interactions between the digital media and common coding research communities would be fruitful in developing novel computational applications, behavioral experiments, and theoretical models that extent the limits of human cognition.[4]

Notes

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1. Hebbian learning is a form of learning where any two cells or systems of cells that are repeatedly active at the same time tend to become 'associated', so that activity in one facilitates activity in the other. This is roughly captured by the slogan "cells that fire together, wire together".

2. This model showed that purely reactive agents (which have only perception and action modules) could discover and use the strategy of generating and storing information structures (such as pheromones) in the world, and the exact same learning mechanism could also lead to storing of structures in the head (memories). Since reactive agents learn both these "representation" strategies using the same learning mechanism, this model considerably weakens the (currently influential) view that there is a clear-cut distinction between situated/dynamic/non-representational approaches to cognition and symbolic approaches to cognition. (For a wider discussion of this point, and how common coding bridges the situated/symbolic cognition divide, see Chandrasekharan and Osbeck 2010). Further, the paper shows that because the stored internal structures (memories) are "constructed" purely from the states of the perception and action modules (in different environmental contexts), these memories have an event/common coding character, which supports action simulations. This means the current disagreement over embodied and simulation-based accounts of cognition is one about levels of description, and not category.

3. One reviewer pointed out that common coding could explain the efficacy of other media technologies as well, such as direct manipulation interfaces; so a common coding explanation of the cognitive effects of video games is not surprising, and therefore not really novel. This criticism runs together possibility and actuality, or equivalently, theory and practice. To see how, consider the following analogy. Fluid dynamics models have been extended to develop applications in medicine. Upon encountering such a fluid dynamics application (say, optimization of heart surgery sutures in infants), it is possible to raise the following criticism: blood is a fluid, so it is possible to have fluid dynamics models of everything related to blood flow, therefore the heart surgery optimization is not novel. However, this criticism is *post-hoc* (raised after a specific extension is developed and implemented), and based on the possibility of *potential* applications. The possibility and potential does not lower the novelty of the specific application of fluid dynamics theory to the heart, and the resulting *actual* heart surgery optimization. Potential possibilities do not devalue actual applications — the potentials are moved closer to reality with each actual implementation.

4. Both digital media and common coding are interdisciplinary communities with membership from a broad range of academic disciplines, including, but not limited to, cognitive science, neuroscience, psychology, kinesiology, philosophy, ICT, literature, and anthropology.

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Authors' addresses

Sanjay Chandrasekharan
School of Interactive Computing
Georgia Institute of Technology
GVU Center, TSRB 221B
85 5th St. NW
Atlanta, GA 30332-0760
U.S.A.

sanjayan@cc.gatech.edu

Alexandra Mazalek
Digital Media Program
Georgia Institute of Technology
GVU Center, TSRB 333
85 5th St. NW
Atlanta, GA 30332-0760
U.S.A.

mazalek@gatech.edu

Michael Nitsche
Digital Media Program
Georgia Institute of Technology
GVU Center, TSRB 333
85 5th St. NW
Atlanta, GA 30332-0760
U.S.A.

michael.nitsche@gatech.edu

Yanfeng Chen
Digital Media Program
Georgia Institute of Technology
GVU Center, TSRB 333
85 5th St. NW
Atlanta, GA 30332-0760
U.S.A.

ychen@gatech.edu

Apara Ranjan
Department of Psychology
University of British Columbia
Okanagan Campus, 3333 University Way
Kelowna, British Columbia
V1V 1V7 Canada

apara.ranjan@ubc.ca

About the authors

Sanjay Chandrasekharan obtained his PhD in Cognitive Science from Carleton University, Ottawa. He is currently a postdoctoral fellow with the School of Interactive Computing, Georgia Institute of Technology. Previously, he was a postdoctoral fellow with the Cognitive and Motor Neuroscience lab, Faculty of Kinesiology, University of Calgary, and a faculty member at the Centre for Behavioral and Cognitive Sciences, University of Allahabad, India.

Alexandra Mazalek completed her PhD in Media Arts and Sciences at the MIT Media Lab. She is an assistant professor in Digital Media with the School of Literature, Communication and Culture, Georgia Institute of Technology.

Michael Nitsche completed his PhD in Architecture at Cambridge University. He is an associate professor in Digital Media with the School of Literature, Communication and Culture, Georgia Institute of Technology.

Yanfeng Chen holds an MS in Human-Computer Interaction from Georgia Institute of Technology. He currently works in the software industry.

Apara Ranjan holds an MA in Cognitive Science from the Centre for Behavioral and Cognitive Sciences, University of Allahabad, India. She is currently pursuing her PhD in Psychology at the University of British Columbia, Okanagan.