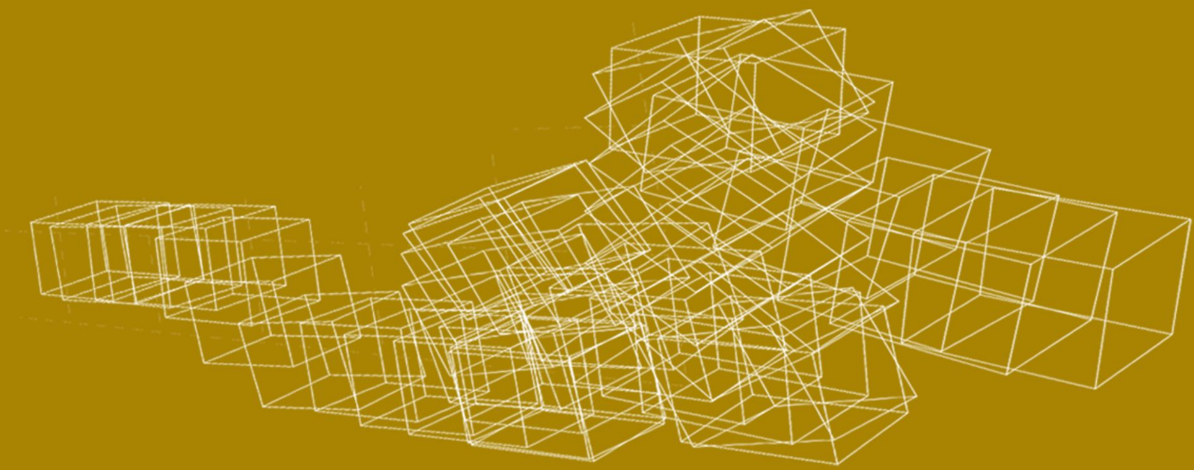
MTSB 2019

Movement That Shapes Behaviour

Rethinking how we can form relationships with non-humanlike embodied agents



Edited by Petra Gemeinboeck, Rob Saunders and Elizabeth Jochum

PREFACE

The AISB 2019 Symposium on Movement that Shapes Behaviour (MTSB'19), organized by Petra Gemeinboeck, Elizabeth Jochum and Rob Saunders, offered a transdisciplinary forum for exploring the potential of movement to shape robots' capacities to become social agents. Robots, designed and built to share our social spaces, are expected to affect every aspect of our lives in the near future. Currently, social robot designs often mimic humanlike or animal-like features, both in terms of how they look and how they behave. The aim of MTSB'19 was to explore how movement and its expressive, relational qualities can mediate between humans and machines by promoting alternative, embodied ways to 'read' robots. The social potential of movement could hold the key to diversifying the design of social robots by widening the spectrum of human-robots relationships, without relying on a human- or pet-like veneer.

The importance of movement and its potential to shape behaviour can be traced back to early cybernetic experiments and artworks, such as, Grey Walter's tortoises, Gordon Pask's conversational systems and Edward Ihnatowicz's SAM. In cognitive psychology, Heider and Simmel's classic experiments demonstrated the potential of movement to generate social meaning using simple animated geometric figures. MTSB'19 emphasised the importance of methods and practices from the fields of robotic art, dance, design, performance, and theatre. Grounded in embodied knowledge, they offer valuable insights for embodied AI, e.g., by working with movement as a material, embodying 'other bodies', meaning-making through movement qualities, or forming new relations through movement dynamics, embodied perception, and kinesthetic empathy.

MTSB'19 presented the second iteration of a transdisciplinary research community-building around questions of movement, embodied meaning-making and human-robot relationships, following a Special Session at RO-MAN 2018, Nanjing. The AISB 2019 Symposium brought together scholars and practitioners from a wide range of fields, including choreography, cognitive psychology, creative robotics, dance, machine performance, mechanical engineering, and design.

CONTRIBUTIONS

Louis-Philippe Demers's keynote talk 'Experiencing the Machine Alterity' offered unique insights into situated bodies in motion and how we perceive their agency beyond morphological mimicry. Demers is Director of the Creative Lab at QUT, Brisbane, Australia, and a multidisciplinary artist and researcher, whose practice focuses on large-scale installations and machine performances. His award-winning works, including *The Tiller's Girls*, *The Blind Robot* and *I Like Robots, Robots Like me*, eschew anthropomorphic familiarity in favour of embodied experiences of machine alterity. Placing audiences in close, sometimes tangible encounters with strange machine agents, Demers argues that robots' perceived agency emerges from their embodiment of intent through movement, embedded in a carefully crafted performance scenario.

Catie Cuan, Ellen Pearlman, and Andy McWilliams explore human-robot relationships through a discussion of their live dance performance *OUTPUT*, featuring a live human performer and video recordings of an industrial robotic arm that has been choreographed by the dancer. The paper outlines the development of two software tools, CONCAT and MOSAIC, to realise the artist's goal and accommodate the choreographic work with a non-portable robotic arm. The performance investigated the inherent tensions emerging from technologically mediated experiences of robots, demonstrating both analogue and digitised modes of human agency that controlled seemingly autonomous processes.

Roshni Kaushik and Amy LaViers explore the limits of using verticality to classify motion in their analysis of the Indian classical dance styles of Bharatanatyam and Kathak. Their analysis of similar movements from the two styles observed differences in position and tension. The authors discussed limitations of their verticality metric and introduced new movement measures that may be more appropriate for highlighting differences across the two dance styles. The paper touches on potential applications, including the development of robots that need to sense human motion across different cultures.

Sarah Levinsky and Adam Russell discuss their choreographic development system, 'Tools that Propel'. The authors examine the dialogue emerging from dancers' movements and the behaviour of their computational system using two interrelated frameworks. Firstly, as an 'extended bodymind', where choreographic thinking happens across both the dancer and the system, and secondly, as a pair of agents, such that the system intervenes on the dancer's decision-making, and the embodied knowledge of the dancer acts on the system. The authors argue that through sustained dialogue new choreographic thinking emerges such that movement shapes behaviour and behaviour shapes movement.

Caroline Yan Zheng's and Kevin Walker's paper explore the promise of soft robotics to create emotionally engaging human-robot interactions. They reported on a preliminary study of the affective qualities of four soft robotic artefacts, which suggests that such artefacts are able to elicit emotional engagement. The authors discuss opportunities for designing affective interaction that afford novel sensory experiences, concluding that the biomorphic movement quality of soft robots has great potential to significantly impact affective relationships with users.

Aleksandar Zivanovic explores the motion control system of Edward Ihnatowicz's pioneering work The Senster (1970). The paper provides a detailed technical account of the hybrid control system using analogue circuits to generate smooth motions from the outputs of a digital computer. Using aesthetic judgement, Ihnatowicz produced a motion controller able to produce smooth movements resembling natural movements, e.g., of the human arm. To implement similar movement qualities using low-powered micro-controllers, Zivanovic provides an efficient algorithm using exponential smoothing.

Nathalia Gjersoe and Robert H. Wortham review the relevant literature on the development of anthropomorphism as a psychological bias in children. They conclude that there is substantial evidence that children and adults attend to robot behaviours as much as (or more than) robot appearance when attributing mind but that it is unclear whether there is developmental change in this psychological bias. The authors propose a programme of research to expose the key behavioural drivers that elicit anthropomorphism and examine how responses vary with the age of users and robot design.

Florent Levillain's and Selma Lepart's contribution directly engages with the question of expressive movement in non-humanlike robots, targeting the nature of expressivity and its perception. Their paper discusses a participatory study to identify and characterize the expressive movement qualities embodied by a simple robot. The authors argue that expressivity can be perceived as a distinct modality of evaluation, separate from other movement qualities. Initial results indicate that expressivity is primarily associated with movements possessing specific movement patterns that they call granularity and readability.

Petra Gemeinboeck's and Rob Saunders's paper investigates the social capacity of robots as an emergent phenomenon of the situated exchange between humans and robots, rather than an intrinsic property of robots. Deploying their Performative Body Mapping (PBM) approach, they have developed an abstract robotic performer for investigating how the social presence of a robot-in-motion emerges in the encounter between human and robot. Preliminary results from a study involving experts from performance and design suggest a shift from an attribution of qualities to the emergence of qualities, propelled by the enactment of agency in the encounter itself.

Each of these contributions presents us with a different, original approach to understanding the potential of movement for expanding and diversifying human-machine relations. Together, they attest to the importance of cross-disciplinary collaborations and trans-disciplinary conversations to not only tackle this challenge but also to reflect on our approaches and the views and assumptions they inevitably bring with them.

Petra Gemeinboeck and Rob Saunders

CONTENTS

OUTPUT: Translating Robot and Human Movers Across Platforms in a Sequentially Improvised Performance

Catie Cuan[1], Ellen Pearlman[2], and Andy McWilliams[3]

Abstract. "OUTPUT", a performance piece between a fifteen foot tall ABB IRB 6700 robotic arm named, "Wen", and a human performer was created over the course of a 16-week "Mechanical and Movement" residency at ThoughtWorks Arts in New York City, in conjunction with the Pratt Institute's Consortium for Research and Robotics (CRR). The performance's purpose was to create relationships between vestiges of real (human) and technologically captured bodies. This piece also initiated the development of two new software tools, CONCAT and MOSAIC. This paper explores tensions between the impact of a live human or a live robot and their representation by reprocessing through machines - cameras, animations, sensors, and screens.

1 ARTISTIC MOTIVATION & CONTEXT

Contemporary popular media often reinforces fearful notions of the future between humans and robots: a dystopian, hierarchical landscape where menacing robot overlords rid humans of agency, subjugating them into mere perfunctory slaves. Humans appear physically and mentally inadequate while robots are dominant and inviolable. These sentiments may be especially threatening for individuals who do not have personal, real-life experiences with robots.

However, different non-fiction views contrast this robot apocalypse. A 2018 study by researchers from Uppsala University and the London School of Economics demonstrated that the introduction of industrial robots (like the Wen) increased wages for employees, as well as the number of highly skilled jobs across 14 industries in 17 countries, from 1993 to 2007 [1]. A 2018 survey article in Science Robotics listed power sources for long-lasting mobile robots and functional artificial intelligence as unresolved and critical challenges [2]. Many of today's robots, from the iRobot Roomba to Google's Alpha Go, are single purpose robots requiring a human collaborator in order to function meaningfully in the real world.

Narrative discourse and live performance are methods to not only initialize, but also reshape individual's impressions concerning their relationship to robots. For example, how might a nine-foot Wen arm be recast when modified into an animation or film presented alongside a dancing human performer? Cuan personally experienced this reshaping while experimenting with the robot. After an initial work session with the Wen, Cuan recognized two opposing identities embedded within the robot. In the first, the Wen was a physically large, power-devouring, and forceful robot, capable of stretching steel and slicing at high speeds. In the second, the Wen had a limited motion range, was confined to an indoor track, and relied on activation through laborious, error-ridden programming. The physical identities were contradictory, with the latter directly contrary to the idea of a dominant, fear-inducing robot.

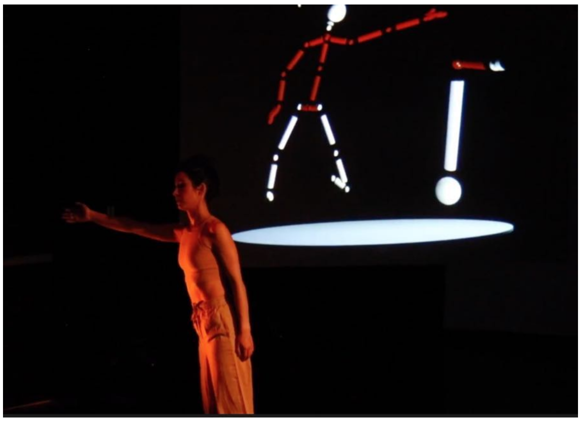


Figure 1. Cuan in performance with the CONCAT software.

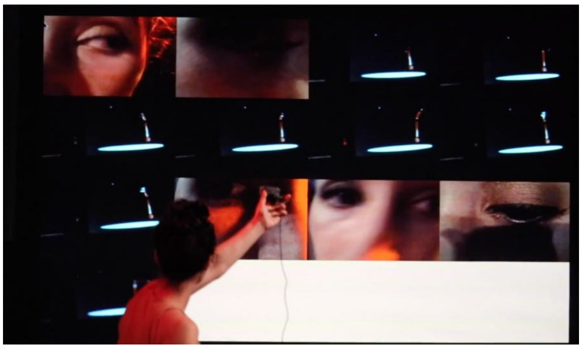


Figure 2. Cuan holds a web camera and wireless mouse to create an improvised grid of captured videos with MOSAIC.

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Figure 3. Cuan in performance with projected video of the Wen robot in the background.

In addition, this ABB model is primarily utilized in manufacturing and research contexts; one could imagine stark lighting, repetitive motion, and industrial scenery at those junctures. Yet when Cuan first experienced the robot, her immediate reaction was to find it beautiful, cloistered like a secret on the third floor of a Brooklyn warehouse, lit warmly by the enormous windows blanketing one wall. The robot's painted monochromatic grey limbs punctuated by colored wiring and raised text inspired her to consider the robot's aesthetic qualities equally to its functional ones.

Cuan observed the distinctive movement qualities of the Wen, recognizing the smooth continuity and fixed speed of each joint in relationship to the other. The cylindrical nature of the robot removed many of the planar attributes typical to a human body (ex. Front corresponding to the face and eyes) and thereby provided a new palate of choreographic potential. She elected to create choreography for the robot that would emphasize these distinctive qualities and choreography for herself that would initially support and then oppose them.

A central artistic motivation emerged to reframe the Wen robot as an attractive source and performer of dance, rather than an intimidating, industrial machine. In doing so, OUTPUT formulated and highlighted the tension between the functional and aesthetic qualities of humans and machines, as well as their respective expectations and representations when live versus recorded. The representations of both the human performer and the robot were reprocessed through digitized methods: cameras, animations, software, sensors, and screens. Sensors, video, and joint angles perform a similar function of parsing a complex entity into discrete re-represented elements. OUTPUT showed these elements together on stage in a narrative manner – beginning from and returning to the whole form of the human and robot with the representations in between - to accentuate the complexity and limitations of each.

ThoughtWorks, a global software consultancy, incubates contemporary art and technology works through its ThoughtWorks Arts program [3]. OUTPUT was created during Catie Cuan's 2018 artistic residency at ThoughtWorks, in conjunction with ThoughtWorks developers Andy Allen, Andy McWilliams, and Felix Changoo, filmmaker Kevin Barry, and CRR staff Mark Parsons, Gina Nikbin, Nour Sabs, and Cole Belmont. OUTPUT premiered September 14th, 2018 at Triskelion Arts' Collaborations in Dance Festival in Brooklyn.

2 BACKGROUND

The history of science fiction paints robots as terrifying and enchanting, from Mary Shelly's *Frankenstein* to the first appearance of the word "robot", in Karel Capek's "Rossum's Universal Robots" [4]. Later stories in other mediums have echoed these sentiments, from "The Terminator" to "Black Mirror". This historical context backgrounds the work of roboticists and artists alike.

Roboticists and performing artists have collaborated on performance and interface projects for many years in order to explore human and robot interaction. Robotic technologies were presented in the context of theater towards the development of sociable robots [5]. A narrative performance explored relationships between humans and caregiving robots [6]. Prior work described developments about nonverbal interaction between humans and robots during theatrical practice [7]. A performance was created featuring a cast of humanoid robots [8]. Dancers generated expressive movement for robots in [9].

Dancers' movement expertise was utilized to create a model for non-anthropomorphic robots' socialization and interaction [10]. An improvised performance between a dancer and two industrial robot arms explored questions of space and movement in dance and architecture and improvised control methods for robots [11]. Creative approaches for generating robot motion developed in entertainment robot contexts was described in [12]. Robot motions were generated from a model employing ballet warm up exercises and demonstrated in performance [13].

Choreographers have utilized motion-capture technology to generate animation, videos, and new movement for live performance in collaboration with programmers and digital artists [14] [15] [16]. Animation has been used within live performance including dance and theater [17]. The body of a machine in performance illuminates distinctive questions from that of a human body, as explored in [18].

For dancers, sensory information like the feeling of the stage floor and the visual effect of lighting are integral to expression and self-protection. Similarly, robots are equipped with sensors to safely and expressively actuate through their environment. Brooks [19] stated the need for robotic motion to be based on sensor motor coupling in conjunction with joint position sense and hand-eye coordination. Goldberg [20] wrote extensively on the relationship of distance and knowledge in relation to robots and their operators. This has led to a perceived tension between the sensory motor input information of a robot in relation to the desired simulation of that movement.

3 PERFORMANCE DESCRIPTION

OUTPUT is a multi-part project composed of choreography, software, short films, an improvisational structure, and a methodology for choreographing robots. These elements have been presented individually in installation formats and were composed into a live performance also referred to as OUTPUT and described below.

OUTPUT created sensor-based motion capture, animated and cinematic relationships between the vestiges of real (human) and captured (technological) bodies in real and time-delayed sequencing using the CONCAT and MOSAIC software. It achieved this by employing a narrative arc that started with a single female dancer engaged in a solo, after which the dancer journeyed through the representations of her and her movement as translated onto the robot. Choreography specifically created for the robot was demonstrated via video, while the dancer attempted to move similarly in an improvised segment. The arc closed with the same single dancer and original solo movement material, now performed with the video of the Wen projected in the background. The dancer performed the solo facing the projected Wen video rather than the audience, to reveal the Wen as both partner and inspiration for the performance process throughout (Figure 3).

The first representation after the opening solo was a projected animation of the dancer's live skeleton gathered through the Kinect infra-red depth sensor. Partway through this segment, a second animation, of the Wen robot, appeared next to the human skeleton on one projected screen. The software CONCAT created the combination of this live Kinect skeleton with the rendered robot. All three elements on stage: the live dancer, her Kinect skeleton, and the animation of the Wen, were moving in the same sequence. A second software, MOSAIC (Figure 2), facilitated a layering of these three elements into video grids with a live web camera on a second projected screen.

The set elements were two screens with projectors on stage in addition to a wireless keyboard, web cam, two laptops, and a Kinect v2. The MOSAIC and CONCAT software tools were projected onto these different screens at the back of the stage. MOSAIC functioned by Cuan selecting various keys on the wireless keyboard to record short videos and layer them together into expanding and contracting grids of videos. Cuan improvised with the MOSAIC software during the OUTPUT performance to craft new projected grids throughout the show.

Cuan served as both a performer and choreographer with these two different software tools, effectively bringing the audience into the process of composition and performance. The improvisational elements of the performance, governed by specific physical and technological parameters, led to a feeling of being "inside the machine". This also demonstrated the human agency behind seemingly autonomous processes.

4 SOFTWARE IMPLEMENTATION

OUTPUT was aided by the development of two new software tools, CONCAT and MOSAIC.

The artistic motivation necessitated different representations of the Wen through software. The creation of CONCAT allowed Cuan to generate choreographic material for herself, utilizing the moving Wen as inspiration, outside of the CRR space. The fact that Wen could not be transported from CRR due to its sheer bulk and size also supplemented the desire for CONCAT [21]. Thus Cuan as the dancer was able to practice and respond to the Wen movements from any physical location outside of the CRR lab. The limbs of the human (highlighted in red), and the Wen robot's movements (animated in white), were both framed against a black background (Figure 5). CONCAT ran live time using a Kinect and laptop computer during the final performance (Figure 1).

The CONCAT code combined two input sources into a single visualization: one input represented a dancer's real-time movements, and the other represented the movement of the Wen robotic arm.

For the representation of the Wen, first Cuan choreographed a movement sequence for the robot by mapping the robot's joints onto her own body. For example, during one work session, she elected that joint one – the uppermost joint of the robot referred to as the head – would map to her head, and that joint seven – the lowermost joint – would be her right ankle. She internalized the capabilities of each joint – from simple hinge motion to full rotation – while choreographing from this basis. A second strategy Cuan employed was to formulate moving notion for the robot, for example, "recoiling in shame after extending too far" and visualized ways to achieve this with the robot's motion.

These motion sequences could then be programmed onto the robot in two ways: 1 - by drawing a line with a mouse inside the Rhino 3D desktop modeling software that the robot's head (uppermost joint) would follow or 2 – by programming each joint individually to move sequentially or simultaneously using the ABB native software and a joystick with two degrees of freedom. In the first case with Rhino, the precise joint angles of the remaining joints (not the head) are determined by the software to minimize the space traveled by each joint in order to reach the desired head position. Therefore, the joint angles could not be known until the movement sequence runs. In the second case with the ABB native software, the sequence was tested at several intervals before running from beginning to end, to ensure none of the programmed joint angles violate the robot's joint limitations. Both programming processes were incorporated to choreograph the robot.

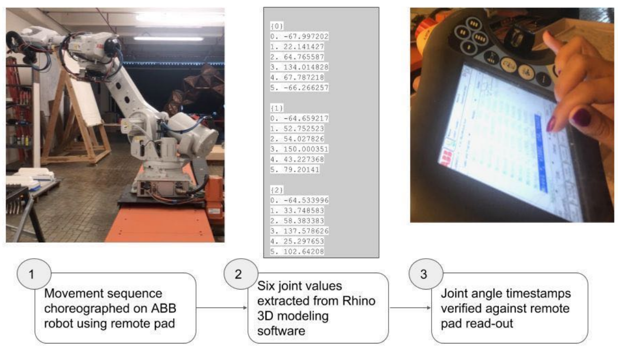

Figure 4. The phases of the translation process: from the original Wen movement (1) into a series of joint angles (2) matched to timings on a remote pad (3).

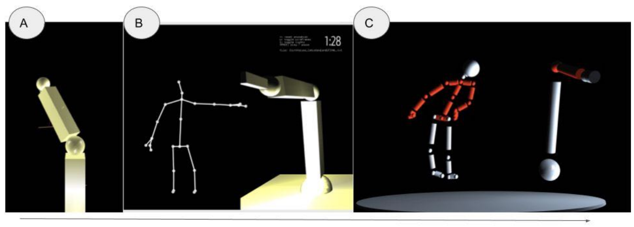

Figure 5. The changing visual representation of the original Wen robot (A), then with the added Kinect skeleton in two dimensions (B), and the final appearance of the three dimensional skeleton and Wen (red highlight) (C).

The Wen robot then executed the sequence and its joint angles were captured on video and on the tablet with corresponding timestamps. The recording of the Wen joint angles were mapped to a rendering of a 3D representation of the robot movements on a screen (Figure 4). The dancer's body was simultaneously monitored using a Microsoft Kinect v2 infra-red depth camera. The motion data from the Kinect was exported from Microsoft Visual Studio with a plugin that broadcast the motion data to a C++ OpenFrameworks program. The final sideby-side representation of the Wen joint angles and the dancer's body was also written in the OpenFrameworks toolkit.

The OUTPUT performance included an improvised platform in the form of the second specialized software MOSAIC, created by creative coder Jason Levine [22]. MOSAIC used a web cam to make small, short videos, and displayed them in a grid using various key commands. It layered looped videos of human movements from multiple sources and angles onto a live time projected screen. These software displays were shown alongside the video of the moving robot and the live dancer as part of the performance (Figure 2).

5 CONCLUSION

The performance piece OUTPUT created a unique relationship between traces of a real human and a captured technological body by using a nine-foot tall ABB IRB 6700 robotic arm named, "Wen". It explored the space and inherent tensions of a simultaneously live and remote representation between these entities in order to reshape people's perceptions of a looming, dystopic future with robots. The artistic motivation and the Wen's non-portability necessitated the development of two new software tools, CONCAT and MOSAIC. These tools led to a sentiment of ubiquitous computing and live-time development during the performance, parsing complex sections into discrete re-represented elements. OUTPUT demonstrated that artistic, analogue, and digitized methods of human agency were behind seemingly autonomous processes. This contributed to the perception of a more symbiotic relation between humans and robots.

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Using verticality to classify motion: analysis of two Indian classical dance styles

Roshni Kaushik [1] and **Amy LaViers** [2]

Abstract. The Indian classical dance styles of Bharatanatyam and Kathak have many similarities in movements and hand gestures, but their execution varies greatly. Analysis of similar movements from two styles results in observed differences in position and tension. Limitations in a previously developed motion capture metric (verticality) are discussed. Other movement measures are introduced that may be more appropriate to highlight differences in the two styles. Potential applications include robots that need different measures to appropriately sense human motion in different cultures.

1 Introduction

The Sanskrit text Natya Shastra (500BCE to 500CE) delves into the ancient Indian performing arts [2]. The dance section describes hand/feet positions and conveying emotions through movement and expression. The Indian National Academy for Music, Dance, and Drama recognizes eight styles of Indian classical dance - Kathak, Bharatanatyam, Kuchipudi, Kathakali, Manipuri, Odissi, Sattriya, and Mohiniyattam.

Bharatanatyam and Kathak, from southern and northern India respectively, diverged significantly from their common ancient dance ancestor due to historical, cultural and regional differences. Sharpness, tension, and straight lines in arms and legs characterize Bharatanatyam movements. In contrast, Kathak movements are softer with less tension in elbows and wrists.

Qualitative features of these dance styles have not been quantified and pose challenges to typical capture processes. How do we quantify small differences observed in similar movements from these two styles? Similar research has compared other pairs of dance styles, such as Kathak and Flamenco [7].

Working with a trained ballet dancer, our research has previously used motion capture to compute reduced DOF models recording human motion. Using motion capture of two interacting individuals observed by a Certified Movement Analyst, we correlated their movement using a single DOF measure, called verticality. Verticality measures leaning of the spine during a movement [4] (Figure 1). We also presented motion segments for which a low DOF simulated robot motion based on verticality imitated the human motion capture skeleton better than a robot following a pseudo-random signal [3].

Since Western dance primarily motivated our previous research in verticality, this measure may not directly apply to other dance forms. In this extended abstract, we will further examine qualitative differences between two Indian dance styles (Section 2). We will then consider how verticality would represent those differences and suggest improved measures based on our observations (Section 3).

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Figure 1. Verticality vector (green) with respect to positive z-axis of the mover (black). **Left:** Motion capture skeleton with angle from z-axis to verticality vector θ labelled. Figure from [4]. **Right:** A Kathak (left) and Bharatanatyam (right) dancer performing similar movements. The verticality vector does not capture differing hand gestures or tension in limbs. Screenshot from [5]

2 Kathak and Bharatanatyam movement comparison

We will observe similarities and differences in an analogous position and in hand gestures performed in both dance styles. These observations were performed by the first author who has trained in both the Lucknow school of Kathak and Kalakshetra school of Bharatanatyam.

2.1 A similar movement in two styles

Figure 2 shows a movement performed in both styles (left:Kathak, right:Bharatanatyam). Both dancers extend their left arm to the upper-back-left corner and point their right foot towards the bottom-front-right corner. Their right hands point inward at chest level with head turned looking at their left hand. Their bodies are angled, pointing towards the front-left. However, the Bharatanatyam dancer extends her left elbow while lunging, right knee unbent. The Kathak dancer bends her left elbow and has a more balanced stance. We therefore conclude that these dancers are performing similar movements in different styles.

The positions in Figure 2 also differ in hand gestures, named using [1]. The Bharatanatyam dancer's left hand is in *alapadma* (fingers splayed), and her right hand is in *katakaamukha* (first two fingers touching thumb with other two fingers splayed). The Kathak dancer's left hand is in *pataaka* (fingers outstretched and together with thumb slightly tucked inward), while her right hand is in *araala* (index finger touching thumb with other fingers outstretched and together).

Figure 2. A Kathak (left) and Bharatanatyam (right) dancer performing similar movements with left arm pointing up and right foot extended out. Weight shift, tension in the limbs, and hand gestures differentiate the two positions. Screenshot from [6]

2.2 Hand Gesture Comparison

The same hand gesture still exhibits subtle differences when performed in these two styles. Figure 3 illustrates the differences in two hand gestures (*pataaka* and *araala*) performed in Kathak and Bharatanatyam. The purple circles highlight differences in thumb positioning. The Kathak gesture has lower tension in the thumb, lightly touching the side of the hand, while the Bharatanatyam gesture has higher tension in the thumb, held forcefully into the hand.

The green circles emphasize differences in muscular tension in the entire hand. In Bharatanatyam, this tension is created by arching the tightly squeezed fingers and can be observed through veins standing out prominently in the wrist. The Kathak gesture has fingers placed flatter, not pressed together as tightly, and lower tension in the wrist. These subtle differences in hand gestures exemplify the stylistic differences between Bharatanatyam and Kathak.

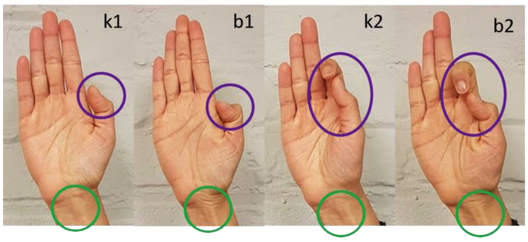

Figure 3. The Kathak(k) and Bharatanatyam(b) hand gestures *pataaka*(1) and *araala*(2) compared. The purple circles call attention to the thumb's positioning, and the green circles emphasize the increased tension in the wrist, spreading to the entire hand.

3 Verticality and other possible measures

After observing the similarities and differences in the two dance styles, we will now attempt to apply verticality, developed in prior work, to quantify these differences. We will also discuss the arising limitations and introduce a few preliminary measures that could address those limitations.

3.1 Verticality and its limitations

We will apply verticality developed in prior research to differentiate Kathak and Bharatanatyam movements. Figure 1 (right) illustrates a Kathak and Bharatanatyam dancer in a similar position (mirrored). The verticality vector (green), connecting the lower neck and pelvis, indicates the spine leaning away from the z-axis (dotted black). The roughly corresponding angles formed by the two verticality vectors demonstrates the movements' similarity. However, nuances in hand gestures, limb positions, and tension are not captured by this metric.

3.2 Proposed other measures

We will propose a variety of measures to detect differences in the two dance styles not evident through verticality. For example, we can extend the mathematical process used to compute verticality to construct other vectors on the motion capture skeleton. A measure of angles made by arms and legs with the vertical may yield a richer representation of motion. Evaluating such measures is the subject of our current research.

An alternative method may look at specific angles in the data set. These could include the angles between the hand and wrist, forearm and upper arm, and lower and upper leg. For example, in Figure 1, the elbow angle varies in the two positions because Kathak dancers tend to keep a greater bend in the elbow, to preserve the softness of the movement.

Tracking differences in tension, especially in hand gestures, may be difficult to measure. A hand motion capture system, integrated with a full body motion capture system, may be capable of tracking small differences in the hand positions between styles. However, these differences in tension may not be distinguishable through motion capture alone, requiring the use of other types of sensors.

4 Conclusions

We have presented a set of observations comparing similar movements executed with different movement features (e.g. hand gestures and muscular tension) in two Indian classical dance styles. We have described limitations in a previously developed motion capture metric, verticality, to discriminate between the two styles. We have also discussed other potential measures to quantify differences in similar movements for this comparison.

Examining static positions in the two dance styles yields useful information. However, analyzing motion data sets from both dance styles where dancers perform similar movements will provide a richer quantitative comparison of Bharatanatyam and Kathak. This comparative framework can generate better motion representations valuable in a variety of applications. The previously developed measure of verticality was useful within the context of Western dance but can break down when differentiating between two Indian dance styles. Similarly, in-home robots may need additional metrics for sensing motion in users of different cultures or environments.

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Agency in dialogue: how choreographic thought emerges through dancing with *Tools that Propel*

Sarah Levinsky[1] and **Adam Russell**[2]

Abstract. This paper discusses *Tools that Propel*, a digital interactive installation developed by Adam Russell and Sarah Levinsky, with reference to its impact as a choreographic development system, and to the performative skills and embodied knowledge that dancers bring to their relationship with it. It examines the different implications of two interrelated frameworks for understanding this relationship and how movement and the behaviour of the computational system shape each other. The first sees the system as part of the dancer's 'extended bodymind', unpacking how the body's choreographic thinking happens across both its embodied cognitive processing *and* that of the system. The second sees *Tools that Propel* as 'other', curiously *acting on* the dancer and vice versa. In this second proposition, the various 'things' that make up *Tools that Propel* act as agents in their own right, intervening on the dancer's decision-making as much the skill and embodied knowledge she brings to the assemblage of distributed agencies acts on them. Finally the importance of sustained dialogue with *Tools that Propel* is emphasised, a long-term digital intervention through which new choreographic thinking emerges; an interplay between extensions of bodymind and indifferent digital interventions, in which movement shapes behaviour and behaviour shapes movement.

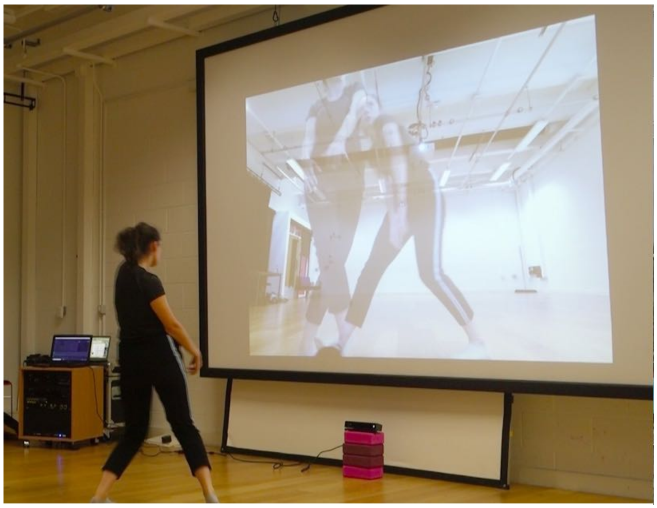

Figure 1. Dancer Maria Evans improvising with *Tools that Propel*.

1 INTRODUCTION

Confronting the 'interactor' with a life-size projection of themselves and other bodies, *Tools that Propel* blends live 'mirror-like' video and recorded fragments from the recent past that resemble their current movement. The computational system compares what it sees in real-time with gestures/movements it has previously tracked, recorded, and categorised, and models the likelihood that the real-time movement might be a re-performance of any of these previous movements. If this likelihood is above a certain threshold then it plays the recorded footage ('memory') of that gesture/movement *instead of* or *blended with* the real-time live projection of the interactor on screen. The interactor improvises with 'ghosts' of themselves and others tracked by the sensor before them; the entanglement encourages breaking of habits and mining of memories, exploring subtle variations.

Tools that Propel was born out of a collaboration between Sarah Levinsky and Adam Russell, at the intersection of their interrelated but separate PhD research projects: one concerned with the potential and affordances of AI and motion capture technologies to intervene in choreographic practices in ways that disrupt habitual movement patterns in improvising dancers and catalyse the emergence of new movement material with its own choreographic agency; the other concerned with how digital tools can support processes of playing at not knowing what we are doing by interactively folding past time into co-incidence with present action. There are many potential applications of *Tools that Propel*. It has been shown as a gallery installation [21] which the public encountered with no prior knowledge and it could be optimised for this purpose. However, this paper discusses it with reference to its use in dance improvisation and for developing new choreographic thought-in-action. If, as discussed by Erin Manning and Brian Massumi in [22], '[e]very practice is a mode of thought, already in the act' what are the possibilities for developing new modes of thought, within a new expanded practice, when we create dance in dialogue with the computational system that is *Tools that Propel*?

The arguments within this paper are based on observation and analysis of dancers and dance students using the system at sporadic intervals over the course of a year and a half, as well as semi-structured interviews with them and documented discussions during studio sessions. In a studio session on November 1st 2018, Yi Xuan Kwek, an undergraduate dance student from Falmouth University, remarked that *Tools that Propel* '[now it] feels like an extension of me…before we felt like it was an other' [18]. This comment led to the examination of *Tools that Propel* in relation to 'The Extended Mind' thesis expounded by Andy Clark and David Chalmers in 1998.

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Through this theoretical framework this paper considers how the system becomes part of the 'extended mind' [4] of the dancer, and something that 'change[s] the way we encounter, engage and interact with the world', something that 'change[s] our minds', as David Kirsh discusses in [16]. Understanding the dancer's interaction with the system in this way, this paper unpacks how the body's choreographic thinking happens across both its embodied cognitive processing and that of the system. It examines how the dancer draws on the external information in the choreographic output on screen – the 'memories' which bring back ephemeral movement previously lost and which blend with or disturb the projection of their real-time self – and uses the system as an extension to the decision-making processes internalised in his/her bodymind. This comes about when the dancer opens themselves up to the perceptual shift that occurs through symbiosis with the system and the computational affordances which enable them to dig deeper within their habitual movement patterns and explore new movement possibilities affected by the reconfiguration of their previously internalised understandings of time and space.

Equally though, whilst Xuan Kwek's comment suggests a shift in her embodied understanding of working with the system *from* 'other' *to* 'extension', the validity of seeing *Tools that Propel* as 'other' demands further interrogation. Here it is curiously *acting on* the dancer and vice versa. Examining this second theoretical framework with regards the interaction of the dancer with *Tools that Propel* this paper draws on the ideas discussed in Jane Bennett's *Vibrant Matter: a political ecology of things* [1], to argue that the various 'things' that make up *Tools that Propel* act as agents in their own right, intervening on the dancer's decision-making as much as the skill and embodied knowledge she brings to the assemblage of distributed agencies acts on them. This paper proposes that the 'things' that make up the encounter with and operation of *Tools that Propel*, including the material body and mind of the dancer, are part of an assemblage of distributed agencies that together allow new thought (movements, traces, decisions) to emerge. In a dialogue between them, new choreographic thinking unfolds; movement shapes behaviour and behaviour shapes movement.

2 TECHNICAL BACKGROUND

Extensive discussions between us took place over several months in Winter 2016/17 towards an imagined system, before any working code was written. This led to a proposal accepted for the Choreographic Coding Lab #8 (CCL8) in Amsterdam May 2017. A wide-ranging review of potential software frameworks led us to settle on Derivative's *TouchDesigner*, which although limited to the Windows OS at that time (now also available for MacOS), provided an attractive hybrid of visual dataflow for sensor and video processing, with Python code on the backend allowing access to a wide range of machine learning libraries. Python is an extremely popular environment in data science for providing a lightweight rapid prototyping language for computationally-efficient but syntactically dense C++ code. A very early version of the system was shown in Amsterdam at the end of CCL8, running in *TouchDesigner* but using a very crude placeholder method to index the video recordings.

The fundamental technical concept of *Tools that Propel* was always to combine recording and playback of live video footage with a gesture recognition system that begins as a *tabula rasa* and adds new gesture classes to its model as the dancer(s) move, repeatedly switching the video display between the live feed and recent 'memories' when previous patterns are recognised. The motion data is currently provided by Microsoft's Kinect 2 sensor, a markerless skeletal tracker based on a structured-light infrared depth camera. This sensor also conveniently provides an RGB image feed for the video recordings and live projection[3].

Most gesture recognition systems have two significant constraints which we wanted to overcome. They are typically trained *before* use on a number of known gesture classes (supervised learning), and then identify known gestures from a time-series of sensor data *after* they are performed (offline segmentation). As our aim was to confront the dancer(s) with footage of their own recent past while they were performing motions identified by the system as 'similar' to previous examples, we were particularly keen to achieve both *online unsupervised learning* and *online recognition* - meaning that the system trains itself during interaction, and continually estimates a 'current' gesture class from an incoming stream of sensor data. This latter feature is often termed gesture *following* as opposed to gesture recognition.

The second of these aims was satisfied by the XMM library developed at IRCAM Paris by Jules Francoise and others [2, 12] 'a portable, cross-platform C++ library that implements Gaussian Mixture Models and Hidden Markov Models for recognition and regression [...] developed for movement interaction in creative applications [...] with fast training and continuous, real-time inference.' In particular, the XMM library provides a Hierarchical Hidden Markov Model (HHMM) capable of estimating likelihood *and progress* within M gesture classes of mean length K using a sliding time window of length T in only $O((KM)^2T)$ time [11]. During continuous recognition, this provides a *constant* time cost, which in our case running on commodity PC hardware with 10-20 gestures each a few seconds in duration using 6 screen-space bone positions, gives an HHMM update time of ~50ms i.e. we can achieve interactive frame rates.

2.1 Probabilistic editing

The first of our aims, to achieve online unsupervised learning of gesture classes, had a more crude and unorthodox solution. We attempt no kind of clustering to form gesture classes from multiple examples. Instead each class is trained on only one example, formed the first time a movement is seen which is insufficiently likely to be produced by any prior classes. At initial startup, or after a manual reset, the HHMM is empty and we begin recording live video and storing frames of accompanying motion data. After a maximum duration parameter is exceeded (typically ~5-8secs), the recent recording is added to the memory as a new 'phrase' (i.e. HHMM class). At this point, we start recording another new phrase and at the same time receive a continuously-varying likelihood estimate (i.e. calculated per frame) that we are in an existing gesture class. As soon as the likeliest class likelihood exceeds some threshold parameter, we stop recording and begin playback of the corresponding memory video, continuously adjusting the playback position to follow the progress estimate for the current (i.e. likeliest) class. As soon as the likelihood falls below another threshold (lower than first to provide hysteresis), we stop memory playback and again begin recording a new phrase. There is also the possibility of switching directly from one memory to another if the likeliest class changes.

As shown in figure 2, both the live and memory states involve updating the HHMM filter, which updates the likelihood estimates of all currently-known classes. The only time we are not updating the model is when we lose motion tracking data e.g. if no body is in

[3] There is no technical reason why the RGB camera has to be in the same viewing position as the motion tracking sensor, and future iterations may employ separate points of view

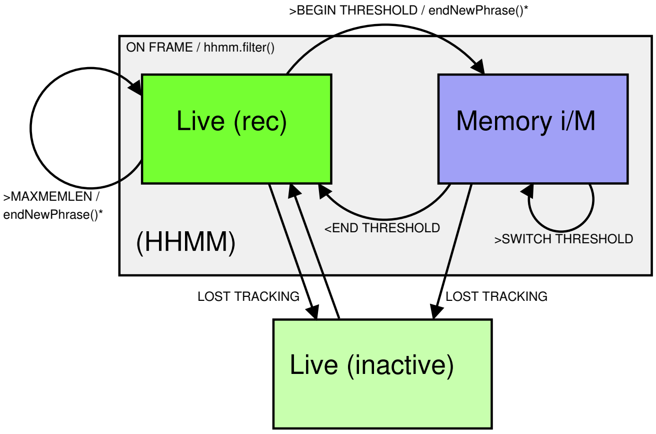

Figure 2. Unsupervised learning and video playback driven by HHMM gesture following (*: retrains model)

front of the Kinect sensor. In this case we can still show live video on the display, but are not recording. Finally, as indicated in figure 2 by the transition arcs exiting and re-entering the HHMM, when a new phrase is added we must retrain (very short live recordings below a minimum duration parameter are discarded). Since the model cannot be trained incrementally this step is far more expensive than the normal per-frame update, as we must reset and retrain the entire model from scratch on all recorded phrases of motion data, and can introduce a perceivable delay to the interaction of at least several hundred milliseconds.

Note that although the *dancer(s)* might consider subsequent new phrases to be similar to existing classes, as mentioned earlier the system does not and they are always added as new classes based on a single example phrase. This makes the total set of classes at any stage extremely history-dependent; different orders of introduction of movement material will result in different classifications. Furthermore because the new gestures are often formed by exceeding the maximum duration of just a few seconds, the classes are also extremely timing-dependent; slight variations in pace might result in very different 'cuts' between classes. As discussed later in section 5.1, although this deliberately *ad hoc* approach to unsupervised segmentation through probabilistic editing leads to some very strange decisions, this strangeness was found very valuable.

2.2 Screen space gestures

If the memory size were permitted to grow without limit, the system would gradually slow down to non-interactive frame rates as the filtering step time is quadratic in the number of classes. Furthermore the retrain time on adding a new phrase would become extremely disruptive, taking several seconds or more. The number of sensor dimensions is also a concern - IRCAM's XMM was developed for gesture control of sound synthesis environments where there might typically be one or two 3D accelerometers (e.g. attached to a baton) providing 3-6 Degrees Of Freedom (DOF) per frame. Here by contrast the Kinect 2 skeletal tracking data can track up to six bodies simultaneously, each with 25 estimated joint positions (in both 2D camera space and 3D physical units) and 13 of these also offer joint orientation data, roughly 600 DOF which is far too many for interactive frame rates on commodity hardware.

For these reasons we limit the data size in several ways. Firstly by only recording a subset up to 6 bones from one tracked skeleton - typically the head, pelvis, hands and feet to sufficiently differentiate large-scale body pose variations (although the bone set can be reconfigured). Secondly we constrain the number of memories to some maximum, typically a dozen classes. To maintain a progressive dialogue with the system (see section 6), rather than stop adding new memories once we reach this maximum, we instead discard a previous memory when adding a new one. There are several possible discard policies in the system configuration such as most-frames-played, most-times-entered - typically we just select the oldest class based on when it was first added. Finally, to reduce the cost of each tracked bone, we used 2D camera space positions instead of 3D physical space. This choice was initially made for speed and convenience, with the expectation that we might at some stage switch to a set of more sophisticated derived parameters such as relative joint angles or accelerations. However the screen space gesture classes had unexpected benefits and so we stuck to this approach. In particular it meant that gesture classes were primarily differentiated by position in the visual frame, which strongly supported the 'mirror-like' quality of the wall projection. As discussed in section 4.1, this allowed dancers to use the screen space as an index into past configurations of the studio space, looking for traces of prior activity.

Figure 3. Dancer Katherine Sweet assisting system diagnostics (here showing console log, memory table, likelihood graph and current class)

3 PRIOR WORK

Framing this practice-based research in relation to antecedent computational systems for dance creation, it is important to note that using computers to generate and elucidate choreographic ideas is in itself not something new. The development of software designed to destabilise the choreographer's or dancer's habitual movement vocabularies, and historically-embodied thinking patterns, goes back at least as far as Merce Cunningham's use of *Life Forms* [14]; and indeed Cunningham's chance methods used a far more basic technology to bring about surprising choreographic ideas - dice. Through his particular way of using *Life Forms* Cunningham created choreographic phrases using key-frame animation that often defied the laws of physics and human physicality. His demands on dancers to realise sometimes near-impossible movement sequences, originally created with the software, brought about unexpected, imaginative and novel solutions within his dance creation in the studio (where Cunningham did not take the computer). Other computational systems for choreography such as the *Choreographic Language Agent (CLA)*, created by OpenEnded Group for choreographer Wayne McGregor [9], expands the dancer's physical imagination and acts as a form of interactive notebook. As Scott deLahunta discusses, '[w]ith its digital memory, the *CLA* uniquely documents aspects of [the dancers'] decision-making – making part of their choreographic thinking process available for revisiting and examination.' [6]. DeLahunta compares it to William Forsythe's CD Rom *Improvisation Technologies: A Tool for the Analytical Dance Eye* [10], which elucidates the dancer's potential arcs, shapes and trajectories during improvisation through simple graphic lines and curves which overlay the dancer's movements, stating that while Forsythe's 'dancers had to be holding sets of ideas in mind and problem-solve with them while moving, the *CLA* moves parts of this process to its computer canvas as a page for working out choreographic ideas interactively.' [6].

3.1 Making live decisions

Yet, like *Life Forms*, both the *CLA* and *Improvisation Technologies* involve the dancers in a (mostly) retroactive translation of the digitally-revealed choreographic possibilities offered by each system (as tool, agent or otherwise). Conversely, *Tools that Propel* aims to reflect back and challenge the movement decisions of the dancer in a real-time interaction. In this, we have drawn on the learning from the *Reactor for Awareness in Motion* or *RAMDanceToolkit* [15], in which computation transforms the dancers' tracked movement data into visual geometric outputs which reconfigure what they are doing (reorienting limbs to different joints, or making visual imprints of dancers' movements in time, for example). These real-time visualisations act as external stimuli for the dancer to draw on in the creation of new rules – or mental imagery that dancers use whilst creating movement ideas [7] - conditioning their internal movement decisions throughout the course of the improvisation.

But *Tools that Propel* departs significantly from *RAMDanceToolkit* in its aesthetics and the visual rendition of the body's movement after its digital transformation. In the interaction between dancer/choreographer and computation, the question of 'body' emerges frequently in terms of visual outputs and was a consideration in determining the 'mirror-like' aesthetic of *Tools that Propel*. With *RAMDanceToolkit* the geometric renditions of the body of the dancer require significant mental translation on behalf of the improviser. Thus interactive installations such as *Danceroom Spectroscopy* [24] and Klaus Obermeier's *Ego* [26] provided as much of a framework for the development of *Tools that Propel* as choreographic software, in particular with regards the feedback loop developed between the interactor and the visual output of their computationally-manipulated movement. In both installations, albeit in very different ways, the virtual rendition of interactors' movement data went from the familiar (reflecting the shape of a human body) to the unfamiliar, 'other'. *Danceroom Spectroscopy* offered participants a metaphysical, almost spiritual experience through the exploration of the nanosphere, with their virtual selves often transitioning from 'extremely literal, "personshaped" energy fields to more abstract energetic representations' [24]. *Ego* catalyses physical play in interactors by rendering their virtual reflections as a stickman/woman doing longer, stretchier, bouncier versions of their live movements. The tacit understanding of the gap between their real and projected selves reverberates in the gap between the movements they feel themselves doing and those that they see simultaneously reflected, feeding disinhibition and a playful exploration of their bodies in motion. *Tools that Propel* attempts to take learning from how interactive installations catalyse embodied play and to develop an *evolving* feedback loop between the dancer and the system that increases embodied knowledge, heightens compositional awareness and focuses performative intention.

4 EXTENDED BODYMIND

In terms of embodied cognition and the expansion of the dancer's mind through the computational tool, the emphasis is perhaps on the augmentation of the dancers' capacities. If we take the notion of '*active externalism*' expounded by Clark and Chalmers which is 'based on the active role of the environment in driving cognitive processes' [4] we have to assume that encountering new sources of information that offer perceptual shifts in our understanding and experience of the world will bring about new cognitive processing. This means that an encounter or movement exchange with *Tools that Propel* can bring about new choreographic thought-in-action, at least in the moment of the interaction.

'Bodymind' might often be thought of as the site and source of internal physical decision-making. This paper understands 'bodymind' as also encompassing a relationship - mental, physical, conceptual - with external sources of information, imagination, and impulses to move and think through moving. With regards their work with Wayne McGregor's company of dancers in the development of the *Choreographic Thinking Tools*, Scott deLahunta, Gill Clarke and Phil Barnard discuss the way that dancers use mental imagery – visual, sensorial, aural, kinaesthetic – in the improvisational and creative tasks that lead to the development of dance phrases and performances. They acknowledge how dancers are '[n]ow embraced as creative contributors to the generation of a work and its movement language' meaning that 'skills of attention, imagination and curiosity 'thought through' the body become tools as essential for the dancer to develop as their physical proficiency.' [7]. The notion of 'attention, imagination and curiosity 'thought through' the body' underlies the use of the term 'bodymind' in this research. We can also understand 'bodymind' through Merleau-Ponty's discussion of the 'body's unity' as a 'lived integration in which the parts are *understood* in relation to the meaningful whole'. Here the 'body-mind in all its parts "*perform*(s) a single gesture"'. [23]. Crucially, for Merleau-Ponty bodily engagement with the world is part of what constitutes its consciousness.

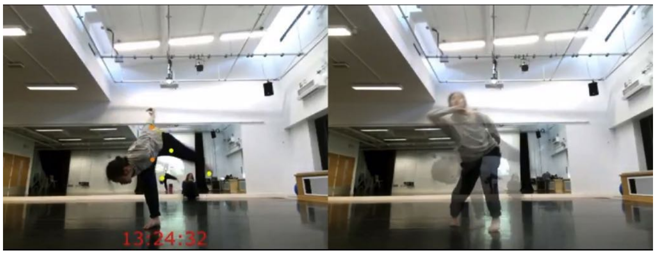

Figure 4. Dancer Yi Xuan Kwek in a 'session video' which records a continuous side-by-side comparison of the live camera input (with tracking data and timestamp) and displayed video out for later analysis

4.1 Extension of imagery

Mental imagery in dance creation is just that – mental – but it is derived from the dancer's experience of external stimuli. Dancers have to hold that information in their bodyminds as they move around it, through it, and with it in the creation of new movement. As deLahunta el al. state '[w]e can draw on well-drilled habitual pathways and movement patterns in choreographic problem-solving, where thinking remains detached, somehow 'thought-alongside' or we can skilfully pay attention to and through the passage of the movement whilst it is in process, whether in response to internal environment or external image, intention or 'affordance', allowing the movement to become 'thought-filled', itself the instrument of cognition.' [7]. When thought is done 'alongside', or at 'one remove from the moving' they argue 'the solutions suggested by the body are likely to stay within the limits of our habitual movement patterning.' *Tools that Propel* could be thought of as an aide-memoire, bringing into being another mental architecture as an expansion of the dancer's own. It gives reminders of movement and motifs that the dancer has explored before, brought back for more complex and nuanced exploration. Sometimes it brings back movements half way through the trajectory the dancer might usually associate with that movement, breaking into the flow of another movement, disrupting the train of physical thinking and habitual movement patterning. As such, it also offers a set of visual rules with which to inform and provoke the improvisation and new ways of moving. Reflecting on an improvisation with *Tools that Propel* during a studio session held on 18th October 2018, Yi Xuan Kwek reports that she was walking around looking for spots that were trigger points for memories; then became interested in blending people together; then transitioned into finding free space and uncharted territory, which after a while got quite saturated and led her to look for old memories of people and explore how long she could hold them there whilst subtly changing their movement. She also commented on the incidental capturing of other dancers in the memories and stated that she had enjoyed 'holding the space', bringing back and holding memories which had people moving elsewhere in them, filling the room with their presence. She remarked to the other dancers 'your heat signatures are left there' [18]. Through its affordances *Tools that Propel* is triggering the creation of these creative rules, acting as part of her cognitive apparatus, and informing her physical thinking; it is extending her bodymind.

4.2 Extension of habit

Perhaps, however, it could be argued that *Tools that Propel disembodies* the act of thinking, separates it out from the bodymind. In materialising the computational decision-making on screen, seen in the blending of bodies performing real-time and past movements, the overlaying of people and time, it displaces the thought to being 'alongside' the dancer; and thus, perhaps it encourages movement generation along the lines of dancers' habitual movement patterns. Indeed, in a workshop delivered with Company Van Huynh on December 4th 2018 at Centre 151 in London two dancers suggested that it actually brought them back to their habitual movements rather than enabling them to escape them [19]. It is important to consider this further with regards the impact of the system across a greater range of dancers, of course, but it was noticeable in the Company's warm-up that their practice was somatically-driven and it is possible that the requirement to feed off external information in the moment of improvisation was not something that they were necessarily used to or personally drawn to. In contrast to these dancers, two others at the workshop suggested that working with *Tools that Propel* had opened them up choreographically, making them think about space and composition more in their improvisation. The interplay between following internal movement impulses and maintaining a compositional eye can be difficult and it has been observed that dance students who have used the system over a sustained period of time, improvising with it in numerous studio sessions go through a process whereby they learn to succumb to it. As one student said in interview, 'I got frustrated a lot, so I would go from frustration to more curiosity...then that would change "Oh it's not going how I want it to go", so it's kind of discovering... that it's not about working out how it does it, just enjoying how [*Tools that Propel*] works with you' [20].

Figure 5. Group improvisation during a live-streamed performance

It is clear that some dancers discover new possibilities within their own habitual movements re-presented in front of them; they enter a dance in dialogue with them. We might consider here Deleuze's statement in *The Logic of Sensation* that the artist has to 'enter into [the cliché] precisely because he knows what he wants to do, but [. . .] he does not know how to get there.' [8]. As an extended bodymind *Tools that Propel* brings a dancer's habits back to them and through the intriguing way those habitual movements are represented through the folding of time and layering of bodies, for example, it encourages the dancer to engage in a deep process of digging into the cliché to find more within it. *Tools that Propel* works to train, or slowly seduce, dancers into practising the vital skills of 'attention and imagination' [7] through engagement with the overlaying of, and fitting inside, their movement, their own and other people's bodies, editing and evading the projected footage through embodying it, giving it kinaesthetic empathy [13, 27] through the movement of their real bodies on the studio floor, and allowing the perceptual disruption of linear time to open up new possibilities.

4.3 Performing *Tools that Propel*

Expanding the capacities of the dancer through this extended bodymind might suggest a one-way direction of travel. But by examining the displacement of formerly non-machinic functioning within the dancer (memory, mental imaging and peripheral vision, for example) to the functioning of this computational system, and in relation to this, the expanded capacity and skills we see within the dancer in return, we can get a clearer sense of the performative skills going into the creative act of thinking in dance. We can see that in turn these shape the machine's behaviour (and its choreographic output): some of these inputs by the dancer might be understood as compositional awareness, intention, attention, movement articulacy, kinaesthetic energy and empathy - the same skills and qualities it is helping to elicit in them. Through these, dancers generate an interplay with the system, inventing new movements, manipulating old ones, and testing its decision-making; they are keeping it 'on its toes' by moving the visual output, its choreographic decisions materialised on the screen, by inhabiting the 'ghosts' and by offering up movement for its tracking eye in order to keep it in play. If we are looking at *Tools that Propel* and the dancing bodymind as what Andy Clark calls 'human-technology symbionts', that is 'thinking and reasoning systems whose minds and selves are spread across biological brain and non-biological circuitry' [3] we might argue that the decisions made by the thinking body, the bodymind, as part of this 'human-technology symbiont' are perhaps made in the acquisition of new performative skills, knowledge, and articulacy, ever-evolving with and inseparable from the system itself; that new movement awareness, thinking patterns, and processes are *made with* the system, and shape its behaviour from within the extended bodymind that is made of both.

5 A DANCE BETWEEN 'THINGS'

But what different insights does a consideration of the system as an 'other' offer? Practical use of *Tools that Propel* also yielded the idea that all the components (dancers, Kinect sensor, projector, computer, algorithms, room, mirror, space, time, body, memories. . .) form a distributed agency acting to catalyse the discovery and recognition of the choreography 'as "not ours" but rather "animating" us' [29], unfolding with its own logic. *Tools that Propel* appears to look back at the dancer and to be making decisions. It feels uncanny: reflecting the 'reality' of the room but presenting the dancer's body as estranged and housed within another's; projecting their current self in their previous movements and those of others before them; offering a collapse of the linear trajectory of past and present; and blending matter and memory in both the virtual and physical realms. But *who* or *what* is doing the moving? W.J.T Mitchell writes that 'Things . . . [signal] the moment when the object becomes the Other, when the sardine can looks back, when the mute idol speaks, when the subject experiences the object as uncanny. . . ' [25]. Here, rather than seeing the 'agent' (the dancer) 'spread[ing] into the world' [4] we can understand the objects of the system themselves as having agency. We might conceptualise them as Bennett does when she writes about '*[a]ctant[s]*. . . Bruno Latour's term for a source of action', as neither objects nor subjects, but 'interveners' akin to the Deleuzean 'quasi-causal operator' [1]. Here we would see that the components of *Tools that Propel*, as 'actants' or 'interveners' impact on the dancer's bodymind as much as the dancer *acts*, *intervenes*, *operates* on them, through the 'things' that make up her own performative skill and embodied knowledge. In collapsing the hierarchy between subject and object, human and machine, we begin to understand the dialogue that takes place – the 'dramaturgical conversation' as Mark Coniglio calls it [5] – between them, and that the new thinking (materially traced as choreography unfolding on the floor and on the screen) emerges out of this, also a 'thing' with its own sense of agency.

5.1 Indifferent to dance

In her elaboration of the ways in which dance communicates kinaesthetically, Mary M. Smyth discusses motor theory in terms of its 'view that the ability to perceive depends on the ability to articulate', before stating that this is 'inappropriate for understanding dance communication.' [28]. She states that '[t]he important part of the message in dance is not "what was that movement?"' and goes on to argue that 'for the spectator who is not a dancer, being able to discriminate one movement from another is not the problem.'. But in developing *Tools that Propel* that was a vital problem to overcome. What is a movement? How do you distinguish one gesture from another? What is the beginning and end of a gesture? As discussed earlier in section 2.1, the system determines the end of a gesture in one of two ways – either on the first frame at which the estimated likelihood that the current motion is produced by one of the 'known' classes exceeds some threshold, or on the frame at which the duration of the current recording exceeds some defined maximum (typically 5-8 seconds). It has nothing to do with how we perceive meaning in the movement; its expression, its energy, its arc or trajectory. It is, as Adam Russell has termed it, quite 'psychopathic' in its decision-making and flagrant disregard for meaning. But this very refusal (or inability) to apply any other more multimodal sense to the movement – unlike the 'practical multimodal experience evidenced in dance expertise' in all its richness and nuance [7] – is part of what makes it 'other' and warrants curious appraisal of its qualities, affordances and agency from a non-subject-oriented perspective.

As Sofie Hub-Nielson, dance undergraduate at Falmouth University, commented in a studio session on October 10th 2018, *Tools that Propel* encourages dancers to use what she termed 'human movement', which is movement that is not normally used in dance but at the same time portrays and uses the human body [18]. It is its indifference to meaning, narrative, and prior relations that shifts what is perceived as dance. The dancer can offer whatever he or she wants to the system, to the tracking eye, but the factors by which it determines value do not adhere to either representational, historical or embodied conceptions of what constitutes dance. Hub-Nielson stated that she found it interesting that a computer could push the natural human body forwards towards our frame of reference as we are dancing, rather than a non-natural or technological rendering of a body. We are faced with material reality, however indirectly we reach it. The recognition of the agency of the technological components involved in the assemblage that makes up dancing with *Tools that Propel* – seeing them not as objects to be used or overcome or extended out into, by and from our subject-oriented perspective, but able to act on us, even from their withheld, indifferent existence in the space – actually allows the interactor to journey deeper into the human rather than farther away. The dance between 'things' opens up new perspectives, possibilities, and intrinsic insight into and understanding of the nature of our material being. An undergraduate dance student has described how *Tools that Propel* will 'do something unexpected and it's an invitation, it's an opening'. Another describes how a memory of yourself or someone else on screen leads 'not so much [to] sensing the physicality but just listening to your own mental process [. . .] it's enough stimulus to make you think differently'; and a third, describing the reflection of the room as 'raw' talked about going on a 'journey [. . .] together [. . .] a relationship we were moving on together.' She said 'I think it helped me accept myself more [. . .] just kind of accept the way I move in a strange sort of way.' [20]. It is this 'opening up' of the centre of the moment and place we are in, coming about through the distributed agency between the dancing body and

Tools that Propel that builds compositional awareness, attention and intention within the movement decisions carried out in the dancer's bodymind; and as these skills and qualities are applied by the dancer to their improvisation with the system, the 'opening up' gets deeper.

6 AGENCY IN DIALOGUE

When the OpenEnded Group and Wayne McGregor developed the *CLA* the aim was to create an 'independent dance agency [...] an entity that could respond to and solve the kinds of choreographic tasks that [McGregor] set for his dancers. [17]. *Tools that Propel* is less of an agent than the *CLA* in that sense; it cannot generate choreography on its own or respond to choreographic tasks. It needs the bodies of the dancers interacting with it to come to life at all. But therein lies its specificity too. In this interaction it can respond to the dancers and what they give it in *real-time*, and it can also surprise them. It can take them into themselves and deeper into the moment of improvisation. In its ability to dialogue, challenge, and reveal, it sustains dancers' engagement over long, evolving, improvisations and inspires them to improvise with it over and over again.

6.1 Digital intervention in real-time

Of course, there have been countless installations created over the decades that respond to interactors in real-time, and numerous digital dance performances in which visuals and sonic outputs are controlled by dancers' movements. Many of these installations and digital dance performances would fall under the banner of what Mark Coniglio calls 'digital reflection'. This he defines as being when technology acts as the protagonist in the performance and is used to empower and augment the performer, expanding the space of their performance, through interactive systems, for example, that use performers' gestures to trigger sounds and video. But the development of *Tools that Propel* was inspired by Mark Coniglio's arguments for what he calls 'digital intervention' a modus operandus he positions in opposition to 'digital reflection'.[5] Whilst often producing spectacular visual performances, Coniglio believes that the work he defines as 'digital reflection' is never really memorable or profound because it has not earned what he calls the ecstasy of great art through any sense of conflict. He also argues that whilst the body as an instrument 'is incredibly high-resolution and responds very dependably to the commands sent to it by their brain [...he] can think of no digital gesture-sensing system that offers anything near the same level of resolution and responsiveness.' In contradistinction, Coniglio cites *Life Forms* as an example of 'digital intervention'; an approach to using technology in creating performance in which the technology acts as an 'antagonist' to the human performers, challenging rather than expanding their capabilities, and thereby producing new forms that would not have come about otherwise. *Tools that Propel* uses computation to *intervene* in the dancer's decision-making in *real-time*. It explores digital intervention as a mode of stimulating and producing new choreographic thought-in-action *as the dancer improvises* and *as the computational choreography unfolds* in relation to, and propelling, new emergent movement.

6.2 Negotiating bodies

The *CLA* might indeed be described as an 'extended mind'; James Leach has called it a 'kind of prosthetic dancer's brain' and 'an extended digital notebook' [17]. It was built on the foundations of extensive, invaluable research into how the choreographic process works and is designed to produce choreographic possibilities that are different from those of McGregor's company of human dancers, inspiring them to explore and investigate new terrain. Leach states that the 'agency' of the *CLA* 'was a function of having some degree of autonomy, tightly coupled with choices the user would make' and discusses how it was not the 'choreographic entity that had been envisaged'. This revelation led to a further investigation into the need for the agent to have a 'body' and what that meant for McGregor and his dancers; following this came the creation of *Becoming*, a more recent iteration of the *CLA* which McGregor described as an 'eleventh dancer' [17]. *Becoming* was designed to give 'body' to the computational tool, reflecting McGregor and his dancers' desire for something that had a sense of matter, energy, presence and movement.

But it is the description of what McGregor and his dancers said about bodies in relation that is most important to a recognition of the contribution that *Tools that Propel* might also bring to this field of research. Leach writes that '[m]aking movement material with others, or with others in mind is about the relational aspects of movement. When articulating the qualities of working with others in a studio, or in tasking situations, dancers said that they are aware of a constant negotiation of feeling and presence, of desire, shame, imposition, power, politeness, domination, or facilitation. These are qualities *felt and worked with* in making movement material.' [17] As such *Becoming* was developed to be a bodily presence in the studio with the dancers, 'an aesthetically and kinaesthetically compelling presence', designed to 'elicit a kinaesthetic response' in dancers working with and alongside it. It still does not explicitly respond to what they are doing, however. It is not in 'constant negotiation' with them even if it is constantly present and constantly negotiating its own body.

Tools that Propel though significantly different in aesthetic to *Becoming* also has such presence and also brings out kinaesthetic responses in people working with it. It too has body, despite its visual output being projected on a flat screen or wall. But where it differs from *Becoming*, beyond the programming and computation informing its particular mode of bodily thinking of course, is that it challenges and responds to dancers; it negotiates with their bodies. It has been described by undergraduate dance students as 'predictable but also unpredictable'; as something that 'takes what your offering and offers back, whether that's [by] breaking your offering or developing your offering' and that 'makes you conscious of what you're doing [. . .] helping you to retain that sort of clarity in your thought'. It is acting on the dancers and they are able to act on it. Describing *Tools that Propel* as being '[l]ike one of those dynamic abstract paintings where you don't really know what's going on but you have to stand there for a long time and figure it out' one dance student stated that 'some people might want to just challenge it and others might want to kind of like use it, and live in it almost'. One student said that it 'supported me and pushed me to break my boundaries more with my movement and open my mind a bit more' and others spoke of having 'a fluid kind of conversation', 'like a relationship, a conversation, communicating with each other', 'just bouncing off each other', 'adopt[ing] the mindset of like looking at her as a performer' and having 'days when we did not get on' [20]. *Tools that Propel* is *digital intervention happening in real-time*, and the movement that emerges with agency of its own and in dialogue with all the bodies in the system could not have pre-existed this relationship.

7 CONCLUSION

This paper interrogated the experience of the dancers improvising with *Tools that Propel* with reference to two apparently opposing critical frameworks, exploring whether the movement emerges within the dancers' own extended bodymind, that is through human-technological symbiosis, or in dialogue with the system's 'otherness' as part of an assemblage of distributed agencies acting on each other, embroiled in a dramaturgical conversation. It concludes that it is in the interplay between both conceptualisations of the relationship between the human-body-in-movement and the computational decision-making that new choreographic thought-in-action occurs. This interplay might be understood as being between computation as an expansion of the dancer's capacities and computation as an unpredictable, surprising and sometimes disturbing intervenor.

Through examining the relationship between the dancer and *Tools that Propel*, this paper has also explored the performative and embodied know-how that the dancer is revealed to bring to the interaction and suggests that this know-how might also be specific to the interaction itself. Whilst movement does indeed shape the system's behaviour, this very behaviour shapes the movement too; in this entanglement it is not always clear who or what is doing the moving.

If there is a sense of agency perceived in *Tools that Propel* and/or brought about by improvising with the system, this is not because of an intentionality on the part of the programming. Agency is felt in the feedback loop evolving between the dancer and the system; expanding, ricocheting and pulsing *with* and *because of* all the collisions that occur between the mode of thinking enacted by the fleshy dancing matter and the mode of thinking enacted by the computational system.

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Soft grippers not only grasp fruits: From affective to psychotropic HRI

Caroline Yan Zheng [1] and **Kevin Walker** [1]

Abstract. Soft robots are an emerging class of biologically inspired machines. From the point of view of affective human-robot interaction design, we hypothesise that they are a promising medium to create more emotionally engaging human-robot interaction experiences. We report a preliminary study and early analysis of the affective qualities of four silicone-based soft robotic artefacts. Results gathered so far suggest that they are impactful in eliciting emotional engagement. We discuss the material and kinetic properties that may contribute to such an impact. The findings suggest opportunities for designing affective interaction that afford novel sensory experience. Meanwhile we question how this new class of robotic artefacts that do not look or feel like machines will impact the affective relationship of human users.

1 INTRODUCTION

Soft robots are an emerging class of "elastically soft, versatile and biologically inspired machines", made primarily of easily deformable materials such as fluids, gels and elastomers which match the properties of biological tissues and organisms [1]. Compared with conventional robots, which are kinematic chains of rigid links that prioritise control, soft robots allow a redundant, or 'infinite', degree of freedom (DoF) in their movement [2]. One of the most practical applications is for grasping and manipulation task in the form of soft grippers [3,4]. Although an infinite degree of freedom poses a challenging issue of control for the roboticist to address[2,5], it creates an appearance of smooth, continuous and organic-like motion. Such a kinetic feature indicates promising potential for aesthetic and relational serendipity, suggesting that soft robotics may be an excellent material for art and design practitioners. There is emerging attention from the creative community to explore the aesthetic potential of soft robotics as an expressive medium: e.g.[6,7,8]. The opportunity and risk in affective relations have been pointed out [7,9] but have been less widely explored in practice.

A typical soft gripper such as [3] and Figure 1a and 1b, consists of bending gripper fingers or elements around an object. Compliable silicone rubber material is used. There are inner chambers designed to allow air or liquid to be injected into the chambers, which causes the deformation of the gripper fingers to "grasp". By configurating the physical structure of the inner chambers and by adding reinforcement into the surface layer, the morphology of movement can be articulated. During earlier interaction with soft grippers, the researcher observed strong emotional reactions toward the robot's biomorphic disposition. As part of a research project for programmable materials suitable for designing affective Human-Robot Interaction (HRI), we are exploring the affective qualities of soft robotics artefacts made from silicone rubber. This short paper presents the results of a preliminary study and an early analysis of the affective qualities of kinetic soft robotic actuators that may contribute to this emotional engagement. By affective quality, we refer to "the ability of an object or stimulus to cause changes in one's affect" [10]. By breaking down the holistic disposition to material and interactive elements, we aim to facilitate the study of each designable module.

2 PRELIMINARY STUDY AND ANALYSIS

2.1 Material and method

The artefacts

As shown in Figure 1, four artefacts were made and presented to participants to interact with. They have been selected to include the basic kinetic features of soft robotic actuators: expansion, contraction and bending [11]. The artefacts shown in Figure 1a, 1b and 1d were adapted from existing designs.[2] A short video of these artefacts can be found in the link below.[3] These artefacts could be controlled manually by participants via a hand-squeeze bulb. Participant could freely touch and manipulate the artefacts in their hands or position on their bodies. Participants were also encouraged to interact with each other using the artefacts.

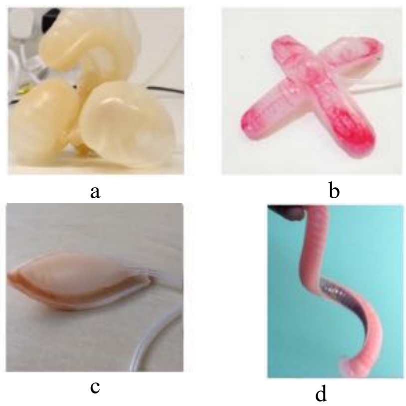

Figure 1. Artefacts Used in the Preliminary Study

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[2] https://www.instructables.com/id/Air-Powered-Soft-Robotic-Gripper/ and https://softroboticstoolkit.com/book/fiber-reinforced-bending-actuators

[3] https://feuetbois.net/2016/02/01/preliminary-study-on-affective-qualities-of-soft-robotic-artefacts/

Participants

The questionnaire evaluation on the affective qualities of the soft robotic artefacts is part of the activities during two co-design workshops. These were first an AcrossRCA 2016 workshop [12] in which Master's students from various art and design programmes at the Royal College of Art were recruited by a dedicated project coordinator, and second, one that was held during the 2016 STATE of Emotion festival in Berlin [13], where willing adult festival audiences emailed the workshop coordinator to register their participation.

Of the workshop participants, 24 completed the questionnaire (n=24). The age ranged from 18 to 49, with half participants between 18-29 and the other half between 30-49, 15 female, 7 male, 2 not indicated.

The questionnaire

A questionnaire was provided for the participants to document how they felt about interacting with the artefacts. The questionnaire asks five questions, as shown in Table 1. In Question 1, 24 emotion labels were taken from Plutchik's "Wheel of Emotions" [14], shown in Figure 2. Participants could choose more than one label. If none of the labels applied, participants could choose "other" and write down their own emotion labels.

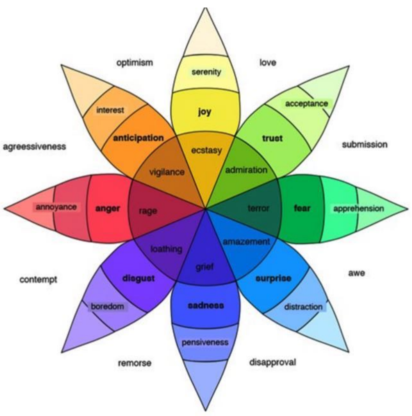

Figure 2. Plutchik's Wheel of Emotions (2001)

Figure 3. Word Cloud of Response for Question 1.

	Question	Response
1	How does the artefact make you feel?	Figure 2
2	With what property do you associate the feeling(s)?	100% movement 75% surface texture 50% touch 17% other 8% sound
3	Why does it (the artefact) evoke such a feeling?	Grouped in six features: a. aliveness b. novelty/uncanniness c. tactile sensations d. unpredictability e. activeness f. intentionality
4	Would you say it is a positive or a negative feeling?	79.1% positive 8.3% neutral 4.2% mixed 4.2& negative 4.2% other
5	How strongly does the artefact affect your feeling? 1 being no impact at all, 10 being most impactful.	Mean value 6.58

Table 1. Questions and Responses

2.2 Results and Analysis

The results are shown in Table 1 and Figure 3.

The response to Question 1, "How does the artefact make you feel?" has been mapped onto a word cloud, shown in Figure 3. The words shown include both the 24 emotional labels provided and those suggested by the participants. The emotional labels suggested by the participants include "delight", "affection", "rejection", "sexual", "pleasure", "basic", "primal", "empathy (twice)", "kindness", "affective". The top-rated labels are "joy", appearing 14 times, "surprise" 13 times and "interest" 11 times.

The response to Question 2 suggested strongly that movement, surface texture and tactile were the properties that evoked the most emotion.

In Question 4, participants responded overwhelmingly with positive emotions towards the soft robotic artefacts. And in Question 5, the average rating for the level of impact of the artefacts was 6.58 out of a score of 10.

Question 3 was open ended, and asked participants to discuss "Why does it (the artefact) evoke such a feeling?" We preliminarily inferred six features (Table 1) based on the responses. We discuss what material and interactive elements may have contributed to such attribution and we include participants' responses, below.

Aliveness

The responses indicated that movement, organic kinetic forms and the morphology of the soft silicone rubber material give an animal-like visual impression. A pneumatic air supply enables a pulsating movement. The sound during inflation and deflation resembles the sound of inhaling and exhaling. The combination of

the movement and the sound may contribute to the association with life or breathing. For example, participants wrote:
"Heartbeat", "suspended between life and death", "It's filled with breath!", "It seems like it's a little live pet".

Novelty/uncanniness
The responses indicated that there was an element of surprise between the artefacts' kinetic behaviour and participants' expectations, and participants had not yet experienced an existing category of identity to associate with this type of artefacts. For example, participants wrote: "It's something alien", "I've never seen something like this before", "new & unusual shape change", "Surprising movement".

However, this level of confusion of identity did not lead to a feeling of threat, but rather to positive surprise. For example, one participant wrote: "Element of surprise, leading to delight, unexpected quality".

The quality of tactile sensation
The quality of tactile, skin-like sensation contributed to the association of human touch. For example, participants wrote: "The feeling of the material when it moves against my hand", "Feels human".

Unpredictability
Some feedback indicated the unpredictability of the movement with participants commented as "surprising". Research has shown that unpredictability in robot motion leads to increased attention from human interactants and make the robot appear to be more "natural" and lifelike [15,16].

Activeness
Static, passive artefacts require human to enact the touch action for physical contact. Vibratory motors are popular medium to introduce tactile sensation; however, they do not produce visual movement. Compared with the above two, these soft robotic artefacts are capable of performing "active touch" through visual shape changing to enable physical contact with the participants. For example, participant wrote: "… it moves against my hand".

Intentionality
Participants seemed to empathise and project identity and intentionality onto the artefacts. For example, participants wrote: "Appears helpless, in pain", "It is looking for a connection".

We have summarised the results. Participants rated the hand-sized soft robotic artefacts as impactful for invoking emotions, and they overwhelmingly attribute positive emotion. The highest-rated emotion labels are "joy", "surprise", and "interest". Among the listed elements, movement and tactile stimuli are highest rated elements to contribute to the association with an emotional response. From participants' description of what they think contribute to evoking emotional responses, we preliminarily inferred six features of the soft robotic artefacts: aliveness, novelty, tactile sensations, unpredictability, activeness, intentionality.

3 DISCUSSION

The findings suggests that artefacts designed with soft robotics with biomorphic movements have strong agency in attracting emotional investment from users or an audience, which echoes Arnold and Scheutz's remarks about soft robotics, in terms of "how easily people can attribute emotionally charged personal qualities to a robot, even when it is fairly clear that the robot cannot reciprocate feelings of any sort" [9]. However, this emotional quality is not found through deliberate design into the machine by mimicking a human or animal veneer, but emerges from the artefact's biomorphic quality in its compliant material and kinetic forms. It is these characteristics that contribute to the enactment of agency and evoke interactants' anthropomorphic projections.

Anthropomorphism plays an important role in the human projection of relations with objects. Anthropomorphism is the projection of human-like agency onto non-humans [17]. It involves the interpretation of an entity as a character, with emotions, intentions and purpose. Vidal[18] considers it the most spontaneous register through which humans establish strong relationships with artefacts or other non-human beings.

Movement plays a significant role in triggering such projections. Wolf and Wiggins[19] investigated how different types of movement affect people's affinity with robots to associate them with machines, animals or humans. The result of Question 2 evidenced this attribution.

Opportunities for designing affective HRI
Given the findings, if the soft grippers are only considered in relation to their functionality e.g. applications in handling fragile objects and for safer interaction with human users, an opportunity will have been missed. It is exciting to imagine a new space for designing interactive robots that are emotionally engaging and afford novel sensory experiences, now that this novel medium with such emotionally engaging properties are at the disposal of designers for affective HRI. The affective characteristics lie in several sensory channels – visual, tactile and acoustic – which suggest that soft robotic artefacts could be designed for multi-model sensory experiences.

A more emotionally engaging HRI experience could be designed by exploiting anthropomorphism and the affective qualities of soft robotic mechanisms. Several studies have already advocated affect-centred design for HRI. They propose that high affective quality agents help designers create a more positive user experience and more harmonious results [10,20].

Risk for affective HRI
However, such a level of emotional engagement might be a double-edged sword. It also suggests risk and unintended relational outcome. The ostensible purpose might be subverted when human users unexpectedly bond emotionally with such robots. "Unidirectional bonding" with social robots is a phenomenon that continues to draw scrutiny [21,22]. When humans respond easily to the affective qualities of the soft robotic artefacts with trust and openness, it also suggests a state of vulnerability to emotional exploitation. A projection of the unpredictable and psychotropic emotional relations caused by the mediation of robotic interiors boasting high affective qualities can be found in J.G. Ballard's science fiction story 'The Thousand Dreams of Stellavista' [23,24]. The dexterity developed in soft grippers not only enables them to grasp soft fruits and manipulate objects[3]: they can also be emotionally manipulative agents. Arnold and Scheutz call for more thorough investigations of the "experienced behaviour or disposition" of soft robots, and a fuller grasp of their "relational consequences" [8]. Such a task calls for collaborative and cross-disciplinary efforts in the fields of creative design, social science, robotic engineering and affective computing.

4. LIMITATIONS AND FUTURE WORK

The analysis on the emotion evoking features is rather preliminary and needs further analysis which may involve re-grouping, elaboration and putting in context of thorough review on relevant literature and practice. This preliminary study had a small sample size. The findings, however, are valuable for informing a more rigorous study design in a specific application context as part of future work to facilitate more in-depth inquiries on the relational impact. In this study, the soft robots could be manually controlled by participants. Research has shown that robots with different degrees of autonomy influence the way human users' respond emotionally. For example, in the study by Złotowski et al.[25], exposure to more autonomous robots evoke more negative attitudes. Future work includes employing studies of soft robots with different degrees of autonomy.

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Elegant, natural motion of robots: lessons from an artist

Aleksandar Zivanovic[1]

Abstract. This paper examines the use of the control system used by the artist Edward Ihnatowicz (1926–1988) in his sculpture *The Senster* (1970). The limitation of the computer technology of the time led to the use of a digital-analogue hybrid system, where analogue circuits were used to modify the output of the computer to generate smooth motion. The artist used his aesthetic judgement to choose the particular characteristics of the response. This paper shows that the response resembles natural movement (e.g. the movement of the human arm). It goes on to present an algorithm developed by the author to achieve a similar outcome using micro-controllers, with a low computation and memory requirement. It is hoped that this would be of use in the development of robots to interact with humans, as this kind of movement appears to be more attractive than conventional motion control techniques used in robots.

1 A BRIEF BIOGRAPHY

Edward Ihnatowicz [1][2][3][4] was born in Poland in 1926, left at the outbreak of war in 1939 and eventually arrived in Britain in 1943. He studied sculpture at the Ruskin School of Art in Oxford from 1945 to 1949 but also had wide-ranging interests including photography, film-making and electronics. He worked as a photographer and a junior partner in a small furniture company until, in 1962, he left the business and his home to live in a garage and return to making art. During this period he developed "Sound Activated Mobile" (SAM) [5], which was exhibited at the Cybernetic Serendipity exhibition in 1968 and later toured the United States of America, ending at the Exploratorium in San Fransisco. He then started working on his greatest work, "The Senster" which was exhibited in 1970 at the "Evoluon," Philip's newly-opened exhibition centre in Eindhoven, the Netherlands. By that time, he had established a close relationship with a number of people in the Department of Mechanical Engineering at University College London (UCL) and was appointed to work as a research assistant there. He worked on a number of research projects and produced one further work of robotic sculpture, called "The Bandit." He eventually left UCL in 1986 to set up his own company mainly involved with computer graphics. He died in 1988.

Photographs, sketches and videos of his work, together with unpublished articles by Ihnatowicz are available on the Senster website [6]. His family retain an archive of his papers and SAM survives in their custody.

The remains of The Senster were acquired in 2017 by the AGH University of Science and Technology in Krakow, Poland and restored by the "Senster 2.0" project team, led by Anna Olszewska[7][8].

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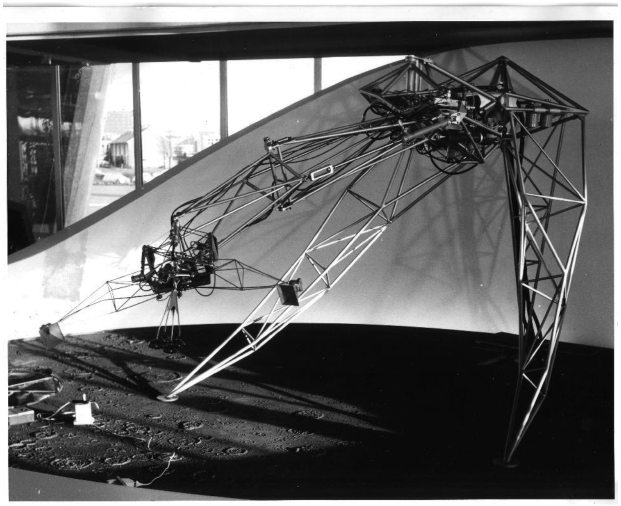

Figure 1. The Senster at the Evoluon in Eindhoven, the Netherlands in about 1970. Photograph by Edward Ihnatowicz.

2 THE SENSTER

The Senster (see Figure 1) was developed for Philips' technology showcase, the Evoluon, in Eindhoven, the Netherlands and went on display to the general public in 1970. Ihnatowicz was helped by engineers at University College London (UCL), Philips and Mullard.

The Senster was large: 15 feet (4.6m) long and 8 feet (2.4m) tall at the shoulder. It was made of welded steel tubes, with no attempt to disguise its mechanical features. There were six joints along the arm, actuated by powerful, quick and quiet hydraulic rams. Two more custom-made hydraulic actuators were mounted on the head to move the microphone array. The microphones were arranged in vertical and horizontal pairs and sound localisation was carried out in software by a process of cross-correlating the inputs on each pair of microphones. The actuators in the head moved the microphones very quickly in the calculated direction of the sound, in a movement reminiscent of an animal flicking its head. The rest of the body would then follow, making the whole structure appear to home-in on the sound if it persisted. Loud noises would cause the body to move upwards and sideways given the appearance of it shying away from the source of the noise. In addition, two Doppler radar units were mounted on the head of the robot, which could detect the motion of the visitors. Low level movements, such as waving or clapping hands, would cause the structure to move towards the source of the movements. Large, or violent movements made it move away, giving the impression that The Senster was frightened.

3 TRAJECTORY GENERATION USED IN THE SENSTER

Fortunately, Ihnatowicz's family have kept an archive of his papers with technical specifications and schematics of the control system. The following description was derived from studying this material.

The computer used to control The Senster was a Philips P9201 with 8k core memory, which used punched paper tape to load the program. It was very similar to the more common Honeywell 16 series. An assembly code program listing exists. Several racks of custom electronics interfaced the computer to The Senster and it is fortunate that most of the circuit diagrams survive.

There were eight hydraulic actuators in total (including the two in the head) and they were controlled in pairs, so, essentially, there was one standard output circuit repeated four times. The following description is for one such circuit.

The output from the computer was latched as 16 data bits. The 16 bits were split into two sets of 5 bits, which represented the next required position for an actuator, thus each joint had 32 possible discrete positions. Each set of five bits was passed to a digital to analogue converter and thence to a circuit Ihnatowicz called *the predictor*. The remaining 6 bits were used by *the acceleration splitter* circuit described below.

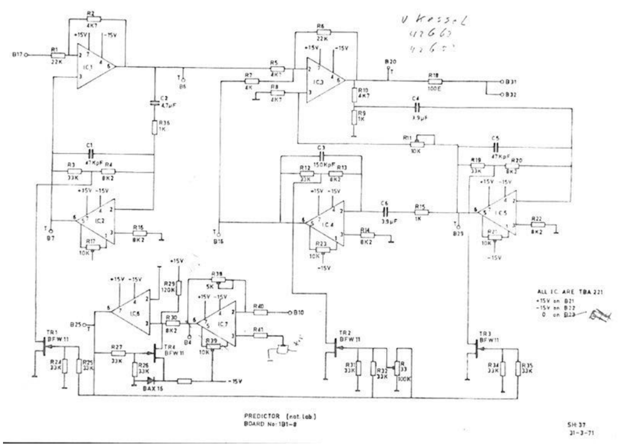

Figure 2. The Predictor circuit. From papers kept by Ihnatowicz's family.

The predictor (see Figure 2) was a second-order low-pass filter, with an adjustable roll-off frequency set by a circuit called *the acceleration splitter*, fed by three spare bits from the latch, via another digital to analogue converter. This circuit distributed an analogue voltage, with a resolution of 8 values, to the predictor circuits, which altered their roll-off frequencies. It effectively set the time by which all the joints had to reach the next set positions, so that they all arrived at the same time. There were two separate acceleration splitters: one for the hydraulics which moved the microphones and another for the joints in the rest of the structure, thus the microphones could flick quickly, while the main structure moved at a more sedate pace.

The predictor filtered the analogue voltage output so that it followed a smooth curve. The computer was not fast or powerful enough to do this in real-time, hence the use of analogue circuits. The output from the predictor circuit was fed to a closed-loop hydraulic servo system, so that the actuators followed the analogue voltage in a proportional way.

Fortunately, the circuit diagram for the predictor survives and was simulated using SPICE, a standard circuit simulation software package. Figure 3 shows the effect of the circuit. At time = 1s, the output from the computer (via a digital to analogue converter) undergoes a step change from 0 to 10V. The predictor filters out the high frequency components, so that the robot starts and stops smoothly. The different curves illustrate the effect of changing the value output by the acceleration splitter.

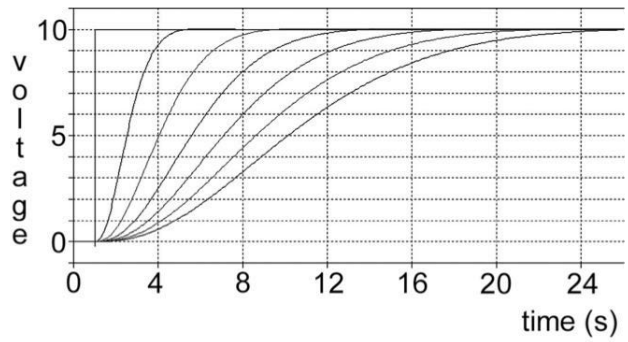

Figure 3. Predictor output for different values output by the Accelerator (position is proportional to voltage)

The derivative of one of these curves is shown in Figure 4a. Figure 4b is a graph of normalized velocity against normalized time of a tracked human arm[9]. It can be seen that shape of the velocity profiles match quite well, so The Senster moved with similar characteristics as biological motion (specifically, a human arm).

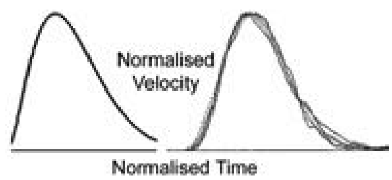

Figure 4. a: Velocity profile from Predictor circuit; b: Velocity profile of human movement (from [9])

4 DIGITAL FILTER IMPLEMENTATION

4.1 Selection of digital filter

The implementation of smoothing Ihnatowicz chose for The Senster was a clever approach to overcome the weaknesses of the computer technology of the time. However, now it is much easier to implement digital filters rather than use analogue circuitry in that way. There are a wide range of standard filters described in the field of Digital Signal Processing (DSP). See, for instance [10]. Exponential smoothing was chosen as is it easy to implement and uses very little computational resources.

4.2 Exponential Smoothing

Exponential smoothing is a technique for smoothing time series data using the exponential window function. The output is the weighted average of the current input value T and the previous smoothed value

$S_{k-1}^{(1)}$. If the time series starts at $k = 0$, the simplest form of exponential smoothing is given by:

$$S_0^{(1)} = T_0 \quad (1)$$
$$S_k^{(1)} = \alpha T_k + (1-\alpha)S_{k-1}^{(1)} \quad (2)$$

where α is the *smoothing factor* and $0 < \alpha < 1$. In this application, where the technique is used to smooth the movement of a robot joint, values of α close to one will ensure that the joint will reach its target angle quicker than when low values of α are used.

Note that the (1) superscript notation is used to indicate single exponential smoothing - the technique of double and triple exponential smoothing is introduced below.

Exponential smoothing has many advantages over other techniques. It produces an output as soon as two data points are available (c.f moving average filters). It will not overshoot. It takes the same length of time for the joint to reach its target, no matter the size of the movement, so that if multiple motors (e.g. in a robot arm) are being controlled all the joints will arrive at their commanded position at the same time. The *time constant* is the amount of time for the smoothed output to reach $1 - 1/e \approx 63.2\,\%$ of the original signal. The relationship between this time constant, τ, and the smoothing factor, α, is given by:

$$\alpha = 1 - e^{\frac{-\Delta T}{\tau}} \quad (3)$$

where ΔT is the sampling time interval.

A key advantage of exponential smoothing is that it is very simple to implement, with a very low processor and memory requirement. It can easily run on micro-controllers (e.g. Arduino) and imposes a low overhead.

A straightforward implementation in C of an exponential filter is:

```
S1 = (a * T) + (b * S1p);
S1p = S1;
motor_position = S1;
```

Where `T` is the target value of the particular joint. `a` is the smoothing factor α, `b` is $(1 - \alpha)$, `S1` is the smoothed value and `S1p` is the smoothed output from the previous iteration of the code.

This code is run in a loop, or using an interrupt handler, so that it is regularly updated at an appropriate frequency (e.g. 50Hz) so that the step changes in position are not noticeable. Each iteration requires two multiplication and one addition operation, and only the previous value needs to be stored in a variable. The initial value for S1p is something of an issue. It makes sense for the robot system to read the real value of the joint and use this value for S1p, when the robot is first switched on.

Exponential smoothing is equivalent to applying a first-order Infinite Impulse Response (IIR) filter as used in digital signal processing (DSP). The advantage with using the smoothing approach is that it is so simple. There is no need for expertise in DSP. The smoothing factor α and the sampling frequency are all that needs to be set and they can be determined in an empirical way.

As the name suggests, exponential smoothing produces an exponential output from a step change input. At the start of a step change in the input, the smoothed output changes quite suddenly. This sudden change can, itself, be smoothed by running the smoothing algorithm on the already smoothed output. This is called double exponential smoothing. The process can be repeated again, to get triple exponential smoothing:

$$S_0^{(1)} = S_0^{(2)} = S_0^{(3)} = T_0 \quad (4)$$
$$S_k^{(1)} = \alpha T_k + (1-\alpha)S_{k-1}^{(1)} \quad (5)$$
$$S_k^{(2)} = \alpha S_k^{(1)} + (1-\alpha)S_{k-1}^{(2)} \quad (6)$$
$$S_k^{(3)} = \alpha S_k^{(2)} + (1-\alpha)S_{k-1}^{(3)} \quad (7)$$

A simple implementation in C is:

```
S1 = (a * T) + (b * S1p);
S2 = (a * S1) + (b * S2p);
S3 = (a * S2) + (b * S3p);
S1p = S1;
S2p = S2;
S3p = S3;
motor_position = S3;
```

Table 1 shows the output of this algorithm for the first 29 steps time steps, for $\alpha = 0.3$ and a step change in T from 0 to 100 at $k = 1$, and Figure 5 plots the results.

Table 1. First 29 steps of the algorithm, for $\alpha = 0.3$ and a step change in T from 0 to 100 at $k = 1$

k	T	S1	S2	S3
0	0	0.00	0.00	0.00
1	100	30.00	9.00	2.70
2	100	51.00	21.60	8.37
3	100	65.70	34.83	16.31
4	100	75.99	47.18	25.57
5	100	83.19	57.98	35.29
6	100	88.24	67.06	44.82
7	100	91.76	74.47	53.72
8	100	94.24	80.40	61.72
9	100	95.96	85.07	68.73
10	100	97.18	88.70	74.72
11	100	98.02	91.50	79.75
12	100	98.62	93.63	83.92
13	100	99.03	95.25	87.32
14	100	99.32	96.47	90.06
15	100	99.53	97.39	92.26
16	100	99.67	98.07	94.00
17	100	99.77	98.58	95.38
18	100	99.84	98.96	96.45
19	100	99.89	99.24	97.29
20	100	99.92	99.44	97.93
21	100	99.94	99.59	98.43
22	100	99.96	99.70	98.81
23	100	99.97	99.78	99.10
24	100	99.98	99.84	99.33
25	100	99.99	99.89	99.49
26	100	99.99	99.92	99.62
27	100	99.99	99.94	99.72
28	100	100.00	99.96	99.79

Figure 6 shows that it takes the same amount of time to reach the target destination, no matter how big the step change in the input. This means that if multiple joints of a robot are being controlled, if the same α if used, they will arrive at their destinations at the same time.

To examine the velocity profile, the difference between each output value and the previous value is plotted in Figure 7. Only S3 is shown because it is of the same order as the analogue filter used in The Senster. Indeed, the graph very closely matches the simulation of the circuit. If the algorithm is repeatedly applied to get S4, S5, etc. the effect on the graph is to keep the same general shape, but to add more of a curve to the initial rise.

The velocity profile exhibits many of the characteristics of natural motion: smoothness and asymmetry, and that it compares well with

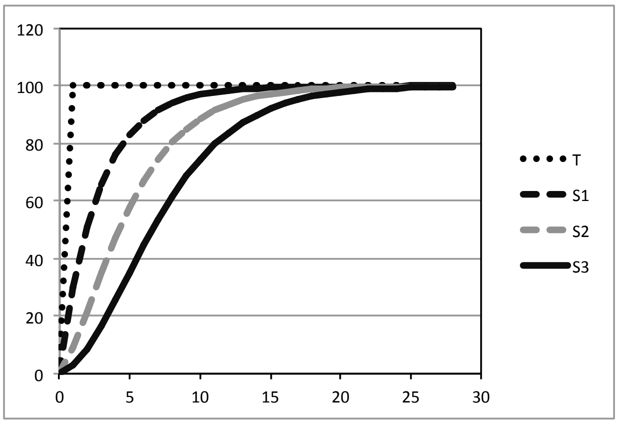

Figure 5. A plot of the input T, and S1, S2 and the output, S3, for $\alpha = 0.3$ and a step change of T from 0 to 100 at $k = 1$. X axis are in units of time steps, Y axis are appropriate position units

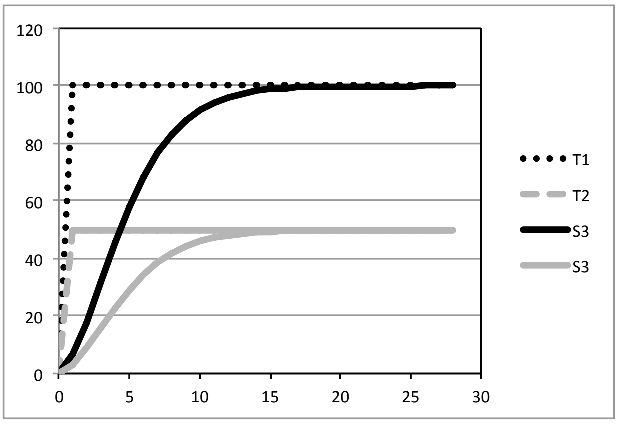

Figure 6. A plot of the input T, and S3, for $\alpha = 0.3$ and a step change of T from 0 to 100 at $k = 1$ and a step change of T from 0 to 50 at $k = 1$. X axis are in units of time steps, Y axis are appropriate position units

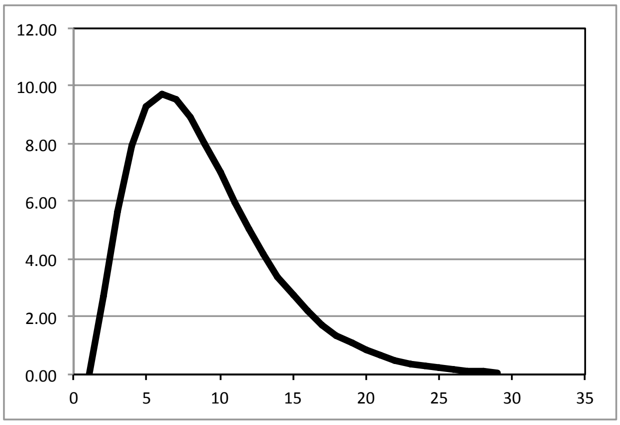

Figure 7. Velocity profile of S3. X axis are in units of time steps, Y axis are the change in position per time step

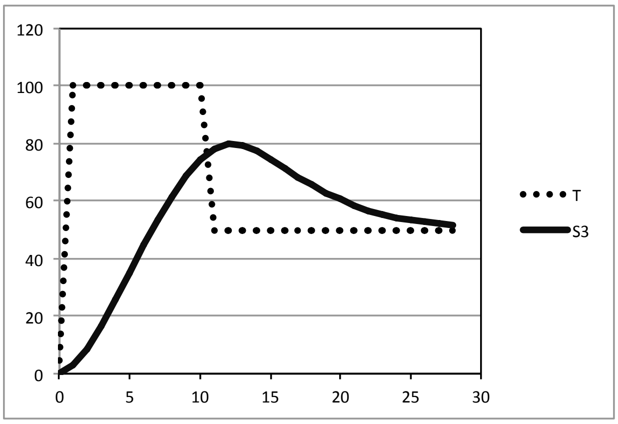

Figure 8. S3, for $\alpha = 0.3$ and a step change of T from 0 to 100 at $k = 1$ followed by a step down to 50 at $k = 11$. X axis are in units of time steps, Y axis are appropriate position units

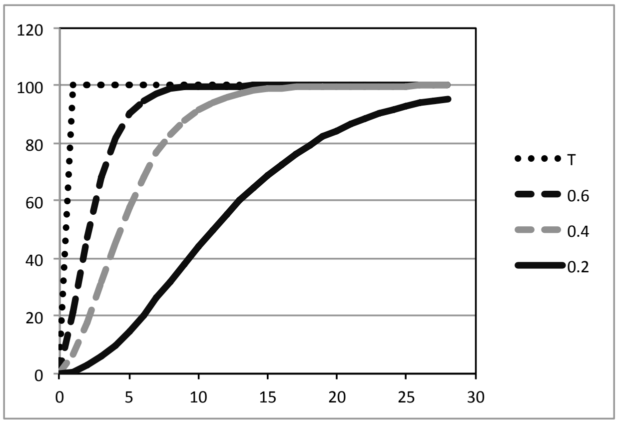

Figure 9. A plot of S3, for $\alpha = 0.6, \alpha = 0.4, \alpha = 0.2$ and a step change of T from 0 to 100 at $k = 1$. X axis are in units of time steps, Y axis are appropriate position units

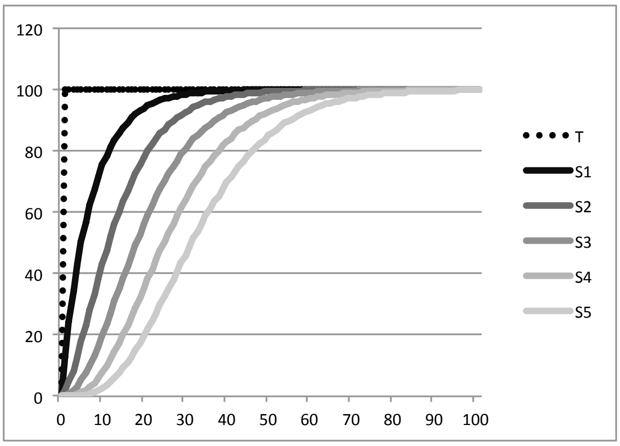

Figure 10. Repeated exponential smoothing

both The Senster's and the human arm velocity profile shown in Figure 4. It should be noted, however, that this algorithm does not aim to simulate biological movement, but to simulate the movement of The Senster. Ihnatowicz was not deliberately trying to simulate animal motion: he states in his papers that he was aiming to achieve a *pleasing* movement.

Figure 8 shows the response of the algorithm to a change in the input before the output has a chance to settle. In this case the input value changes from 100 to 50 at time step 11. It can be seen that the algorithm tracks the change smoothly.

Figure 9 shows the response of the algorithm to a variety of values of α. It demonstrates that the choice of the value of α sets the speed the joint moves to its destination.

Figure 10 shows the result of repeated exponential smoothing, up to S5. It is clear that the output becomes smoother, especially at the beginning of the curve. However, significant lag is introduced. Simulations have shown that there is not much to be gained by applying smoothing more than three times.

5 CONCLUSION

Some initial work has been carried out to explore the subjective impression this style of movement has on observers[11]. In this study, a robot arm was programmed to carry out three gestures: a simple point-to-point motion, a waving action and a bowing action. The robot was controlled using an algorithm very similar to the one described in this paper and the acceleration was varied from low to high. Observers were asked to rate the emotional content of the movement using Russells, the Tellegen-Watson-Clark and the PAD models for measuring emotions. The results showed that people were prepared to ascribe emotions to the movements, with most ascribing sadness, unhappiness or tiredness to low acceleration; happiness, pleasure or calmness to medium acceleration and excitement, alertness, arousal or surprise to high acceleration movements. Observers commented that the movement seemed ”natural” and not ”robotic”.

Research which started as an investigation into the details of how Edward Ihnatowicz's Senster worked has led to the development of a simple method of generating smooth, natural movement for multi-joint robots.

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What behaviours lead children to anthropomorphise robots?

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Abstract. Anthropomorphism is the attribution of human-like thoughts and feelings to a non-human entity, typically animals, toys or technological devices. Adults readily anthropomorphise even simple geometric shapes with no personifying features, evidence that anthropomorphism is elicited by the way an object behaves as much as the way that it looks. Recent regulatory concerns with regards user-confusion has led many robot designers to seek out non-humanoid robot forms, yet relatively little research is exploring how robot behaviours in the absence of personifying features may be both helpful and unhelpful for appropriate user engagement. Key to understanding what factors contribute to robot-anthropomorphism is a better understanding of its foundations in human thought. Current models of the development of anthropomorphism are outdated and fail to capture the interaction between perceiver and perceived. Here we review the relevant literature on the development of anthropomorphism as a psychological bias in children. We propose a new programme of research to expose the key behavioural drivers of anthropomorphism and examine their effectiveness for children of different ages.

1 INTRODUCTION

Rule 4 of the Principals of robotics [1] states that 'Robots are manufactured artefacts. They should not be designed in a deceptive way to exploit vulnerable users; instead, their machine nature should be transparent.' Key to concerns about exploitation is the knowledge that anthropomorphism: attribution of human-like thoughts and feelings to non-human entities, is a common and unavoidable feature of human-robot interaction [2, 3]. This psychological bias is exacerbated if the robot has human-like features [4, 5, 6] and so regulatory bodies are considering the advantages of a move away from humanoid robots with faces and human-like body-parts towards more zoomorphic or mechanomorphic forms. For example, the IEEE Ethically Aligned Design initiative [7] has a standards committee (P7001) actively working on standards for Transparency of Autonomous Systems, including considerations to avoid anthropomorphic misunderstanding of robots. However, anthropomorphism is not triggered by appearance alone. Adults readily anthropomorphise even simple geometric shapes with no personifying features [8, 9, 10, 11]. Critical to anthropomorphism are behaviours [12] which we define here as actions such as speed of motion [13], orientation [12, 13, 14, 15] and unpredictable responses [16]. Although robot behaviour is potentially a much stronger trigger of anthropomorphism than appearance, relatively little research is examining how robot behaviours might be deliberately manipulated to increase or decrease user anthropomorphism. Children are one of the key target markets for robots and potentially most vulnerable to deception [e.g. 17]. Here we propose a scheme of research that begins the task of identifying robot behaviours that elicit anthropomorphism in children of different ages using a non-humanoid robot.

Anthropomorphism is a widespread, likely automatic psychological bias, most often associated with animals, toys and technological devices [18]. Although top-down cognitive reasoning is involved, Gao and Scholl [9] show that low-level visual processing also traffics in animacy and intentionality, triggering a cascade of social reasoning and responses unconsciously when presented with appropriate stimuli. Although widely observed, the determinants of anthropomorphism are poorly understood. There is considerable variation in the degree to which humans anthropomorphise [19]. Differences in experience, cognitive reasoning styles and ongoing emotional attachments to other objects or people can all predict the degree to which an individual will anthropomorphise an object. If the object is perceived as sufficiently novel or complex, users are more likely to rely on their understanding of other human minds in order to understand, control and predict the object's behaviour. People who score higher on scales measuring 'need for control' and 'need for closure' are also more likely to anthropomorphise, as are those who are chronically lonely or are induced to feel lonely [20].

2 DEVELOPMENT OF ANTHROPOMORPHISM

It is unclear from the literature whether differences in anthropomorphism can also be predicted by a person's age. The traditional model suggest that young children (typically aged 3-7) are rampant anthropomorphists, treating everything they encounter as having thoughts and feelings like themselves [21]. This model predicts that by age 9 children will reliably categorise entities into those with human-thought and those without and that anthropomorphism will be rare in adults. However, everyday experience and more recent research [22] shows that older children and adults routinely anthropomorphise. To capture this, more recent models propose that anthropomorphism actually gets stronger with age, in line with increasingly sophisticated social reasoning [e.g. 23]. One of the author's (NG) [24, 25] has previously shown that children as young as three years of age are surprisingly nuanced and will anthropomorphise toys that they have a strong emotional attachment to but not other toys they own. These other toys have faces and names and the children frequently use them in imaginary play, and yet it is only those to which they are emotionally

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bonded that they treat as having thoughts and feelings. This suggests that the development of anthropomorphism is more complex than current psychological models have so far captured. Young children may, in fact, be more sensitive to variation in anthropomorphic cues than adults are.

3 BEHAVIOURS THAT ELICIT ANTHROPOMORPHISM

Users are more likely to anthropomorphise when the object has a face, body or motion that is human-like [13, 14, 15, 16]. A growing body of research is identifying the psychological impact of robot appearance on user experience and expectations, perhaps most notably the ABOT database which has compiled a range of robot appearances with associated ratings of 'humanness' [5]. However, the degree to which a robot is anthropomorphised will inevitably be an interaction between its appearance, its behaviour and the situation [26]. A static object with a face will be anthropomorphised less than an object without a face that moves contingently with the user, exhibits surprising behaviour and moves at a human-like speed. A simple white box that moves in delicate and dynamic ways is rated by users as being high on agency and intelligence despite having no personifying features [27].

There is little extant literature on the impact of behaviour on anthropomorphism in adults. Objects that act unpredictably evoke the need for control, and therefore seem more mindful than those that act predictably. In a series of studies, Waytze and colleagues [16] showed that the more unpredictable a person's computer, a novel gadget or robot was, the more participants anthropomorphised it. Users anthropomorphise more when the outcome of unpredictable behaviour is negative than when it is positive [28]. Imaging revealed that the same areas of the brain were activated when reasoning about unpredictable gadgets as typically associated with social reasoning about other humans, and that this was not the case when the same gadget acted predictably. To our knowledge, no direct replication has been done with children but Lemaignan and colleagues [29] found that while children aged 4-5 were more engaged with a robot that acted unpredictably than one that acted predictably, they subsequently anthropomorphised it *less*. More research is required to examine whether this contradiction reflects methodological differences, differences in the robot being used or developmental sensitivity.

Speed of motion has also been identified as a strong cue for anthropomorphism. Morewedge and colleagues [13] show that people are more likely to attribute mental attributes such as intention, consciousness, thought and intelligence to animals, robots and animations if they moved a natural speed than if they moved faster or slower. Wheatley *et al* [30] show that areas of the brain implicated in the perceptual and conceptual processing of biological motion and social stimuli are activated when observing geometric shapes interact.

Finally, orientation, degree and type of interaction with the user have also been shown to be important behavioural components in human-robot and child-robot interaction. For instance, Fink *et al* [29, see also 30] show that young children more readily engage with a simple robot that exhibits proactive behaviour (cuing joint attention with the child to target objects) than one that shows only reactive behaviour.

4 WHY MANIPULATE ANTHROPOMORPHISM?

Despite concerns about deception, the ethical question of whether or not robots should be designed to elicit anthropomorphism is a complicated one [3]. On the one hand, anthropomorphised robots have the potential to be emotionally confusing, especially to those users who are most vulnerable and least scientifically literate such as children and the elderly. Anthropomorphism at its best can elicit feelings of care and closeness from the user [22,24], making them more powerful tools for manipulation by unscrupulous corporations. Anthropomorphic expectations can lead to disappointment and dislike when not met and anthropomorphised objects are sometimes considered unlikable, untrustworthy and disgusting [33].

However there can be very positive psychological consequences of anthropomorphism. For instance, users who anthropomorphise their cars like them more and take better care of them than those who don't. Anthropomorphised objects have been rated as more likeable, more trustworthy and more understandable than matched items that have not been anthropomorphised [22]. And this seems to be a two-way process: liked objects are anthropomorphised more than unliked objects. Children remember and learn more from educational robots if they have anthropomorphised voice modulation than if they do not [34]. Perhaps most importantly in the context of children's companion robots, anthropomorphism has been shown to be a powerful tool for alleviating loneliness [24]. Adults who are chronically lonely anthropomorphise more than those who are not and use this as a mechanism to relieve their distress [18, 35]. Adults induced to feel lonely under experimental conditions subsequently felt less lonely if given the opportunity to anthropomorphise [ibid.]. There are many potential psychological risks but also benefits of robot anthropomorphism and the balance will need to be determined by the type of user and the purpose of the interaction. Without a better understanding of what cues elicit anthropomorphism for different users, designers have little control of this important variable.

5 PROGRAMME OF RESEARCH

It is widely recognised that significant moral confusion exists regarding the status of robots [36, 37]. In addition, wider societal concerns related to the deployment of artificial intelligence at scale motivate the study of human anthropomorphic responses to autonomous intelligent systems: robots [38]. Improved models of the human anthropomorphic response may enable engineers to design robots such that they may be more usefully understood by humans. These improved models will also provide a foundation for effective standardisation and regulation of products and services, such that products may be tested and certified as compatible with well established, internationally recognized, standards [7]. Standards compliance increases trust and acceptance of new technology, leading to increased usage and uptake of products. Eventually, such an understanding may support design of genuine human-machine relationships that don't rely on the attribution of human-like characteristics.

Our research is to expose the key drivers for anthropomorphism of robots, focusing on behaviours as distinct from robot appearance or form factor. Anthropomorphism is a human universal and creates expectations about robots that could help but also hinder. Our research has a strong methodological agenda. We and other researchers will be able to leverage this work in many ways to advance understanding and creation of new human interaction models for embodied autonomous systems. Previous literature has established unpredictable actions, speed of motion and orientation as critical behavioural cues that elicit anthropomorphism [5, 13, 14, 15, 16]. Little work has examined the importance of these cues in child-robot interaction and, what research has been done has sometimes found contradictory results [e.g. 31]. The first stream of proposed research is a systematic review of the human-robot interaction and psychological literature to identify any other potential behavioural cues that may be manipulable variables for anthropomorphism. This will include a review of databases of human-robot interaction, most importantly the PiNSoRo dataset [39] which comprises 45+ hours of videos of child-child and child-robot interaction, coded for engagement and social responses and including data on gaze direction, skeletal movements and vocalisation.

Once a set of key behavioural variables are identified that may potentially elicit anthropomorphism, we will compare their impact on user anthropomorphism. Relatively low cost non humanoid robotic platforms have been found effective for the study of naive human responses to robots, for example the R5 robot [40]. Similar commercial robots such as the Husarion ROSbot [41] and Anki Vector [42] may also serve as effective experimental platforms. As proof of concept, these will first be used to measure adults' responses after observing videos of the robot behaviours online and rating them on a series of scales (to include, among others, the Individual Differences in Anthropomorphism Scale (adult and child version) and the Godspeed) to measure anthropomorphism. Children and adults will then be filmed interacting with the robots in controlled (a lab) and uncontrolled (a science museum) conditions as they exhibit behaviours that have been previously established in the literature (e.g. speed of motion, contingent response & errors) along with those that emerge fro the piloting and secondary data analysis. Anthropomorphism of the robot will be rated using a range of age appropriate measures. The traditional model of the development of anthropomorphism predict that children at 3-4 years of age should anthropomorphise to the greatest extent, 9-10 year olds less so and adults not at all [21]. We will focus on these age groups in our studies to explore if these critical stages in the development of anthropomorphism predict differences in the effectiveness of anthropomorphic behavioural cues. Alternatively, it may be that these cues become more effective cues for anthropomorphism as users get older, reflecting increasingly sophisticated social reasoning and awareness. A contingent stream of research will explore how children and adults with autism respond to the same behavioural cues. Children with autism present a theoretically interesting comparison because anthropomorphism is conceptualised as a mis-attribution of social reasoning, a capacity known to be compromised in those with autism [43]. Yet anecdotally and in several case-studies, children with autism readily interact with robots, engage with them socially and may even be able to use them to practice and learn social skills for carry-over to their human-human interactions [44]. Children with autism may in the future be a specific target market for certain types of education and companion robots [45] so understanding how their responses are similar to or different from those of age matched typically developing children will be a valuable contribution both theoretically and practically.

6 CONCLUSIONS

There is substantial evidence that children and adults attend to robot behaviours as much as (or more than) robot appearance when attributing mind. It is unclear whether there is developmental change in this psychological bias. Here we propose a programme of research to expose the key behavioural drivers that elicit anthropomorphism and to examine how these responses vary with the age of the user and the robot design.

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Looking for the minimal qualities of expressive movement in a non-humanlike robot

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Abstract. We tackle the issue of expressive movement in non-humanlike robots, conducting a study with the goal of providing a characterization of expressive qualities embedded in the movements of a simple robot. We provide evidence that expressivity can be considered as a distinct modality of evaluation, distinct from other ways to consider a movement. Our first results indicate that expressivity is primarily associated to movements possessing a form of granularity and readability.

1 INTRODUCTION

What is an expressive movement? A colourful movement? A meaningful movement? A movement that carries aesthetic properties? Like all attributes that partake of cognitive and social qualities (What is beauty? What is justice?), expressivity may be easier to recognize than to define. As we may easily sort out an expressive from an inexpressive behaviour, we may struggle to determine on which behavioural aspects our judgment is based.

In the framework of nonverbal communication, expressivity may be considered one of the possible communication channels humans can navigate through. From that perspective, expressivity can be equated to the channel conveying information about the intensity, rather than the content, of a nonverbal message: the 'how' vs the 'what' [1]. While raising an arm may signal, for instance, the willingness of a student to answer a question (the content of the message), the speed or amplitude of the gesture may indicate a degree of agitation or eagerness (the expressivity of the gesture). Here we can distinguish a general movement pattern (e.g. raising one arm above the head) that encodes a shared meaning [2] from expressive variations that, although not directly participating in the content of the message, transmit nuances about the intended message.

Expressive variations in general movement patterns are also apt to reveal information about the characteristics of the messenger, that is to reveal idiosyncratic information [2]. An expressive movement can be considered one that transmits a particular emotion, an attitude, or a general disposition to act and react in certain ways [3,4]. Studies investigating the expressivity of behaviour in relation to idiosyncratic information typically look to identify the combinations of gestures and postures, as well as behavioural patterns, that convey a specific emotion or attitude [5,6,7]. This domain of research has applications in the automatic recognition of affects [8,9] and the design of robots that look to reproduce human expressive gestures [4].

The two major accepted meanings of expressivity: expressivity as information about the intended message, and expressivity as information about the messenger, are both reliant on the configurations allowed by the human body to generate meaningful expressions. Yet, there are reasons to think that expressive qualities can be at least partially abstracted from specific body expressions related to attitudes and emotions. The literature on robot expressivity, while often focused on the replication of human postural and gestural expressions, proves at least that a biological body is not a necessary condition to perform an expressive motion [10,11]. Moreover, studies investigating the expressive movement associated to dancers or musicians performers suggest that expressive qualities exist beyond the constraints of nonverbal communication. First, most dance movements have no goals or objectives other than to transmit a certain expressive content [12]. Although they may convey an emotional content, they are not completely correlated with the representation of specific emotions or attitudes. Second, the fact that expressivity can be conveyed with other modalities than vision [13] is an argument in favour of the existence of expressive patterns abstracted from body expression and possibly multimodal. Recently the domain of non-humanoid robotics has proven a promising field for the exploration of expressive qualities [14]. Robots that bear no resemblance to humans (or even animals) explore modes of expression that rely on the psychological attributions triggered by their behaviour [15]. Deprived of the features deemed essential to nonverbal communication (a human-like or animal-like morphology), they harness a form of expression carried almost exclusively by movement attributes [16].

2 METHODS AND RESULTS

As a preliminary attempt to tackle the issue of expressive movement in non-humanlike robots (and more generally the nature of expressive movement itself), we conducted a study with the goal of providing a characterization of expressive qualities embedded in the movements of a simple robot. Is expressivity a specific channel in the communication of non-verbal information? To what extent is it related to other ways of qualifying a movement? Expressivity is often considered in the context of effort, such as in Laban movement analysis [17], where effort represents a specific component of the system and is associated to the subtle qualities associated to the inner motivation of a movement. Expressivity is also often associated to an increase in the quantity of bodily movement [18], such that a behavior considered more expressive may also be characterized by a higher level of activity. Is there a direct relationship between movement quantity and expressivity? Is there a strong association between expressivity and the sense of effort imparted by a perceived movement? To answer those questions, we devised an experiment in which variations in a

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robot's movements had to be evaluated according to different criteria. We were especially interested in determining whether expressivity is correlated to the overall activity perceived in a robot's behaviour. We also wanted to test if expressivity is directly linked to internal attributes, such as effort or discomfort.
We constructed a robotic structure that we animated with oscillating patterns varying in terms of speed and amplitude. Using the MisbKit robotic toolkit[2] (http://misbkit.ensadlab.fr), we devised a structure composed of two motors linked together with a flexible plastic rod (Fig. 1a), as well as two leather strips positioned laterally to consolidate the structure. We then wrapped the structure into a thin white fabric to hide the mechanism (Fig. 1b). When a motor is actuated, the structure undulates, producing contractions similar to those produced by a caterpillar. Depending on their amplitude and velocity, those movements may evoke a calm respiration, or more dramatic contortions when the motor rotation is increased. The motor was animated with a sinusoidal movement, with variations in the motor's speed of rotation and amplitude of rotation. From the robot's motion, we produced 6 ten seconds long video sequences (https://youtu.be/DfoxcqWtVfk) resulting from the combination of 3 rotation velocities (low, medium and high speed) and 2 rotation amplitudes (low and high amplitude).
20 participants were recruited from Ensadlab students with the task to watch the 6 sequences and rank these sequences, from the most representative to the least representative of the following criteria:

a) the robot is active
b) the robot is making an effort
c) the robot's movements are regular
d) the robot feels discomfort
e) the robot's movements are expressive

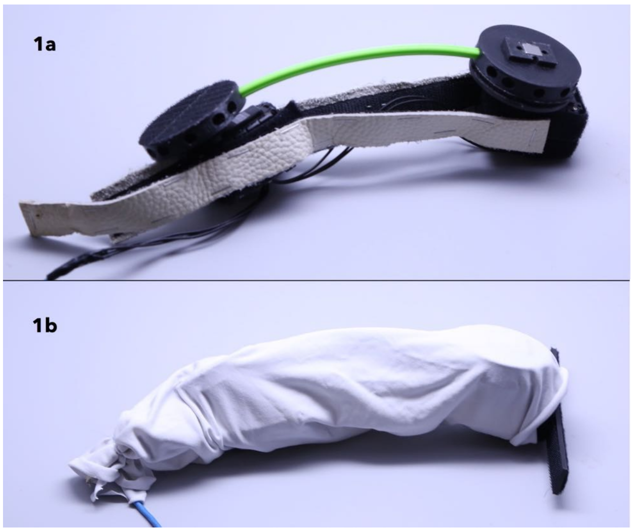

Figure 1. A simple robotic structure to evaluate the expressive qualities of movement.

Comparing the rank attributed to the sequences according to the criteria, we could determine whether the rank based on expressivity correlates with the other ranks. Our first results are in favour of considering expressivity as a modality of evaluation distinct from the others (Figure 2). We did not observe a significant correlation, positive or negative, between the way people rank the sequences according to expressivity and the way they rank the sequences according to the other criteria. In other words, when they evaluate the expressive nature of a movement, participants do not elaborate the same classification as when they consider activity, regularity, effort and discomfort. As far as we can tell, expressivity cannot be reduced to the overall activity perceived in a motion sequence. In fact, when participants favour fast and ample movements as most representative of a high level of activity, they tend to choose slow and ample movements as the most expressive. Similarly, the effort conveyed by an action seems not to be a critical component of expressivity, as participants consider that a combination of medium speed and low amplitude is the most representative of an effortful action.

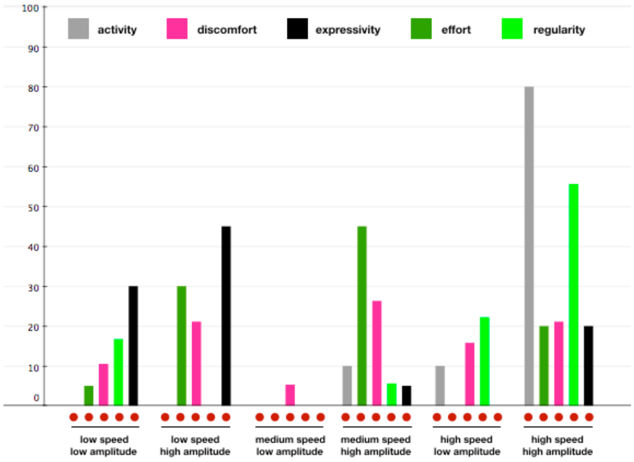

Figure 2. This figure represents, for each condition of speed and amplitude, the percentage of participants that chosed this condition as the most representative of a given criterion (activity, discomfort, expressivity, effort, or regularity). We can see for instance that 45% of participants selected the low speed/high amplitude condition as the most expressive, whereas none of them considered it the most active.

Based on those results and informal observations from participants, we can tentatively assume that expressivity is primarily associated with properties we could call 'granularity' and 'readability', that is the possibility to observe details in the way a movement pattern unfolds and to identify specific moments inside this pattern. The low speed/high amplitude condition, the most expressive for a majority of participants, is often considered less mechanical and more charged with emotion, which may be related to the slow unfolding of a large undulation, giving time to observe the different ways the fabric stretches and ripples, and break down the different phases of the movement.

3 FUTURE WORK

This research inaugurates a series of studies on the minimal properties of expressive movement. On the notions of granularity and readability, it remains to be proved whether a movement

[2] The MisbKit has been elaborated by the Reflective Interaction research group (http://reflectiveinteraction.ensadlab.fr) for the purpose of quickly prototyping animated structures in the context of workshops.

with more identifiable details and giving more possibilities to break down different temporal episodes is indeed considered more expressive than simpler movement patterns. Materials constituting the robot may also matter to its expressive potential. The expressivity of a movement may be related to the possibility to identify physical constraints governing the way a particular material deforms in specific situations. Further studies should include a systematic examination of the expressive potential associated to a movement pattern when realized with different structures and materials.

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Exploring Social Co-Presence through Movement in Human-Robot Encounters

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Abstract. This paper explores the social capacity of robots as an emergent phenomenon of the exchange between humans and robots, rather than an intrinsic property of robots as is often assumed in social robotics research. Using our Performative Body Mapping (PBM) approach, we have developed a robotic object for studying how social meaning is enacted when movement qualities meet kinesthetic empathy. In this paper we introduce PBM and how it harnesses performers' kinesthetic imagination and movement expertise for designing the movement potential and movement qualities of abstract, non-humanlike robots. We then present our recent study of how the social presence of our robotic object-in-motion emerges in an encounter, involving experts from performance and design. Preliminary results of this study show that our robotic object can successfully convey movement qualities and their intended expressions as embodied by a dancer as part of the PBM process. Finally, we discuss how our observations can shift our focus from attributing qualities to the object to an emergence of qualities, propelled by the encounter. We believe our study provides a glimpse into the dynamic enactment of agency and how it requires both sides to 'give' for the robotic object's characteristics and the participants' experience to evolve.

1 INTRODUCTION

Our desire to create artefacts and machines that are life-like and with whom we can connect on an emotional level is age-old [1]. Research in social robotics often strives to materialise human-machine relationships that are reminiscent of the human likeness of Maria in Fritz Lang's Metropolis [2], the companionship of Star War's metallic-shiny humanoid C-3PO and witty can-shaped droid R2-2D, or the cute demeanour of Pixar's WALL-E.

Pepper, for example, featuring soft feminine curves, a perky voice and an innocent cheekiness is marketed as an 'emotional' robot that "wants to be your friend" [3]. Much of current research favours human likeness over abstract, machinelike designs based on the belief that social agency can be 'given' to a robot by mimicking human appearance and behaviours [4, 5]. This technical view of social agents suggests that successful human-robot relationships should model human-human relationships [4]. Furthermore, it understands a robot's social capacity as a property that is a primarily intrinsic to the agent [5], without considering the social potential of the interactional exchange and situation [6].

But what if the relational dynamics unfolding in the encounter between a human and a robot play a significant role in rendering the latter a social agent? Locating social capacity not inside the machine but in the encounter or evolving relationship, shifts the design focus from the *representation* of agency to how agency is *enacted*. Such a distributed, enactive approach to social agency could open up a more diverse array of entry points into human-robot relationships, beyond simply mimicking the human. Instead of modelling humanlike appearance and behaviour, an enactive approach requires us to develop a deeper understanding of what happens in the encounter, i.e., how exchanges are negotiated, and how dialogical relationships are initiated and propelled. Importantly, these could be genuine human-machine relationships that embrace the differences of the mechanical.

From an aesthetic viewpoint, a non-humanlike and yet still expressive or affective robot, capable of initiating and/or propelling social exchanges with humans open up a much richer and less predetermined design space of possibilities. Also, robot designs that don't rely on familiar, organic bodies allow for encounters that are not constrained by "preconceptions, expectations or anthropomorphic projections … before any interactions have occurred" [7]. The challenge of this open playground is to find a starting point, from which to explore the social potential of machinelike agents.

Our project, Machine Movement Lab (MML), takes movement as a starting point to investigate the connection-making, relational potential of non-humanlike machines and how it can open up social situations. According to Erin Manning, movement *is* bodying or becoming-body, rather than "something the body *does*" [8]. Given this generative capacity of movement, we investigate whether movement can transform an abstract machine-object into an expressive performer. Bringing together creative robotics, dance/performance and machine learning, MML's enactive approach harnesses choreographic knowledge and kinesthetic expertise of performers to design a robot's movement mechanics and its capacity to learn to move in ways that support connection-making through movement qualities. To support this exploration we have developed a mapping methodology—Performative Body Mapping—that allows performers to inhabit the abstract shape of a robot design to bodily explore and enact its unique identity-in-motion (see Section 3).

Importantly, our aim in working with choreographers and dancers is not to render the robot more human but rather to investigate the ecology of social relations and how they get

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activated through movement and kinesthetic experiences. Rather than understanding robots as mechanical artefacts that are 'implanted' with social qualities, our project looks at human-robot interaction as an enactment and how a robot contributes to this productive social performance through the transformative qualities of movement.

This common focus on a built-in agency also shapes the ways in which we study humans interacting with robots. Typically, human-robot interaction studies bind participants' focus to a tightly orchestrated frame of interactive tasks [9], where robots' social capacities are measured in terms of how well they perform existing human social tasks. Often, this tight framing doesn't allow for much space to accommodate participants' imagination and experiences, let alone study them. Furthermore, this limited focus on how well a robot performs a social task promotes the idea that a machine's social agency can be predefined and programmed into it; and the more successfully so, the more the robot can replicate human qualities in performing the task. What is missing is getting a better understanding of what makes a robot social in this exchange, including the scenario it is embedded in. Granted, studying immeasurable and often difficult to articulate feelings of connectedness and sensations of resonance is a challenging task, and results are not nearly as decisive and comparable as more typical study outcomes. So far, we have completed two studies with participants with the aim of probing into their social experience of our delicately moving robotic object. We don't claim to have an answer to the challenging task of exploring how the social is enacted between humans and machines. But if we keep dismissing the more ambiguous, difficult-to-capture constituents of social encounters, we are more likely to invest in humanlike robots simply because we lack the understanding of alternative social human-robot relations.

In this paper we will discuss related research, introduce our Performative Body-Mapping (PBM) methodology, and present preliminary results from a recent study with expert participants encountering our robot prototype.

2 RELATED WORK

Our project is situated in the emerging interdisciplinary research area of Creative Robotics, which explores human–robot relations from both a creative and a critical, socio-cultural perspective. The practice of Creative Robotics builds on a rich history of kinetic sculpture, robotic art, and machine performance.

Movement and its capacity to evoke affective responses has been central to a number of artists working with machine-driven agency. Edward Ihnatowicz's pioneering cybernetic work *The Senster* exhibited life-like movements to express its machine intelligence [10]. Simon Penny's *Petit Mal,* resembling a strange, responsive unicycle, according to the artist, takes on the role of "an actor in social space" [11]. *The Table* by Max Dean and Raffaello D'Andrea animates an ordinary looking wooden table that appears to choose visitors to develop a relationship with [12]. Louis-Philippe Demers' performance work *The Tiller Girls* features a troupe of up to 32 abstract, simple robots that generate their behaviours based on the specifics of their embodiment and interactions without using underlying computational models. These works materially manifest various forms of machine agency as it is enacted across the machine's performance and the audience's perception. Demers affirms this, stating that "the machine performer needs the co-presence of the audience to be fully materialised" [13].

Collaborations between robotics and performance domains have provided a testbed for evaluating robots' expressive capacity [14]. Many of these collaborative projects explore the theatrical value of machine performers, showing a tendency to integrate a robotic element within a conventional performance framework or event. Most relevant to our research are interdisciplinary projects that develop a performance-led methodology to investigate human-robot interaction, including Jochum et al's study of artistic strategies [15], including traditional puppetry methods, to inform robot motion design, Lu et al's approach for human actors to teach robots how to interact socially [16], and LaViers et al.'s somatic approach to robot motion design [17].

3 METHODOLOGY: MAPPING BETWEEN DANCERS AND MACHINE OBJECTS

This section introduces our methodology for exploring how non-humanlike robotic agents can look, learn and affect us, and take on a social presence. To investigate the potential of movement for expression and the enactment of agency without a humanlike veneer, our project develops an embodied approach to social interaction for designing a robot's mechanical structure and its capacity to learn how to move. From the outset, our aim was to expand the envelope of human-robot relationships through the generative potential of movement qualities, rather than teaching the robot a set of specific gestures. At the heart of our methodology is a new embodied mapping method, called Performative Body Mapping (PBM), that harnesses performers' kinesthetic imagination and movement expertise. The purpose of PBM, in a nutshell, is the design of (1) an autonomous robot with an abstract, non-organic form and (2) a capacity to learn how to move in ways that are unique to its own machine body, shaped by the movement qualities it acquires from human dancers inhabiting the machine body [18].

The underlying conceptual premise is based on social interaction being grounded in embodiment and, with it, the bodies' kinesthetic experiences [19]. In this notion of embodiment, our thoughts, feelings, and behaviours are grounded in our bodily interaction with other bodies and the environment [20]. Vice-versa, these thoughts, feelings and behaviours manifest in embodied ways in what Froese and Fuchs have termed "intra-bodily resonance" [21]. As they manifest, they also express themselves to others, who interpret them based on their own intra-bodily resonance. The resulting "inter-bodily resonance" [21] between bodies in motion is referred to by researchers in dance and dance studies as kinesthetic empathy [22]. The latter is a concept that facilitates our understanding of social interaction and embodied communication [23]. Importantly, from a performance perspective, inter-bodily resonance doesn't only 'translate' feelings but also a bodily processing of forces and tensions expressed in movement qualities and variations of energy, e.g. relations between tension and relaxation, degrees of intensification, weight or sudden stillness. These more ambiguous signals as a basis for initiating or sustaining social interaction, e.g., by communicating degrees of attention or relatedness are of interest to us because they avoid stereotypical, limited emotional categories such as 'sad' or 'happy'.

Figure 1. Early PBM workshop, showing two tube-like costumes inhabited by performers.

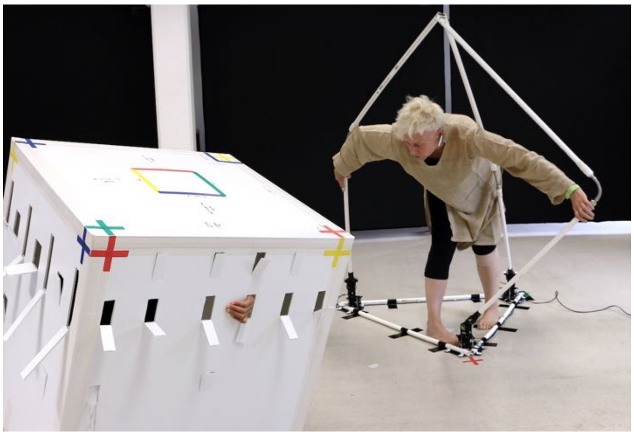

Figure 2. PBM workshop, showing a dialogue between two costumes inhabited by dancers (Tess de Quincey, on the right).

PBM relies on dancers' kinesthetic abilities to embody another, nonhuman body to develop movement qualities and kinesthetic expressions for *and with* this 'other' body. At its core, PBM deploys a 'costume', which stands in for a possible robot body and can be inhabited and bodily activated by a dancer/performer. It is a wearable object that extends the performer's body and constrains their habitual human movement. The PBM costume becomes thus the instrument for mapping between the different embodiments of the human dancer and the becoming-robot and, with it, their different movement capacities. It allows (1) for dancers to 'feel into' the machinic form and learn to embody it, and, later, (2) for a robot, resembling the costume, to learn from the dancer-costume entanglement by imitating its recorded movements. Importantly, this entanglement offers more than an aesthetically interesting movement repertoire. The performers' enactment with the machine's material body and the kinesthetic experience it produces is inseparable from their body's enactment with their social and cultural context [19]. We believe that the robot's movement qualities shaped through this enactment show visceral traces of this social and cultural embeddedness, without anthropomorphizing the robot. The PBM approach as a novel form of demonstration learning and the role of the costume as an instrument for mapping between different embodiments has been explored in more detail in [18].

Early movement workshops focused on exploring and challenging our assumptions and preconceptions with regards to possible machinic forms and movements (Figure 1). Later workshops focused on finding movement 'identities' with specific costumes, and the costumes' movements were continuously recorded (Figure 2). A detailed account of this earlier form-finding stages and movement studies can be found in [24]. So far we realised one of the costume bodies as robotic prototypes: Cube Performer #1 and Cube Performer #2 (see Figures 5 and 6). The movement requirements for the mechanical design of these prototypes were derived from an analysis of over ten hours of motion capture recordings to determine the needed velocity, acceleration and ranges of movements—vertically, horizontally and rotationally.

But why a cube-shaped machine performer? A cube or a box presents a highly abstract, familiar geometric form, which, on its own, is not usually considered to be expressive or having a social presence. But our movement studies quickly showed the potential for movement qualities to transform the simple cube, for example, a sudden tilt, gentle sway or nervous teetering allow for the box to lose its stability and, with it, its 'boxiness' (Figure 3). It is this apparent schism between a cube's shape and its transformation through expressive motion that has motivated us to realize a cube-shaped machine performer.

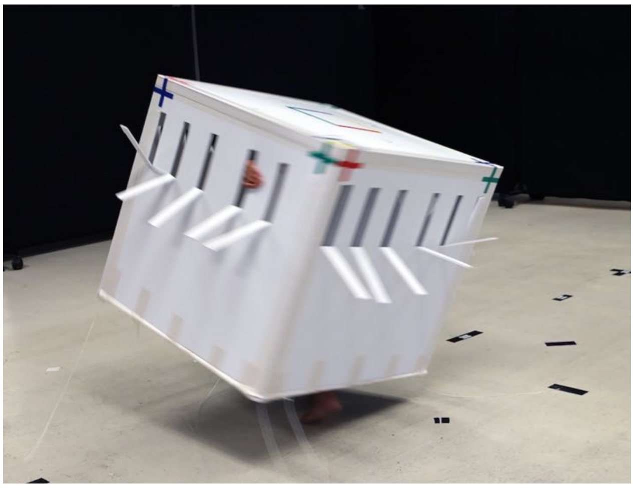

Figure 3. Cube costume activated by a dancer.

Our movement studies unfolded around a three way conversation between (1) a dancer inhabiting (2) a costume and (3) a choreographer, who directed the performer from an outside perspective onto this entanglement and its movements. Transparent costume components offer a window into the specifics of the dancer-costume entanglement and allow the choreographer to directly address body alignments, etc. in relation to the costume's transformation (Figure 4).

Figure 4. Cube costume with transparent sides, activated by Audrey Rochette.

Our process of developing the movement repertoire for the cube performer evolved dramatically over the course of this 3-year research. Earlier movement workshops were primarily exploratory and focused on developing a diverse set of movement characteristics with the cube costume. In later workshops we developed a more systematic approach that explored a number of variations in movement qualities and how they transform the cube's identity along a single movement trajectory. This resulted in motion capture recordings of short movement phrases, where the dancer-inside-the-costume repeated the same phrase but each time exploring a different image or character, e.g., balancing the cube on one corner and raising the opposite corner with varying velocity, rhythm and weight, guided by the image of breath and how it changes according to different bodily states. Naturally, the cube didn't 'breathe' as a result, but the rhythm and dynamics of the motion brought about by this image and performed by a cube exemplify the kind of transformations and connection-making abilities that we are interested in. *It has the effect of rendering the object in motion at once more strange and more familiar.*

4 RESEARCH DESIGN

In the following we present some preliminary observations from a recent study we conducted with expert participants who had a first-time encounter with our robot prototype.

The main aim of our study was to gain expert insights and feedback on the possibility of experiencing kinds of 'inter-bodily resonance' in an encounter with our Cube Performer (#2). The study is part of our evaluation process and builds on a previous study, set in a public exhibition, where we asked audiences to provide feedback on their perception of the robot and its affective qualities [18]. In this study, we wanted to dig deeper into the question of how PBM's wearable costume captures the dancers' movement qualities and allows the robot to mediate them back to affect peoples' experience. In particular, we wanted to get a better sense of what "gets across" in terms of these qualities, and how they are transcribed through the PBM process. We previously described this form of human-machine communication as *human-robot kinesthetics* [18], proposing that the dancers' "distinctive spatio-temporal-energic dynamics" [25] are transcribed into the costume's (external) kinetic dynamics that in the audiences' "kinetically-sensitive eyes" [25] register as kinesthetic empathy. Of course, as with all translation, this is not a loss-free process, and PBM is not about translating between humans and machines. Rather, it is about seeding our machine learning with the aesthetic, social and cultural dimensions that shape the dancers' movement qualities. Since, as we mentioned earlier, the movements that the robot performs are not composed of specific, easily identifiable gestures and are further abstracted by the robot's shape, evaluating the robot's ineffable connection-making capacity is not a straightforward task.

To explore this capacity, we developed an encounter scenario and involved five experts from performance and five experts from design (including three experience/interaction designers), recruited by email, to reflect on and share their experience of encountering our Cube Performer. Designed as a three-stage encounter, we were particularly interested if our participants could recognise specific changes in the robot's behaviour, not only in terms of changes in the movement but also with regards to how it affected them. To develop the encounter, we asked choreographer Tess de Quincey and dancer/performer Linda Luke to develop a short (3-minute) movement sequence with the cube costume and to explore this movement trajectory in three different qualities. As per the choreographer's and dancer's descriptions, one had a light and airy quality, another one a boisterous, 'chunky' quality and the third movement was dynamically situated between the first two, with a playful and less predictable quality.

In an attempt to describe the three movement qualities in a uniform manner, we have applied descriptors from Laban Movement Analysis (LMA). LMA has been applied to analyse human movements in a wide range of domains, from dance and theatre to everyday actions and, in recent years, robot motion design [26]. Given the non-anthropomorphic nature of our robot, we used only the 'effort' qualities of Space, Time, Weight and Flow to describe the movement qualities recorded (see Table 1).

Movement Quality	Space	Time	Weight	Flow
1	Direct	Sustained	Light	Free
2	Direct	Sudden	Strong	Bound
3	Indirect	Sustained and Sudden	Light and Strong	Free and Bound

Table 1. LMA 'effort' descriptions of the three prevailing qualities of the movement sequence developed for the robot.

Cube Performer #2 was then trained to move with these three qualities. The robot's responsive capacities were very limited, only put in place to make the encounter safe. We chose this largely pre-scripted path for our study scenario for two reasons: (1) to compare participants' responses, we wanted them to experience a very similar composition of movement qualities, and (2) the robot's capabilities to adapt its movements *in situ* are still in development. Adapting movement qualities and choreographic structures in response to peoples' behaviours in ways that don't compromise their integrity poses a significant challenge and we have yet to develop these embodied improvisation skills.

The study was setup in a large, empty performance space (Figure 5); we didn't use any special lighting as the encounter was not about "putting a spotlight" onto the robot. Importantly, the robot was only referred to as a "robotic object". While we didn't provide any further details of the object, we deliberately chose to bypass any expectations of this being an encounter with a human- or animal-like robot. The robot itself was only revealed in the encounter and presented as a simple wooden box, with an outer skin made of unpainted plywood. Participants were instructed to enter the space three times to experience a different stage of the encounter. In each stage, the participants experienced the robot performing one of the three movement sequences. The order of the sequences was randomised for each participant to minimise priming effects. Participants were instructed that they could move around in space and make use of the chairs on offer. With regards to providing feedback, we asked participants to reflect on what they had noticed after each stage by making brief notes and subsequently fill in a more detailed questionnaire at the end of all three stages. This final questionnaire was followed by a brief interview, which allowed us to further explore some of the participant responses. Including the three 10-minute encounters with the robot, each study session took about 40 minutes.

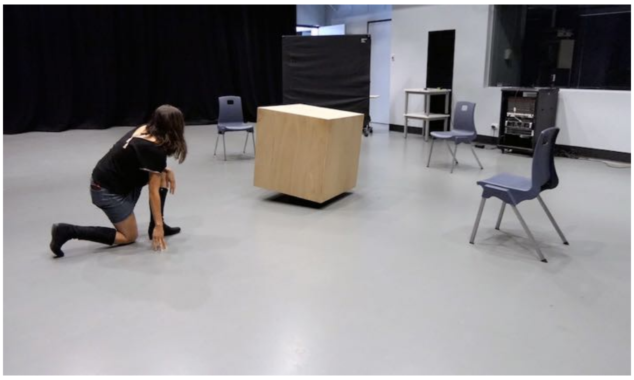

Figure 5. A study participant engaging with robotic object.

5 PRELIMINARY RESULTS

We are still in the process of analysing recordings of the participants' experiences and responses and can only provide preliminary results and observations here.

All ten participants perceived qualitative differences across the three stages, and nine participants described them in terms that align with the choreographer's and dancer's intended qualities, independent of the order they experienced them in (see Table 2). Having previously discussed the communicative potential of human-robot kinesthetics, this result suggests that there is a clear link between the images inscribed into the object by the dancer, the images' expression when externalized through the object's movements, and the participants' kinesthetic perception and interpretation. Seven of our ten participants described the robot's movement qualities as 'emotive' or 'visceral', an eighth participant referred to them as 'being in relation'.

Perhaps not surprisingly, there was a consistent difference in the way in which movement practitioners and interaction designers approached the robotic object, particularly in terms of meaning-making. Performance practitioners were significantly less occupied by a desire to "decipher" the meaning of movements and gestures. They focused more on how they felt connected to the object. For example, one comment was "I was surprised how intimate it was", another participant said: "We were just together". In general, design practitioners were more interested in exploring how they could evoke responses, for example, one participant rearranged the provided chairs to reconfigure the space and test the robot's response.

One of the most surprising results was that all participants perceived the robot as curious or responsive, behaving in relation to their presence. "We are in relation; it is working hard", as one participant commented. Even though from a technical perspective, the robot had very limited adaptive capacities. It is worth saying here that we had no interest in misleading our participants in that regard; we never referred to an 'interactive' or 'responsive' object during our recruitment, introduction, or in the questionnaire. Our survey responses consistently show that participants experienced a sense of co-presence despite its abstract appearance and limited interactivity. One participant commented: "I like its non-humanness … there is a companionability to it. Wow". Asked to reflect on their experience, other participants said: "When I'm still, it moves more, like it wants to play"; and another: "It comes across as playful with an 'honest curiosity', like a wild animal". From an experiential viewpoint, this suggests that the object-in-motion could trigger the participants' curiosity, sustain their interest and affect their own behaviour and evolving impression, despite the largely rehearsed performance of Cube Performer #2. To understand more about how much delicate, decisive or dynamic movement qualities contribute to an object taking on a social presence, we will need to undertake a study in which our Cube Performer also moves like a vacuum cleaner, that is, like we expect a machinelike agent to move.

Stage	Choreographer's & Dancer's Description	Participants' Own Descriptors
1	light–airy	sensitive, tender, tentative, gentle, delicate, timid, less dynamic than other two stages
2	boisterous–chunky	aggressive, more violent, agitated, sharp, competitive, purposeful, show-off, decisive
3	playful–unpredictable	playful, dynamic, attention seeking, intense, animal-like, broader repertoire, moved with attitude

Table 2. Participants' descriptions of different movement qualities perceived in encounter stages 1–3.

6 DISCUSSION

The participants' social perceptions in this encounter could simply be dismissed as mere projections by the participants onto the object. After all, their respective areas of expertise brought a set of sensitivities to the encounter that was useful for providing explicit feedback but that may have also primed their experience. But projections here are more than attributions elicited by specific behaviours. According to Goffman, they play a significant role in shaping any social encounter, whether they are about maintaining projections of a self-image or negotiating projected definitions of the situation [27]. Furthermore, the Cube Performer contributes its own projections—kinetically. Encounters with our cube-shaped robot during public events, as well as in this study, often unfold in surprisingly parallel ways to Goffman's dramaturgical observations about social interactions. Our motivation, however, is for the machine to not actively 'project' human qualities. "I was surprised how intimate it was. I responded to it like another species and increasingly so", said one participant. Due to the robot's familiar but highly abstract shape, it could be argued that the evolving social experience can be entirely accredited to its intricately choreographed movement qualities. However, the specificities of the object's shape come into play with regards to the movements' capacity to transform the object. For instance, the cube seems to 'take on' a face-like front on any of its four sides, along its edges or, suggesting a nose-like feature, by one of its four top corners, depending on one's position in relation to the object's movement dynamics (Figure 6). Some of our participants confirmed this previously observed emergent, expressive effect.

Our approach and participants' responses raise questions regarding movement and its effect of 'animating' objects. Giving on-screen characters the appearance of movement is, as the word 'animation' suggests equated with 'bringing to life'. With this in mind, it could be argued that the animation of machines blurs the boundary between the organic and mechanical. Even though 'giving life' was not what we aimed for with our methodology, the effects of a simple object moving in delicate or playful ways undoubtedly opens up an ambiguous and possibly uneasy zone between subject and object. Animation also commonly presumes a life-like force or quality bestowed onto the object [28]. Looked at from this perspective, animated objects support traditional notions of agency, aligned with a view that agential capacities can be 'given' to an object—a view that underlies many current approaches in social robotics, that as we pointed out earlier are problematic (see Section 1). On the other side of the argument, our studies so far seem to support that a less mimicking approach that offers visceral encounters with machines complicates the simplistic pathway of programming social agency into machines by giving them life-like properties. In our study, five participants from both performance and design compared their experiences to the kinds of responses they have towards animals, while being clear that this analogy is as much about their approach to the object as it is about what the object projected. This recognition of what happens in-between points to a shift in focus from attributing qualities to the object to an emergence of qualities, propelled by the participant and the object, embedded in a specific situation.

Even at this preliminary stage of analysis, our study has given us a glimpse into a dynamic enactment of agency that requires a dance between the two, where both sides need to 'give' for the object's characteristics and the participants' experience to evolve. We believe our embodied, machine-embracing approach and the "disjunction of form and movement" [29] can open up new and interesting human-machine relationships based on kinesthetic empathy rather than mimicry. More studies are required, however, to better understand the transformation of objects/machines through movement, including its potential for deception.

6 FUTURE WORK

Future work will include more studies with both expert and non-expert participants. Our assumption is that the latter will show a preference for less ambiguous, intensity-driven movement qualities in favour of more readily accessible communication signals to connect to the Cube Performer, but this remains to be tested. Important future work also includes expanding our machine learning system to learn to delicately adapt to changes in the environment and behaviours of other agents. Our goal is for the robot and its underlying AI to learn how to improvise based on what it has learned to imitate, grounded in its own unique mechanical embodiment. Will such improvisational skills open up dialogical experiences between participants and the robot, and how will they shape this social enactment, compared to the encounter we discussed here? We are keen to contribute to developing a better, empirical understanding of the aesthetic, social and cultural potential of machinelike agents and how they can participate in enactments of rich social exchanges beyond human mimicry.

Figure 6. *Cube Performer #1* exhibiting a fleeting face-like front in the interaction.

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