Animation and Design Principles for Effective Human-Robot Interaction: The Visual and Movement Design of Social Robots

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the degree of

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and Senior Lecturer Deborah Szapiro

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Certificate of Original Authorship

I, Kerl Galindo declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Design at the University of Technology, Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Kerl Galindo

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I am deeply grateful to Deborah Szapiro for her kindness, compassion, patience, and unwavering commitment. Her guidance has had a profound influence on my development as a researcher. My appreciation for all her support and contributions to my journey is immeasurable.

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Abstract

The human tendency to anthropomorphise inanimate objects and science fiction's ability to actively shape technological futures through its effect on the collective imagination, has transformed the field of human-robot interaction from the pragmatic and functional to the hedonic and social. With the desire to incorporate robots within the domestic setting, the proxemics of the space they occupy encourages interactions on both the social, personal, and intimate level. In order to create robots that feel more like companions, robots must now be functionally useful, efficient, and also be capable of shared emotional experiences.

Despite this perception shift, the processes which dominate social robot design today still have an intense focus on the pragmatic and functional concerns of social robots. This is evident in social robot design papers, which rarely discuss the rationale behind certain design decisions and the resulting effect on human-robot interaction. These processes are the result of misconceptions surrounding what design is and its underlying role in social robotics, and it is common for engineers and computer scientists to only attribute designers to the construction of a robot's exterior for visual beauty and aesthetic appeal. Design plays an all-encompassing role that takes into consideration pragmatic and functional concerns as well as how designed things can reshape, interact, and impact many different aspects of human society all at once.

This research argues that the ability of animation to create and design characters that allow audiences to empathise and establish a level of emotional attachment with non-living entities, demonstrates its potential to address the hedonic and social issues of human-robot interaction. It is possible to say that animation for film is similar to animation for robotics, as both areas deal with the expression of emotion through an embodied medium. The articulation of the interconnected relationship between these two mediums has been largely unexplored. Various aspects of design and animation, such as anthropomorphism, the suspension of disbelief, aesthetics, visual design, observation, storytelling, performance, the articulation of personality through movement and gesture, that are essential for creating the illusion of life in animated characters, can be key in developing socially adept robots.

Utilising the case study of Haru, a prototype for a networked table-top social robot, currently under development by Honda Research Institute, Japan (HRI-JP), this research utilises a Deweyan pragmatic theoretical framework backed by a design thinking approach and looks to the potential of design and animation to encourage human-robot interaction and enhance the expressive capabilities of a social robot's communicative interface for enriched human-robot interaction. It does this by highlighting the importance of a wholistic approach to robotics and focuses on the importance of multimodal communication in social interactions, in particular the visual design of eyes and the movement design of the gestural expressions of eyes. This research aims to utilise the potential of design and animation in order to create new principles and theories surrounding human-robot interaction and contribute to the development of richer, more emotionally motivated social robots in the future.

COVID-19 Impact Statement

This thesis was written and conducted in the period 2018–2023. Two major events impacted the completion of this research. The first was the Covid-19 global pandemic. The second was the subsequent Global Silicon Chip Shortage in 2022, as a result of broken supply chain issues that continued beyond the pandemic.

Originally, a substantial portion of my research focused on direct observational studies of human interactions with social robots. However, due to the prolonged lockdowns resulting from the Covid-19 pandemic, the facilitation of in-person user tests proved to be difficult. Furthermore, the utilisation of the Haru social robot, a pivotal component of this thesis, became impractical. This was attributed to Haru's status as a prototype research robot, necessitating specialist support and equipment from its associated international entities: Honda Research Institute, Japan (HRI-JP), Service Robotics Lab at Universidad Pablo de Olavide in Spain, and IDMind Living Robots in Portugal.

In response to the Covid-19 pandemic, I responded by planning to focus entirely on writing as much of my thesis as possible and then focusing solely on user testing in 2022. Unfortunately, what my supervisors and I did not account for was the continuation of supply chain issues and its subsequent effect on the Global Silicon Chip Shortage late into 2022, which significantly affected the hardware production of the Haru robot and delayed user testing. It was at this point we decided to pivot out of in-person user testing and transition into online questionnaires with video recordings of Haru, as this allowed me to maintain the functional reliability of the social robot and consistency in data capture.

In addition to the above, the Covid-19 pandemic significantly impacted my day-to-day activities as a PhD candidate. There was limited access to campus in Sydney in 2020 and 2021, which meant the loss of a workspace, limited access to resources, supervisors, colleagues, and support networks. Access to certain literature was impacted by the cancellation of inter-library loans and postage to and from Australia was cancelled at various stages of the pandemic and subject to long delays.

The pandemic changed my life and those of many other people. This period was an important and immensely turbulent time to conduct a study on a global scale, when the world was shifting on a near-daily basis. This, coupled with the immense uncertainty of home and work life, had a profound impact on this thesis. Despite these challenges, I am confident that the research conducted and documented here fulfils the original purpose of the thesis and that its findings remain universally applicable in all facets of social robot design.

Chapter 1: Introduction

1.1 The Early Incarnations of Social Robots

The concept of a social robot has been present in human history for centuries. Early accounts and ancient mythologies depicted robots as powerful, divine entities crafted from materials like metal, brass, stone, bronze, and gold. These creations were capable of performing repetitive tasks, providing entertainment, providing wisdom, ensuring protection, and engaging in combat against adversaries (Gera, 2003; Godwin, 1876; Littlejohn & Dippmann, 2012; Mateo-Seco & Maspero, 2009). Prominent examples include the bronze man Talos (Figure 1) built by Hephaestus to defend the Greek island of Crete, the golems featured in Jewish folklore, designed as guardians and labour assistants, and the Brazen heads from Christian legend, who provided wisdom for those who sought guidance. These legendary narratives and mythologies served as precursors to the development of automata.

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Figure 1. Winged Talos armed with a stone as depicted on a silver didrachma from Phaistos, Crete (Cabinet des Médailles, 2010).

During the Middle Ages, automata played a prominent role as sophisticated machines meticulously programmed to carry out predefined sequences of actions or commands (Truitt, 2015). These intricately designed automata, which included devices like automatic bell strikers integrated into mechanical clocks and self-playing puppet musicians, served as compelling showcases of artisan precision, craftsmanship, and innovation. They were primarily employed as dramatic illusions, captivating, and entertaining guests with their mechanical performances. However, inventors of the time were eager to not only create for the purposes of delight and whimsy, but also for the purpose of improving societal well-being (Rosheim, 1994).

Ismail Al-Jazari, a 13th-century polymath celebrated for his contributions in "The Book of Knowledge of Ingenious Mechanical Devices," and often referred to as the "father of robotics," was a prominent figure among the early pioneers who crafted automata with a primary focus on practical application and the mechanisation of labour (National Geographic, 2020). He engineered a number of humanoid automatons such as the waitress, capable of serving water, tea, or beverages, the hand-washing servant (Figure 2), which operated a flushing mechanism now fundamental to modern toilet functionality, and the peacock hand-washing fountain, featuring two attendants providing soap and towels to guests. These automata were among the earliest examples in recorded history and highlighted the potential of autonomous mechanical beings in manipulating the environment for human comfort and heralded a new perspective in artisan craftsmanship that would later form the groundwork of the modern-day robot (Rosheim, 1994)

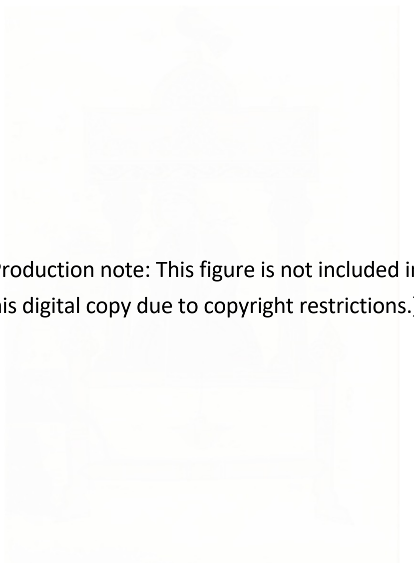

Figure 2. Al Jazari’s Automaton, the hand-washing servant automation (Al-Jazari, 2006).

The Industrial Revolution of the 1700s marked a pivotal period in the emergence of machinery for practical utility, driven by a relentless pursuit of efficiency and enhanced human convenience (Landes, 1969). This era witnessed the increasing accessibility of autonomous machinery, thereby introducing the concept of autonomous technology into the collective human consciousness. As technology and machinery advanced, this pursuit would pervade everyday life in the home through domestic appliances such as the washing machine and vacuum cleaner (Rosheim, 1994). However, it was the influence of science fiction and the development of artificial intelligence and the networked society that gave rise to the long-running narrative of robots that could not only automate repetitive laborious chores but also provide a sense of companionship.

1.2 The Influence of Science Fiction on Social Robots

The cultural vision of social robots has largely been shaped by their portrayal in science fiction media. Robots such as Astro Boy (1951), HAL in *2001: A Space Odyssey* (1968), T-800 in *Terminator* (1984), R2D2 in *Star Wars* (1997), the E.V.A units in *Neon Genesis Evangelion* (1995), *Wall-E* (2008), and Baymax in *Big Hero 6* (2014) are cultural touchstones that have informed our collective cultural aspirations for the development of robotic companions. Film and Media Studies Professor Constance Penley (1997) has illustrated how speculative fiction like *Star Trek* has inspired real-world technological pursuits in NASA's research and engineering activities. She found that the various visions of portable communicators, digital writing pads, and the generation of virtual environments had been explicitly cited in contemporary human-computer interaction research. This claim was further substantiated by Cultural Anthropologists Paul Dourish and Genevieve Bell (2014) stating: "Even for those who are not immersed in the genre, science fiction does not merely anticipate but actively shapes technological futures through its effect on the collective cultural imagination”. Whether the stories are utopian or dystopian, these visions of the future shape the relationship between science and progress and between people and technology. It is an influence that extends deeply into social robot design and is evident in the evolution of robots over the last century.

Eric and Elektro (Figure *3* – middle and right), developed in 1928 and 1939 were pioneering forays into social robot design. Drawing inspiration from Karel Čapek’s 1921 play *R.U.R* (Figure 3 – left), which coined the term *robot*, these robots were designed to demonstrate the potential of machines to mimic human appearances and actions at a time when the concept of robots was still largely confined to the realms of science fiction and speculation (Wright & Kaplan, 1994). Although limited by the technology of the time, these robots could still execute basic human functions such as walking and talking but were limited to pre-programmed walking paths and recorded messages.

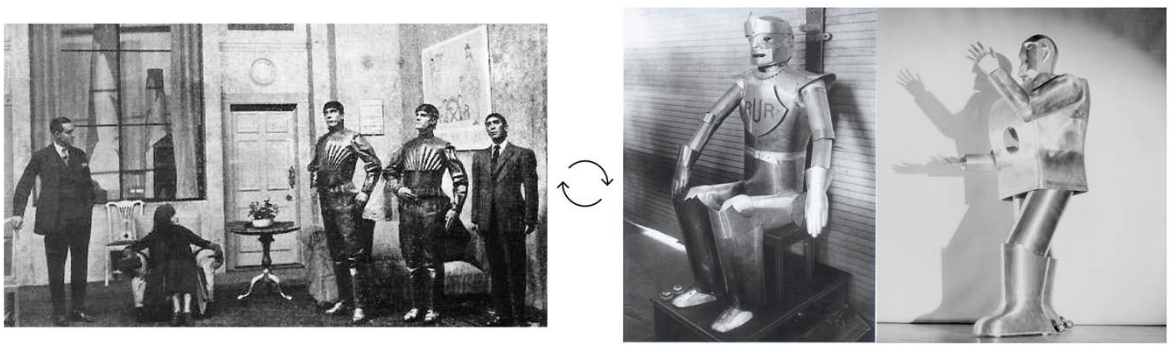

Figure 3. Robots from the play R.U.R (left - Classic971, 1921), which inspired the robots Eric (middle - The London Science Museum, 1928) and Elektro (right - Mansfield Memorial Museum, 1939).

Elmer and Elise (Figure *4*), developed by neurophysiologist and roboticist William Grey Walter in 1947, were robots that served as experiments in neural network design. Coinciding with the science fiction concept of the *electronic brain*, these robots paralleled themes in Isaac Asimov’s 1940s and 1950s *Robot* series, which notably introduced the *positronic brain*, a fictional technology similar to the way electricity functioned that allowed robots to have human-like reasoning and moral judgement. In his seminal paper, “An Imitation of Life”

(1950), Walter explains how he wanted to demonstrate how the connections and simple interactions between a small number of simple electronic systems, or *brain cells*, could give rise to complex behaviours setting up the fundamental principles that would govern autonomous systems and foreshadowing the future development of artificial intelligence in robotics.

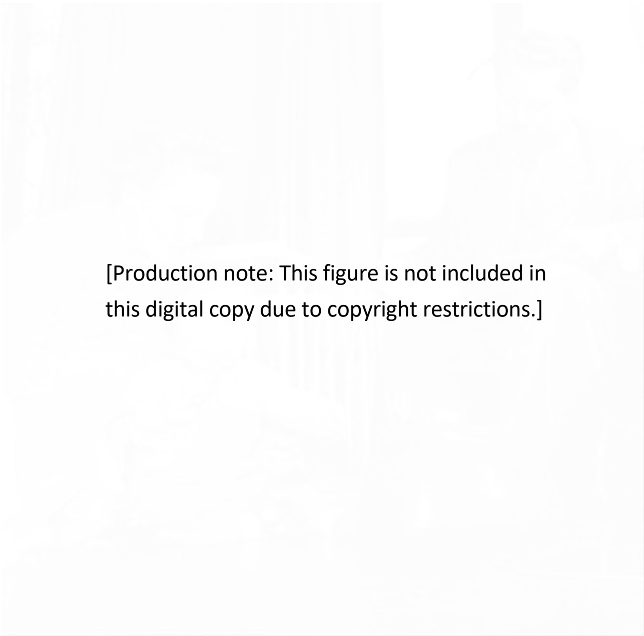

Figure 4. William Grey Walter and one of his robot tortoises heading into its charging location (Cyberneticzoo, 2009).

The concept of the *electronic brain* laid the foundational principles for the evolution and integration of Artificial Intelligence (AI) in the field of social robotics (McCorduck & Cfe, 2004). This conceptual shift marked the transition of robotic applications from purely physical tasks to cognitive ones (McCarthy et al., 2006). Researchers aimed to create autonomous learning systems capable of undertaking tasks necessitating human-like cognitive abilities. The first AI program Logic Theorist was developed by computer scientist Allen Newell and cognitive psychologist Herbert Simon and was able to prove mathematical theorems. Soon after, the programming language LISP was developed by computer scientist John McCarthy in 1958 for processing symbolic structures. This allowed physicist John Kelly to synthesise speech on the IBM 704 computer (Figure 5 – right) in 1962, which also became the inspiration for the disembodied voice of HAL (Figure *5* – left) in Stanley Kubrick's 1968 film *2001: A Space Odyssey* (Bell Labs, 2014).

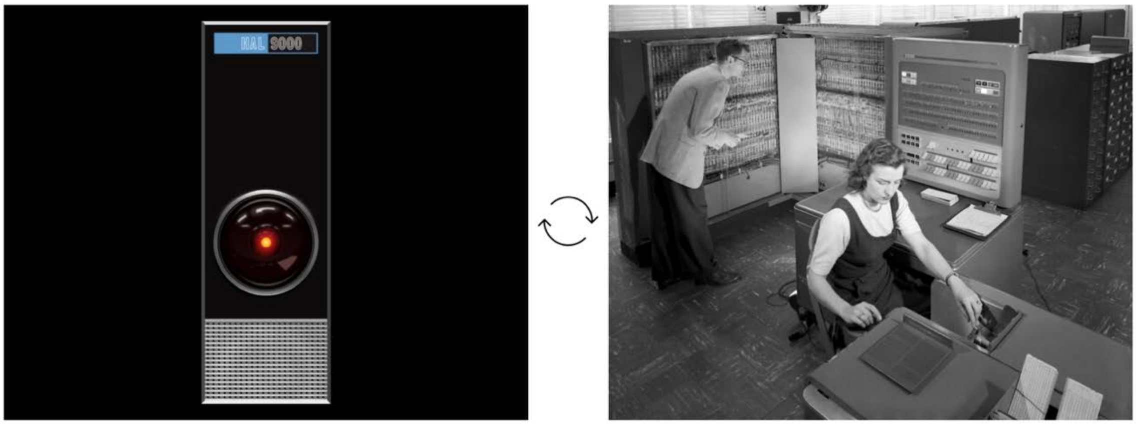

Figure 5. The disembodied robot HAL (left - Kubrick, 1968) and the IBM 704 Computer (right - NASA, 1962) which inspired the voice of HAL

These advancements in AI set the stage to finally bridge the gap between mechanical functionality and human intellect within robotics. A landmark development in this journey was the development of Shakey the Robot (Figure *6* – right) by the team at the Artificial Intelligence Centre at Stanford Research Institute (SRI) International in 1972. Evidently inspired by science fiction icons such as Robbie the Robot from Fred Wilcox's 1956 film *Forbidden Planet* and B-9 from the 1965 TV series *Lost in Space* (Figure *6* – left), Shakey was the first autonomous mobile robot to integrate various AI components – such as computer vision, natural language processing, navigation, planning, and physical action – into a single, unified mobile unit. Unlike its contemporaries, which required step-by-step instructions for tasks, Shakey could autonomously interpret between locations, operate light switches, open and close doors, manoeuvre over and around objects, and relocate movable items. Shakey marked a significant advancement in robotic autonomy and had profound implications for future research in human-robot interaction (H. P. Moravec, 1991).

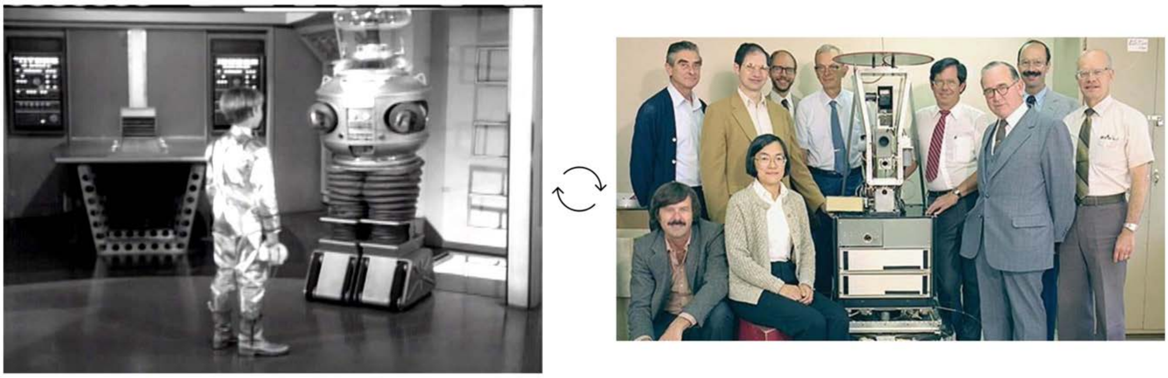

Figure 6. Robbie the Robot (left - Kinoshita, 1956) and Shakey the Robot (right - SRI International, 1972) look strikingly similar.

Over the next several years, the field of Artificial Intelligence (AI) made substantial progress in areas such as logical reasoning, representation of knowledge, strategic planning, machine learning, natural language processing, sensory perception, and physical manipulation (McCorduck & Cfe, 2004; Rosheim, 1994). This progress enabled engineers and computer scientists to advance the concept of autonomous humanoid social robots, drawing inspiration from anthropomorphised social robots in science fiction media such as Rosie the Robot Maid from the 1962 television series *The Jetsons* (Figure *7* – left top), C-3PO (Figure *7* – left bottom) from the 1977 film *Star Wars* and the 1999 film *The Iron Giant* (Figure *7* – left middle).

The development of humanoid robots, with their human-like physical characteristics, has been central to social robotics research, facilitating more natural and intuitive human-robot interactions. For instance, WABOT II (Figure *7* – right top), developed in 1984 by the Engineering and Science Department at Waseda University, had the ability to play the organ, interpret musical scores, and accompany human musicians.

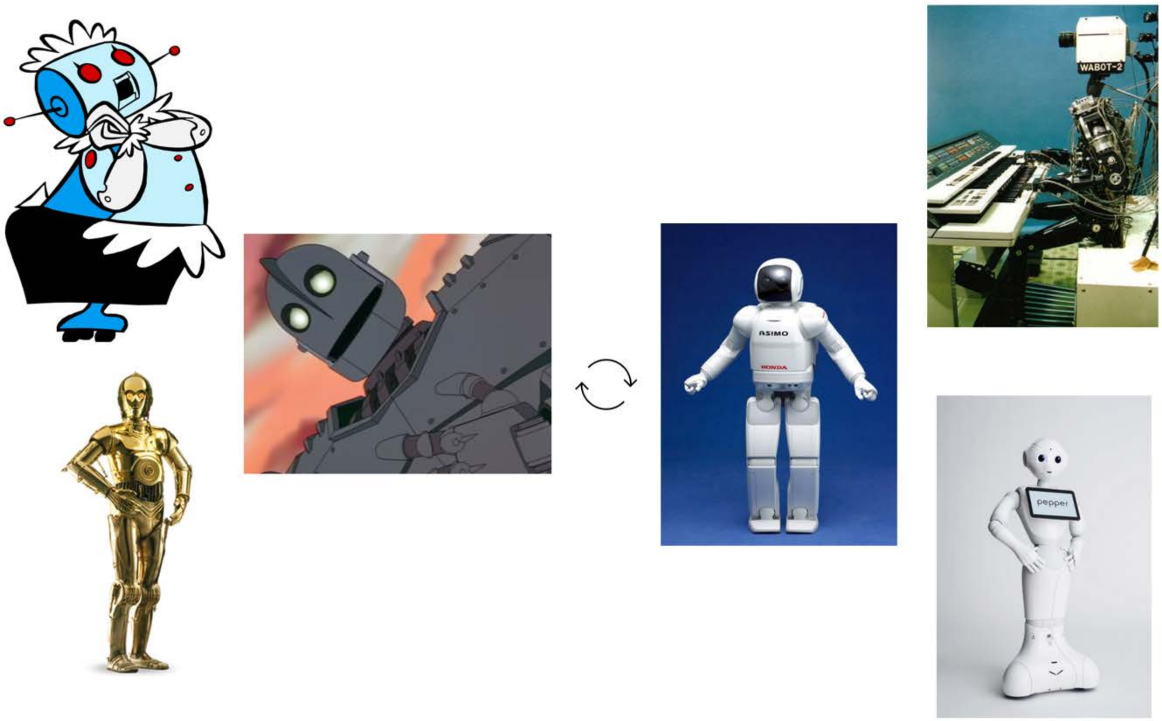

Figure 7. Rosie the Robot Maid (left top - Hanna-Barbera, 1962), The Iron Giant (left middle - Bird, 1999), and C-3PO (left bottom - Lucas, 1977) which advanced the idea of autonomous humanoid robots such as WABOT-2 (right top - Waseda University, 1977), ASIMO (right middle - Honda, 2000), and Pepper (right bottom - SoftBank Robotics, 2014).

ASIMO (Figure 7 – right middle), developed by Honda in 2000 at the turn of the century, was a pioneer in human-like social interaction capabilities, including face, name, and voice recognition and posture interpretation. With a total of 57 degrees of freedom, ASIMO was also the first robot to push the physical boundaries of autonomous robot movement with its ability to run, climb stairs, and jump. In addition, with 26 of the 57 degrees of freedom in its hands, ASIMO was also able to physically communicate with a variety of body gestures such as shake hands, wave, nod, point, and communicate in American Sign Language (ASL).

The Inkha robot, created in 2002 by the Department of Informatics at King's College London, further enhanced the communicative capacities of robots by using articulated facial features to display emotions. Today, leading examples of anthropomorphised humanoid social robots include Pepper (Figure *7*– right bottom) and Nao from SoftBank Robotics, the iCub developed by the Italian Institute of Technology, and UBTECH's Walker robot. These robots represent the forefront of humanoid social robotics, showcasing the ability for diverse, human-like interactions in general-purpose settings.

In the pursuit of developing social robots with human-like physical features for enhanced human-robot interaction, roboticists have significantly pushed the visual fidelity and expressive capabilities of social robots. A prime example is the series of robots developed by Hiroshi Ishiguro: Geminoid HI-1 (2006), Geminoid F (2010), and Geminoid DK (2011). These robots, as depicted in Figure *8*, represent a breakthrough in achieving hyper-realism with their lifelike appearances and integration of social functionalities, such as human tracking, voice recognition and synthesis, and natural motion generation to replicate real-life human social interactions.

Figure 8. From left to right, Geminoid F (2010), Geminoid-HI-1 (2006), Feminoid DK (2011) with their real-life counterparts, a Japanese woman who elected to keep her identity hidden, Hiroshi Ishiguro himself, and Dr Henrik Scharfe (Hiroshi Ishiguro Laboratories, 2011)

The lifelike and eerie nature of Ishiguro's creations has sparked numerous social and ethical debates in striving for hyper-realism in social robot design, such as deception, the evolving dynamics of human-robot relationships and, echoing popular dystopian science fiction narratives, the existential threat to humanity (Fong et al., 2003). These robots served as pivotal influences in shaping various design considerations for future social robot developments.

However, the most profound design implication arising from such lifelike robots was the theory of the Uncanny Valley.

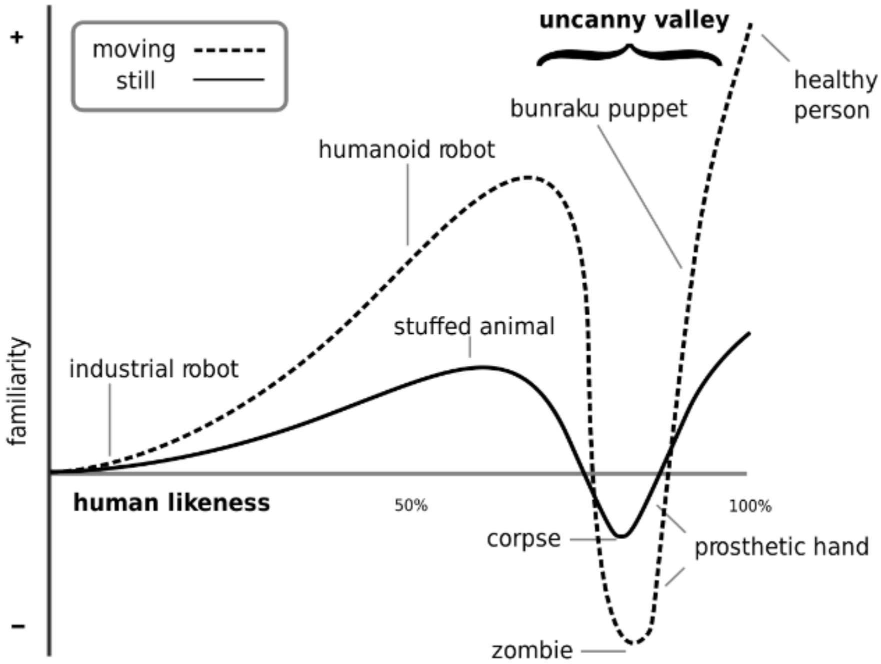

Figure 9. The Uncanny Valley Theory (Mori, 2012)

The Uncanny Valley theory was first articulated by roboticist Masahiro Mori (1970) and describes a unique phenomenon in the field of robotics and anthropomorphic design and is portrayed in Figure *9*. The theory posits that as anthropomorphic entities become increasingly human-like, they raise expectations regarding their movement, behaviour, and appearance. A critical point is reached where these creations fall short of these heightened expectations, resulting in a disconcerting or eerie sensation known as the uncanny. Academic studies have been conducted to understand the cognitive mechanism underlying the Uncanny Valley theory. Prevailing explanations suggest that the essence of this response lies in the heightened awareness of human mortality and the ambiguous intersection of human life, technology, and death, triggering a deep-seated aversion in humans (Bartneck, Kanda, et al., 2009; Jentsch, 1997; Mori et al., 2012; Rosenthal-von der Pütten & Weiss, 2015; Walters et al., 2008).

Figure 10. Bishop from the film Aliens (left - Scott, 1979) and Ava from the film Ex Machina (right – Garland, 2014) are characters inspired by the Uncanny Valley theory.

The Uncanny Valley theory has not only been a subject of academic interest but has also been extensively explored in science fiction media. It frequently serves as a narrative device, particularly in dystopian sci-fi films (Piturro, 2021; Saffari et al., 2021; Tinwell, 2014). Examples include the character Bishop (Figure *10* - left) in the 1979 film *Aliens* and Ava (Figure *10* - right) in the 2014 film *Ex Machina*. Furthermore, the Uncanny Valley theory has influenced the fields of computer-generated imagery (CGI) and motion-capture technology in the development of photorealistic graphics. Despite the technical limitations of hyper-realism and the numerous warnings from science fiction media, roboticists have continued to venture beyond the realm of the Uncanny Valley in the pursuit of achieving human likeness (Fink, 2012; Hameed et al., 2016; von Zitzewitz et al., 2013). Needless to say, the theory of the Uncanny Valley has had significant influence on how social robots have been developed today.

At the opposite end of the humanoid spectrum, recent years have witnessed parallel advancements in the realm of virtual voice assistants, embodied in smart speakers and smartphone applications. Drawing inspiration from the natural speaking virtual assistants HAL9000 (Figure *11* – left middle) from Stankley Kubrick's 1968 film *2001: A Space Odyssey*, J.A.R.V.I.S (Figure *11* – left bottom) from Marvel's 2008 film *Iron Man*, and Samantha (Figure *11* – left top) from Spike Jonze's 2013 film *Her*, devices such as Amazon's Echo (Figure *11* – right middle) developed in 2013, Google Nest (Figure *11* – right top) developed in 2016, and

Apple’s Home Pod (Figure *11* – right bottom) developed in 2018, have become ubiquitous in the consumer market (Prasad, 2019; Shulevitz, 2018).

Figure 11. Samantha (left top - Jones 2013), J.A.R.V.I.S (left bottom - Marvel 2008), and HAL9000 (left middle – Kubrick, 1968), are characters which have inspired the Apple Home Pod (right bottom – Apple, 2018), Google Nest (right top – Google, 2016), Amazon Echo (right middle – Amazon, 2014).

These devices circumvent the unsettling interactions characteristic of lifelike human robots by employing a mono-modal communication method, where interaction is solely through computerised talk-to-text (TTT) vocalisation. Although significant advancements have been made in natural language processing, exemplified by projects like Alphabet's Deep Mind AI Speech Synthesis and OpenAI's ChatGPT, the limited visual design and verbal-only communication channel of these devices constrain their capacity to forge the deep emotional connections inherent in human interaction (Pitardi & Marriott, 2021). This technological trajectory, focusing more on functional communication than on visual realism, represents an alternative approach to integrating social robots into everyday life, avoiding the visual complexities associated with the Uncanny Valley theory.

Over the past five years, research and commercial development in social robotics have increasingly focused on more anthropomorphic, compact, and non-humanoid designs. This shift is influenced by their representation in science fiction media, which often embodies utopian ideals (Duffy, 2003). Notably, the 1952 manga series *Astro Boy* (Figure *12* – left top) features a highly advanced, anthropomorphised robot boy with human emotions who often has to tackle various challenges and threats, embodying themes of justice, empathy, and the positive use of technology. This character represents a utopian vision where advanced robotics harmoniously integrate into society, contributing positively to human life and addressing moral and ethical dilemmas. Similarly, the 2008 film *WALL-E* (Figure *12* – left middle) presents a robot character deeply concerned with environmental and human welfare, and Baymax (Figure *12* – left bottom) in the 2014 film *Big Hero 6* features a healthcare companion robot who exemplifies the utopian vision in healthcare robotics aimed at enhancing personal well-being.

Figure 12. Astro Boy (left top – Tezuka, 1952), Baymax (left bottom – Williams & Hall, 2014), and WALL-E (left middle – Stanton, 2008), are characters which inspired the development of JIBO (right middle – JIBO Inc, 2016), Zenbo (right bottom – ASUS, 2016), Samsung Bot (right top – Samsung, 2019).

Echoing societal aspirations for a utopian social robot, recent developments in social robotics such as JIBO (Figure *12* – right middle), Zenbo (Figure *12* – right bottom), and Samsung Bot (Figure *12* – right top) have attracted considerable attention. These designs resonate with the cultural ideal of the utopian social robot. For roboticists, these designs are preferred as they avoid the disconcerting effects of the Uncanny Valley and, unlike virtual assistants, these robots facilitate a deeper and more meaningful connection through multimodal communication. This trend represents a strategic shift in social robotics, prioritising relatability, and engagement over the pursuit of human-like appearance (Airenti, 2015; Duffy, 2003).

Exploring the evolution of social robots through the lens of both science fiction and real-world developments reveals a reciprocal relationship. Fictional depictions of robots have profoundly shaped societal perceptions and expectations about the relationship between humans, science, and technology (Dourish & Bell, 2014; Penley, 1997). This, in turn, has influenced social robot research and design and vice versa. From powerful divine mythological representations to functional automata and machinery and further to companionship social robots, this evolution underscores a significant shift in the conceptualisation of robots for the future.

1.3 The Current State of Social Robot Design

Over the last century, the human perception of human-robot interaction has experienced a transformation from functionality and efficiency to the hedonic and social (Bartneck, Kulić, et al., 2009; De Graaf & Allouch, 2013). The human tendency to anthropomorphise inanimate objects (Reeves & Nass, 1996), the influence of popular social robots in science fiction media, and science fiction's ability to actively shape technological futures through its effect on the collective imagination, has resulted in social robots that are no longer assessed solely by their practical application, but also the emotional experience they provide their user. This is reflected in how individuals often articulate their interactions with both fictional robots in media and real-life robots, attributing intentional, mental, and emotional states to these entities (Breazeal & Velasquez, 1999). As a result, the success and acceptance of a social robot hinge on two criteria: the emotional response they evoke in users and their functional effectiveness. Despite this perception shift, however, there is still an intense focus on the functional and efficiency concerns of social robots.

Social robotics is an emerging field of study and there are many technical challenges and considerations that are constantly evolving. One of the prevailing challenges faced by contemporary social robots is Moravec's Paradox (1988), which observes:

> Tasks that are relatively easy for humans to perform, such as recognising faces and understanding natural language, tend to be difficult for robots and artificial intelligence systems, while tasks that are difficult for humans, like complex mathematical calculations or precise repetitive tasks, are often easy for machines to execute.

This paradox highlights the disparity between the expectations set by popular science fiction media of the 1950s and 1960s and the current state of technological development. For instance, physical movement and autonomous robot locomotion continues to be a major technological obstacle, with simulated human gait being one of the most challenging areas for humanoid social robots. Other technical challenges such as the cognitive capabilities of AI architectures are still limited, using only simplified or representational models of human intelligence which limit a robot's ability to reason, plan, and problem solve quickly and efficiently in a variety of situations. Certain actions and ways of thinking that would have otherwise been straightforward with human physicality and cognition are often major challenges in social robotics.

As a result of the difficulty of developing moving social robots that are also able to reason, plan, and problem solve autonomously, it is unsurprising that research typically revolves around techno-centric discourse (Dourish & Bell, 2014; Šabanović, 2010). Under this research paradigm, hedonic and social considerations are considered secondary to the functional and efficiency concerns of social robots. This is evident in the lack of stylistic evolution in the visual design of social robots since the space-race period of the 1950s and 1960s, where a Google Image (as shown in Figure *13*) search shows predominantly humanoid or animal-like robots with gleaming white surfaces. Further evidence supports the perceived trivial nature of hedonic and social considerations with the prominence of 'robot fail compilations' on YouTube or the amusing r/shittyrobots subreddit. These internet memes satirise how social robots today are still unable to perform basic human social functions with their slow, rudimentary, and unnatural bodily movements. It is clear that engineers and computer scientists have yet, or lack the time, to understand or develop the processes necessary for designing a robot that is sufficiently capable of being hedonically and socially appealing for human-robot interaction.

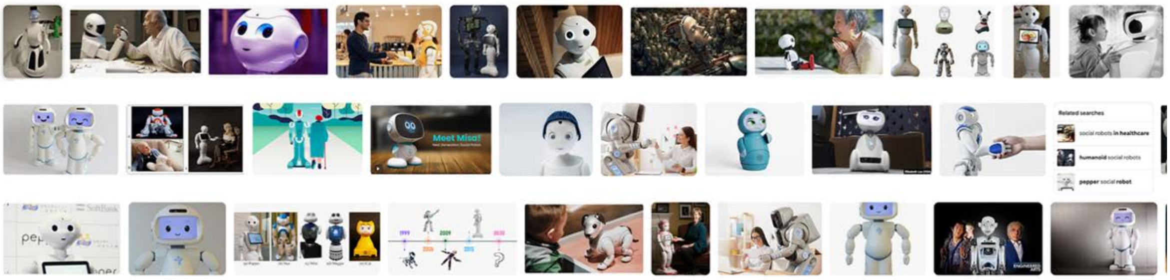

Figure 13. First page Google image search for 'social robots' featuring predominantly humanoid robots with gleaming white surfaces (Google, 2025).

Many of these issues are the result of the misconceptions regarding what design is and its underlying role in social robotics. This is evident in social robot design papers, which rarely discuss the rationale behind certain design decisions and the consequences for human-robot interaction. It is common for engineers and computer scientists to only attribute designers to the construction of a robot's exterior for visual beauty and aesthetic appeal. This presents a significant challenge, as the delayed involvement of designers in addressing hedonic and social aspects often leads to constrained design solutions due to the pre-established *final* form of the social robot.

In an ideal approach, design should be integrated with the functional and efficiency aspects of engineering and computer science from the outset of the development – a wholistic perspective that acknowledges design not merely as an aesthetic consideration but also an enhancement of the concerns of functionality and efficiency by recognising how design impacts the way individuals interact with each other, their environment, and how it ultimately shapes their experiences. In short, this would require the incorporation of design expertise early in the development process to ensure that social robots are not only technically efficient but also resonate with human social and emotional considerations.

This thesis seeks to investigate how incorporating animation design expertise can address the critical gap in hedonic and social considerations in social robot design. It will focus on how the combined application of animation design principles can contribute to more engaging and socially attuned robots thereby improving the overall quality and effectiveness of human-robot interactions.

1.4 The Application of Animation in Social Robotics

It is possible to say that animation for film is similar to animation for robotics, as both areas deal with the expression of emotion through an embodied medium. In the same way that stop motion and 3D CGI animated characters for film are limited by the integrity of the character's skeletal rigs, robots are limited by the Degrees of Freedom designed into the internal structure of the robot. Both are also limited by technological means and real-world physics, and both mediums aim to push the boundaries of their embodied design in the most effective manner possible. The similarities between the two mediums demonstrate the potential of applying animation knowledge and expertise to address the issues of communicational and emotional affordance in robots.

In the one hundred and forty years since the first screening of the animation, *Pauvre Pierrot* by Charles-Emile Reynaud, animators have continually honed their skills to create characters that are designed to be appealing while simultaneously factoring the readability and expression of emotion through visual design, movement, and performance (Thomas & Johnston, 1995). In conjunction with an animator's ability to observe human behaviour and translate the physiological and psychological underpinnings of human communication into their characters, this has created a highly specialist set of skills that has allowed animation to flourish (Hooks, 2017).

Key elements that animators consider when bringing a character to life are encapsulated in what is commonly known as the Twelve Principles of Animation. These principles, developed since the 1930s by numerous Disney animators through experimentation and reflective practice were formally articulated by Ollie Johnston and Frank Thomas in their seminal 1981 book, *The Illusion of Life*, and later revised in their 1995 edition. These principles provide basic guidelines for producing the illusion of life in characters by adhering to the fundamental laws of physics while dealing with more abstract issues such as visual design, emotional timing and character appeal. These principles, in conjunction with other elements of animation, such as anthropomorphism, the suspension of disbelief, aesthetics, observation, storytelling, performance, articulation of personality through visual design, movement, and gesture, and the physiological and psychological understanding of human nature, are what have allowed animators to not only control how an audience feels about these characters but also to build emotional attachment (Bishko, 2014c; Hooks, 2017; Thomas & Johnston, 1995). The application of animation in robotics might be the key to addressing the social, hedonic, and practical application factors necessary for effective human-robot interaction.

Animation has significant potential in creating robot behaviours that look and feel believable; however, the application of animation has only begun to be explored within the field of social robotics (Breazeal, 2004; Ribeiro & Paiva, 2012; Takayama et al., 2011). Aside from Kuri by Mayfield Robotics, JIBO, and COZMO by Anki, few companies have acknowledged the significant correlation between animation and social robotics. To address this issue, this thesis aims to build upon this knowledge by exploring how animation can enhance human-robot interaction by increasing the communicational and emotional affordance of social robots.

This research utilises a case study of Haru, a table-top social robot prototype currently being developed by Honda Research Institute Japan (HRI-JP). Haru will be used to examine how design and animation can augment the expressive capabilities of a social robot's communicative interface, thereby enhancing human-robot interaction. More specifically, the study focuses on the visual and movement design of Haru’s eyes, a critical aspect of a social robot’s communicative interface. The objective is to explore how the strategic design and animation of a robot's eyes can make human-robot interactions more intuitive, relatable, and affective, contributing to a more meaningful and engaging experience.

1.5 Purpose and Aim of This Research

This thesis aims to develop theoretical frameworks addressing how design and animation can enhance the field of social robotics. The central research question guiding this thesis is:

> **How can design and animation make a positive contribution to social robots for affective human-robot interaction?**

To comprehensively explore this question, the thesis will focus on the visual and movement design of social robots. The following sub-questions guide the research of this topic:

- What does design mean in the context of social robotics?
- How can an animator's understanding of design and animation be leveraged to improve human-robot interaction in social robots?
- In what ways can an animator's understanding of movement enhance social robot expressivity?
- What role do eyes play in human social interaction, and how can this understanding be translated into the design of social robots?

1.6 Thesis Structure and Chapter Outline

To elaborate on the potential ramifications of design and animation in the field of social robot design, this thesis is divided into three parts. The first part encompasses chapters 1, 2, and 3, with a primary emphasis on clarifying design discourse within social robot design and underscoring the imperative for interdisciplinary research in the realm of social robotics. The second part encompasses chapters 4 and 5, focusing on the visual design of social robots. The third part encompasses chapters 6 and 7, delving into the realm of movement design for social robots. The thesis concludes with Chapter 8 followed by appendices and a bibliography.

Chapter 1 provides an in-depth analysis of the field of robotics and its gradual transition from the pragmatic and functional to the hedonic and social, and how, in spite of this evolution, discourse on the more social aspects of a social robot's design is noticeably lacking. This chapter explores the potential of animation design expertise in addressing these social challenges by highlighting the interconnected history of animation, its influence on the collective cultural imagination, and its subsequent effects on real-world social robot development. The chapter concludes with a breakdown of my core research question followed by an outline of the structure of this thesis.

Chapter 2 focuses on the prevalence of techno-centric discourse, exploring how this perspective has led to a widespread misconception of the role of designers in social robot design. This misunderstanding positions design primarily as a tool for aesthetic enhancement, focusing on the visual beauty of a robot's exterior. To address this issue, the chapter seeks to clarify the multifaceted role of design in social robotics, beginning with foundational definitions. It then explores the connection between design and ecological psychology through the notion of affordances and highlights the necessity for interdisciplinary contributions in social robot design through the concept of framing. Through this lens, the chapter then critiques existing design frameworks in social robotics, arguing that an imbalanced emphasis on techno-centric discourse and a singular focus on efficiency and standardisation have led to stagnation in social robot development. The chapter concludes by emphasising the need for a theoretical framework that can rebalance design values, as well as a methodology that can accommodate the wider perspectives of a variety of different design perspectives.

Chapter 3 articulates a theoretical framework and methodology aimed at rectifying the limitations inherent in techno-centric design approaches. The chapter begins by describing the philosophy of Deweyan Pragmatism as the core theoretical framework for this thesis and its ontological relationship with design discourse. Following this, the chapter introduces design thinking as an epistemological methodology, serving as a pragmatic framework for examining a diverse array of design perspectives. This is then supported by the Universal Design Principles as a guiding framework towards accessible, inclusive, and user-friendly social robots. The purpose of integrating these frameworks is to pave a way for social robots to become more than just functional machines, but also intuitive, empathetic companions that enrich the lives of as many people as possible. The chapter concludes by describing the specific methods that were used as well as important ethical considerations in the research.

Chapter 4 seeks to highlight the critical role of visual design in social robotics through the concept of visual social semiotics. The chapter begins by exploring the lack of visual diversity in social robot design and how this could lead to the reinforcement of existing harmful stereotypes within the context of human social interactions. It then explores the existing design approaches which led to these stereotypes and then advocates for an approach that considers all visual design elements and principles and the semiotics associated with their cultural and social use, as well as the technical requirements. Acknowledging the field's limited grasp of visual design principles, the chapter concludes by offering a primer on the fundamental elements and principles of visual design and how they can affect individual semiotic interpretations and meanings.

Chapter 5 is a case study which aims to substantiate personalisation as a means for overcoming the Uncanny Valley theory in social robot visual design. The study underscores the potency of personalisation in social robot design by illustrating how even subtle visual adjustments can significantly influence individual perceptions. This concept is explored through the lens of Deweyan Pragmatism, particularly John Dewey's notion of *art as experience*, and Scott McCloud’s concept of *the picture plane*. This investigation focuses on the personalisation of a singular design element, namely, the robot's eyes. Participants were asked to rate and comment on a total of 54 different eye variations, encompassing six distinct eye designs, each with 9 different eye colour options. Contrary to the Uncanny Valley theory, a qualitative examination of the data unveiled that the primary determinant of a social robot's visual design effectiveness was not its degree of human likeness. Instead, it was the individual perceived meanings attributed to the visual designs that played a pivotal role in shaping participant perceptions. A conference paper (Galindo, Szapiro & Gomez 2024) based on this case study is currently under review for the 19th ACM/IEEE International Conference on Human Robot Interaction (HRI 2024).

Chapter 6 aims to emphasise the importance of movement design in social robotics through the examination of gestures in human communication. The chapter delves into an analysis of the current state of social robot movement design, addressing the prevailing stereotype that characterises robot movement as slow, crude, and janky. The chapter then engages in a critical analysis of the current design processes, such as the pragmatic, mimetic, and expressive approach, and design concepts, such as the Uncanny Valley theory, which have contributed to this stereotype. It then highlights that the principal driver behind the Uncanny Valley theory phenomenon is not the social robot's inability to replicate human-like movement faithfully but rather the creation of any movement lacking motivation, intentionality, and contextual reference. Once again, introducing the Deweyan Pragmatic notion of *art as experience* in conjunction with Leslie Bishiko's work on *The Uses and Abuses of Cartoon Style in Animation*, the chapter advocates for the development of a movement design framework that not only takes into account human gestural expression but also movement that considers the context of human-robot interaction.

Chapter 7 is a case study which aims to discuss the design and evaluation of the prototype LMA12-O framework for the purpose of maximising the emotive communication potential of expressive eye gestures in social robots. The LMA12-O framework is a methodology that synthesises the existing movement frameworks of Laban Movement Analysis (LMA), the 12 Principles of Animation (12PA), and oculesics (O) in order to create a new movement framework that allows for the development of different gestural expressions and styles that are unique to the design of a particular social robot but are still situated and grounded within the context of human communication. Results of initial user testings evidenced LMA12-O to be effective in designing affective emotional eye gestures in the test robot with important considerations for future iterations of this framework. While the LMA12-O framework is limited to eye gestures, the framework was built to be applicable to other areas or body parts of a social robot's visual design. A conference paper (Galindo, Szapiro & Gomez 2022) based on this case study was published in the 31st IEEE International Conference on Robot & Human Interactive Communication (RO-MAN 2022).

Chapter 8 is a reflection on the contributions my research has made to the visual and movement design of social robots with the aim of enhancing human-robot interaction. This chapter begins by delving into the fundamental themes and inquiries introduced at the beginning of the thesis. It assesses the current state of technology discourse and emphasises the need for techno-centric disciplines to collaborate with socially centred disciplines at the beginning and throughout the entire design process of developing social robots. Following this, the chapter highlights the unique and wholistic perspective that animators and designers offer to the advancement of social robots and emphasises how adopting a genuinely interdisciplinary approach can pave the way for novel ideas and processes in a field that is in dire need of design innovation.

Chapter 2: Design in Social Robotics

2.1 Introduction

The field of social robotics and human-robot interaction is an emerging yet rapidly evolving area of study at the junction of multiple disciplines including robotics, psychology, cognitive science, social science, philosophy, anthropology, artificial intelligence, computer science, engineering, human-computer interaction, art, and design. Collaboration is paramount in advancing social robots (Dautenhahn, 2007) and yet, the field is still predominantly driven by techno-centric discourse (Breazeal & Velasquez, 1999; Dorst, 2011; Peltu et al., 2008) resulting in human-robot interactions that are stereotypically slow, rudimentary, and awkward.

2.2 Techno-Centric Design in Social Robots

Techno-centrism refers to a perspective or approach that places technology at the centre of focus, often prioritising technological solutions and viewpoints over other considerations. This philosophy tends to emphasise the importance and superiority of technology in solving problems, shaping human experiences, and driving progress. In various fields, especially those involving innovation and development, techno-centrism can lead to an over-reliance on technological solutions, sometimes at the expense of social, cultural, ethical, or environmental factors (Mason, 2012; Papert, 1988).

In the context of social robotics, this techno-centric bias primarily stems from the intricate technical challenges in developing social robot hardware and software, necessitating substantial resources, time, and expertise from the disciplines of engineering, computer science, and AI. This dominance of more techno-centric fields of study has created an intense focus on positivist research paradigms where social interactions are typically measured by functionality, productivity, frequency, and efficiency. In contrast, interpretivist approaches, which delve into the intricate, individual, and real-world interactions with social robots, are often overshadowed (Breazeal & Velasquez, 1999; Peltu et al., 2008).

The problem with techno-centric discourse is that it often results in social robots designed with fixed properties overlooking the *interpretive flexibility* of technology beyond its design phase and constraining innovation through *design in use* (Chandrasekhar & Ghosh, 2001). This approach enforces a strict separation between the robot's design and its actual real-world application (Heeks, 2005; Stewart & Williams, 2005), prioritising technical prowess over hedonic and social design issues (Dourish & Bell, 2014; Sung et al., 2009). Consequently, without user involvement in the development process, the final robot design may not align with user needs, leading to underutilisation, abandonment, substitution, or modification of certain features to make them useful.

The concept of *interpretive flexibility* in social robotics is crucial, as it allows for continuous user-driven innovation through local customisation and configuration, making these robots useful and meaningful within specific individualised contexts. Williams et al. (2005) describe this user-led innovation through two processes:

1. Innofusion – the adaptation of the social robot to specific situations.
2. Domestication – the creative integration of the robot into local practices, purposes, and culture.

This usefulness and meaningfulness of technology emerges from both the practical efforts to develop the technology and the actions taken to imbue it with meaning, thereby enabling the technology to become part of the individual user's identity and the broader cultural fabric of the community (Stewart & Williams, 2005).

The concept of interpretive flexibility extends beyond merely incorporating interpretivist research paradigms into social robot design as a counter to the techno-centric discourse. Rather, it advocates for the simultaneous and equally influential collaboration of socially centred disciplines with technically centred disciplines throughout the entire design process as opposed the application of one after the other (Dorst, 2011). The interdisciplinary nature of social robotics demands that researchers move beyond siloing themselves into singular perspectives, as no one approach could ever fully capture the complex nuances of effective human-robot interaction (Dalsgaard, 2014; Dewey, 1958, 2008/1934). An open interdisciplinary approach is essential for understanding the convergence of multiple disciplines in the single embodied medium of a social robot.

The lack of proper interdisciplinary collaboration may stem from misconceptions regarding the role of socially centred disciplines throughout the design process. Upon my six years of reviewing the literature in social robot design and my personal anecdotal experience working as a design intern for the Haru Project at the Honda Research Institute, Japan (HRI-JP), it is clear that there is a prevalent misunderstanding that design is solely about aesthetics and art. This misunderstanding overshadows the vital contributions that design can offer in developing effective human-robot interactions. The following section aims to elucidate what design is and how it relates to social robot design.

2.3 The Relationship of Design and Aesthetics

The Cambridge Dictionary (2023) defines design as a plan or specification for the construction of an object, system, activity, or process in order to satisfy certain goals or constraints. However, especially within social robotics, design has come to be associated with art and aesthetics and, in particular, the idea of visual beauty. While visual beauty plays an important role, this narrow perspective denigrates the role of designers and undercuts the true value of aesthetics in social robot design.

Aesthetics, deriving from the Greek word *aesthesis*, refers to sensory perception and understanding, or what can be termed as sensuous knowledge (A. Goldman, 2005; Hekkert, 2006; McClelland, 2005; Zeltner, 1975, 1975). This is a branch of philosophy concerned with the nature of beauty, focusing specifically on what people enjoy seeing, hearing, feeling, smelling, or tasting, and delves into understanding why this is so by examining the subjective and sensori-emotional values of individuals (Zangwill, 2003). Under this nuanced definition, aesthetics in design transcends mere visual beauty, focusing instead on the individual's experience of the interaction (Dewey, 1958, 2008/1934). This encompasses the sensory interactions between a user and a designed object, the context and environment of the interaction, the meanings ascribed to different design elements, how visual cues can convey an object's purpose, and the emotions and feelings they evoke (Folkmann, 2010; A. Goldman, 2005; Hekkert, 2006).

In this sense, design is evident in everything from the built environment to the clothes we wear to the various organisational systems in society. Essentially anything in which we alter the natural environment to change what the environment affords to us, is designed (Dorst, 2011; Gibson, 1979). The objects we interact with co-shape our actions and interpretations of the world, influencing human behaviours, perceptions, and fosters new practices and lifestyles (Verbeek, 2008). Therefore, design is inherently contextual, capable of simultaneously reshaping, interacting with and impacting various facets of human society – including the psychological, physiological, functional, ethical, economic, environmental, and socio-political aspects, and considerations spanning past, present, and future (Dorst, 2011; Folkmann, 2010; Gibson, 1979). In essence, design creates an ecosystem that interlinks an object with its context and its use. In design, this relational dynamic is referred to as Gibson's Theory of Affordances.

2.4 Affordances – An Ecological Approach

Gibson's most recognised definition of affordance is derived from his seminal book, *The Ecological Approach to Visual Perception* (1979). In this work, he describes affordances as:

> The affordances of the environment are what it offers the animal, what it provides or furnishes, *either for good or ill*... I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment. (Gibson, 1979, p. 127)

Gibson's Theory of Affordances is a theoretical construct of ecological psychology that provides a wholistic perspective to the philosophical underpinnings of design practice. It focuses on the interconnectedness of the environment and the behaviours that result from what an animal can perceive within that environment. By placing emphasis on the interconnectedness of the environment and the animal, we are able to understand and explain an animal's actions within a given context and design in a way that considers an animal's individual needs over time.

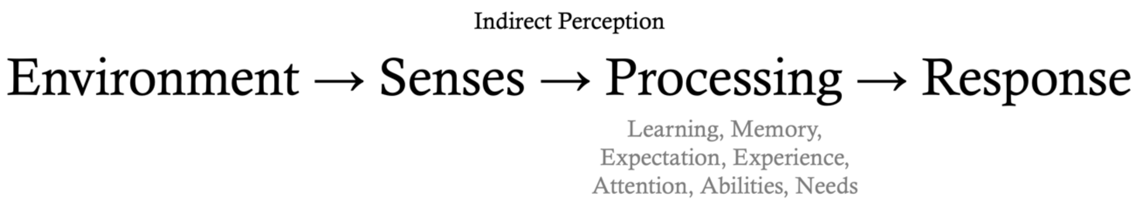

Figure 14. The model of indirect perception (model illustration by the author).

The concept of affordances was revolutionary for its time. Gibson observed that most cognitive science research was focused on the human information processing model of perception (Bongers, 2022). This model posits that a subject perceives a stimulus through their senses and processes this information using existing knowledge – such as learning, memory, expectations, experiences, and attention – to produce a response (as portrayed in Figure *14*). This approach was favoured as it facilitated objective study in controlled research experiments. However, Gibson critiqued this model, asserting that it "left too much out of account" (Gibson, 1966, p. 45). Instead, Gibson advocated for the notion of direct perception, which posits that the meanings and information that guide interactions between an animal and its environment are inherent in the objects and environments themselves, therefore bypassing the need for internal information processing (as portrayed in Figure *15*).

Direct Perception

Environment → Senses → Response

Figure 15. The model of direct perception.

This notion of direct perception places emphasis on the idea of perception as an activity where the animal must be actively exploring the environment in order to make a behavioural activity possible (Bongers, 2022). An affordance is, therefore, not bestowed upon an object by a need of an observer and its act of perceiving it. Instead, an affordance is relational between an animal and another entity (be it substance, object, or another animal) that defines what could take place between them (Scarantino, 2003). In that sense, "an affordance cuts across the dichotomy of the subjective and the objective… it is equally a fact of the environment and a fact of behaviour" (Gibson, 1979, p. 127). This perspective underscores the dynamic nature of interaction, supporting the notion that an object or environment can hold different meanings for different perceivers across different times (Bongers, 2022).

Social robots occupy an interesting space in that their internal mechanisms force them to perceive the world in the traditional information processing model of perception. That is, they need to be able to detect low-level information in the environment, process that information through internal algorithms that are built upon learning, memory, expectation, experience, and attention, decide the best course of action, and then act upon it. Yet, due to the context of their use, they must also be able to look and behave as if they were like autonomous animals able to act and react to the environment and other animals around them over time. In its application to social robot design, the notion of affordances and direct perception reveals a core underlying problem that underpins the practice of social robot design – that we are trying to make social robots which are inherently driven by indirect perception and trying to make their actions seem like they are driven by direct perception.

Given the manner in which computers function, it is unsurprising that much social robot design research is focused on indirect perception. However, as posited by Gibson's Theory of Affordances, this approach in the real world may be limited as it overlooks the interactions of the social robot in relation to other animals and with its surrounding environment. It is important to consider that a design can be perceived differently by different people depending on their knowledge, experience, abilities, approaches, values, mindsets, behaviours, needs, and the way they perceive something can also change over time (Bongers, 2022). For example, a social robot featuring a tablet screen for a face might be perceived as a source of emotional interaction by an individual seeking companionship. Conversely, the same robot might be seen as a tool for quick information retrieval by someone more interested in functional utility, viewing the tablet screen primarily as a touch screen interface. This variability underscores the inherent challenge in social robot design – that despite its intended use case, it is impossible to fully anticipate or control all the different ways an individual might interact with a social robot.

In light of Gibson's theory of affordances, it is insinuated that effective social robot design involves integrating direct perception. That is to say that effective social robot design is the presentation and offering of affordances that intuitively guide a social robot's potential use and utility over time for different individuals alongside the indirect information processing models of perception to which social robots are intrinsically linked. Gibson's theory offers a framework and vocabulary that guides design processes and the application of social robots in a manner that remains adaptable and relevant. This approach does not fixate on static properties but rather concentrates on the evolving relationships and interactions, ensuring that the design remains responsive and attuned to the diverse and changing needs of users (Bongers, 2022).

There are numerous perspectives from which a designer can explore the relationships between the environment, its inhabitants, and the social robot's perception of that milieu. By understanding these diverse perspectives, designers can not only address the technical and functional aspects of a social robot's design, but also the psychological, social, and cultural dimensions essential to effective human-robot interaction. The following section will explore these different perspectives through the concept of design frames.

2.5 Design Frames of Understanding

Design frames, as conceptualised by Kees Dorst (2011), are cognitive structures that enable designers to approach and comprehend complex problems from various perspectives. These frames encompass the designer's interpretation of the problem, its context, potential solutions, and their impacts. Such frames are particularly useful in navigating wicked problems characterised by incomplete, contradictory, or evolving requirements. In this manner, design frames are a tool for both understanding design problems and for generating creative solutions through particular perspectives.

For instance, when adopting a gender frame, designers focus on the design's impact on and perception by people of different gender, addressing gender-specific needs and experiences to ensure inclusivity. A cultural frame, on the other hand, emphasises the importance of cultural relevance and respect, integrating diverse cultural practices, values, and norms into the design process. By integrating different frames, designers can create more comprehensive, empathetic, and contextually relevant solutions. This approach is especially crucial in the field of social robotics, where designs significantly affect various aspects of human life and society, ensuring solutions are not just technically proficient but also socially responsible, culturally sensitive, and ethically grounded. The following section will delve into an array of distinct frames, examining how each presents unique considerations for social robot design.

2.5.1 Problem Solving Considerations

Design as Problem solving in social robot design embodies a pragmatic approach which denotes a problem-solving attitude that focuses on practical and efficient solutions (Buchanan, 1992). This approach in design prioritises functionality and efficiency, tailoring solutions to meet specific needs and contexts. It involves a clear understanding of the problem at hand and a results-oriented mindset. Designers utilising this approach focus on creating products or systems that are not only technically sound but also economically feasible. The emphasis is on finding workable solutions that may not be perfect but are the most effective under given constraints. In this paradigm, theoretical ideals or aesthetic considerations, while important, are secondary to the practicality and utility of the design (Jen, 2018; Kaplan, 2022; Supreeth, 2023). The ultimate goal is to develop solutions that are not only innovative but also directly address the users' needs, enhance efficiency, and improve the overall experience.

In the development of a domestic robot helper, for example, the design frame of problem solving might focus on the development of a robot's sensors or arms for navigating the layout of a home to perform household chores such as cleaning, organisation, and cooking in the kitchen efficiently and safely. Another instance might be the development of a robot educator for children, where the focus would be on the development of voice recognition to interact with children with natural language, a display screen for visual learning aids, and sensors for detecting and responding to children's actions and gestures to create a design that is engaging, durable, and interactive, capable of sustaining children's attention. In the development of assistive care robots for the elderly, the focus may be on the development of visual or auditory reminders for medication, robot arms for mobility assistance, and generative speech AI and vocalisation for cognitive stimulation and companionship.

In each of these cases, the design process is guided by a practical, results-oriented mindset, focusing on creating solutions that are technically sound, economically viable, and flexible enough to adapt to user feedback and changing requirements. The emphasis is on crafting functional and efficient robots that effectively meet user needs, with theoretical and aesthetic aspects playing a secondary role (Jen, 2018; Kaplan, 2022; Supreeth, 2023).

2.5.2 Ethical Considerations

Design as ethical entails the integration of ethical considerations into the process of developing a social robot (Latour & Venn, 2002; Verbeek, 2008, 2011). This approach underscores the responsibility of designers to consider the extensive repercussions of their designs on individuals, society, and the environment. Given the intimate nature of human-robot interactions in varied and often sensitive settings, prioritising an ethical framework is vital. This encompasses adhering to moral principles and values across various dimensions, including safeguarding privacy and ensuring data security (Lutz et al., 2019), upholding user autonomy and consent (Lutz & Tamó-Larrieux, 2020), ensuring transparency and clarity in the robot's functionalities (Wortham & Theodorou, 2017), addressing potential issues of dependency and dehumanisation (Misselhorn et al., 2013), and considering sustainability and ethical decommissioning of social robots (Winkle et al., 2021). The overarching aim in adopting an ethical approach is to create social robots that are not just functionally effective and efficient but are also in alignment with ethical standards that contribute positively to human welfare with respect of societal values and norms (Dodig Crnkovic & Çürüklü, 2012; Šabanović, 2010).

In the development of a domestic robot helper as a kitchen assistant, for example, the integration of an ethical design consideration may involve programming the robot to promote joint cooking activities within the family, rather than completely assuming control of the cooking tasks, to maintain familial bonding and skill development. Similarly, in designing a robotic educator for children, an ethical approach would focus on ensuring the robot enhances, rather than replaces, the human teaching experience, thereby supporting the child's learning journey and preserving the vital role of interactive, human-led education. In designing assistive care robots for the elderly, adopting an ethical framework may involve acknowledging the emotional bonds seniors may form with their robotic companions and carefully considering the ethical implications of decommissioning these robots.

Design as ethical in social robot design is an approach that is not just about functionality and efficiency but also about enriching human experiences in a manner that is respectful, inclusive, and mindful of the ethical complexities of human society. By incorporating ethical considerations, designers ensure that social robots serve as beneficial additions to human life as opposed to replacements.

2.5.3 Social Considerations

Design as social entails the development of social robots that seamlessly integrate into and positively contribute to social contexts and human interactions (Šabanović, 2010). This approach revolves around designing robots that are not only technologically sophisticated but also acutely attuned to social nuances and cultural sensitivities. This may include developing robots that can effectively communicate and interact with people in a manner that is both intuitive and respectful of diverse social norms. This includes social integration and acceptance in different cultural contexts and social situations (Veruggio et al., 2016), mitigating biases and preventing discrimination (Addison et al., 2019), accessibility for a diverse range of individuals including those with disabilities (Yew, 2021), and ensuring equality and inclusivity across various marginalised groups including those defined by race, gender, and age (Robertson, 2010; Sparrow, 2020). The overarching aim of adopting a social approach is to develop social robots that not only coexist harmoniously with humans but also enhance social cohesion, understanding, tolerance, and empathy, thereby positively influencing the dynamics of human social interaction (Lim et al., 2021; Onyeulo & Gandhi, 2020; Šabanović, 2010).

In the development of a domestic robot helper, for example, a social design consideration may involve the customisation of robot behaviour to respect different cultural practices and routines within different households, such as the use of particular rooms during particular events. Similarly, in designing a robotic educator for children, a key social consideration might be ensuring inclusivity and accessibility through the incorporation of communication features such as voice commands, braille interfaces, or sign language recognition to cater for children with specific disabilities. In the development of assistive care robots for the elderly, an important social aspect could involve incorporating functionalities that promote community engagement, like offering updates on local events, aiding in arranging transport, and facilitating virtual community participation. This approach aims to encourage seniors' active participation and connection within their broader community, rather than limiting their social interactions with their social robot assistant.

Design as social in social robot design is an approach that underscores the necessity of creating robots that are not just technologically advanced but also deeply integrated into the social fabric. It is about developing social robots that contribute positively to social dynamics, enriching human interactions, and enhancing the collective experience of communities.

2.5.4 Speculative Considerations

Design as speculative in social robot design involves envisioning future possibilities and potential scenarios that extend beyond current technological and societal norms. This approach allows designers to explore the broader implications of social robots in a future context, contemplating not just the immediate functional applications but also the long-term societal, ethical, and cultural impacts (Johansson-Sköldberg et al., 2013; Luria & Candy, 2022; Šabanović, 2010). A speculative approach to social robot design might consider scenarios where social robots become integral to daily life, altering human interactions, social structures, and even ethical boundaries. It might also involve considering potential risks and unintended consequences, such as the impact on employment, privacy, or human autonomy. By engaging with speculative design, creators of social robots can anticipate and address future challenges and opportunities, ensuring that these technologies evolve in ways that are beneficial, ethical, and in harmony with human values and societal progress.

In the development of a domestic robot helper, a speculative design approach might ponder the societal ramifications of its widespread adoption, particularly how it could exacerbate economic disparities, as those who can afford such technology gain significant advantages in time management and quality of life. In designing robot educators for children, there is potential for these robots to identify and nurture individual talents and skills for career progression, but it also raises concerns about an over-reliance on technology for personal development, privacy concerns when monitoring children's progress, and potentially overlooking skills not prioritised by AI. The development of assistive care robots for the elderly may lead to their evolution into sophisticated health monitoring and companionship tools, able to detect early health issues, yet this raises ethical questions about constant monitoring, the potential of reduced human caregiving, and the psychological impact of strong emotional attachments formed with robotic caregivers.

To design without foresight forces an entirely reactive state of designing, a methodology which does not consider its ethical and social impacts (Johansson-Sköldberg et al., 2013). Speculative design enables possible alternatives for our future by offering space for the collective imagination. Guided by current provable drivers, designed plausible scenarios allow designers and users to gain a deeper understanding of a social robot's impact on daily life, human interactions, and societal norms, and shape those futures in a more desirable, flexible, and responsible manner. The speculative design frame serves as a reminder that the trajectory of social robotics should not be guided just by what is technologically feasible, but also by what is beneficial and ethical, ensuring that these advancements align with and enhance human values and societal well-being (Luria & Candy, 2022; Šabanović, 2010).

2.5.5 Storytelling Considerations

In social robot design, the concept of design as storytelling is important, as the design of systems, products, and services act as mediators that can shape human perceptions and experiences of the world (Balagtas, 2019; Dourish & Bell, 2014; Meretoja, 2018; Ringfort-Felner et al., 2023; Verbeek, 2011). In this respect, social robots are not seen merely as tools or passive devices, but as active contributors to the human experience. Design as storytelling integrates various design perspectives – including problem solving, ethical, social, and speculative frameworks – into a cohesive narrative that focuses on the individual experience. It fosters empathy and a deeper understanding of others' perspectives, desires, and challenges, thereby guiding the creation of more comprehensively considered social robot designs. Emphasising the need for a reflective and conscientious design process, design as storytelling draws attention to the importance of being keenly aware of the narratives and experiences a design may foster or constrain (Ostrowski et al., 2021; Ringfort-Felner et al., 2023; Visser, 2010).

For example, the development of a domestic robot helper equipped with advanced high-tech features forwards the narrative of technologically adept users by meeting their desire for sophisticated customisation and control, yet simultaneously constrains the narrative of less tech-savvy individuals, who might find it overly complex and inaccessible. In the development of a robot educator designed to enhance literacy skills in children, the use of interactive storytelling and language games will cater to the narrative of children who are auditory and visual learners, while potentially neglecting the narrative of children who might require a more tactile or less language-dependent approach to learning. In the design of an assistive care robot for the elderly, features like medication reminders and mobility assistance support the narrative of seniors seeking independence in their homes but may overlook the narrative of elderly individuals who value more human interaction and community support.

In each of these cares, the presence or admission of certain robot features may inadvertently shape the narratives of different individuals. Design as storytelling in social robot design thus demands a nuanced wholistic approach, one that balances technological innovation with a deep empathic understanding of an individual's perceptions and experiences of themselves and the world around them.

2.6 Design Values

Design values are the foundational beliefs and guiding principles that inform and shape the design process across various disciplines (Dorst, 2011; Lawson & Dorst, 2013). The prioritisation of specific design values influences the approaches a designer or design team might adopt in developing products, systems, or services. This prioritisation is deeply connected to design frames, as each value often aligns with specific frames.

The prioritisation of specific design values often serves as a hallmark of a particular field of study (Lawson & Dorst, 2013) . For instance, a discipline that emphasises problem solving and functionality, such as mechanical engineering, will likely focus on creating solutions that are technically efficient and practical. In contrast, a field like social psychology, which prioritises ethical and social values, may concentrate on understanding and addressing human behaviours and societal impacts. This variance in value prioritisation not only defines the identity of the discipline but also guides the types of challenges it might address and the methods it might employ (Buchanan, 1992; Dorst, 2011). The resulting design solutions, therefore, reflect the unique perspective and expertise of each field, contributing to a diverse and comprehensive approach to problem solving across different domains.

The delineation of disciplines based on their prioritised design values offers a strategic advantage in addressing specific design challenges. When confronted with a particular design problem this understanding enables the quick identification of designers whose value system aligns closely with the needs of the task (Lawson & Dorst, 2013). Such a targeted approach ensures that the selected designers or teams are well-equipped with the relevant expertise and perspective, optimising the chances of developing effective and customised solutions. For instance, in a scenario requiring innovation and cutting-edge technology, an engineer would be ideal as their design values prioritise technological advancement and problem solving. Conversely, for a project where user empathy and emotional engagement are critical, a psychologist would be ideal as their design values prioritise emotional intelligence and social interaction. This strategic matching of design challenges with the appropriate discipline, guided by their core values, significantly enhances the efficiency and effectiveness of the design process (Buchanan, 1992; Dorst, 2011).

However, this form of problem solving works effectively only when the desired value and problem are clearly defined, allowing for the assignment of a suitable discipline (Dorst, 2011). Design problems become more complex when faced with multifaceted problems where a single discipline approach may not suffice. These complex challenges are termed *wicked problems* in design (Buchanan, 1992; Cooke et al., 2020; Dorst, 2006), a term that is often used to describe issues that are complex and multifaceted, with no clear-cut solutions that can be adequately resolved through the siloed perspective of a single discipline.

The development of a social robot is a perfect example of a wicked problem, as its design encompasses a vast array of factors – from technical functionality and user interface to psychological impact and ethical considerations. This complexity stems from the need to integrate advanced technology with the nuanced realms of the human social experience. The challenge is compounded by the evolving nature of both technology and societal norms, which are in a constant state of flux, making the design requirements for social robots both moving targets and inherently ambiguous. This dynamic environment means that solutions which may seem viable at one point can become obsolete or inappropriate as conditions change. Additionally, the ethical considerations in social robot design, such as privacy, autonomy, and social impact, add layers of complexity that are not easily navigable through the lens of a single discipline.

Moreover, the unpredictable ways in which users might interact with social robots, each bringing their own expectations, biases, and behaviours, further complicates the design process. As a result, no single discipline can wholly encompass and address the myriad of perspectives involved in the development of a social robot. The multifaceted nature of the design problem, coupled with the need for solutions that are sensitive to changing technological and social landscapes, makes social robot design a quintessential wicked problem. Such a problem necessitates a broad, integrative, and collaborative approach across various disciplines to ensure that as many possible outcomes are considered.

2.7 Interdisciplinary Design

Interdisciplinary design is a collaborative approach that transcends traditional disciplinary boundaries, integrating knowledge and methodologies from various fields to foster innovative solutions (C. Jones, 2010; Urbanska et al., 2019). This approach is characterised by a deep level of collaboration where team members from different disciplines work in unison, not just contributing their expertise, but actively blending and synthesising their diverse perspectives and techniques. The essence of interdisciplinary design lies in this fusion of ideas and approaches, leading to novel solutions that might not emerge within the confines of a single discipline (Boradkar, 2017; Hocking et al., 2016; Pohl et al., 2017). It encourages a holistic view of problem solving, where the complexities of a project are addressed through a multifaceted lens. Interdisciplinary design is particularly valuable in tackling wicked problems, where insights from one field can illuminate and enhance the approaches of another, resulting in more comprehensive, effective, and innovative outcomes (Dorst, 2011).

The field of social robotics inherently demands an interdisciplinary approach due to the complex interplay of technology, human psychology, ethics, and individual experience in the final design outcome (Sabanovic et al., 2007; Zeller & Dwyer, 2022). In this context, interdisciplinary design necessitates collaborations among experts from engineering, computer science, psychology, art, design, and the social sciences to blend and synthesise their diverse perspectives leading to social robots that are not only technologically advanced but also adept in socially and ethically sensitive interactions with humans. Despite the intrinsic need for interdisciplinary collaboration, there remains a prevailing dominance of techno-centric approaches in social robot design, which relegate more socially centred disciplines as secondary to the overall design process or viewing them as mere additions after technical considerations have been settled (Hoffman & Ju, 2014).

To some social roboticists, simply including socially centred disciplines in this manner might appear to counteract techno-centrism by ostensibly broadening the design process to encompass different frames of understanding – a characteristic of the interdisciplinary approach. However, in the design process, the reality is often that by the time social robots reach the stage where socially centred disciplines are brought in to contribute, the design is largely finalised due to time and resource constraints (Hoffman & Ju, 2014). As a result, when socially centred disciplines are eventually consulted, their capacity to effect significant change is limited. Their input may be constrained by the already established design parameters of the social robot, or changes might be deemed too resource-intensive to implement. This pattern of engaging socially centred disciplines after key design decisions have been made does not constitute true interdisciplinary design. Instead, it aligns more closely with a multidisciplinary approach, where different disciplines contribute in a sequential or additive manner, rather than collaboratively shaping the project from its inception (Nissani, 1997).

While a multidisciplinary design approach is efficient in bringing together diverse perspectives, it does not fully capture the key concepts of innofusion, domestication, and Gibson's Theory of Affordances, as discussed in Section 2.3 and 2.4 respectively. Innofusion, which involves the adaptation of technology to specific user situations, and domestication, the creative integration of technology into local practices and cultures, require a continuous, iterative process of design and feedback, deeply rooted in a thorough understanding of various social and cultural contexts (Stewart & Williams, 2005; R. Williams et al., 2005). A multidisciplinary approach, where disciplines contribute in isolation or in a defined sequence, lacks the fluidity and ongoing interaction necessary for these concepts to be fully realised.

Moreover, considering Gibson's Theory of Affordances, it is crucial to acknowledge that the ways individuals interact with a social robot cannot always be predicted or controlled based solely on its intended use (Bongers, 2022). Mitigating unintentional uses or interpretations requires a design approach that explores and develops the social robot through the synthesis of diverse frames of understanding (Dalsgaard, 2014; Dorst, 2011). This necessitates a cohesive, unified approach in which technological, psychological, and social factors are simultaneously and interdependently considered – an approach that is more aligned with interdisciplinary design. In contrast to a multidisciplinary approach, interdisciplinary design fosters a more holistic and integrated exploration of these concepts, ensuring that the design of social robots is more responsive to the complexities of human interaction and the relationships with their surrounding environments.

Interdisciplinary design is the key consideration that sets up the groundwork needed to adopt theoretical frameworks and methodologies that better represent the multifaceted and highly integrated nature of social robots. The following section will delve into the philosophy of Deweyan Pragmatism, the methodology of Design Thinking, and the Principles of Universal Design. This exploration is intended to address the constraints of techno-centrism in social robot design and serve as a practical response to the considerations of innofusion, domestication, and Gibson's Theory of Affordances.

Chapter 3: Theoretical Frameworks and Methodologies

3.1 Introduction

The study of social robotics is inherently interdisciplinary, transcending traditional dichotomies such as positivism versus interpretivism, quantitative versus qualitative, and technical versus social approaches. Instead, it focuses on the real-world applications of social robots and the resulting relationships that emerge from human-robot interaction. As a result, this thesis adopts the theoretical framework of Deweyan Pragmatism and employs the design thinking methodology informed by the Universal Design Principles. This approach will facilitate a comprehensive exploration of how these frameworks and methodologies can create social robots that are not only functionally efficient but also aesthetically appealing, emotionally engaging, and culturally and ethically situated.

3.2 Deweyan Pragmatism

Pragmatism, a philosophical movement originating in the United States towards the late 19th century, posits that truth and meaning are found through practical, real-world applications and the consequences of ideas, emphasising the importance of experience and action in shaping understanding (Kaushik & Walsh, 2019). Prominent early proponents include Charles Sanders Pierce (1839–1914), William James (1842–1910), and John Dewey (1859–1952). While often perceived as a singular school of thought, pragmatism actually encompasses a variety of distinct philosophies and as such, it is important to distinguish between its different strands.

First, it is important that we disambiguate from the *pragmatic* approach (lower case p) and *Pragmatism* (upper case P). The *pragmatic* approach to problem solving, as mentioned previously in Section 2.5.1, emphasises practical, straightforward problem solving, creating solutions that are efficient and effective in real-world applications valuing simplicity and results-based outcomes. This approach is typically linear and goal-oriented, aiming for the most efficient path to a viable solution. This is different to *Pragmatism* as a philosophical framework, which is characterised by the practical application and consequences of ideas, positing that truth is dynamic and shaped by experiences and real-world effectiveness. It emphasises human experience as a key source of knowledge, blending facts with values and viewing thought as a tool for continuous learning and problem solving (Kaushik & Walsh, 2019; Shalin, 1986).

To further conflate the issue, there are several strands of Pragmatism that diverge from the works of Pierce, James, and Dewey. This thesis, however, will not delve into the nuances differentiating these strands due to its specific scope and focus. The central emphasis will be on the works of John Dewey whose scholarly contributions surpass the analytical scientific boundaries established by Peirce and the religious-oriented inquiries of James. Dewey's extensive oeuvre, which spans democracy, psychology, moral philosophy, ethics, logic, experiential learning, and aesthetics, provides a comprehensive framework that is particularly pertinent to the interdisciplinary nature of social robot design (Hildebrand, 2023).

The emergence of Deweyan Pragmatism was largely influenced by the dualistic discourse of positivism and interpretivism, which dominated metaphysical discussion at the time. What Pragmatists identified in these discussions was a gap between the sciences, philosophical knowledge, and the everyday experiences of living and acting in the world (Dewey, 1958; Kaushik & Walsh, 2019; Shalin, 1986). In his seminal work *Experience and Nature,* Dewey offered the following criticism:

> …the most serious indictment to be brought against non-empirical philosophies is that they have cast a cloud over the things of ordinary experience. They have not been content to rectify them. They have discredited them at large. (1958, p. 387)

To address this issue, Pragmatists sought to abandon philosophical discussions around such dualisms and instead focus on the practical consequences and implications of people's experiences in practice (Kaushik & Walsh, 2019). Pragmatism, therefore, bases itself on the principles of usefulness, workability, and the practicality of ideas, policies, and proposals. It stresses the concepts of action over doctrine, experience over fixed principles, and holds that ideas gain meaning from their consequences, and their truth from verification (Dalsgaard, 2014; Wakkary, 2009).

Deweyan Pragmatism offers a compelling counterpoint to the techno-centric discourse in social robot design, which often focuses predominantly on technological advancements and engineering feats at the expense of social considerations. By integrating Dewey's principles, roboticists can shift their focus towards the practical implications of social robots in real-world settings, evaluating their effectiveness not merely in technical terms but also in their ability to enrich and facilitate more effective human-robot interactions. This perspective of valuing the consequences of specific design choices enables a more wholistic approach to robot design. It encourages continuous inquiry and adaptation in real-world settings, ensuring that social robots are developed with an understanding of and responsiveness to a diverse range of human needs, behaviours, and social dynamics (Dalsgaard, 2014; Dixon, 2020; Wakkary, 2009)..

The following section will detail the fundamental tenets of Deweyan Pragmatism, elucidating how this philosophical framework can effectively address enduring issues in social robot design and research into human-robot interaction.

3.2.1 Theory and Practice are Intertwined to Form Experiences

The foundational proposition of Deweyan Pragmatism, the *Pragmatic Maxim* posits that the significance of our worldviews – our ideas, theories, and assumptions – should be evaluated through their practical consequences and implications, a concept highly relevant in tackling the complexity of wicked problems in design (Dalsgaard, 2014). This philosophy suggests that design concepts should stem from practical experience, with their effectiveness measured by their ability to improve understanding and solve real-world issues (Dixon, 2020). Such an approach is crucial for addressing the evolving and ambiguous nature of wicked problems, encouraging the creation of solutions that are adaptable, responsive, and grounded in practical reality. Dewey’s emphasis on experience as a key factor in understanding the world further enriches this perspective. He argued that experience arises from the interaction between individuals and their environment, a similar sentiment echoed by Gibson's Theory of Affordances. In design, this means crafting solutions that go beyond theoretical understanding and technical feasibility, focusing instead on being aligned with the actual contexts and needs of the individual (Dalsgaard, 2014).

The Pragmatic Maxim, with its focus on practical outcomes and experiential understanding, is particularly vital in the design of social robots. The pragmatic approach encourages designers to consider the real-world implications of their designs, ensuring that social robots are not just technologically advanced but are also responsive to the nuanced dynamics of human behaviour and societal norms (Seibt et al., 2018). By prioritising individual experience and the practical consequences of design choices, pragmatism helps in developing social robots that are adaptable, empathetic, and capable of seamlessly integrating into human environments. This approach is essential for the successful deployment of social robots in various sectors, including healthcare, education, and personal assistance, where understanding and responding to human needs and emotions are as critical as technical proficiency.

3.2.2 We Interact with an Emerging World

Deweyan Pragmatism is a philosophy that perceives the world as an ever-evolving entity, never fully realised (Shalin, 1986). This perspective is particularly relevant in design, where problems and solutions develop in tandem, with designers not only addressing known issues but also delving into the deeper nature of the problem itself (Dalsgaard, 2014). This is exemplified in the concept of wicked problems, where the design space itself is in a state of flux, evolving throughout the design process (Buchanan, 1992; Dorst, 2011). Within this framework, emergence suggests an experimental approach to human-robot interaction, where the interplay of ideas, theories, and problems can alter the significance and meaning of an experience.

For example, as social robots become more commonplace and integrated into daily life, their novelty diminishes, leading to changes in user perceptions and expectations (Broadbent, 2017; Sung et al., 2009). Similarly, rapid technological advancements driven by factors like Moore's Law (Schaller, 1997) constantly reshape the possibilities and boundaries of what can be achieved in robot design. Pragmatism in design, therefore, underscores the importance of flexibility, continuous learning, and adaptation, allowing designers to navigate the ever-changing nexus of technology, user needs, and societal impacts effectively. This philosophy thus equips designers with the mindset and tools to create solutions that are not only innovative but also deeply attuned to the complex and evolving nature of human-robot interactions.

3.2.3 All Human Activity is Situated

Deweyan Pragmatism emphasises the *situated* nature of all human activities, highlighting how our perceptions and interactions are deeply rooted with their surrounding environment (Dalsgaard, 2014). In this view, our thoughts, actions, and even the objects and events around us are deeply intertwined with the context they exist in. This interconnectedness means that to fully grasp the essence of any person, object, or event, we need to consider them within their entire environmental and situational context (Bongers, 2022; Dewey, 1958; Gibson, 1979). This perspective is crucial for understanding the transition from determinate to indeterminate situations.

In pragmatic theory, situations are classified as either determinate or indeterminate based on the harmony or discord among their various components (Dalsgaard, 2014). A determinate situation is one where all elements – people, objects, spaces, and norms – seamlessly align, creating a sense of stability and coherence. Conversely, an indeterminate situation arises when these components are misaligned, leading to a sense of discord or incompleteness. Such situations are often perceived as problematic or in need of improvement. Recognising this, individuals or groups may strive to transform these indeterminate situations into more stable, determinate ones. This process of transition and transformation is a key focus in pragmatic thought, highlighting the dynamic and evolving nature of our interaction with the world around us (Dalsgaard, 2014; Dixon, 2020; Steen, 2009).

This understanding of situated activity and the distinction between determinate and indeterminate situations is particularly relevant in the field of social robot design. When designing social robots, it is essential to understand and consider the complex and nuanced environments they will inhabit. A social robot designed without considering these factors may result in an indeterminate situation, where the robot does not seamlessly integrate into the environment or meet user needs effectively. Conversely, a well-designed social robot, one that is attuned to the nuances of its operational context, can create a determinate situation. In adopting a Deweyan Pragmatic Approach, social robot design demands an in-depth understanding of the environments where these robots will function including adapting to the complex dynamics of social and cultural environments.

3.2.4 Inquiry Transforms Indeterminate Situations.

Dewey describes inquiry as the controlled or directed transformation of an indeterminate situation into one that is so determinate in its constituents, distinctions, and relations has to convert the elements of the original situation into a unified whole (Dalsgaard, 2014; Dewey, 1958; Hildebrand, 2023). In other words, inquiry is the process of working to find a solution to a recognised problem situation. Our initial understanding of a problem is shaped by past experiences and habits. When these habitual responses do not yield expected outcomes, we recognise a situation as indeterminate, which initiates the process of inquiry (Dalsgaard, 2014).

The process starts with identifying the problem, followed by developing ideas, theories, and hypotheses to address it. The crucial step is testing these ideas in real-life situations to see if they help resolve the problem. Problem solving in real-life situations is often complex and iterative, involving iterative cycles of defining the problem, coming up with solutions, and evaluating their effectiveness. Since addressing one aspect of a problem can affect others in unexpected ways, the continuous adjustment and revaluation of the problem and solutions are necessary until a clear, unified resolution is achieved (Dalsgaard, 2014; Dixon, 2020; Dorst, 2011; Hildebrand, 2023).

The framework of inquiry is particularly relevant in the context of social robot design. Designers frequently grapple with complex, evolving challenges where the needs and interactions of users, the capabilities of the technology, and its ethical implications are not immediately evident. By applying the approach of inquiry, designers embark on an explorative journey, using their understanding shaped by previous experiences to initially define the problem space (Dorst, 2011). They then develop and test various conceptualisations, such as different design features or interaction protocols, to see how they affect the robot's functionality and the individual's experience. This process is iterative and adaptive and may require them to work with other disciplines in order to further refine their hypotheses based on the outcomes of their tests (Buchanan, 1992; Dalsgaard, 2014; Hocking et al., 2016; Pohl et al., 2017).

3.2.5 Transformation is the Motivation for Situated Inquiry

In Deweyan Pragmatism, transformation is the motivation for situated inquiry, turning indeterminate situations into determinate ones. "The process of transformation may involve the transformation of one, or more of its constituent components and may include the inquirer themselves. The emphasis is on the transformation" (Dalsgaard, 2014). In design, this idea is integral; designers engage in inquiry not only to understand the situation better but also to actively transform it. For instance, a designer (the inquirer) might gain insights that change their perception of a design challenge, thereby altering the situation from indeterminate to determinate (Dalsgaard, 2014). This shift is often the result of expanded knowledge and perspective. Alternatively, the designer might transform the situation by redesigning elements of it – modifying the environment, changing how people interact within it, or creating new artefacts. In this way, design utilises the transformative power of inquiry to actively shape and redefine situations, aligning them with intended goals and outcomes. The process of design, therefore, is not just about creating new things but also about reshaping the context and experiences around those creations (Dalsgaard, 2014; Dixon, 2020; Dorst, 2011; Hildebrand, 2023).

This concept of transformation through inquiry is particularly relevant in the field of social robot design. Designers of social robots engage in a continuous process of understanding and reshaping the interaction between robots, users, and their environments. Initially, a social robot design might present an indeterminate situation with various challenges and uncertainties, such as how the robot should behave in different social contexts or how individuals might respond to it. Through inquiry, designers expand their understanding of these complexities, transforming their perspectives and approaches. This could involve altering the robot's design to better suit user needs, modifying its interaction protocols to be more intuitive, or even redefining its intended purpose based on user feedback. Additionally, the transformation might occur in the designer themselves, as they adapt to and learn from interacting with the robot. Therefore, in social robot design, transformation is a dual process: it involves changing the robot and its functionalities to better fit into its intended use case as well as the evolution of users' perceptions and interactions with the social robots (Dalsgaard, 2014). This dynamic interplay demonstrates how both the inquirer (designer) and the subject (social robot and its users) co-evolve to create a harmonious, determinate situation (Dewey, 1958).

3.2.6 Technology as a Tool for Transformation

In Deweyan Pragmatism, technology is viewed as the use of instruments or means to achieve desired outcomes, playing a central role in the transformation of situations through inquiry (Dalsgaard, 2014; Dewey, 1958; Dixon, 2020). This perspective echoes Media Scholar John Culkin's famous observation that "we become what we behold. We shape our tools, and then our tools shape us" (1967, p. 67). In the design process, technology is more than just a means to create products; it is fundamental in understanding and transforming situations. Designers employ a range of technologies, from physical tools and digital software to conceptual methods like language to both understand and reshape their design contexts (Dalsgaard, 2014; Dixon, 2020). This mirrors Deweyan Pragmatism where technology is seen as both shaping our experiences and enabling their alternation (Dewey, 1958). It facilitates thinking, learning, and problem solving and is integral to the design process, aiding designers in experimenting, prototyping, and communicating concepts, thereby transforming indeterminate situations into determinate situations. Therefore, in the context of design, technology transcends its role as a mere feature of the end product, becoming an integral part of the entire design journey as it guides the process of inquiry and plays a crucial role in the creative evolution of ideas that help to shape and refine indeterminate situations into determinate situations (Dalsgaard, 2014).

In social robot design, the role of technology becomes even more pronounced. Social robots, by their nature, are embodiments of advanced technology, but their design goes beyond the mere application of technical skills. Here, technology acts as a bridge between the robot's functionalities and the human environments they are intended to interact with. Designers of social robots leverage technology to not only build the robot's physical and software components but also to understand and enhance the robot's interaction with humans (Dalsgaard, 2014; Dixon, 2020). This involves employing technologies to simulate human-robot interactions, testing different communication methods, and even using AI to adapt the robot's responses to various social situations. The technology used in social robot design thus serves a dual purpose: it is part of the product itself and a tool for understanding and shaping the robot's role in human environments. It is not just about building a functional product, it is about crafting a robot that can seamlessly integrate into human lives, enhancing interactions and experiences (Sabanovic et al., 2007). This holistic use of technology aligns with Dewey's concept of inquiry and transformation, where technology is a means to both explore and realise the full potential of social robots in their intended contexts.

To summarise, Deweyan Pragmatism, emphasising experience, interaction, and continuous learning, offers a philosophical foundation deeply pertinent to design, especially in social robot design (Dalsgaard, 2014; Dixon, 2020). This pragmatic approach highlights the importance of understanding contextual and experiential aspects of design challenges and promotes a process of interactive exploration and problem solving. The upcoming section delves into Design Thinking, a methodology that practically implements Deweyan Pragmatism's fundamental principles (Dalsgaard, 2014). Design Thinking is structured to emphasise empathy, creativity, and rational problem solving, making it exceptionally suitable for addressing the intricate and multifaceted challenges inherent in social robot design. By integrating Deweyan philosophical insights, Design Thinking provides a comprehensive framework for developing social robots that are not only technologically advanced but also attuned to the complex dynamics of human interaction and experience.

3.3 Design Thinking

Design thinking, is a process that combines analysis and creativity, involving experimentation, creation, prototyping, feedback gathering, and redesigning to achieve a desired value (Dorst, 2011; Razzouk & Shute, 2012). At its core, Design Thinking is human-centred, emphasising empathy and a deep understanding of the users' experiences and needs through different frames of understanding. This approach, popularised by IDEO and the Stanford d.school, encourages designers to step into the users' shoes and see the world from their perspective, ensuring that the solutions developed are genuinely relevant and valuable to the people who will use them.

Design Thinking is a process that aligns closely with the principles of Deweyan Pragmatism, intertwining the objectives of design and research within real-world contexts. This integration fosters a dynamic feedback loop where research and design continually interact with and adapt to real-world scenarios (Dalsgaard, 2014; Joseph, 2004). Emphasising interdisciplinary research, iteration, evolution, rapid prototyping, and a human-centred design ethos, design thinking serves as a method for practicing the philosophy of Deweyan Pragmatism.

The Design Thinking process is an overarching, iterative, and non-linear methodology, encompassing six modes of inquiry: Problem Definition, Research, Ideation, Prototyping, Implementation, and Problem Re-definition. The following sections will delve into these diverse modes of inquiry and explicate their role in the design process.

3.3.1 Problem Definition

The initial stage of problem definition involves the designer identifying and understanding the problematic aspects of an indeterminate situation, a concept that resonates strongly with Dewey’s approach to inquiry (Dam, 2023; Joseph, 2004; Schön, 1983). At this stage, the designer starts to unravel the complexities and uncertainties inherent in the situation. The aim here is not just to identify what the problem is, but to also establish a clear goal or *aspired value* that guides the transformation of the situation from its current, indeterminate state to a more resolved, determinate state (Dalsgaard, 2014).

This aspired value serves as a guiding light throughout the design process, ensuring that all efforts are purposefully aimed towards a meaningful and relevant outcome. It necessitates a deep engagement with the problem's context, resonating with Dewey's emphasis on the interconnectedness of experience and environment. The designer must understand the needs and perspectives of those affected and articulate a vision for a successful resolution.

By establishing this aspired value, the designer is not just setting the direction for the design process but is also laying the groundwork for a focused and intentional inquiry. This approach underscores the importance of clarity and purpose right from the start. Therefore, in the context of design thinking, problem definition sets the stage for effective and impactful solutions that are deeply rooted in the real-world context of the problem.

3.3.2 Research

Following the initial problem definition in the design thinking process, the Research phase is crucial for situating the design problem within its real-world context, embodying Dewey's emphasis on understanding problems as part of their environment (Dalsgaard, 2014; Dam, 2023; Joseph, 2004). It involves an in-depth exploration to understand the boundaries, parameters, and various elements of the indeterminate situation identified earlier. This research phase is critical for dissecting and analysing the situation in its entirety.

The constituents of the situation that need investigation are diverse and extensive. These may include interactions between people, objects, places, and artefacts; the physical and psychological environment; existing solutions; and social constructs like norms and rules, along with memories and the historical context (Wakkary, 2009). This aligns with Deweyan Pragmatism, which advocates for a holistic understanding of the situation and the various other factors at play.

The research methods employed can vary from theoretical literature reviews to more practical approaches like pilot studies, interviews, and questionnaires. Direct engagement with the subject matter through observational studies or participatory design methods can provide deep insights, mirroring Dewey's principle of learning through direct experience (Dalsgaard, 2014;

Joseph, 2004). This phase aims to gather comprehensive information to guide the subsequent stages of the design process. The goal is to build a complete and nuanced understanding of the problem, essential for developing effective, innovative solutions. This approach ensures that the design solutions are not just theoretically sound but also practically applicable and contextually relevant.

3.3.3 Ideation

Building upon the research phase, the next crucial mode in the design thinking methodology is Ideation. This stage is where creativity and innovation come into play, guided by the insights gathered during research. Ideation is the process of generating a wide range of ideas, theories, and hypotheses that have the potential to convert the previously indeterminate situation into a determinate one (Dam, 2023; Joseph, 2004).

In ideation, the goal is to think broadly and freely, considering various possible solutions without the constraints of practicality or feasibility at the outset. It's about exploring different avenues and perspectives that could address the defined problem. Designers typically draw upon their professional practice and experiences during this phase using a repertoire of processes that they adapt and apply to fit the specific requirements of the project at hand. These processes are essentially approaches or methods that have proven effective in previous projects and are usually tweaked or expanded to suit new challenges (Dalsgaard, 2014; Dorst, 2011; Lawson & Dorst, 2013).

The ideation phase is critical as it establishes the groundwork for prototyping and testing. Here, the most creative and transformative solutions are conceived. This stage embodies the Deweyan idea of inquiry as an active exploration (Dalsgaard, 2014; Dewey, 1958), where generating a multitude of ideas enhances the potential for innovative solutions that not only address the problem at hand but also enrich the user experience. It underscores the need for creativity and an open mind in the design process. In the spirit of Deweyan Pragmatism, ideation in design thinking is not just about finding a solution, but about evolving the understanding of the problem itself and expanding the possibilities for its resolution (Dalsgaard, 2014).

3.3.4 Prototyping

In the design thinking process, Prototyping is a critical phase where the designer actively engages in transforming the previously identified problematic experience into a tangible solution (Dam, 2023; Dixon, 2020). This stage is about bridging the gap between theory and practice by creating a physical or digital model, product, artefact, or system that embodies the ideas, theories, and hypotheses generated in the ideation phase. Prototyping is essential because it moves the design process from abstract concepts to concrete examples (Dalsgaard, 2014).

The prototypes developed in this stage are not final products but rather tools for learning and exploration. They allow designers to test the feasibility of their ideas in a real-world context and gather valuable feedback. Prototyping makes it possible to evaluate the practicality and effectiveness of a design, moving beyond mere theoretical assumptions. This hands-on approach to problem solving enables designers to identify potential issues and areas for improvement early in the process, saving time and resources in the long run (Dorst, 2011).

Moreover, prototypes facilitate communication and discussion among designers, stakeholders, and users (Dalsgaard, 2014; C. Jones, 2010; Sabanovic et al., 2007). They provide a visual and tangible representation of the solution, making it easier for everyone involved to understand and contribute to the design. In essence, prototyping is a pivotal step in the transformation of a design problem into a viable solution, embodying the principles of Deweyan Pragmatism by uniting theoretical knowledge with practical application (Dalsgaard, 2014).

3.3.5 Implementation

Following the creation of a prototype, the next crucial step in the design thinking process involves its implementation in a practical setting to test its effectiveness in resolving the previously identified indeterminate situation. This phase is pivotal as it provides an opportunity to observe how the prototype operates in real-world conditions and assess its impact on the situation. This stage typically involves various methods of gathering feedback and insights, such as focus groups, group discussions, interviews, questionnaires, and surveys (Dalsgaard, 2014; Dixon, 2020).

These methods are employed to gain a comprehensive understanding of how the prototype interacts with and influences the various elements of the situation it is designed to improve. Focus groups and discussions can offer in-depth qualitative insights into user experiences and perceptions, while interviews allow for more personalised feedback. Questionnaires and surveys, on the other hand, can provide quantitative data regarding the prototype's performance and its acceptance by a larger group of users.

This implementation phase embodies the Deweyan concept of inquiry as an active, experiential process (Argyris & Schon, 1974; Dewey, 1958; Schön, 1983). By testing the prototype in real-world situations and gathering feedback, designers engage in a cycle of action and reflection. This approach ensures that the design not only meets theoretical criteria but also proves effective and beneficial in practical use. It highlights the iterative nature of design thinking, where continuous learning and adaptation based on real-world experiences are crucial for refining the prototype and effectively addressing the initial problem.

3.3.6 Problem Re-definition

In the design thinking process, if a prototype fails to effectively address the indeterminate situation, the designer must re-engage with the design cycle, equipped with new ideas, theories, and hypotheses (Dalsgaard, 2014; Dorst, 2011; Wakkary, 2009). This cycle reflects the inherent complexity of real-world situations, rarely are problematic situations resolved in a linear or straightforward manner due to the situated nature of all human activities. There is seldom a definitive endpoint to any problem; instead, potential solutions are evaluated on a continuum of better or worse effectiveness.

This iterative approach is reflective of Dewey’s view of inquiry as an active, ongoing process of engagement with and transformation of the world (Argyris & Schon, 1974; Dewey, 1958; Schön, 1983). It acknowledges that solutions to design problems are not static but evolve over time as the designer’s understanding of the situation deepens and adapts. Consequently, the resolution of indeterminate situations in design is a continual, evolving process, grounded in the Deweyan approach of learning through experience, experimentation, and reflection (Dalsgaard, 2014; Dixon, 2020). This process underscores the value of iteration and the role of failure as a learning tool in the journey towards more effective and contextually relevant design solutions.

In conclusion, the Design Thinking methodology effectively applies the principles of Deweyan Pragmatism. This methodology, deeply rooted in empathy, ideation, prototyping, and testing, aligns with Deweyan Pragmatism's emphasis on experiential learning and the interactional relationships between individuals and their environments. It ensures that solutions are not only innovative but also resonate with the individual human experience. As we move from Design Thinking to the Universal Design Principles, we further the pragmatic approach by explicitly incorporating inclusivity and accessibility. Universal Design Principles enhance the scope of Design Thinking by explicitly ensuring that social robots are designed to be accessible and beneficial to all users, thus extending the Deweyan concept of practical, real-world application and continuous adaptation. Integrating these principles into social robot design represents a more complete holistic approach, combining Deweyan Pragmatism and Design Thinking to ensure that these advanced technologies are not only responsive and considerate of the individual experience but also universally accessible and equitable. This blend of methodologies and principles promises to amplify the positive societal impact of social robots, making them valuable and inclusive companions for many individuals in diverse environments.

3.4 The Universal Design Principles

The Universal Design Principles are a set of principles that aim to unify all the various design values from a range of disciplines by recognising the fact that design inherently affects all people and animals in one way or another. Originating from the vision of architect and product designer Ron Mace (1997), the primary aim of Universal Design was to create a design process that inclusively caters to everyone to the greatest extent possible, without necessitating adaptation or specialised design.

It is important to clarify that the concept of Universal Design does not convey the notion of a single universally accessible product that is suitable for every individual (Tobias, 2003). In addition, while related terms like barrier-free design, accessible design, inclusive design, and design for all emphasise aspects of accessibility and inclusivity, these terms oversimplify the concept and can lead to many misinterpretations.

The essence of Universal Design lies not in achieving a final, universally perfect product, but in the ongoing pursuit of design solutions that consider and accommodate as wide a range of users as possible (Mace, 1997; Tobias, 2003). It is a process-oriented approach where the aim is to maximise accessibility, usability, and inclusivity at every stage of the design process. It is about constantly evaluating and re-evaluating designs in the context of diverse user needs and striving to make products that are as inclusive as possible within the constraints of practicality and feasibility. The following section will outline the seven basic principles of Universal

Design (Mace, 1997; Ostroff, 2011; Story et al., 1998) and how they relate to social robot design.

3.4.1 Equitable Use

The first principle of Universal Design emphasises the importance of creating designs that are useful and marketable to people with diverse abilities. In social robot design, this translates to developing robots that are accessible and beneficial to all users, including those with disabilities. For instance, a social robot could be equipped with features that make it operable through voice commands or touchscreens, accommodating users with varying levels of physical ability.

3.4.2 Flexibility in Use

This principle focuses on accommodating a wide range of individual preferences and abilities. Social robots should be adaptable, offering different modes of interaction to suit the user's comfort level and capabilities. For example, a social robot designed for elderly care might have adjustable settings for speech speed and volume, catering to the varying sensory abilities of older adults.

3.4.3 Simple and Intuitive Use

The design should be easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level. Social robots should have straightforward, intuitive interfaces that do not overwhelm or confuse users, especially important for those not familiar with technology.

3.4.4 Perceptible Information

This advocates for the effective communication of necessary information to the user, regardless of ambient conditions or the user's sensory abilities. Social robots should be designed to communicate clearly, using visual, auditory, and even tactile cues to ensure that messages are conveyed effectively to all users.

3.4.5 Tolerance for Error

Designs should minimise hazards and adverse consequences of accidental or unintended actions. In social robot design, this might involve implementing fail-safes or emergency stops to prevent harm to the user, particularly in scenarios where the robot is performing physical tasks.

3.4.6 Low Physical Effort

The design should be comfortably usable and with minimal fatigue. Social robots should be designed to be easily manoeuvrable and operable without requiring excessive force or complex actions.

3.4.7 Size and Space for Approach and Use

Design should provide appropriate size and space for approach, reach, manipulation, and use, regardless of the user's body size, posture, or mobility. Social robots should be of a size and shape that is approachable and usable by all users, including those who might use wheelchairs or other assistive devices.

To conclude, the incorporation of Universal Design Principles in social robot design marks a significant step towards creating more accessible, inclusive, and user-friendly social robots. These principles, which advocate for designs that are equitable, flexible, and intuitive, align closely with the tenets of Deweyan Pragmatism and Design Thinking (Dalsgaard, 2014; Dorst, 2011; Östman, 2005; Saffar, 2019). Deweyan Pragmatism, with its emphasis on practical, experiential learning and adapting to the needs of diverse users, is reflected in the Universal Design approach to social robots, ensuring they cater to a wide spectrum of individual abilities and preferences. Similarly, Design Thinking's iterative, human-centred process complements

Universal Design by focusing on empathetic and inclusive solutions. The integration of these approaches in social robot design ensures the development of social robots that are not only technologically advanced but also deeply attuned to the varied nuances of human interaction and accessibility. This harmonious blend of Universal Design, Deweyan Pragmatism, and Design Thinking paves the way for social robots to become more than just functional machines but also intuitive, ethical, and empathetic companions that can enrich the lives of all people irrespective of their individual capabilities or circumstances.

3.5 Research Methods

This thesis employs a diverse array of data collection methods, drawing from those commonly used in social robot design and human-robot interaction research. Centred around understanding people's problematic experiences with social robots, the research primarily focuses on qualitative methods, enriched with quantitative elements to broaden the applicability of the research. However, as highlighted in the Covid-19 impact statement at the beginning of the thesis, the unforeseen Covid-19 global crisis brought forth unique challenges, significantly influencing the methodological approach initially planned for the study.

Originally, the plan included hands-on methods such as Wizard of Oz experiments and in-person focus group studies, which are vital for direct, interactive insights into human-robot interactions. The pandemic's widespread effects, particularly supply chain disruptions, hindered the development of the Haru social robot. Moreover, restrictions on physical gatherings and the fact that in-person technical support was not available necessitated a re-evaluation of the research approach. Consequently, to adapt to these challenges and ensure timely completion of the thesis, the focus shifted towards more feasible and reliable online research methods.

The following section will detail these adapted research methods, highlighting how they contributed to a comprehensive understanding of the application of animation principles in social robot design in a constrained, pandemic-affected research environment. This adaptation not only underscores the flexibility required in academic research but also illustrates the resilience of specific research methodologies in adapting to unforeseen challenges.

3.5.1 Case Studies

The case study method is a research method that involves an in-depth, detailed examination of a single case or a small number of cases and aligns well with the principles of Deweyan Pragmatism and Universal Design (Ascher, 2015; Campbell, 1975; Fidel, 1984; Johansson, 2007; Yin, 1992, 1994). This method, often used in social sciences, allows researchers to explore complex issues in real-life contexts. It provides a thorough understanding of the case in its natural setting, making it particularly useful for gaining insights that might be lost in more broad-based research methods (Yin, 1992, 1994). A case study can involve qualitative data, such as from interviews and observations, or quantitative data, such as statistics and numerical analysis. The goal is to gather comprehensive information that contributes to a deeper understanding of the case, often resulting in rich, contextualised knowledge (Fidel, 1984; Yin, 1992, 1994). This method is especially effective in generating hypotheses for further research, understanding unique or idiosyncratic phenomena, and offering detailed insights that can inform theory or practice. It is a valuable tool for researchers seeking a pathway for developing solutions that are both innovative and deeply attuned to the complex dynamics of human interaction, adhering to the inclusive principles of Universal Design and the experiential learning advocated by Deweyan Pragmatism.

In this thesis, the prototype networked table-top social robot Haru, under development by Honda Research Institute Japan (HRI-JP), will be utilised as a case study (Gomez et al., 2018). The research will encompass a comprehensive and integrative approach, seeking to uncover and explain how expertise in design and animation can influence social robotics for positive and impactful human-robot interaction. Utilising Haru as a case study is crucial for the advancement of social robotics as it provides a practical and relevant platform for applying and developing new theories that are pertinent to the design of all social robots.

3.5.2 Literature Review

A literature review is a comprehensive survey of existing scholarly work in a specific field or on a particular topic (Snyder, 2019; Whittemore & Knafl, 2005). It involves collecting, evaluating, and synthesising published research to establish what is already known, identify gaps in current knowledge, and provide a context for new research. In a literature review, the researcher critically assesses studies, articles, and other relevant sources, summarising key findings and methodologies, and discussing various perspectives and findings within the field (Paré & Kitsiou, 2017).

When it comes to applying animation principles in social robot design, a literature review plays a crucial role. It allows researchers to explore how animation has been used historically in robot design and the effects of these applications. The review can uncover insights into effective animation techniques for conveying emotions, intentions, and personality in robots, drawing from fields like art, design, computer graphics, human-computer interaction, and psychology. By reviewing existing literature, researchers can also identify best practices and innovative approaches in animation that could enhance the design and interaction quality of social robots. Furthermore, a literature review helps in understanding user perceptions and responses to animated features in robots, providing valuable information for designing more engaging and relatable social robots.

3.5.3 Surveys and Questionnaires

Surveys and questionnaires are research tools used to collect data from a sample of individuals, providing insights into their opinions, behaviours, attitudes, or characteristics (Groves et al., 2009; Kahneman et al., 2004). Surveys often encompass a broader research strategy that might include various data collection methods, while questionnaires refer specifically to the instruments consisting of a series of questions designed to gather information. These tools can be administered in various formats, such as online, in-person, or over the phone, making them incredibly useful during the lockdown restrictions of Covid-19, and can include both open-ended questions, which allow for detailed qualitative responses, and closed-ended questions, which offer more structured quantitative data (Jamsen & Corley, 2007; Schwarz et al., 1998).

In the context of applying animation principles to social robot design, surveys and questionnaires are invaluable for gathering user feedback and preferences. They can be used to assess how different animated features on a robot, such as facial expressions, gestures, or movements, are perceived by users. By surveying a diverse group of potential users, designers can gather quantitative data on aspects like the appeal, understandability, and emotional impact of animated features in social robots. Questionnaires can also specifically probe user preferences, experiences, and expectations regarding the integration of animation in social robots facilitating the gathering of qualitative data to enhance user interaction and engagement with social robots.

3.5.4 Experimental Studies

Experimental studies are a research methodology designed to test hypotheses and establish cause-and-effect relationships by manipulating specific variables while controlling others. In these studies, variables are carefully controlled or altered by the researcher to observe the effects on the outcomes being studied (Bijou et al., 1968; Campbell & Stanley, 2015; Miller et al., 2020; Rogers & Revesz, 2019; Slack & Draugalis Jr, 2001). This approach allows for a high degree of control over the research environment and conditions, providing clear insights into the direct effects of the manipulated variables.

In the context of applying animation principles to social robot design, experimental studies are particularly useful for systematically assessing how the application of different animation principles impact user interaction and perception. In this thesis, a comprehensive empirical research approach is utilised to evaluate the impact of visual and movement design elements on user interaction with the social robot Haru. The first series of studies focuses on the robot's visual design, where participants are exposed to different iterations of Haru, each featuring unique visual characteristics. Complementing these studies, a second series of empirical investigations examines the influence of Haru's movement design, particularly its ability to convey emotions through slight changes in the robot’s motion. In these studies, the goal is to explore the extent to which Haru's movement design can effectively communicate emotions, despite its non-human-like visual appearance.

By employing experimental studies, we can gather empirical evidence about the effectiveness of various design and animation techniques in enhancing the functionality and appeal of social robots. This approach provides valuable insights that can inform the design process, ensuring that the integration of animation principles into social robots is both user-friendly and impactful.

To conclude, this thesis employs a comprehensive array of research methods, including case studies, literature reviews, surveys and questionnaires, and experimental studies, to delve into how animation design principles can enhance human-robot interaction. Case studies provide practical insight into real-world applications, while literature reviews offer theoretical foundations and context. Surveys and questionnaires enable the gathering of diverse perspectives and preferences, and experimental studies offer empirical evidence on the effectiveness of animation principles in social robot design. This multi-method approach aligns with the philosophical underpinnings of Deweyan Pragmatism, the methodology of design thinking, and the principles of Universal Design. It provides a holistic view of how nuanced expressive movements and visual designs can foster more positive and effective human-robot social interactions in real-world scenarios.

3.6 Ethically and Socially Responsible Research

This research project, conducted under the University of Technology Sydney (UTS), adheres to the highest ethical standards as outlined in the UTS research policies (2022b) and codes of conduct (2022a). These standards include principles such as honesty and integrity in the treatment of human research participants, animals, and the environment; good stewardship of public resources; appropriate acknowledgment of all contributors to the research; and the responsible communication of research results.

To ensure compliance with these ethical standards, especially given the involvement of human participants in the case study, the research has undergone a rigorous ethics approval process with the UTS Human Research Ethics Committee (HREC). The project has been approved under the ethics code ETH19-3968 and was be conducted in strict accordance with the UTS Research Ethics and Integrity Policy (UTS, 2016). This includes a commitment to the dignity, rights, and welfare of participants, avoiding potential harm, and ensuring that the research is conducted in a respectful and ethical manner.

Furthermore, participants in this study are afforded the right to withdraw at any point, including after data collection has begun. Should a participant decide to withdraw, any data collected from them will be excluded from the research and destroyed, ensuring their autonomy and control over their involvement.

Additionally, the confidentiality and anonymity of participants are paramount. All data gathered will be securely stored in protected locations and on secure hard drives. The anonymity of participants will be maintained throughout the research process, with no disclosure of names or personally identifiable information at any stage. These measures are integral to protecting participant privacy and maintaining the ethical integrity of the research.

Chapter 4: The Visual Design of Social Robots

4.1 Introduction

Humans tend to form impressions of other people through visual social cues to categorise based on age, gender, and race (Brooks & Hébert, 2006; Fiske, 1998; Jackson & O'Neal, 1994; Koller, 2008; McDermott & Pettijohn, 2011; Tatum, 2017). Similarly, in the realm of social robotics, the visual design of robots carries significant social and ethical implications, influencing human perceptions and behaviours towards robots (Beer et al., 2012; Kalegina et al., 2018; Otterbacher & Talias, 2017; Robertson, 2010; Sparrow, 2019). Despite this, there is often a lack of detailed discussion in academic literature regarding the rationale behind the use of specific visual design principles and elements in social robots. This oversight stems from a limited understanding of the semiotics of visual design elements and principles, and their potential impact on users. This gap highlights the need for a deeper exploration of the visual factors that shape human-robot interaction.

This chapter will address this gap by examining the visual design of social robots through the lens of a designer and animator. It will delve into the concept of visual social semiotics to understand how altering certain elements and principles can transform the dynamics of human-robot interaction. This exploration aims to shed light on how visual aspects of social robots are not merely aesthetic choices but are imbued with meaning and significance to individuals that can profoundly affect human-robot interaction. By applying principles of visual social semiotics, the chapter will explore how thoughtful design choices can enhance effectiveness, acceptability, and sensitivity towards cultural and ethical considerations within individual social environments.

4.2 Visual Social Semiotics

Semiotics is the study of signs and symbols and their use or interpretation (Caesar, 2013; Eco, 1976; Leeuwen, 2005; Oswald & Oswald, 2012; Scholes, 1982). It is a field that explores how meaning is created and communicated through various sign systems, not just in language, but in a wide array of cultural symbols and practices. Semiotics examines everything that can be taken as a sign, such as words, images, sounds, gestures, and objects, and looks at how these elements convey specific messages and meanings in different contexts.

Visual social semiotics is a branch of semiotics that explores how visual elements convey meanings and messages within a social context (Aiello, 2006, 2020; C. Harrison, 2003; Jewitt & Oyama, 2001). It focuses on understanding how images, symbols, colours, spatial arrangements, and other visual components function as signs that communicate ideas, values, and ideologies (Karl et al., 2013). For instance, the type of clothing one wears can signify social status, professional roles, cultural identities, or even personal beliefs. A business suit might convey professionalism and formality, while a uniform can indicate one's occupation or role within an organisation. Visual Social Semiotics offers a framework to analyse and understand these interpretations, highlighting how visual elements, like clothing, can significantly impact perception, communication, and social interaction.

Key to visual social semiotics is the idea that visual language, like verbal language, has its own grammar and structures that can be analysed to understand how meaning is constructed and communicated (C. Harrison, 2003; McCloud & Martin, 2017; Moerdisuroso, 2014). In design this is referred to as the elements and principles of visual design. These *visual grammars* encompass the way elements like colour, composition, line, and form are used and understood within a given cultural context. Just as verbal language uses syntax, vocabulary, and grammar rules to construct and convey meaning, visual language employs these visual grammars to create and communicate messages and ideas (Kandinsky, 1912; Kandinsky & Rebay, 1926; McCloud & Martin, 2017). Visual design is, therefore, not the result of a singular, isolated, creative activity, but is a social process where its use of signs and their meaning is a negotiation of social, cultural, and political beliefs, values, and attitudes between the designer and the people (Caesar, 2013; Kress & Leeuwen, 1996; Lemke, 1990).

Visual Social Semiotics is crucial for examining the role of visual elements in shaping and reflecting cultural norms, social identities, and ideologies. For instance, the way colours are used in a culture can signify different emotions or values; red might signify danger or passion in one context and celebration or luck in another (Granger, 1955; Kauppinen-Räisänen & Jauffret, 2018; Koller, 2008). Similarly, the composition of a visual scene, the interplay of light and shadow, and even the orientation and size of objects within an image can all convey specific meanings or evoke certain emotional responses (Leeuwen & Boeriis, 2016; Sadowski, 2017). By analysing these visual structures and their meanings, we can gain insights into how they influence individual behaviour and societal attitudes.

Designers and animators are particularly skilled in visual social semiotics and understand its profound communicative impacts (Hooks, 2017; McCloud & Martin, 2017; Thomas & Johnston, 1995; R. Williams, 2012). In design and animation, every visual element – from character designs and background settings to colour palettes and motion dynamics – is meticulously crafted to convey specific messages and evoke emotional responses. Designers and animators leverage visual social semiotics to create meaningful, engaging, and culturally resonant content. They understand that visual choices are not merely aesthetic but are loaded with semiotic significance that can influence perceptions, tell stories, and build immersive worlds. This expertise in visual storytelling and character design is particularly invaluable in the design of social robots. By carefully considering a social robot's visual design, the application of an animator’s expertise can help make these machines more relatable and approachable thereby enhancing human-robot interaction.

4.3 The Current State of Social Robot Visual Design

Just as people form impressions of others through visual social cues based on age, gender, and race (Brooks & Hébert, 2006; Fiske, 1998; Jackson & O’Neal, 1994; Koller, 2008; McDermott & Pettijohn, 2011; Tatum, 2017), perceptions of social robots are similarly influenced by their visual design. The appearance of a social robot plays a crucial role in shaping perceptions of its functionality, personality, and interactive capabilities (Duffy, 2003; Eyssel & Loughnan, 2013; Hoffman & Ju, 2014; Kiesler & Goetz, 2002). Various studies have demonstrated the significant impact of visual design in social robotics. For example, the shaping of a robot's body or the styling of its *hair* in ways that conform to gender stereotypes can lead to the attribution of gender to social robots (Eyssel & Loughnan, 2013; Otterbacher & Talias, 2017; Siegel et al., 2009). Similarly, the colour of a robot's eyes has been found to influence perceptions of its internal mental states (D’Amico & Guastella, 2018; Gamboa-Montero & Salichs, 2020; Lindberg et al., 2017).

Given the ease with which robots can be categorised based on simple visual cues, the resulting social and ethical implications are substantial. These visual elements can significantly affect how people interact with and respond to social robots and the way they are visually designed and perceived can lead to important behavioural outcomes in human-robot interactions (Koller, 2008; Sparrow, 2017; Wallace, 2019). Despite the significant impact of these visual design elements, there is a notable lack of in-depth discussion in academic literature regarding the rationale behind these visual aspects.

In teams that do acknowledge the importance of visual social semiotics, discussions about design often remain superficial, with decisions frequently based on intuitive *gut feelings* or rudimentary design theories (Hoffman & Ju, 2014; Vihma, 2007). Pedalled by techno-centric discourse, such approaches generally prioritise practical and functional aspects, focusing on the user's ability to operate the design rather than exploring how various individuals in different contexts might interpret and derive meaning from these forms (DiSalvo et al., 2002; Haring et al., 2013). As a result, a significant gap exists in recognising the potential of these visual cues in enhancing user experience and interaction. This oversight underscores the need for a more comprehensive interdisciplinary approach in social robot visual design – one that integrates a deeper appreciation of visual social semiotics and considers the diverse interpretations and meanings these visual elements can convey across different user groups and cultural contexts in conjunction with functional considerations.

This prevailing approach in social robot design has led to a notable lack of visual diversity in social robots both available and under development today (Addison et al., 2019; Bartneck et al., 2018; Eyssel & Loughnan, 2013). As discussed previously in section 1.2 and illustrated in Figure 13, this homogeneity is evident from a simple Google image search for 'social robots', which predominantly displays humanoid robots characterised by gleaming white surfaces. This trend is also reflected in leading social robot research platforms like Nao, Pepper, and PR2, which commonly feature white, plastic materials and often embody a *cute* aesthetic in their design (Bartneck et al., 2018; Pütten & Krämer, 2012; Riek & Howard, 2014).

However, as social robots are increasingly integrated into human society as active participants, the lack of visual diversity in their design raises significant concerns. It could potentially lead to problematic outcomes and discriminatory behaviours mirroring those in human interactions, such as racism, sexism, and ageism (Bartneck et al., 2018; Duffy, 2003; Eyssel & Loughnan, 2013; Hoffman & Ju, 2014; Kiesler & Goetz, 2002). The uniformity in robot appearance might inadvertently reinforce certain stereotypes or biases, and it overlooks the opportunity for robots to represent a wider range of cultural, social, and individual identities. This underscores the need for a more inclusive and diverse approach in social robot design, an interdisciplinary approach informed by the principles of Universal Design that considers a broader spectrum of visual representations and aesthetics, reflecting the diversity of the societies in which these robots will function.

The following section will explore how a limited grasp of visual social semiotics has led to prevalent visual stereotypes within social robot design. It will critically assess how unintentional uses of certain visual design elements such as colour, material, and form have contributed to these stereotypes, and how without full awareness of their semiotic implications they may inadvertently reinforce current social and cultural stereotypes.

4.4 Social Robot Design Stereotypes

The prevailing emphasis on techno-centric discourse, coupled with a limited understanding of visual social semiotics, has led to the emergence of visual design stereotypes in the field of social robot design. Such interpretations result from a number of issues, including the dominance of white male science fictionists and roboticists throughout history, and the biological underpinnings that foster nurturing and care-taking behaviour in humans. Today, this has manifested itself within three design stereotypes – sexy, cute, and white – all of which continue to dominate the collective cultural imagination of the modern-day social robot.

This section of the thesis will delve into the origins of these stereotypes, exploring how historical, cultural, and biological influences have shaped the current landscape of social robot design. It will also critically examine the implications of these design choices for future social interactions with robots and their impact on human relationships. By understanding the roots and consequences of these stereotypes, this discussion aims to shed light on the need for more diverse and inclusive approaches in social robot design, moving beyond the limitations of current trends and towards designs that reflect a wider range of human experiences and values.

4.4.1 Sexy Social Robots: Masking the Horrors of the Uncanny Valley

The concept of a sexy, attractive robot has been a longstanding trope in science fiction, dating back centuries. This idea is evident in ancient Greek mythology with the story of Pandora and extends to early cinematic representations, such as the femme fatale robot Maria in Fritz Lang's 1927 film *Metropolis*, and even in more contemporary depictions like the male prostitute robot Gigolo Joe in Steven Spielberg's 2001 film *AI* (Andersen, n.d.; De Fren, 2009; The New York Times, 2018). Despina Kakoudaki, Associate Professor in Comparative Literature, has observed that the allure of robot sex has been a recurring fantasy throughout history, appealing due to the notion of control: the creation of a being that is perfectly beautiful, ageless, and indestructible, with interchangeable parts (2014).

While the explicit design of social robots to be *sexy* remains a niche interest within ASFR (alt.sex.fetish.robots) communities, the enduring presence of the *sexy* aesthetic in our collective cultural imagination has influenced the design of social robots (Andersen, n.d.; De Fren, 2009; Penley, 1997; The New York Times, 2018). Elements that were once confined to the realm of science fiction have gradually made their way into the mainstream design of social robots, contributing to the stereotype of the *sexy* robot. This incorporation of sexy design elements from fictional narratives into actual robot designs reflects the broader cultural influences shaping our technological creations and raises important questions about the societal implications and perception of social robots.

The human fascination with "sexy robots" can be linked to the sense of uncanniness arising from the juxtaposition of human sexuality, technology, and death (the inanimate). This phenomenon is rooted in Japanese roboticist Masahiro Mori's *Uncanny Valley* theory (1970), previously discussed in Section 1.2 and illustrated in Figure 9, which addresses profound human anxieties about mortality and the boundaries between life and death. Media scholar Allison de Fren (2009) observes that Mori's theory assumes humans derive emotional investment and pleasure from the non-human. It offers an aesthetic framework for enhancing this pleasure through a dedicated artificiality, represented by the first peak of the uncanny valley curve, rather than through a full simulation of humanness, which is represented by the second peak. In this context, the interplay between human sexuality, technology, and death becomes a focal point, amplifying the uncanny effect and our complex emotional responses to humanoid creations.

However, as roboticists, such as Hiroshi Ishiguro, continue to push the boundaries of hyper-realism, other factors – such as a social robot's ability to articulate movement, respond appropriately within specific contexts, and engage in the nuances of human social interaction – have become more pressing concerns for social roboticists. In the end, the true challenge lies in creating natural and meaningful human-robot interactions as opposed to crossing an objective *visual* uncanny valley. So, in the face of uncertainty and the blurring of boundaries between human sexuality, technology, and death, the reasons that social robots may appear more sexual to such an exaggerated degree may lie in the fact that sexiness can help mask the *horrors* of the Uncanny Valley (De Fren, 2009; Kakoudaki, 2014; Springer, 1996) (see Figure *16*).

> In cases such as these, other boundaries become more vigilantly guarded. In the case of social robots, the gender boundary between male and female is one border that remains heavily guarded despite new technologised ways to rewrite the physical body in the flesh (Balsamo, 1996, p. 9)

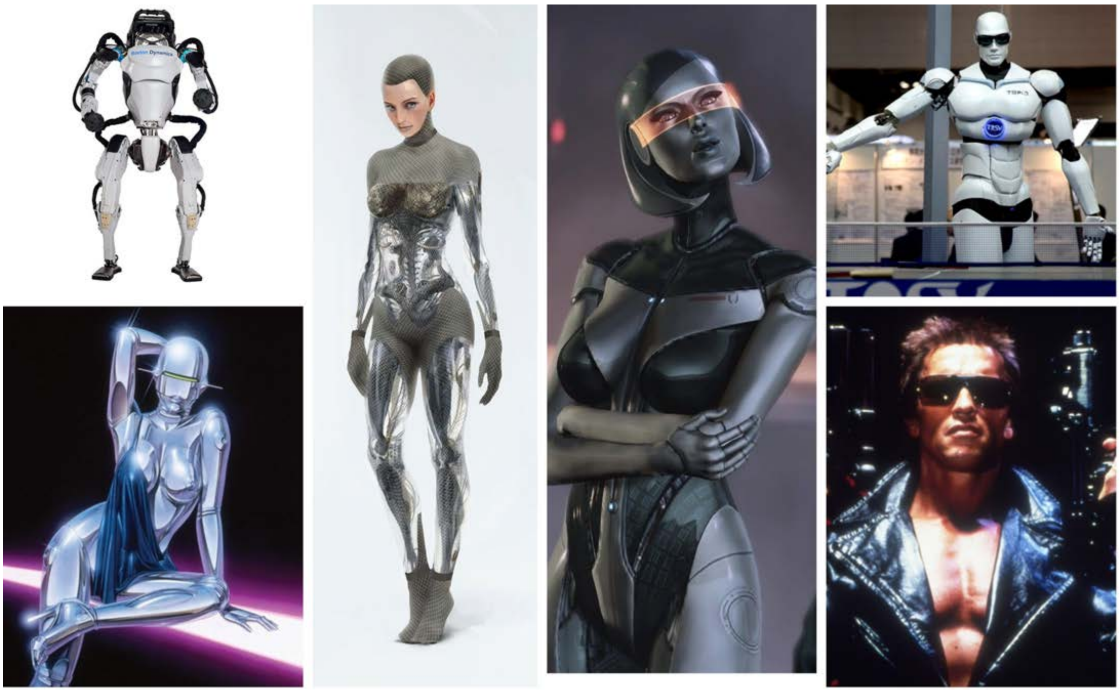

Figure 16. The robots Atlas (left top – O'Connor, 2016), Sexy Robot (left bottom – Sorayama, 1990), Ava (left middle – Garland, 2014), EDI (right middle – Bioware, 2012), TOPIO (right top – TOSY, 2009), and Terminator (right bottom, Cameron, 1984) are robot design which mask the horrors of the Uncanny Valley with sex appeal.

In addition to the influence of the Uncanny Valley, research from psychology and social sciences provides insights into how attractiveness affects human interactions, a factor that extends to social robots. Studies consistently support the *what is beautiful is good* stereotype, indicating that people perceived as attractive are often judged more positively across various dimensions, including their potential for intimacy and satisfaction, and are generally preferred as interaction partners (Brislin & Lewis, 1968; Dion et al., 1972; Tesser & Brodie, 1971; Walster et al., 1966). This tendency to favour attractiveness is not just limited to human-to-human interactions but extends to our perceptions of anthropomorphic objects, including social robots.

The concept of imbuing objects with sexually appealing anthropomorphic qualities was perhaps best exemplified by the iconic 1915 Coca Cola *contour* bottle (Figure *17*), often referred to as the Mae West, named for its distinctly feminine proportions reminiscent of the famous actress. This bottle design marked a significant departure from the straight, featureless bottles common at the time. Its unique shape was not just a novelty; it also elicited a range of anthropomorphic projections such as health, vitality, sexiness, and femininity. These qualities were particularly resonant with the predominantly female consumer base of that era (Curry, 1996; Lidwell et al., 2010; The Coca-Cola Company, 2020).

Figure 17. A Coca Cola Bottle with distinctly feminine proportions reminiscent of famous actor Mae West (Curry, 1996).

The human tendency to perceive and interpret certain forms and patterns as human-like plays a significant role in how we interact with objects, including social robots. Research suggests that attributing attractive, human-like features to social robots can lead to more positive human-robot interactions (Heider & Simmel, 1944; Hutson, 2012). Therefore, if appearance plays a vital role in how people perceive and interact with the world around them, and the goal of human-robot interaction research is to encourage humans to interact with robots, then the creation of an anthropomorphic form that is visually attractive can be seen as almost essential to social robot design (Duffy, 2003; Fink, 2012).

However, while it could be argued that there isn't anything necessarily wrong with designing a sexy robot to encourage human-robot interaction, the use of this visual design aesthetic can become problematic when its reasons for use, whether intentional or unintentional, are out of context, unclear, or not well justified. Such processes can result in many discriminatory behaviours towards not only the genders these robots represent but also, in the near possible future, the robots themselves.

In a field where our collective cultural imagination of the modern-day social robot has been cultivated predominantly by techno-centric, euro-centric, and male-dominated science fictionists and roboticists throughout history (De Fren, 2009; Hornyak, 2006; Mulvey, 1996; Springer, 1996), issues such as sexual objectification, racial biases concerning cultural beauty standards, and the re-enforcement of negative traditional gender roles are topics that must be considered in the visual design of a social robot.

4.4.2 Cute Social Robots: Cute as the New Sexy

Compared to their *sexy* robot counterparts, *cute* is the most popular visual design aesthetic that continues to pervade contemporary science fiction and social robot design. Given their impact on the collective cultural imagination throughout history, robots such as Astro Boy (1952), K-9 (1977) the robot dog from the Doctor Who series, R2D2 (1997) from the Star Wars franchise, The Iron Giant (1999), and WALL-E (2008), social roboticists have continued to lean towards the *cute* visual design aesthetic. Although this aesthetic has become the current default, research regarding the use of *cute* is often not well justified.

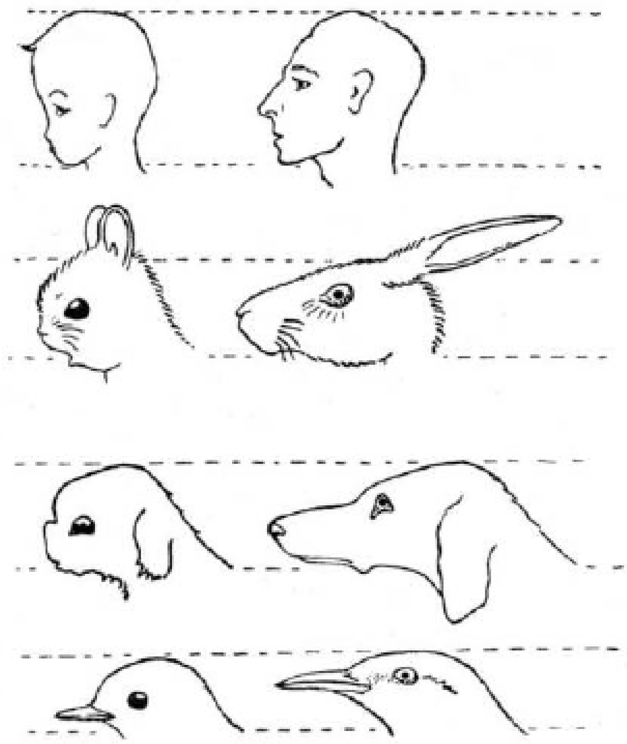

Figure 18. Illustrated example of the Innate releasing mechanism for parental behaviour (Lorenz, 1970)

Building on Charles Darwin's theory of natural selection, Zoologist Konrad Lorenz (1970) notes that the reason we find things to be cute is that they possess certain qualities that we find in our offspring. Developing the *baby schema* ("Kindchenschema"), he identifies and schematises common physical and behavioural characteristics in young children and baby animals that define cuteness. Illustrated in Figure 18, Lorenz described these features as, "a relatively large head, predominance of the brain capsule, large and low-lying eyes, bulging cheek region, short and thick extremities, a springy elastic consistency, and clumsy movements". A notable example of this schema at play (Figure *19*) is how Mickey Mouse and Pikachu's visual design have progressively transformed to align the cartoon character closer to Lorenz's baby schema. Cultural symbols of youth, such as the teddy bear, have also been subject to this effect (Hinde & Barden, 1985).

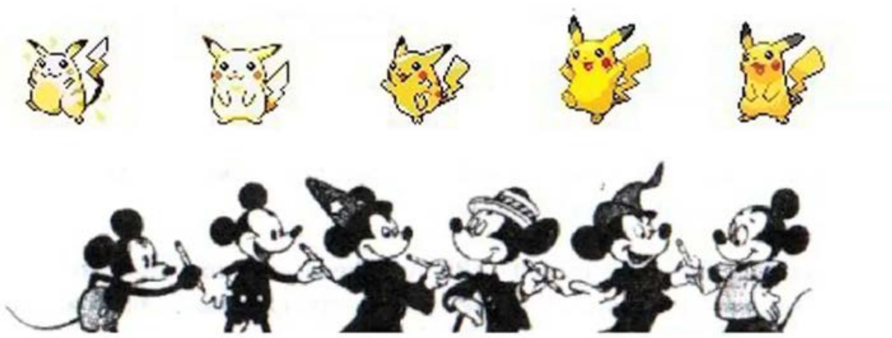

Figure 19. The evolution of Pikachu and Mickey Mouse over the last century becoming cuter over time (Vsauce, 2012).

These physical and behaviourally *cute* characteristics are such powerful forces on the brain that they can trigger the *nucleus accumebens*, the pleasure centre in the brain (also targeted by cocaine and meth) responsible for releasing dopamine into our internal rewards system (Glocker et al., 2009). The effect is so powerful that anthropomorphised and inanimate objects can also elicit the experience of cuteness. For example, the Exploratorium (2008) in San Francisco demonstrates this affect in an interactive show, where the application of Lorenz's baby schema on a hammer turns the utilitarian object into "a cute small toy seemingly made for babies" (Vsauce, 2012) (Figure 20). Recent scholarship has also begun to discern the more precise aesthetic qualities of cuteness that may precipitate such affective responses, including body size and proportion, personality, colour, texture, motion, and sound (Cheok, 2010).

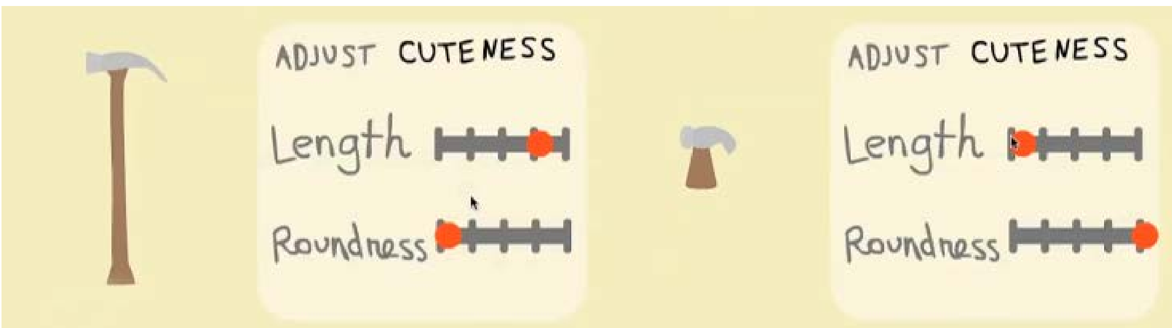

Figure 20. A hammer that has become cute-ified by shortening its length and increasing its roundness (Exploratorium, 2008).

Similar to its use in the design of *sexy* robots, the human fascination with *cute* robots can also be attributed to the same idea of masking the horrors of the Uncanny Valley. Where the design of sexy robots plays on the principal stereotype of *what is beautiful is good*, cute robots play on our innate biological tendencies to protect and nurture our offspring (Lorenz, 1970; Vsauce, 2012). Given the fact that cuteness also fosters several other key subject/object dynamics such as shared affect, empathic responsiveness, pro-social behaviours including communication and companionship, and the quelling of contemporary anxieties, such as the anxieties of the Uncanny Valley (Dale et al., 2016), it is not surprising that cute robots continue to be the visual design default for many social robots today (see Figure *21*).

Figure 21. Bellabots (left top – PUDU, 2020), Kuri (left bottom – Mayfield Robotics, 2017), Wall-E (middle top – Stanton, 2008), AIBO (middle bottom – Sony, 2017), Leka Robot (right top – Leka Smart Toys, 2017), and BUDDY (right bottom – Blue Frog Robotics, 2014) are cute social robots that engage our innate biological tendencies to nurture our own offspring.

When executed correctly, cute design is a visual design aesthetic that can improve human-robot interaction. However, in a similar fashion to sexy robot design, the failure to be explicit about underlying intentions can result in many discriminatory and unethical behaviours (BBC Newsnight, 2017). For instance, the normalisation of gender power inequalities and the sexualisation of youth to render social robots non-threatening by using cuteness as a concealment of agency (Kakoudaki, 2015; McIntyre, 2015; Robertson, 2010). Cuteness even has the potential for political gain in the form of soft power, as seen in Japan's "cool Japan" campaign and heavy investment into kawaii culture, where a country can gain global influence by shaping the preferences of others through appeal and attraction by exploiting the commercial capital of a country's cultural industry (Daliot-Bul, 2009; Valaskivi, 2013; Yano, 2009).

While *cute* lends itself to many pro-social behaviours, the use of the *cute* visual design aesthetic in social robot design without understanding the psychological, cultural, and political underpinnings can become problematic when cuteness is seen as a facile commodity aesthetic as opposed to a deeply rooted behavioural mechanism that draws upon innate biological responses of the human brain (BBC Newsnight, 2017; Dale et al., 2016; Glocker et al., 2009; Lorenz, 1970; McIntyre, 2015). Social roboticists must be aware of the ethical implications that the visual design aesthetic of *cute* might be concealing when designing social robots.

4.4.3 White Social Robots: Visual Symbols of Power and Intelligence

The current visual landscape of social robots was not always so *clean*, *pristine*, and *shiny*. Robots of early legends described powerful, human-like beings made of metal, brass, stone, bronze and gold (Gera, 2003; Godwin, 1876; Littlejohn & Dippmann, 2012; Mateo-Seco & Maspero, 2009). These were materials that could withstand the immense pressures of battle, and symbols representing wealth, power, and the height of human technology and intelligence, and for the most part, it was these materials that would continue to shape the visual design of robots for centuries to come. Starting with the mechanical knight in armour automaton by Leonardo da Vinci in 1495 (Figure 22 – left), to the gold-plated Digesting Duck, by the French inventor Jacques de Vaucanson in 1739 (Figure 22 – middle), all the way to the iconic art deco interpretation of the robot Maria in the film *Metropolis* in 1927 (Figure 22 – right), for many centuries, the visual design of robots was rooted within the mechanical and the machine.

Figure 22. The mechanical knight in armour automaton (left – Moran, 2006), the gold-plated Digesting Duck (middle – Wood, 2002), and Maria from the film Metropolis are earlier interpretations of robots throughout history (right – Lang, 1927).

However, no other film has had a sustained impact on our collective cultural imagination of the modern-day social robot than the 1968 film *2001: A Space Odyssey* (Dourish & Bell, 2014). Noted for its scientifically accurate depiction of space flight, pioneering special effects, and ambiguous imagery, the film was regarded as one of the greatest and most influential films ever made.

Created by filmmaker Stanley Kubrick and sci-fi veteran Arthur C. Clarke, the film follows astronauts aboard a spaceship controlled by the sentient AI computer HAL as they investigate alien artefacts found on the moon. During the film's production, NASA was scrambling to put the first man on the moon, so Kubrick and Clarke knew that their sets and props had to envision beyond the new technologies of its time or else the film would rapidly become outdated or incorrect. Their solution was to hire astronomical artists, aerospace engineers and ex-NASA employees, who advised on spacecraft design (Fuge, 2018; Murphy, 2018).

As a result, it was images of white and silver spaceships and space suits, clean, pristine, spacious interiors clad with glowing bright buttons, and complex touch screen computers and communication devices that were featured throughout the film (Figure 23). This close consultation created a sense of scientific accuracy and produced visionary predictions about humankind's future technologies based on real possibilities. As it so happens, it was these very possibilities that inspired the *then* younger generation to become the *now* future sci-fi storytellers, filmmakers, engineers, and scientists to create the technologies that we now have today (Fuge, 2018; Murphy, 2018). In many ways, the film has become today's reality, with the film's influence still present in the conceptualisation, design and application of various technologies, especially the modern-day social robot (Fuge, 2018).

Figure 23. The design aesthetic of the film 2001: A Space Odyssey (Kubrick, 1968).

As opposed to metal, bronze, stone, brass, and gold, the space exploration design aesthetic became the new symbols of wealth, power, and the height of technological intelligence. To replicate this aesthetic and evoke the sense of wonder associated with 'the bleeding edge of technology' famously portrayed in *2001: A Space Odyssey*, roboticists turned to cheap, white plastic exteriors. This design choice became a defining characteristic of modern-day social robots, as reflected in a Google search for "social robots," previously discussed in Section 1.2 and illustrated in Figure 13.

The aesthetic choices in *2001: A Space Odyssey*, particularly the use of white and silver for spaceships and spacesuits, were deeply rooted in the practicalities and necessities of space exploration, raising questions about their relevance in the design of modern-day social robots. The use of white in space technology is primarily functional: white effectively reflects radiation in space (Clara Moskowitz, 2010; Shira Polan, 2019) and offers high visibility for spacewalkers against the stark backdrop of space (NASA, 2012). In the harsh environment of space, every aspect, from colour properties to human biology, must be meticulously considered to ensure safety and efficiency.

However, translating this *white* space exploration aesthetic directly to social robot design overlooks the fact that these robots operate in vastly different environments. The conditions that necessitate white and silver in space do not apply to the typical contexts in which a social robot might function. Applying the same colour scheme to social robots without considering its original functional purpose may lead to design choices that are aesthetically driven rather than functionally justified (Addison et al., 2019; Eyssel & Loughnan, 2013; Kandinsky, 1912). When the colour white is removed from its functional space context and examined from a human-robot interaction perspective, its use becomes more symbolic than practical.

The historical and cultural use of colour to classify certain social groups throughout human history means that within the context of human-robot interaction, the colour white takes on new meaning (Gage, 1999; Koller, 2008). A small number of studies have explored the idea of people implicitly attributing race in their interactions with social robots and given the lack of visual diversity in social robot design the prevalence of the colour white may encourage notions of white colonialism and discrimination (Eyssel & Hegel, 2012; Eyssel & Loughnan, 2013; Fiske, 1998, p. 199). There are many social contexts in multi-racial societies wherein a person's race plays a crucial role in people's attitudes, beliefs, and behaviours towards them. If all robots pertain towards a single design aesthetic, then these robots might be unable to be taken seriously on specific topics or relate effectively to people on a more personal basis (Bartneck et al., 2018).

In conclusion, the exploration of the origins and implications of prevalent stereotypes in social robot design is a crucial step towards fostering a more inclusive and diverse future in this field.

Historical, cultural, and biological influences have undeniably contributed to the current homogenised design landscape, often at the expense of broader social representation and sensitivity. As we critically assess these influences and their consequences on human-robot interactions and societal perceptions, the need for a paradigm shift becomes evident. The next section of this thesis will focus on the existing approaches in social robot visual design, highlighting how they have perpetuated these stereotypes and the challenges they present and how we can design social robots that are not only technically proficient but also culturally empathetic and socially responsible.

4.5 Existing Approaches in Social Robot Visual Design

The stereotyped sexy, cute, and white aesthetic that continues to prevail in the landscape of social robot visual design is largely the result of processes that emphasise the engineering design values of functionality and efficiency over all other values. This, in conjunction with the misconceptions surrounding the role of designers over the last century, has resulted in design processes that have divided social robot development into two distinct and separate phases (Hoffman & Ju, 2014; Mital et al., 2014; Nelson & Stolterman, 2014).

- The first phase – where engineers are tasked with solving practical or functional problems.
- The second phase – where designers are relegated to work on aesthetic elements of surface, appearance, and styling for aesthetic appeal.

The following section describes three approaches to social robot movement design that have resulted from the dichotomy of these two phases and aims to discuss how each approach has contributed to the current visual landscape of social robot design.

4.5.1 The Pragmatic Approach

Situated within the design values of engineering, a pragmatic approach to designing personal social robots, according to Hoffman and Ju (2014), focuses on the underlying philosophy of the robot as a tool (the pragmatic approach described by Hoffman and Ju here is different to the theoretical framework of Pragmatism as described earlier in Section 3.2). It is a techno-centric approach to design that views technological change as an inevitability and focuses on "how to adapt to technology, not how to shape it" (MacKenzie & Wajcman, 1999; Šabanović, 2010).

The pragmatic approach is the result of the technical difficulty of developing hardware for social robots, as robots require an incredibly high level of resources, time, and expertise from the disciplinary fields of engineering, computer science and artificial intelligence in order to engineer an autonomous, digitally operated, and programmable robot that can also withstand the basic forces of gravity. Hence, functionality and efficiency are the value sets that continue to have the largest influence in personal social robot design, and this is evident in the literature where there is often a lack of discussion of visual design-related problems and a reliance on outsourcing such problems to designers after the fact (Hegel et al., 2011; Young et al., 2009).

In this approach, visual design, and by extension visual social semiotics, is typically not considered a core concern and is even considered a hindrance to the robot's functional ability (Frennert & Östlund, 2014). Hoffman and Ju (2014) note that in some cases, after developing the robot's core movement capabilities, a shell is designed in order to cover internal mechanisms and achieve a particular *look* for the robot. Constrained by the robot's existing core, this shell's structure and shape usually follow its lines and proportions closely to cover internal mechanisms and achieve a particular look for the robot. For reasons of mechanical optimisation, these limbs are often structured as chains of cantilevers from a rotation point and follow the principles of symmetry, orthogonality, and concentric relations. In some cases, roboticists reason visual design decisions with some basic visual social semiotic research from the fields of human social psychology and interaction, such as basic colour theory, cute design, and theories in avoidance of the Uncanny Valley; however, its implementation is often superficial and in service to the more functional aspects of the robot's design (Frennert & Östlund, 2014; Wallace, 2019).

The resulting design is typically an assembly of limbs with the parts of the robot, such as actuators and cables, exposed with tacked-on tablet screens featuring a simple facial interface made to communicate the robot's more social features. Figure *24* features robots designed with the pragmatic approach in mind. SAM (Figure *24* – left) is a roving lectern robot with the ability to communicate through text-based emoticons on a large tablet screen. Sawyer (Figure *24* – middle) was initially designed as an industrial robot arm and later given the ability to communicate through a tablet screen. And Alter 3 (Figure *24* – right) is a realistic humanoid robot that features exposed limbs and actuators in the head and body to optimise realistic movements in the face and hands.

Figure 24. SAM Robot (left – Luvozo, 2017), Sawyer (middle – Rethink Robotics, 2015), and Alter 3 (right – Hiroshi Ishiguro Laboratories, 2020) are robots designed with the pragmatic approach in mind.

4.5.2 The Visual Approach

According to Hoffman and Ju (2014), a visual approach to designing personal social robots focuses on the idea of the idealised social robot. It differentiates itself from the pragmatic approach through the specification of a social robot that prioritises appearance and is typically heavily inspired by the representation of robots within media. The undertaking of this approach is typical when expressive interaction is the core intention of the design. In this approach, a group of robot users specify the features, such as eye movements, facial expressions, communicative hand gestures, and colours, required for designing a social robot given the context of a specific interaction. Subsequently, the visual designers then decide how far along the humanoid spectrum to place their design (Figure *25*), which, in turn, affects the choice of shape, material, body and facial parts, as well as the amount of detail sculpted into the robot's form (Duffy, 2003). However, this isolated developmental process from pragmatic considerations results in a significant compromise when the final design is given to engineers to build and implement.

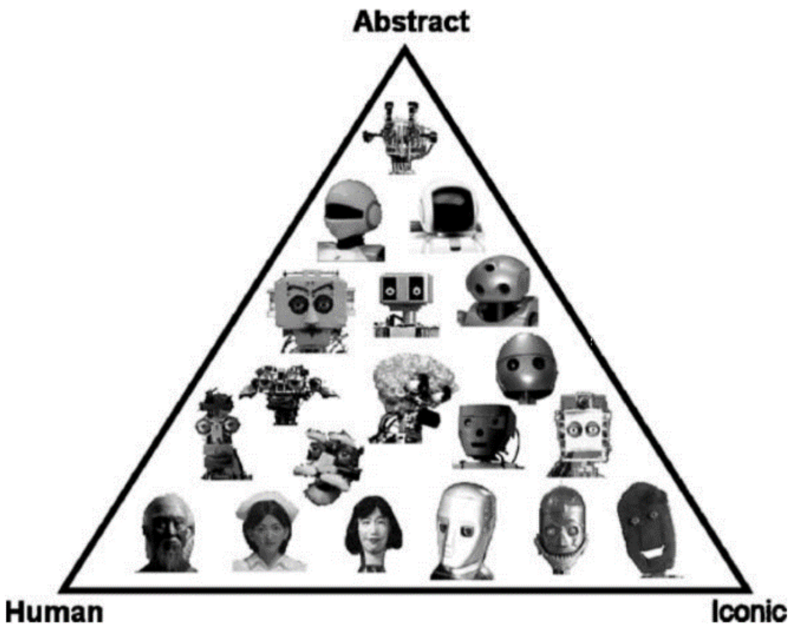

Figure 25. Anthropomorphic design space for robot heads (Duffy, 2003).

As these designs are, in the end, still subject to the engineering values of functionality and efficiency, as they must still be able to function within the real-world, visual designers are typically pigeonholed into a particular design aesthetic that forces them to look towards popular robots in film and television to cater to the general population. In the end, the robot's visual design is the result of the justification of its aesthetic mass appeal as opposed to its visual social semiotic applications for human-robot interaction (Kandinsky, 1912; McCloud & Martin, 2017; Vihma, 2007). As a result, the visual approach typically pertains to the stereotypical sexy, cute, white social robot designs detailed in Section 4.3.

4.5.3 The Movement-Centred Approach

In response to the problems associated with dividing social robot development into two distinct and separate phases, Hoffman and Ju (2014) articulated the Movement-Centred Approach to reconcile the two phases and refocus the attention towards the importance of movement for emotional expression in social robots. This approach bases itself upon the human theory of mind, where humans are typically inclined to attribute human-like characteristics such as emotion, intention, identity, and gender to autonomous moving objects (BBC Newsnight, 2017; Heider & Simmel, 1944). In its original conception, this approach's core aim was to consider the expressive quality of movement in conjunction with its engineering and visual design limitations throughout the entire design process as opposed to after.

Hoffman and Ju (2014) were able to anchor functionality and visual design to the expressive quality of movement through various techniques. The techniques they included involved: 3D animation gesture studies for visualising potential designs and simulating various movement patterns, skeleton prototype studies that could physically test the real-world feasibility of certain robot designs, wizard of oz studies that could experiment dynamically with a system's performance and including a human user in the design loop, video prototyping which built on all the previous techniques by allowing for user feedback in a more controlled environment, and an interactive degrees of freedom exploration through a proprietary software tool for the interactive exploration of degrees of freedom configurations for expressive robots. The approach then utilises all the information gained within these techniques to create the best possible robot design solution.

As this approach focuses more on the expressive quality of movement, the resultant design pertains to a particular design aesthetic that Hoffman and Ju describe as "typically non-humanoid, displaying a formal simplicity and abstract geometrical shapes while exhibiting its complexity and sophistication primarily through carefully designed movement qualities." (as portrayed in Figure *26*). In this approach, the visual design of a social robot is seen as a factor that could potentially distract users from the semiotic potential of movement, and hence, robots designed with this particular approach in mind pertain towards the stereotypical white social robot design. In the context of a research lab, the visual semiotics of the colour white is intended to represent a clean, pristine, and neutral design in which users can project their image onto the robot (Bartneck et al., 2018; Rose & Björling, 2017; Sparrow, 2019). However, as mentioned in Section 4.3.3, the semiotics of the colour white within different contexts can be vastly different for a diverse range of people.

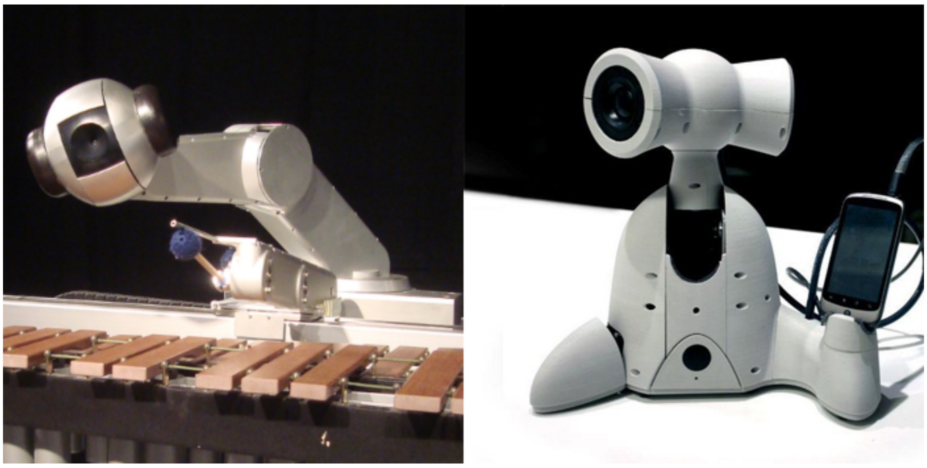

Figure 26. Shimon the Marimbaist and Travis the Robot Musical Companion (Hoffman & Ju, 2014).

4.5.4 Critiquing Current Approaches to Social Robot Visual Design

Social robots are designed to interact with other humans on a more personal and intimate basis. Within this realm of interaction, social robots must interact with humans on a functional basis and engage in the nuanced intricacies of human interaction all at the same time. Given that human social interaction is a highly intricate and interconnected system that has been driven throughout history by our biology, society, and culture, designing a social robot is, therefore, not just about designing something functional, visually appealing, and designing something that can effectively display human emotional displays of expression. It is also about understanding and inscribing the ever-changing social context, nuance, and potential ethical impacts of such technology on future societies simultaneously (Davis & Nathan, 2015; Hoven et al., 2015).

> Visual knowledge is as dependent on lived, embodied, specific knowledge as any other field of human endeavour, and integrates other sense data as part of cognition. Not only do we process complex representations, but we are imbued with cultural training that allows us to understand them as knowledge. *(Drucker, 2014, p. 20)*

However, as demonstrated above, the siloed processes of the pragmatic, visual, and movement-centred approaches do not have the scope or flexibility to address the interconnected and nuanced intricacies of human social interaction. While the pragmatic, visual, and movement-centred approaches offer many insights, it would be naïve to assume that merely combining all these approaches would encompass and address all the issues associated with social robot design, this being a typical methodology in the field of social robot design (Dautenhahn, 2002; Duffy, 2003). This situation is akin to the metaphor of Mary Shelly's *Frankenstein's Monster,* where an attempt to combine disparate approaches without a cohesive vision can result in a social robot that resembles a disjointed assembly of various parts. This approach leads to a final design that lacks visual coherence and unity, reflecting the challenges of integrating diverse design elements without a holistic, integrative strategy.

The prominence of such robots stems from a distinct lack of discussion regarding visual social semiotics in social robot design literature and the limited time and space given to discussing visual design-related problems (Frennert & Östlund, 2014; Wallace, 2019). There is an extensive vocabulary in visual design, and a wealth of knowledge, principles, and concepts underutilised in social robot design. Despite this, the literature typically only addresses the more superficial aspects of a robot's visual design with a shallow understanding of how and why they are using specific elements and their resulting impact on users (Davis & Nathan, 2015; Frennert & Östlund, 2014; Hoven et al., 2015; Wallace, 2019). This sort of approach results in the derivate social robot design stereotypes mentioned previously in Section 4.3.

Visual design informed by an understanding of the social impact of the visual has the dual goal of conveying information objectively about real-world features such as a robot's functionality without too much instruction, and subjectively in a form that is sensitive to its cultural, ethical, and social contexts (Hentschel, 2014). There is a whole wealth of knowledge and meaning behind the various principles and concepts that are often unknowingly utilised in social robot design. If social robots are to function as positive active members within human society, engineers must collaborate with visual designers that are skilled in visual social semiotics. This would result in a social robot design that considers all the elements and principles of visual design and the semiotics associated with their cultural and social use, as well as its technical requirements, ironically, to make human-robot interactions more efficient, more nuanced, and all-inclusive by allowing robots to communicate using all of their possible communication channels in a cohesive and carefully considered manner (Henderson, 1998).

The following section aims to demonstrate the various elements and principles that visual designers and animators, who are skilled in visual social semiotics, utilise to achieve a particular look sensitive to social and cultural contexts.

4.6 The Semiotics of the Elements and Principles of Visual Design

Discussions regarding the visual design of social robots typically revolve around the design elements of shape and form, as these elements have the most impact on a social robot's functionality and movement capabilities. Given that human social interaction is an intricate interconnected system that is highly contextual and nuanced, consideration of all the elements and principles of visual design should occur in conjunction with the universal design principles (mentioned previously in chapter 3) to understand their meaning within context. Together, they give a more holistic, more nuanced, and all-inclusive understanding of a social robot's visual design in a form sensitive to its cultural, ethical, and social contexts. This is crucial as seemingly small changes can significantly alter how people choose to interact with social robots. In addition, a basic understanding of the elements and principles of design can also assist in fostering understanding, communication, and collaboration between designers and non-designers.

The following sections will describe each of the elements and principles of design in detail, discuss the semiotics of their use, and then contextualise them within social robot design.

4.6.1 The Elements of Visual Design

The foundational elements of visual design are colour, line, shape/form, texture/pattern, and space. These elements constitute the core components from which all visual design work is built. Mastery of these elements allows designers to create compelling and effective visual compositions, crucial in various fields, including social robot design. Understanding and skilfully applying these elements can significantly impact how social robots are perceived and interacted with, making them more relatable, functional, and engaging for users. The following sections will delve into each of these elements in more detail and explore how they might affect social robot design.

4.6.1.1 Colour

At the basic level, colour describes the intrinsic hues found in light and pigment. In design, numerous systems exist to categorise, name, and classify colour for various applications. However, the basic premise of colour begins with three fundamental dimensions: hue, value, and chroma. Hue is what identifies colours on a simple spectrum of primary and secondary colours. These colours include red, violet, blue, green, yellow, and orange. These colours can then be divided into further subsections of the same colour using value and chroma. Value refers to the lightness or darkness of a hue achieved by adding black to a base colour for a shade, and white for a tint. Chroma refers to the vibrance or dullness of a hue achieved by altering a hue's strength.

This system of describing colour is essential for understanding basic colour theory, where different colour combinations and relationships can communicate particular attitudes or moods, enhance compositional space by controlling colour contrast, and help draw attention to specific aspects of a design by accentuating visual hierarchies or by activating specific shapes or spaces (Itten, 1970; Kandinsky & Rebay, 1926).

The semiotics of colour plays a pivotal role in enhancing the practical, cultural, psychological, personal, and expressive dimensions of visual design. The meaning a colour conveys is highly dependent on its context of use (Kauppinen-Räisänen & Jauffret, 2018; Kress & Leeuwen, 1996; Leeuwen, 2005). Different contexts and applications can imbue the same colour with vastly different connotations and effects. For instance, in the context of portraying mood and intent in embodied mediums, red manifested within the pupils of the eyes can be used to indicate anger (Figure 27 – right), whereas red manifested upon the surface of the cheeks can be used to represent shyness (Figure 27 – left), (Conti et al., 2020; Kaya & Epps, 2004; Kędzierski et al., 2013; Nijdam, 2009). In the context of behaviour modulation, the colour red can also be used to indicate danger where a red glowing button can also be used as a symbol to draw attention to and deter specific interactions (Herman et al., 2018; Raudonis et al., 2017; Silic, 2016).

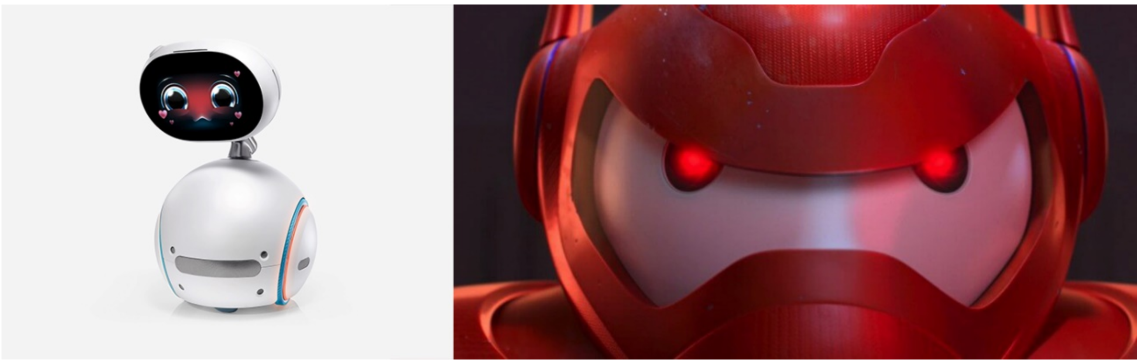

Figure 27. Red across the surface of its cheeks can indicate shyness as portrayed by Zenbo (left – ASUS, 2016) and red within the pupils of the eyes can indicate anger as portrayed by Baymax (right – Williams & Hall, 2014).

The semiotic meanings of colours are shaped by various cultural, historical, and social factors, making it essential to carefully consider the context in which a social robot is designed and used. For instance, the prevalent use of white as the default design aesthetic for many social robots, as discussed extensively in Section 4.4.3, carries significant cultural and historical connotations where differences in skin colour have been a basis for social differentiation and discrimination (T. Jones, 1999; Ware, 2013).

The challenge for social roboticists is to move beyond a one-size-fits-all approach and to be aware of the broader spectrum of aesthetic choices that reflect and respect the diversity of human experiences and cultures (Kandinsky, 1912; McCloud & Martin, 2017). This approach would not only make social robots more inclusive and relatable but also enrich the range of interactions and connections they can form with users from diverse backgrounds. By acknowledging and addressing the cultural and social implications of colour, designers can create social robots that are better suited to operate with individuals on a more personal level.

4.6.1.2 Line

Line refers to a moving point's path through space due to external causes acting upon a fixed point (Brommer, 2011; Field, 2018). It is the most fundamental design element as it is typically the starting place for most design endeavours. Lines can be directional, horizontal, vertical, diagonal, curved, zigzagged, be of any width, size, shape, direction, interval, density, and can be made up of different colours, textures, or patterns. Lines can also change in direction, change in degree or be a combination of all the above.

In non-design discourse, lines are often thought of simply as tools for outlining and contouring objects. However, in the world of design, lines possess a dynamic nature that allows them to suggest different moods or emotions through variations in their quality (Kandinsky, 1912; Oswald & Oswald, 2012, 2015). The semiotic interpretation of lines is closely linked to their practical and biological representations in the world around us, meaning that the significance we attach to different types of lines often reflects their common occurrences or associations in our environment (Brommer, 2011; Field, 2018; Leeuwen, 2021).

For instance, straight and angular lines are frequently perceived as stiff and mechanical. This perception stems from their prevalent use in technological and mechanical constructs, where practical, geometric shapes dominate. Such lines also have natural connotations; in the natural world, straight and angular lines often signal danger, such as the thorns on a plant or the sharp teeth of an animal. These natural associations can evoke a sense of caution or alertness. Conversely, lines that are organic and fluid often suggest notions of freedom, flexibility, and ease. This interpretation is influenced by the prevalence of such lines in nature, such as the shape of a wave or a shell, where organic forms and fluid shapes are commonly found. These lines can evoke a sense of naturalness, growth, and movement, contrasting sharply with the rigidness and structure associated with straight, angular lines.

Within the context of social robot design, lines are only used to outline and contour the robot's shape. As a result, many social robots today, such as RoboThespian or Stevie II (Figure *28*), typically feature straight, angular lines that do not vary in terms of size or quality. This often results in a stiff or mechanised visual appearance that has become stereotypical of the robot look. To offset the angular use of line and instil a sense of the human-like organic, roboticists typically utilise slight curves and bevelled edges in the robot's exterior to give a more organic or *natural* look to the overall design (Hoffman & Ju, 2014). However, the problem is that this quality of line is typically isolated from the overall design composition. What results is an incohesive use of line against other visual design elements. Hence, the design still pertains to the stereotypical stiff, mechanised robot-like appearance instead of the desired natural organic look.

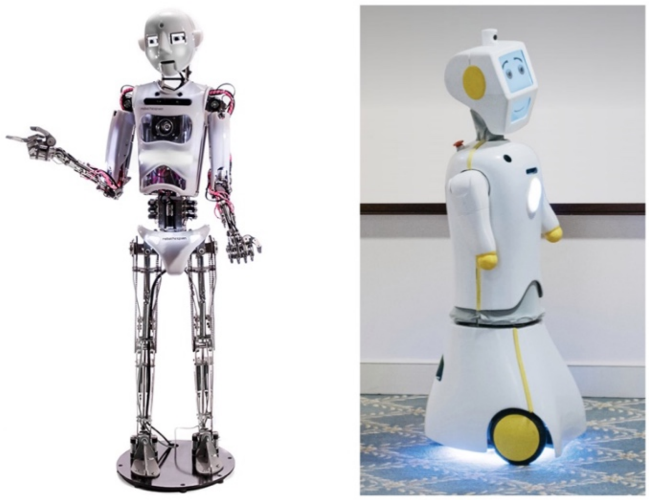

Figure 28. RoboThespian Robot (left – Engineered Arts, 2014) and Stevie II Robot (right – Robotics and Innovation Lab, 2014) are designs which try to use slight curves and bevelled edges to give a more organic or natural look.

In addition to outlining and contouring, consideration for implied lines is crucial in social robot design. Implied lines refer to the invisible lines that emerge due to the placement and alignment of various design elements within a composition (Brommer, 2011; Field, 2018; Osaka et al., 2010). These lines guide viewers' perceptions and interactions with a design, subtly directing attention and engagement in specific ways. For example, the design of the Boston Dynamics Spot Robot (Figure 29) utilizes implied lines to guide users' attention toward the "head," the primary point of interaction. The robot's body structure creates a natural visual flow that highlights the head as the focal point, where its cameras and sensors are located. This intuitive design enhances functionality by ensuring users can easily identify the interaction point critical for human-robot engagement. Moreover, the backward and forward alignment of the legs generates a dynamic visual flow, evoking a sense of anticipation and readiness. This posture communicates a feeling of speed and agility, as if the robot is perpetually prepared to move. By strategically leveraging these visual cues, the design not only makes the robot's purpose clear but also fosters seamless interaction by intuitively informing users about its function and points of engagement.

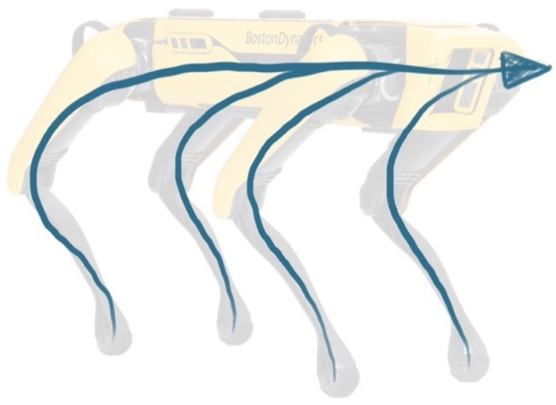

Figure 29. Annotated image of the Boston Dynamics Spot Robot, demonstrating how the alignment and positioning of its legs naturally draw users' attention toward the "head" through implied lines (Boston Dynamics, 2016).

In the context of social robot design, implied lines take on an additional role in conveying moods or emotions. Within individual objects or robots, implied lines can span the entire length of the object to form a *line of action*, a structural line that underpins poses or movements (Hooks, 2017; Thomas & Johnston, 1995; R. Williams, 2012). The semiotics of these lines are closely related to social and biological aspects of human interaction. As demonstrated in Figure *30 – left*, the positioning of this implied line can evoke different emotional states, such as a feeling of enclosure and protectiveness in a deeply curved line, or a sense of pride and openness in an upward curved line.

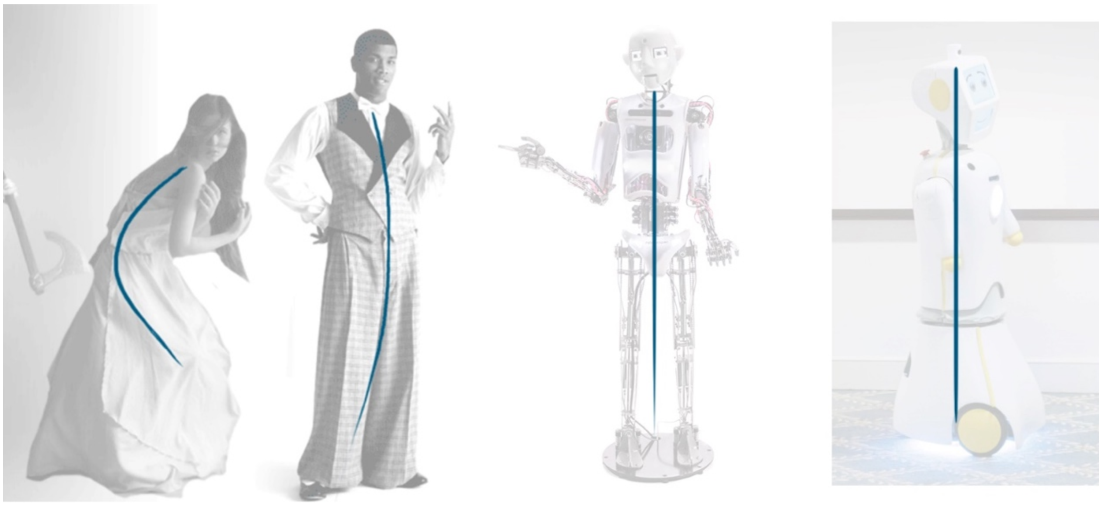

Figure 30. Annotated images comparing lines of action in human body poses (left – Genly Inc, 2012) with those in social robot designs (middle – Engineered Arts, 2014; right – Robotics and Innovation Lab, 2019).

Due to practical considerations like physical balance, most social robots feature straight lines of action that do not vary much in size or quality, as demonstrated in Figure *30 – right*. This design choice, while functional, is relatively rare in the human body (Hooks, 2017; Thomas & Johnston, 1995; R. Williams, 2012) and can lead to stiff and unnatural poses in robots, potentially impacting the fluidity and naturalness of human-robot social interactions. Recognising the potential of varied lines of action could enable designers to create social robots with more natural postures and movements, enhancing their ability to engage in more relatable interactions with users.

4.6.1.3 Shape/Form

A shape in design is essentially a distinct and recognisable area that stands out from its surroundings due to a defined or implied boundary (Brommer, 2011; Field, 2018). This distinction can be created through differences in colour, line, texture, or the utilisation of space. Shapes are fundamental elements in design and can be categorised into various types, each with its own characteristics and implications.

- **Geometrical Shapes**: These are the shapes that are typically drawn using tools like rulers and compasses. They include circles, squares, rectangles, triangles, and other regular forms. Geometrical shapes are known for their precision, uniformity, and often convey a sense of order and structure.
- **Organic Shapes**: These shapes are commonly found in nature and are characterised by their natural, fluid, and irregular forms. They can include the shapes of leaves, flowers, and the contours of landscapes. Organic shapes are often perceived as more natural and spontaneous compared to geometrical shapes.
- **Curvilinear Shapes**: These are shapes composed of curved lines and smooth edges. They often have a gentle, flowing appearance and can be seen as a subset of organic shapes, emphasising softness and fluidity.
- **Rectilinear Shapes**: In contrast, rectilinear shapes are composed of sharp edges and right angles. They exude a sense of stability and rigidity, often associated with man-made objects.

Furthermore, shapes can be two-dimensional or three-dimensional. Two-dimensional shapes are flat and only have height and width, such as a circle drawn on paper. Three-dimensional shapes, on the other hand, have volume and are part of our spatial reality, like a sphere or cube.

The design elements of shape and form are particularly significant in social robot design due to their measurable impact on a robot's functionality (Denys et al., 2004; Hoffman & Ju, 2014).

These elements are crucial in determining how effectively a robot can perform its intended tasks. For instance, a 2-pronged gripper (Figure 31 - left) is ideal for precision tasks, such as placing small components like screws or chips into circuit boards during assembly in a factory setting. In contrast, a 5-fingered robotic arm prosthetic (Figure 31 - right) is better suited for tasks that require dexterity and the flexibility to handle irregularly shaped items in everyday scenarios, such as safely manipulating knives or glassware in a kitchen at home.

Figure 31. Arduino arm featuring a two-pronged gripper (left – MIT Mechanical engineer, 2024) compared to an Arduino arm featuring a five-fingered arm (right – Florida Atlantic University, 2017).

However, the considerations for shape and form in social robot design rarely extend beyond functionality. Since social robots are intended to interact with humans, the aesthetic and emotional implications of their shape and form are equally important, as physical appearance influences how individuals engage in human-robot interaction (Airenti, 2015; Duffy, 2003; Ferrari et al., 2016; Fink, 2012). For example, BAXTER (Figure 32 - right) waves hello with a more human-like hand, which may be perceived as relatable and approachable due to its resemblance to natural human gestures. In contrast, EDI (Figure 32 - left), a variation of the BAXTER robot, waves hello using a mechanical two-pronged gripper. While functional, this design may appear less intuitive for human-robot interaction, as its form and gestural capabilities lack the familiarity typically associated with human communication.

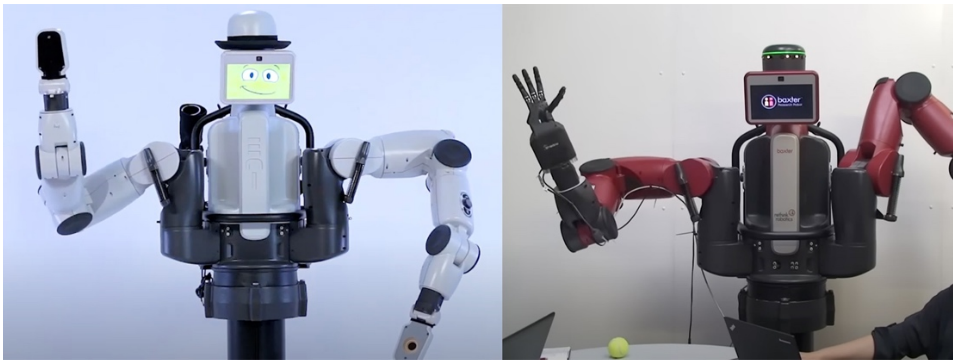

Figure 32. EDI (left – Tempest, 2014) waving hello with a two-pronged gripper in contrast to BAXTER (right – Shadow Robot, 2015) waving hello with a human-like hand.

The semiotics of shape and form are deeply rooted in our biology, environment, and culture, shaping how we perceive and interact with the world. For example, the Kobian robot (Figure 33 - left) features a facial design with angular edges, sharp points, and exposed internal wiring, which can be perceived as harsh or uninviting. This reaction is influenced by our real-world experiences with discomfort and pain, such as those associated with medical surgeries or injuries (Lidwell et al., 2010). The exposed wiring and sharp, angular features of Kobian may subconsciously evoke unsettling imagery of exposed skin or internal anatomy seen during medical procedures, triggering feelings of vulnerability and defensiveness. These design elements amplify the perception of the robot as cold and unapproachable, reducing its visual and emotional appeal.

Conversely, designs with soft, curved edges, like those of the Nao Robot (Figure 33 - right), are often perceived as natural and inviting. These forms are typically associated with organic shapes, which convey fluidity and aesthetic harmony, similar to the concept of the Mae West bottle discussed in Section 4.4.1 and illustrated in Figure 19. Rounded and smooth designs avoid evoking discomfort or unease, instead fostering feelings of warmth, friendliness, and approachability. This stark contrast underscores the importance of thoughtful design choices in creating robots that resonate with human users, especially in social contexts where trust and comfort are essential.

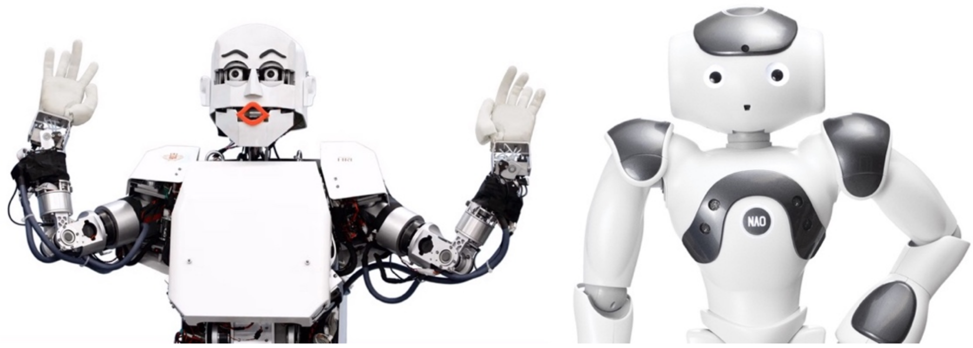

Figure 33. Kobian Robot (left – Kamayashi, 2007) featured and Nao Robot (right – Softbank Robotics, 2008)

The discussion on the visual social semiotics of using specific shapes and forms in social robot design is often overlooked or superficially addressed. Typically, these conversations are limited to basic psychological interpretations, lacking in-depth exploration of the cultural, social, or psychological ramifications within specific contexts. As highlighted in subsection 4.5.4, it is crucial for roboticists to move beyond a purely functional perspective and delve into the semiotic implications of shape and form. This approach involves not only assessing the physical and operational aspects of the robot but also understanding how different shapes and forms might be interpreted by diverse user groups.

4.6.1.4 Texture/Pattern

The term *texture* originally referred to the art of weaving and the qualities of woven materials, but gradually expanded to encompass the tactile, material quality of objects, and the synaesthetic interaction of tactile and visual features (Brommer, 2011; Djonov & Leeuwen, 2011; Field, 2018). Tactile textures refer to the physical three-dimensional texture of an object which can be perceived by touch whereas implied textures refer to textures not detectable by our sense of touch but by our sense of sight – the idea of seeing and feeling. Implied textures suggest an illusion of tangibility, brought about visually by shifts in focus and colour and by patterns of lines and shapes (Djonov & Leeuwen, 2011). For example, a photograph of a rough tree bark creates the impression of a real texture, but the photograph itself would remain smooth to the touch regardless of how rough the represented texture is.

Textures appeal to our sense of touch, allowing designers to create visual interest, incite associations with particular objects, or evoke specific emotional responses from people. In a paper about the semiotics of texture, social semioticists Djonov and Van Leeuwen (2011) proposed six primary qualities used to describe tactile surface texture to understand how tactile sensations might translate into meaning. These properties included liquidity (wetness or dryness), viscosity (stickiness or grippy-ness), temperature (coolness or warmth), relief (the bumpiness or smoothness), density (density or sparsity), rigidity (hardness or softness), and complexity of a texture (degree of consistency).

In each of the categories listed above, the authors provided examples of how specific properties of a texture might incite particular meanings within different contexts. For example, how the *coolness* of an object in specific contexts can be associated with the idea of death in the same way the body goes cold upon dying, or rationality and intellect in the same way a person can *maintain a cool head* in stressful situations. Alternatively, how the warmth of an object can be associated with danger in the same way the extreme heat of fire is hazardous to humans, or affection and tenderness from sensations that we feel during human expressions of intimacy such as the *warm embrace*. In any case, the semiotics behind texture can influence how a person might interact with a design by altering how pleasant or discomforting a particular texture is perceived to be.

Shiny, smooth, plastic shells are the most common textures and patterns that adorn social robot design today due to the media's insistence on replicating the space exploration design aesthetic common during the space-race period of the 1950s and 1960s (Clara Moskowitz, 2010; NASA, 2012; Shira Polan, 2019). The ability for plastic to be produced cheaply and efficiently while still providing sufficient protection for a robot's internal mechanisms make plastic a viable alternative to the more practical white, metal exteriors of spaceship design. However, the need to pertain to this design aesthetic can become problematic within the context of human-robot interaction, as it can create an incongruency between the anthropomorphised human-like or animal-like forms most social robots today aim to replicate. Given that living human and animal skin is typically warm and soft with some sense of relief, the use of cold plastic textures may create a sense of uncanniness resulting from semiotic cultural and biological associations related to death. In addition to this, Djonov and Van Leeuwen (2011) posit that due to plastic's smoothness, the lack of relief in its texture may also make social robots less engaging to interact with as there is nothing to explore in the touch of its surface.

In the realm of social robot design, there is a growing trend of experimentation with diverse materials, moving beyond the traditional space exploration aesthetic of smooth, hard surfaces. Robots like Paro (Figure *34*), which utilise fur, and others that employ silicone elastomers, hydrogels, and braided fabrics, exemplify this shift towards more varied tactile experiences. In that respect, it is important to be aware of the meanings different textures might convey and how they might evoke certain emotional responses from particular individuals.

Figure 34. The fur covered robot seal Paro (Motonari, 2015).

4.6.1.5 Space

Space in design refers to how distances and areas are managed within a composition, encompassing the arrangement and interaction of various design elements (Brommer, 2011; Field, 2018). It is about how these elements are organised and positioned to create visual clarity and impact. There are several key aspects to be aware of when it comes to space in design:

- **Positive and Negative Space**: Positive space in a design refers to the main subjects or areas of interest, the parts of the artwork that draw attention. Negative space, on the other hand, is the space around and between these subjects. Both positive and negative spaces are crucial in creating a balanced and effective composition. The interplay between these spaces can greatly influence the viewer's perception and interpretation of the piece.
- **Perspective and Proportion**: Perspective in design involves creating a sense of depth and dimension in a composition, often using techniques like size scaling, texture, and colour gradation. Proportion, meanwhile, refers to the relative size and scale of the various elements in a design. Both perspective and proportion are essential for creating a sense of realism and spatial harmony in a design.
- **Layering of Elements**: Layering involves arranging elements over one another in a composition, which can help in creating depth and a sense of three-dimensionality. This technique can be particularly effective in designs where conveying spatial relationships is crucial.

Particular uses of space enable designers to exaggerate specific design elements in order to portray particular feelings or emotions. For instance, as displayed in Figure *35*, a design that uses a large amount of positive space by increasing the size of the subject can create a feeling of dominance over the viewer, whereas a minimal use of positive space by decreasing the size of the subject can help create the feelings of insignificance or vastness. Similarly, designs that feature many overlapping design elements can create the feeling of confusion or claustrophobia, whereas a distinct separation between design elements can create a feeling of control or emptiness.

Figure 35. Large use of negative space can create a feeling of emptiness and large use of positive space can create a feeling of confusion or claustrophobia (FCS Art Blog, 2016).

For instance, consider the visual design of a social robot's face. A design that features many overlapping elements, such as in the case of Robelf (Figure *36* – left), can lead to feelings of confusion due to the multitude of facial features conveying information simultaneously. This cluttered design can overwhelm the user, making it difficult to focus on or interpret specific cues. On the other hand, designs like that of ElliQ (Figure *36* – right), which may lack sufficient visual elements in areas intended for significant human-robot interaction, can also lead to confusion. The absence of expected visual cues can make it challenging for users to engage with the robot or understand its expressions and intentions.

Figure 36. Robelf (left – Robelf, 2019) is an example of a robot which features many design elements that use a lot of positive space whereas ElliQ (right – Morby, 2017) is an example of a robot which features a lack of design elements resulting in a larger use of negative space.

The effective use of space in a robot's visual design is therefore crucial in determining how users perceive and interact with the robot. A balanced approach, where neither excessive nor insufficient visual elements are present, is key to creating a clear, understandable, and user-friendly interface. Designers need to carefully consider the placement and number of visual elements, ensuring that they convey the intended message or function without overwhelming or underwhelming the user. This thoughtful approach to the use of space can significantly enhance the robot's usability, making interactions more intuitive, comfortable, and effective.

In addition to the design of the robot itself, space in human-robot interaction can also refer to the interactional distances that people use to engage with each other. This is referred to as social proxemics and refers to the study of the human use of space and the effects that population density has on human behaviour, communication, and social interaction (Cook, 1970; Hall et al., 1968; Harrigan, 2005). In his foundational work on proxemics, cultural anthropologist Edward T. Hall (1990) described human's interpersonal distances in four distinct zones (as displayed in (Figure *37*): the intimate space, personal space, social space, and the public space, where the type of interaction occurs on a spectrum from distance to closeness to other individuals. For instance, the intimate space (the closest distance) is reserved for close friends, lovers, children, close family members, and the public space (the furthest distance) reserved for conversations with strangers, newly formed groups, and new acquaintances.

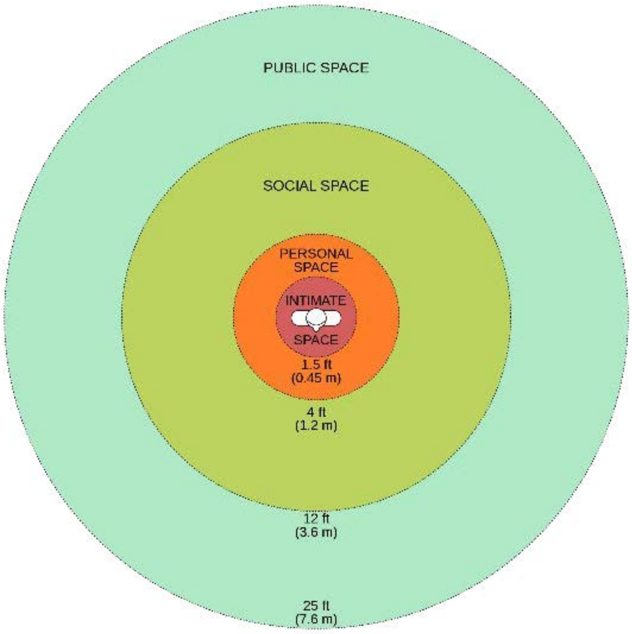

Figure 37. A chart depicting Edward T. Hall's interpersonal distances of human communication (Hall 1990).

Social proxemics research is sometimes used in social robot design to determine the optimal robot size for particular human-robot interactions. For instance, social robot toys, such as Qrio and COZMO for children, are typically miniature to reflect the young demographic in which the robot is marketed (Geppert, 2004). Table-top social robots, such as Haru and JIBO, are typically a forearm length high to mimic the size of general appliances in the home and to allow for enough space for the robot to also communicate within the proxemics of the personal and social spaces through a variety of physical interactions (Gomez et al., 2018; Short et al., 2020). Locomotive robots such as Pepper and Samsung Bot Retail are typically human-sized, allowing for more intuitive interactions with humans within the public spaces where they would typically be standing in such contexts (Lee et al., 2009)

While several studies aim to determine the optimal size and interaction distances of a social robot within different contexts, cultural differences regarding proxemics are an aspect of social robot design that are rarely considered. It is important to note that the distances proposed in Hall's research cater to American culture and social interaction, and that spatial distance is more a matter of cultural background. For instance, in Italian cultures, the standard socially acceptable distance between acquaintances having a conversation is around 0.6 metres, whereas, in North America, that distance is typically reserved for intimate relationships. Understanding such differences can dramatically affect a robot's size or the interaction distances for other cultures (Erickson, 1975; Shuter, 1977).

4.6.2 The Principles of Design

In design, key principles such as unity and variety, balance, emphasis, scale and proportion, and repetition are essential in creating cohesive and effective compositions. These principles guide designers in how they combine various elements to convey specific meanings and enhance the overall effectiveness of the design. The following sections will delve into each of these principles in more detail and explore how they might affect social robot design.

4.6.2.1 Unity and Variety

Unity refers to the organisation of a design's compositional parts and allows people to comprehend the designer's messages. Unity is achieved when all design elements in a composition are in agreement – where no individual component is more important than the whole design itself (Brommer, 2011; Field, 2018). When a composition is in unity, it instils a sense of order, cohesion, and simplicity. Unity, however, must be offset by the complementary principle of variety and is necessary for creating tension and visual interest. The right balance between unity and variety avoids a chaotic, random, or lifeless design. It is the art of balancing visual contrasts where a design can combine elements that, on the surface, do not appear to have anything in common but add to the overall composition itself.

The semiotics of unity and variety in design are deeply connected to the psychological and biological aspects of human behaviour, particularly the concept of boredom and hedonic adaptation (Bench & Lench, 2013; Frederick & Loewenstein, 1999). Hedonic adaptation refers to the human tendency to become accustomed to certain stimuli over time, leading to a decrease in emotional response. This phenomenon is evident in how people react to visual designs:

1. **Unity Without Variety**: A design that emphasises unity without incorporating some sort of variety can become monotonous and uninteresting over time. When design elements are too similar, the lack of diversity can lead to a visually dull and unstimulating experience. This uniformity, while initially appealing for its coherence, may eventually lead to disengagement due to the human propensity for novelty.

2. **Excessive Variety Without Unity**: Conversely, a design that focuses too much on variety without a unifying theme can result in visual chaos. An excessive mix of dissimilar elements can make the design difficult to process and comprehend. The lack of coherence in such a design can be overwhelming, making it challenging for viewers to engage or find a focal point.

Both scenarios highlight the importance of balancing unity and variety in design. A well-designed composition should strike a balance between familiarity and novelty, coherence, and diversity. In essence, effective design must consider the human inclination towards hedonic adaptation, ensuring that visual experiences remain appealing and engaging despite the natural tendency to habituate to constant stimuli (Bench & Lench, 2013; Frederick & Loewenstein, 1999; Jacobs Bao & Lyubomirsky, 2013).

As mentioned previously in Section 4.5.4, it is typical for different parts of a social robot to be designed in isolation from one another to alleviate the difficulty and increase the efficiency of engineering an autonomous social robot. As a result, the social robots' visual design is typically an amalgamation of different functioning robot parts all packed together into a single system. While the different robot parts on their own might possess a sense of unity, the lack of cohesion between all the other robot parts creates too much variety in the overall visual design. Analogous to Mary Shelly's *Frankenstein's Monster*, it results in a dichotomy between the functional and visual, where the lack of cohesion makes human-robot interaction inefficient and unnecessarily complicated as users must first visually understand what they are looking at before engaging in interaction.

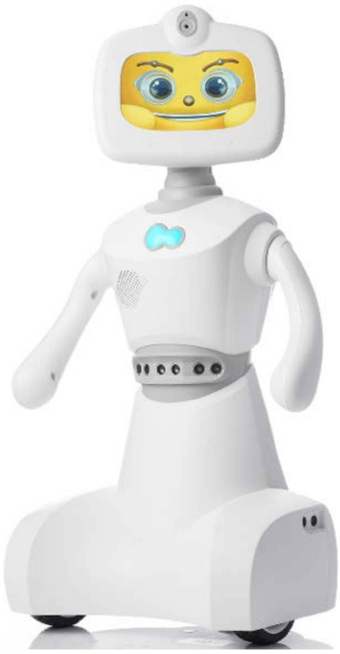

Figure 38. Robelf features a visual design with excessive variety and little unity (Robelf, 2019).

For example, Robelf (as displayed in Figure *38*) features a highly saturated and vibrant yellow face accented by several dull-white, silver, green, and brown facial features. In conjunction with the incohesive use of colour ramp textures on its skin, it creates a face with no central point of attention. In many western cultures, the eye is typically the central point of attention. This is an aspect of human communication that is built into the biology of the human body. The eye features a white sclera that is juxtaposed against a coloured iris (Figure *39*) to help create a focal point of interaction by using strong visual contrast on the face (Kobayashi & Kohshima, 1997; Langton et al., 2000). Similarly, the human hand exemplifies a complex anatomical structure consisting of 27 bones that articulate at multiple joints, facilitating an extensive spectrum of movements and dexterity. The higher density of bone structures in this part of the human body indicates, like the eyes, that this part of the body is particularly important in human social interactions (Holler et al., 2009; Krauss et al., 1995; McNeill, 1992).

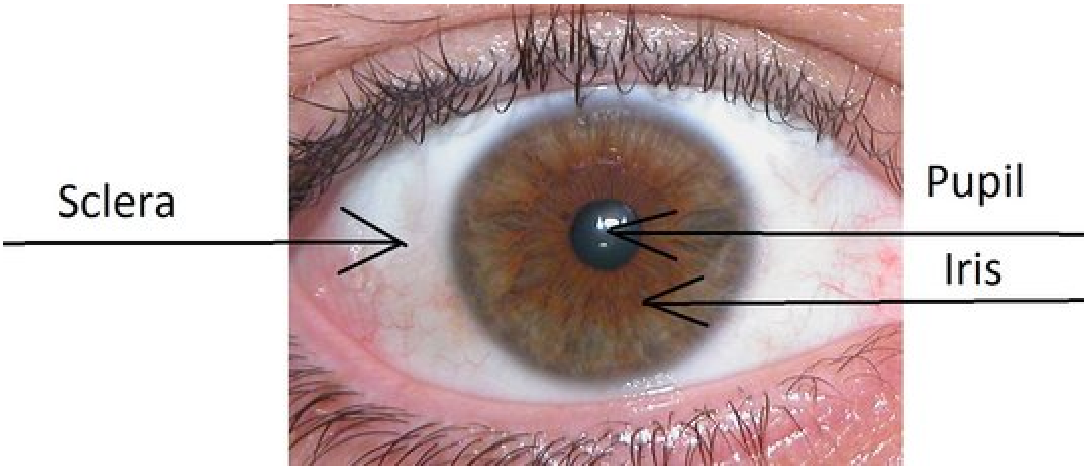

Figure 39. White sclera juxtaposed against the coloured iris creates a central focus point of attention for communication (Das et al. 2013).

It is crucial to find a balance between the functional requirements of each component of a robot's design and its overall visual harmony, as this can allude to particular modes of interaction.

4.6.2.2 Balance

Balance refers to the visual distribution of design elements in a composition to create states of equalised tension and equilibrium (Field, 2018, 2018). There are three types of visual balance: symmetrical balance, asymmetrical balance, and radial balance. Symmetrical balance occurs when elements are arranged similarly on each side of a composition to produce a mirror image. Symmetry is often used to convey a sense of formality, order, rationality, and permanence. Asymmetrical balance, however, is the art of creating balance using different design elements on different sides on an image. This type of balance is often used to convey a sense of variety, visual interest, and liveliness. Radial balance refers to how elements radiate from a centre point, resulting in the overall configuration being concentric. In all these variations, balance can be precise or approximate or combinations of the different balance types.

The concept of balance in social robot design is deeply rooted in the physiological, biological, and psychological aspects of human interaction. In humans, balance is fundamental to movement and interaction with the environment. Impairments in balance, due to issues in the vestibular, somatosensory, or visual systems, significantly affect a person's ability to engage with their surroundings (Cohen et al., 1993). In social robotics, balance is often considered more in terms of physical stability than visual design. To simplify the engineering challenge of creating moving, autonomous robots, designers frequently opt for symmetrical designs typically based on the biological assumption of symmetry in the human body (Hoffman & Ju, 2014).

However, this emphasis on perfect symmetry in social robots overlooks the natural asymmetry present in human faces. Research shows that human faces are not perfectly symmetrical; subtle asymmetries contribute to their natural appearance (Gangestad et al., 1994; Swaddle & Cuthill, 1995). If the aim of social robotics is to facilitate natural and relatable human-robot interactions, incorporating these subtle asymmetries into the robot's design could be beneficial. This approach aligns with an understanding of human biology and psychology, suggesting that a slight departure from perfect symmetry could make social robots appear more natural and approachable (Gangestad et al., 1994; Perrett et al., 1999; Swaddle & Cuthill, 1995).

Robots such as QTRobot and BUDDY, as portrayed in Figure *40*, are examples of robots that pertain towards symmetrical visual balance. So much so that the eye highlights of these robots, which are typically the result of the sun's reflection hitting the eyes from a single source are also reversed, resulting in the illusion of two different and incoherent light sources. Such robots prioritise symmetrical balance to streamline the creation of autonomous robot facial expressions, but the unnatural perfection of such symmetry can hinder the effectiveness of human-robot interaction.

Figure 40. QTRobot (left – LuxAI, 2017) and BUDDY Robot (right – Blue Frog Robotics, 2014) are social robots which are highly symmetrical.

4.6.2.3 Emphasis

Emphasis is created by visually reinforcing a part of the design to create a visual hierarchy that encourages viewers to pay attention to particular parts of a design first (Brommer, 2011; Field, 2018). At the top of the visual hierarchy is the focal point, which is an area of the design with the most significant dominance and visual weight and is where viewers are drawn. Elements of secondary importance are considered sub-dominant, and elements of least visual importance are subordinate. Emphasis can be achieved by using isolation, leading lines, convergence, contrast, anomaly, size, placement, framing, focus, and depth of field. Depending on the elements that are being emphasised, a visual designer can exaggerate a certain feeling or message to make something clear and recognisable.

Visual emphasis and hierarchy are topics that are not often explored in the design of social robots. Such designs are often subject to the same issues as noted within Section 4.5.1, where, due to the engineering design values of efficiency and functionality, the design of social robots is typically a result of an amalgamation of various functioning robot parts all packed together into a single system. This results in a lack of cohesion and an unnecessary amount of emphasis between the different parts of a robot which might exaggerate perceived functionalities or personality traits that may or may not actually be present.

Figure 41. The visual design of Baxter suggests that it can lift heavy objects due to the size of its arms however is only capable of light assembly, sorting, and packaging (Rethink Robotics, 2011).

For example, Baxter (Figure 41) is a robot with a large emphasis on its use of arms. The large size, shape, and use of sharp angular lines, coupled with the coat of bright red on its arms, signal to users that this robot was designed to manipulate heavy objects. However, despite its imposing appearance, Baxter is not actually capable of lifting such heavy loads. Instead, Baxter was designed for repetitive and precision-based tasks in collaborative manufacturing environments, such as light assembly, sorting, and packaging. In addition to this, the cultural and gender associations with such a physique—typically attributed to masculine bodybuilders—may not be appropriate in specific contexts. By correctly emphasising and allocating resources to the parts of a robot's body that best portray its interactive capabilities and personality traits, human-robot interaction could be made more intuitive and effective.

4.6.2.4 Scale and Proportion

Scale and proportion refer to the size relationships between elements within a composition or construction. Designers use scale and proportion to depict or distract from the ideal by exaggerating certain elements in contrast to each other to achieve a certain feeling or attract attention to a certain focal point (Brommer, 2011; Field, 2018).

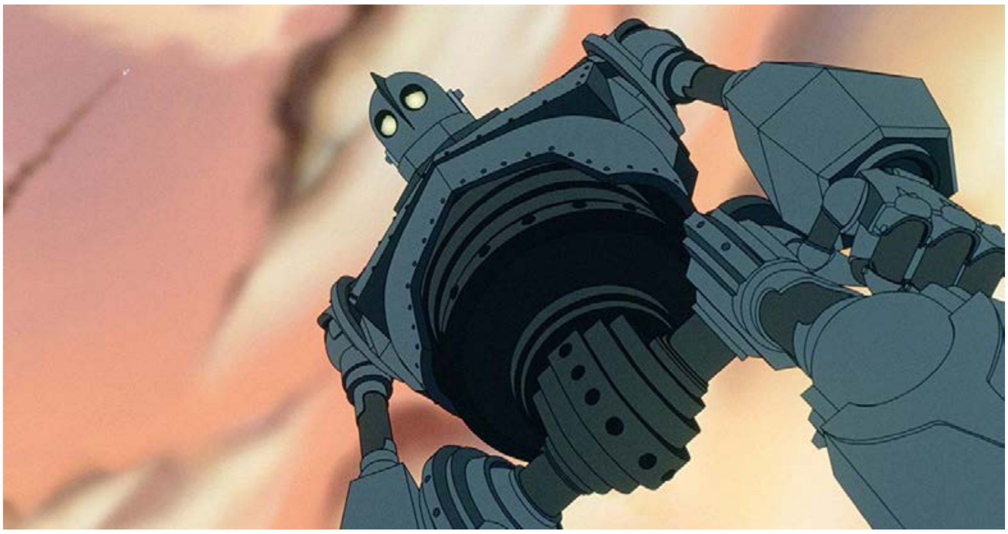

Figure 42. The Iron Giant's colossal size is emphasised by the low angle shot (Bird, 1999).

Scale specifically refers to the size of one object in relation to the other objects within a design. However, when describing scale, it is more common for people to judge the scale of something according to the size of the human body – a design might be termed miniature, small-scale, full-scale, life-sized, large-scale, larger than life, or monumental. The use of scale within a design is typically used to reframe our perspective and relationship with particular objects by bringing attention towards a specific object and playing on our sense of power (Hooks, 2017; Thomas & Johnston, 1995; R. Williams, 2012). For instance, as displayed in Figure *42*, the sheer monumental scale of The Iron Giant in contrast to the human-sized characters below creates a sense of helplessness in the viewer. Here, scale is being used as an expression of power over the viewer. In contrast to this, the miniaturisation of actual objects, such as scale model cars, toy trains, and dollhouses, gives people the sense of power to manipulate realistic-looking objects.

Proportion differs from scale because it pertains to the relative size of the various components that make up an object (Brommer, 2011; Field, 2018). Proportion is typically measured in terms of ratio rather than sizes. For example, typical proportions of the human face are as follows: eyes halfway down from the top of the head, the nostrils and tear ducts of the eyes vertically aligned, the space between the eyes approximately the width of an eye apart, the width of the head approximately five eyes wide, and the corners of the mouth lined up with the pupils of the eyes. Proportions of the human face, which deviate from these typical ratios are used when designers want to attract attention to specific focal points on the face (Thomas & Johnston, 1995; R. Williams, 2012). For instance, characters in Disney animated films and in anime (Figure *43*) typically possess proportionally larger eyes than in real life. This is because large eyes are a neotenous feature which is considered attractive to many individuals as it signals youthfulness (Cunningham, 1986; Cunningham et al., 1990; Keating, 1985).

Figure 43. The size of a character's eyes can change people's perceptions of a character (Taniguchi, 2006).

Social robots are typically of human or animal-like proportions and are usually life-sized or miniaturised versions of their real-life counterparts. Human or animal-like proportions are typically used in social robot design to help build familiarity between the robot and its users to make social interaction with the robot as natural as possible. However, these proportions are typically rough estimates, as the ratios between different body parts and their reasons of use are rarely described in social robot design. For instance, Boston Dynamic's bipedal humanoid robot Atlas (Figure *44*), initially designed for a variety of search and rescue tasks, possesses a proportionally large chest and wide upper body akin to that of a military soldier. The need to possess this visual design aesthetic is not described in the literature and, within the context of a search and rescue mission, may not be appropriate for distressed individuals.

Figure 44. Atlas Robot features a proportionally large chest and wide upper body akin to that of a military soldier (O'Connor, 2016).

The use of life-size or miniaturised robots comes down to the context of use and proxemics. As mentioned previously in subsection 4.6.1.5, there are a number of studies in human-robot interaction research that draw from research in social proxemics in order to determine the optimal size for social robots that operate within certain zones of intimate and personal space.

4.6.2.5 Repetition

The design principle of repetition simply refers to the reusing of similar design elements throughout a design composition (Brommer, 2011; Djonov & Leeuwen, 2011; Field, 2018). Design elements can be repeated, alternated, or arranged in a certain way to create feelings of order or chaos, or feelings of the organic or artificial, and can help with unifying and organising different design elements into the overall composition or assist with the creation of variety through the contrast of differences in repetition. It is important to note here that repetition does not refer to the use of the same design element in the exact same manner every single time, rather the reusing of the same element with slight variations in different parts of the design to create a subtle sense of variety while still maintaining an overall sense of unity.

The semiotics behind the design principle of repetition is derived from the psychological concept of familiarity and pattern recognition (Rimé et al., 1985). Repetition involves consistently using specific design elements, such as shape, colour, or pattern, which cultivates a sense of familiarity and ease of recognition. This principle enhances the overall cohesiveness of a design, contributing to a stronger and more identifiable branding. It also plays a key role in guiding user interaction by highlighting important features or functionalities, thereby making designs more intuitive and user-friendly. Aesthetically, repetition creates a visual rhythm, adding dynamism and appeal to the design. Moreover, it can evoke specific emotional responses, as the consistent use of certain elements can influence the way a design is perceived and experienced (McCloud & Martin, 2017; Thomas & Johnston, 1995; R. Williams, 2012).

As discussed in subsection 4.5.4, the engineering of an autonomous social robot often involves designing its various parts in isolation. This method, while easing the complexity of engineering, can lead to a lack of visual repetition in the final design when all these disparate parts are assembled into one system. This absence of repetitive design elements can make it challenging for users to discern which parts of the robot are interactive, as there is no consistent visual cue for guidance. In contrast, employing repetitive design elements effectively can create focal points in the robot's design, clearly indicating areas meant for interaction. This not only aids in user navigation but also enhances the overall aesthetic coherence of the robot. Repetition, therefore, is not just a stylistic choice but a functional necessity in social robot design, helping to bridge the gap between the robot's technological complexity and user-friendly interaction.

For instance, the robot dog AIBO (Figure *45*) provides an excellent example of the effective use of repetition in design. It features a repetitive matte white body texture, which is subtly contrasted with a shiny silver head. This strategic variation in texture amidst the repetitive theme not only creates an appealing aesthetic but also serves a functional purpose. The shiny silver texture draws attention to the robot's head establishing it as a focal point for visual facial interaction and the matte texture establishes the robot body as a focal point for haptic interaction. This design choice exemplifies how repetition, combined with thoughtful variation, can be used to guide user behaviour, and create a more interactive and intuitive experience.

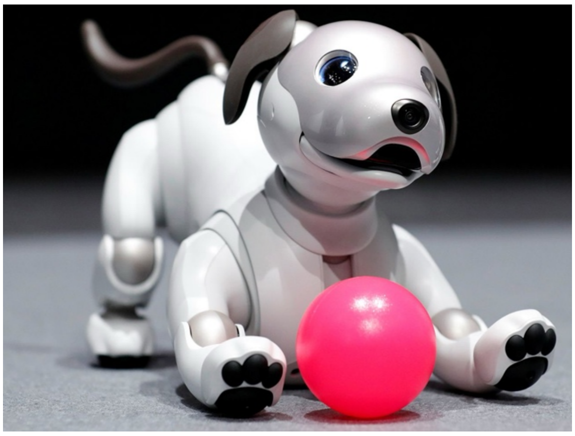

Figure 45. AIBO Robot features a repetitive matte white body texture which is contrasted with a shiny silver head (Sony, 2017).

4.7 Conclusion

In much the same way that humans rely on visual social cues to form first impressions of others, alterations of basic design elements and principles can significantly influence perceptions of a social robot's role, personality, and interactive capabilities. Yet, despite the critical impact of these elements, social robot design today exhibits a noticeable lack of diversity. The prevailing design approach, often siloed into pragmatic, visual, and movement-centred categories, has led to the emergence of three predominant design stereotypes in social robots: sexy, cute, and white.

These stereotypes persistently shape the collective cultural imagination of modern-day social robots.

If social robots are to function effectively and positively within human society, it is problematic to have a homogeneous one-size-fits-all visual aesthetic. The interpretation of design elements can vary greatly, influencing how people interact with and respond to these robots. Therefore, it is crucial for roboticists to collaborate with visual designers well-versed in visual social semiotics. These designers can skilfully navigate the nuanced ways in which different design elements convey meaning, ensuring that social robots are perceived and interacted with in a manner that is intuitive and socially engaging as well as considerate of its social and cultural implications.

Incorporating principles from Deweyan Pragmatism and Universal Design can further enhance this approach. Deweyan Pragmatism, with its emphasis on experience and context, provides a framework for understanding how users might interact with robots in real-world scenarios. Meanwhile, Universal Design Principles advocate for the creation of designs accessible and usable to as many people as possible, regardless of age, ability, or status. Together, these frameworks can guide the development of social robots that are not only aesthetically diverse but also functionally versatile and socially inclusive, resonating with a broad spectrum of users and contexts.

The forthcoming chapter endeavours to incorporate these elements into a visual design framework that encompasses not just the functional and efficiency aspects of social robot design but also addresses social and cultural implications – a design framework that works towards social robot visual diversity.

Chapter 5: Towards Social Robot Visual Diversity

5.1 Introduction

The current trend in the visual design of social robots heavily favours human-like morphologies, a preference that is evident in the field's visual representations and academic studies. When searching for 'social robots' on Google Images, one predominantly finds humanoid robot designs, discussed previously in section 1.3 and illustrated in Figure *13*. This observation is not just anecdotal but is also backed by academic resources such as the ABOT database, which underscores the widespread incorporation of human-like features in social robot design (Kim et al., 2020; Perugia et al., 2022; Phillips et al., 2018).

The primary rationale for designing robots with human-like characteristics is to enhance communication between humans and robots. This design philosophy is based on the assumption that human-like features in robots foster more intuitive and efficient communication channels (Breazeal, 2004; Duffy, 2003; Eddy et al., 1993). This intuition is attributed to the natural inclination among humans to apply their existing social and communicative knowledge when interacting with robots. Therefore, when a robot displays human-like traits, people are likely to utilise their familiar understanding of human behaviour and social norms, facilitating interactions that are both intuitive and natural. This eliminates the need for users to learn new interaction rules or undergo extensive training. Instead, they can interact with the robot using their existing social skills and understanding, which greatly reduces the barriers to effective human-robot interaction and makes these robots more approachable and user-friendly for a broader audience. Within this design paradigm, the concept of *intuitiveness* in interactions with a social robot, as well as its ability to establish emotional rapport with humans, is largely contingent on the extent to which the robot resembles a human.

The *Uncanny Valley* theory, previously discussed in Section 1.2 and illustrated in Figure 9, has been instrumental in justifying the importance of achieving intuitiveness through human-like design while offering guidance on avoiding the pitfalls associated with the uncanny valley. The theory suggests that human emotional engagement and comfort with non-human entities can be optimised by forgoing the extensive effort and resources required to achieve complete human likeness. Instead, it suggests aiming for a design that achieves a *safe level of affinity* through a *moderate degree of human likeness* (De Fren, 2009). In this context, the principal challenge for social roboticists is to determine the optimal allocation of time and resources towards creating a visual design that maximises human affinity while carefully navigating the risks posed by the Uncanny Valley.

5.2 The Optimal Visual Design for Social Robots

As discussed in Section 4.5 of the thesis, in response to the challenges presented by the Uncanny Valley, three distinct design approaches have emerged, each providing a unique strategy for navigating its complexities. Two of these approaches, pragmatic and movement-centred, bypass the Uncanny Valley issues by adopting an abstract aesthetic in their design. This strategy effectively avoids the Uncanny Valley by eschewing any resemblance to human-like features.

The pragmatic approach focuses on functionality and usability, prioritising the robot's practical aspects over its appearance. This method emphasises the importance of the robot's role and tasks, designing features and interactions based on the specific needs and contexts of use. By doing so, it minimises the need for human-like characteristics, thus reducing the risk of falling into the Uncanny Valley.

The Movement-Centred Approach, on the other hand, concentrates on the dynamics of the robot's movements rather than its physical appearance. It explores how non-human forms can engage in expressive and meaningful movements, creating a sense of character and emotionality without relying on human-like visual cues. This approach demonstrates that effective communication and emotional resonance can be achieved through motion and behaviour, independent of a humanoid appearance.

In contrast, the visual approach adopts a more nuanced and sophisticated strategy. While it recognises the potential pitfalls of the Uncanny Valley, it does not completely avoid human-like features. Instead, it carefully calibrates the degree of human resemblance in the robot's design. This approach involves a delicate balance, incorporating enough human-like traits to foster relatability and empathy, while avoiding the eeriness associated with near-human appearance. It requires a deep understanding of aesthetics, human perception, and psychology, as it seeks to find the optimal point where a robot is sufficiently human-like to be engaging, yet distinct enough to prevent discomfort.

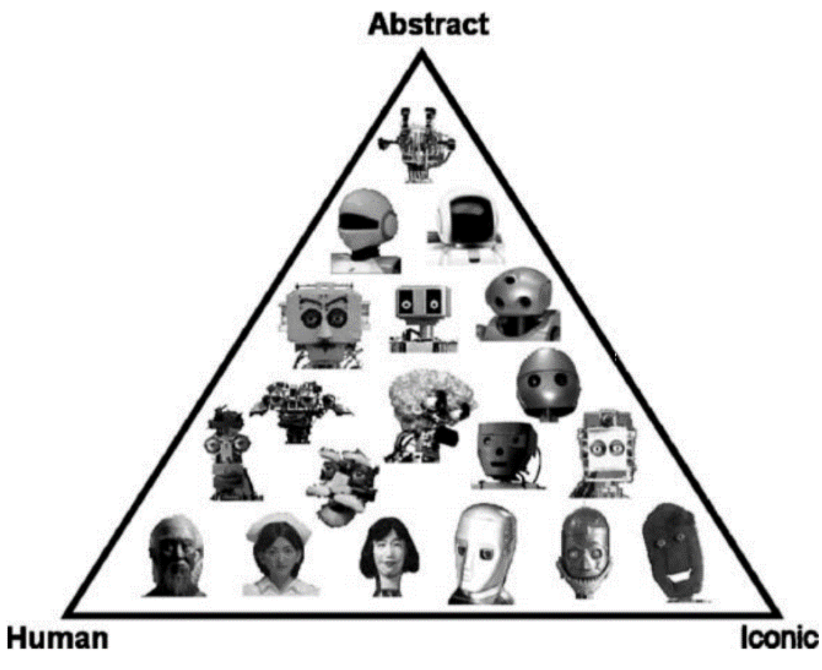

Figure 46. Anthropomorphic design space for robot heads (Duffy, 2003).

Brian Duffy (2003), drawing from an interdisciplinary research base spanning psychology, social sciences, design, art, and philosophy, integrates Scott McCloud's (2017) concept of the Picture Plane from his influential book *Understanding Comics: The Invisible Art*, into his Anthropomorphism Design Space framework (Figure *46*). This framework outlines three primary visual design approaches in robot design:

The Human Approach. This strategy aims for a high degree of human likeness, as elaborated by Dautenhahn (2002). Designers adopting this approach attempt to traverse the Uncanny Valley by creating robots that closely resemble humans in appearance and behaviour, such as Hiroshi Ishiguro's Geminoid F, Feminoid-HI-1, and Geminoid DK as discussed previously in section 1.2 and illustrated in Figure 8. The challenge here is to achieve a level of realism that is convincing enough to elicit empathetic and positive responses from human users, without triggering the unsettling feelings commonly associated with the Uncanny Valley. This approach requires meticulous attention to detail in replicating human features and expressions.

The Iconic Approach. This approach seeks a balanced level of human resemblance. It is influenced by theories of stylisation (McCloud & Martin, 2017) and neotenisation (Lorenz, 1970), which suggest that a moderate degree of abstraction or child-like features can be more universally appealing and less likely to evoke the negative responses associated with near-perfect human likeness. The iconic strategy aims to achieve an optimal balance between resource investment and user affinity, creating designs that are relatable and engaging, yet sufficiently stylised to avoid the pitfalls of the Uncanny Valley. Examples include LuxAI's QT Robot or Blue Frog Robotics' BUDDY, previously illustrated in Figure 42.

The Abstract Approach. In contrast to the first two strategies, the abstract approach eschews human likeness altogether, focusing instead on functional and transparent mechanical design. This approach emphasises the robot's machine identity, avoiding anthropomorphism in favour of clarity and transparency in design (Hoffman & Ju, 2014). By highlighting the robot's mechanical nature, this approach avoids the Uncanny Valley entirely and can be particularly effective in contexts where functionality and clarity of purpose are paramount. An example of the abstract approach include ElliQ as portrayed previously in Figure 38, and Shimon the Marimbaist and Travis the Robot Musical Companion, as portrayed previously in Figure 29.

Duffy (2003) posits that the most efficacious social robots are those that harmoniously integrate human-like attributes, iconic elements, and functional abstract features. This balanced approach is seen as key in crafting robots that are both relatable and effective. By combining human-like characteristics, robots gain a degree of familiarity that can foster more natural interactions with humans. The incorporation of iconic elements, such as simplified or stylised human features, contributes to intuitive understanding and relatability. These elements are easily recognisable and can be processed quickly by the human brain, aiding in clear communication, and reducing potential confusion or discomfort. Lastly, functional abstract features emphasise the robot's problem-solving abilities and its nature as a tool or machine, ensuring that its primary functions are effectively executed. Situated at the approximate midpoint of the anthropomorphism design space, this harmonious blend, on the surface, offers a nuanced resolution to the enduring challenge presented by the uncanny valley theory in social robot visual design.

However, more than 20 years have elapsed since the concept of the Anthropomorphism Design Space was introduced, and it has been over 50 years since the Uncanny Valley theory entered social robot discourse and yet, despite the decades of influence of these frameworks, the field continues to face enduring questions about the efficacy of social robot visual design in facilitating effective human-robot interaction. Despite the longstanding influence of these theoretical frameworks, the field of social robotics still grapples with persistent questions regarding the effectiveness of visual design in fostering efficient human-robot interaction. It is evident that in the realm of visual design, social roboticists have reached an impasse.

This chapter argues that the current design stalemate stems from the inherent limitations and assumptions of prevalent design frameworks that inadvertently champion the notion that an "optimal" universal visual aesthetic exists for social robots. Such an approach simplifies the complex, subjective nature of aesthetic experience, reducing it to a question of human likeness and affinity or the mere balancing act between realism, iconicity, and abstraction. This uniform focus has led to a homogenised landscape in social robot design, one that lacks diversity because it operates under the unchallenged premise of a single, ideal aesthetic.

The pervasive one-size-fits-all model in social robot design is indicative of a wider tendency in technology, centred on the virtues of efficiency and standardisation. For example, Apple's design philosophy, prioritising simplicity and user experience, inadvertently limits opportunities for user customisation and cross-platform adaptability constraining users to a unique interaction paradigm often dubbed *the Apple way* (Gaughwin, 2023). This design philosophy parallels the prevailing methodologies in social robotics, limiting the versatility of robots across varied user needs and contexts. This limitation could reveal a novel facet of the Uncanny Valley, where the social robot's lack of adaptability to a more diverse range of contexts generates a sense of uncanniness.

This case study argues that the goal of an optimal visual design in social robotics has led to a singular design aesthetic that overlooks the complexities of human perception and cultural diversity. The result is a constrained visual medium that falls short in fostering meaningful human-robot interactions. This one-size-fits-all approach not only stifles innovation but also perpetuates harmful stereotypes as mentioned previously in Section 4.4, rendering it unsuitable for the nuanced realm of human social interaction. In response, a new design framework is required, one that acknowledges the different ways in which individuals perceive and engage with their surroundings while also respecting their unique subjective experiences of beauty and aesthetics.

5.3 Art as Experience

John Dewey's concept of *art as experience* (2008/1934) provides a thought-provoking alternative to the prevailing one-size-fits-all design paradigm in social robotics. Dewey, an American philosopher and psychologist, advocates for a democratisation of aesthetics and art, arguing that they should be integral to everyone's lived experience, rather than being exclusive or elitist pursuits.

Dewey challenges traditional dualisms that create a divide between fine art, such as classical painting and sculpture, and everyday experiences. He proposes that the aesthetic value of an experience should not be confined to conventional artistic expressions but should be found in the richness and depth of daily life. In Dewey's view, the aesthetic quality of an experience is not predefined or static; instead, it is determined by the level of active engagement and awareness of the individual experiencing it.

This perspective on aesthetics is deeply rooted in the contextuality of experiences. Dewey emphasises that aesthetic value is not universal but is shaped by social, cultural, and historical contexts. Each individual's experience is influenced by their unique background and personal history, which means that aesthetic appreciation is inherently subjective and varied.

Applying Dewey's philosophy to social robot design suggests a departure from the idea of a universally optimal robot aesthetic. Instead, it encourages the exploration of diverse design approaches that resonate with different individuals' experiences and cultural backgrounds. In this context, the design of social robots becomes a more inclusive and participatory process, where the aesthetic value is not dictated by a set of predefined norms but emerges from the interaction between the robot and its users within their specific social and cultural contexts.

Returning to Scott McCloud's *Understanding Comics* (2017), we find concepts that echo John Dewey's ideas in *Art as Experience* (2008/1934). McCloud's exploration of the picture plane (Figure 47) in his work offers valuable insights that are applicable to robot design. He suggests that artists have the freedom to choose from a spectrum of styles to connect with different audiences, a principle that can be effectively translated into the realm of social robot design. McCloud's analysis of the picture plane reveals that there is no one-size-fits-all in visual expression. Different styles, ranging from realistic to abstract, can each have their unique appeal depending on the context and the audience. This perspective aligns with Dewey's notion of aesthetic experience being deeply personal and context dependent.

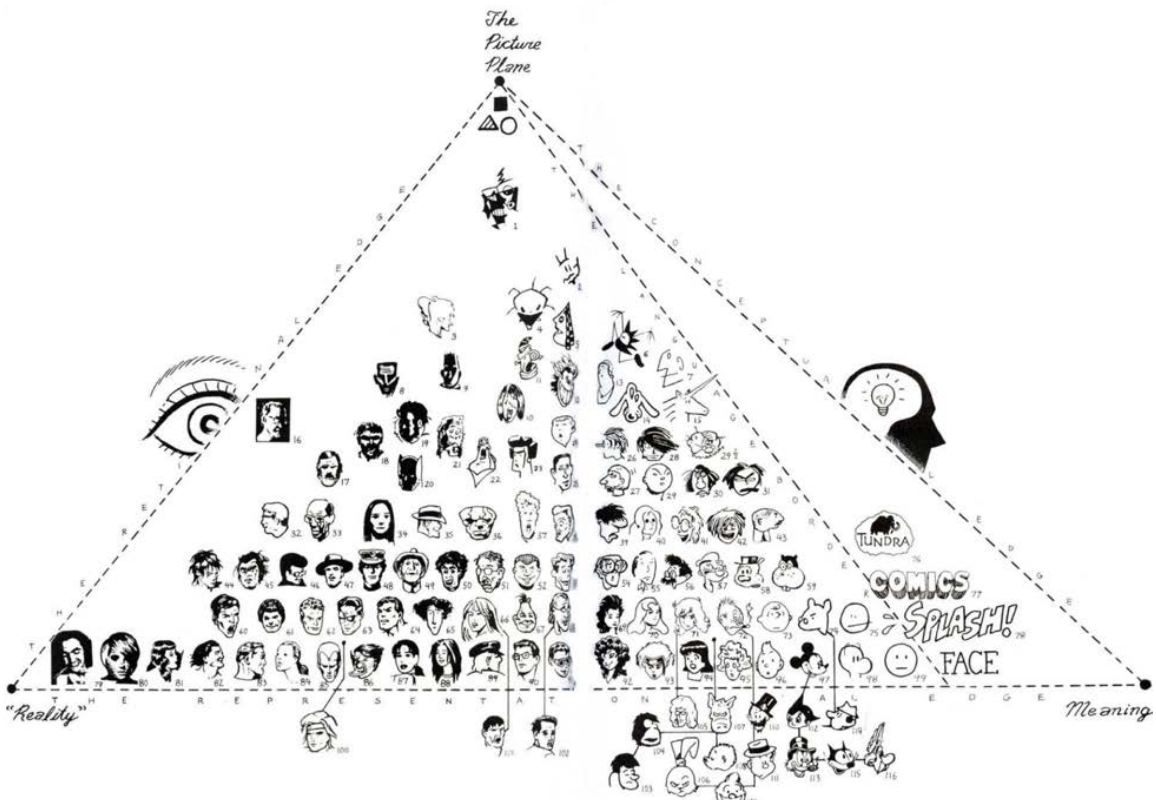

Figure 47. The Picture Plane (McCloud & Martin 2017).

In the context of social robotics, McCloud's insights challenge the pursuit of a universally appealing robot design. Instead, he advocates for the effectiveness of a style being contingent on the specific context in which it is employed and the individual's engagement with it. This approach encourages social robot designers to be aware of art's broader spectrum of visual languages. By doing so, they can create designs that resonate with a diverse array of individuals, each with their own unique preferences, cultural backgrounds, and experiences which, together, create unique and innovative paradigms for human-robot interaction.

The integration of art's diverse visual languages into robotics and the exploration of how unique behaviours arise from the interplay between design, context, and individual experiences is not a novel concept. Since the 1950s, numerous designers at the intersection of art and robotics have embraced this broad spectrum of visual languages. Their work continues to innovate and expand the possibilities of what a robot can do or what it could look like, continuously challenging and redefining the notion of the 'ideal robot aesthetic'.

Figure 48. The Helpless Robot (White, 1987).

A key example is Norman White's *The Helpless Robot* (1987), an innovative piece that subverted traditional robotic design by rejecting utility and efficiency (Figure 48). Designed to be deliberately unhelpful, it engaged passers-by with polite, synthesized requests to be repositioned, only to grow increasingly domineering and manipulative as interactions continued. This escalating behaviour highlighted the robot's ability to evoke emotional responses without anthropomorphic or zoomorphic traits, demonstrating that effective design lies in contextual engagement and challenging user expectations rather than universal likeability.

Figure 49. Petit Mal (Penny, 2006).

Simon Penny's *Petit Mal* (1993) redefined robotic design by prioritising kinesthetic interaction and machine autonomy over traditional mimicry of biological systems (Figure 49). Designed with a distinct physical and electronic identity, its behaviour emerged from the seamless interplay of hardware and software. *Petit Mal* engaged users in real-world spaces, responding to their presence while navigating architectural environments. By focusing on movement and interaction unique to its design, Penny challenged conventional expectations of how robots should look or behave, highlighting the importance of context and individual engagement in shaping meaningful human-robot interactions.

Mari Velonaki's *Fish-Bird* (2003) pushes the boundaries of human-robot interaction by focusing on emotional and physical dialogues that challenge traditional notions of machine design (Figure 50). The work featured autonomous wheelchairs representing two characters engaged in conversations through movement and printed text, weaving a narrative of unrequited love constrained by "technical" barriers. By choosing wheelchairs—utilitarian forms with strong human associations—Velonaki subverted traditional robot aesthetics, blending functional design with deeply humanised behaviours to explore themes of autonomy, communication, and societal perceptions of assistive devices. Velonaki's *Fish-Bird* exemplifies how art's diverse visual languages can be integrated into robotics to create designs that resonate within specific cultural and social frameworks. Her exploration of behavioural and emotional engagement underscores the philosophical and cultural complexities of human-robot interaction, contributing to a more nuanced understanding of how robots can connect with people in meaningful and context-specific ways.

Figure 50. Fish Bird (Velonaki, 2003).

Wade Marynowsky's *The Hosts* (2009) explored the uncanny through abstracted humanoid robots in a robotic masquerade ball, deliberately avoiding lifelike or anthropomorphic design (Figure 51). By using theatrical elements such as automated lighting, darkness, and an eerie soundscape, the work created a surreal and menacing atmosphere that tested whether unnerving effects could be achieved without entering the "uncanny valley." Drawing inspiration from E.T.A. Hoffmann's *The Sandman* and Freud's essay on the uncanny, Marynowsky demonstrated how abstracted forms and behaviours could evoke complex emotional responses.

The Hosts highlights the power of contextual and experiential design, adding to the ongoing dialogue about redefining the aesthetics and interactions of social robots.

Figure 51. The Hosts (Marynowsky, 2009).

Building on these examples, the integration of Scott McCloud's concept of diverse visual languages and John Dewey's focus on interactive experience offers a compelling framework for reimagining social robot design. Rather than pursuing a singular, "optimal" design, the works of Norman White, Simon Penny, Mari Velonaki, and Wade Marynowsky demonstrate the value of creating robots that engage users contextually and dynamically, each with a variety of interactive and adaptable designs, each of which can be customised to suit the specific preferences and needs of the individual. This approach suggests a paradigm shift in social robot design—from a uniform, one-size-fits-all model to a more personalised and user-centric framework. Such a framework acknowledges the diversity of human experiences and preferences, recognising that what is engaging or aesthetically pleasing for one individual might not be the same for another.

5.4 Personalisation as the Antidote to the Uncanny Valley

The ambition to design social robots capable of supporting an infinite variety of interactions presents a formidable challenge from an engineering standpoint. If a single social robot were designed to *do it all*, it might ironically lead us back to the dilemma of the one-size-fits-all design paradigm. This paradox highlights the need for a pragmatic balance in social robot design – one that navigates the boundary between what is technically and logistically feasible and the richly individualised experiences desired by each user.

In practical terms, achieving this balance requires a nuanced approach. While it might not be feasible for a single robot to meet every individual's unique needs and preferences, a more realistic goal would be to create a range of robots, each designed with a certain degree of flexibility and adaptability. This could involve modular designs where certain elements can be customised, or interchangeable software can be tailored to different user requirements.

Incorporating individual perspectives in the design process is crucial. It not only helps in avoiding the reinforcement of harmful stereotypes but also opens the door to more inclusive and representative design choices. By actively seeking input from a diverse range of users during the design process, designers can ensure that the robots they create are more attuned to the varied needs and contexts of their intended users.

Furthermore, embracing a strategy that values individual perspectives could stimulate much-needed innovation in a field that has seen limited visual evolution. For decades, the design of social robots has predominantly adhered to humanoid forms, rooted in the assumption that resemblance to humans is inherently intuitive. However, this assumption overlooks the diverse needs and preferences of various user groups and the specificity of different situational contexts.

By breaking away from these traditional moulds and exploring new forms, aesthetics, and interaction modalities, designers can invigorate the field with fresh ideas and solutions that reflect a deeper understanding of the complex interplay between technology, culture, and society.

Revisiting Scott McCloud's concept in The Picture Plane (2017), we gain insight into the notion that the ideal visual design for social robots does not reside at a single, definitive point. Instead, it spans a spectrum that accommodates a diversity of perceptions. This perspective aligns with the views of interaction design professor Bert Bongers (2022) who advocates for art and design to function as guiding principles rather than rigid, prescriptive solutions. In this context, the power to shape the experience should lie primarily with the individual user.

Figure 52. Mary Fleener's work incorporates a range of different art styles on The Picture Plane not just a single point (McCloud & Martin, 2017).

The concept of the picture plane, as outlined by McCloud, suggests that the ideal visual design for social robots is not a singular point on the picture plane, but rather a range that accommodates varying perceptions (Figure *52*). This range acknowledges that different people will resonate with different points along the plane, depending on their personal preferences, cultural backgrounds, and experiences. Translating this idea to social robot design implies that a range of designs, each catering to different tastes and expectations, is more effective than pursuing a singular, universal aesthetic.

Professor Bongers' emphasis on art and design as guides underscores the importance of flexibility and personalisation in design. In the realm of social robots, this could manifest as small-scale customisation options that allow users to adjust and personalise their interactions with the robot. Such personalisations may not only enhance user comfort and acceptance but also provide a sense of control and predictability in interactions with robots.

This approach can be particularly effective in addressing the challenges posed by the Uncanny Valley. By offering customisable options, designers can enable users to adjust the robot's appearance to avoid discomfort, uncertainty, and unpredictability. For example, a user might prefer a robot with less human-like features to avoid the eeriness associated with hyper-realistic robots, or they might choose to modify the robot's interaction patterns to better align with their communication preferences.

The notion of personalisation within the field of social robotics, while not novel, has predominantly concentrated on aspects of behavioural adaptability (Tarakli et al., 2023). However, when it comes to visual design, personalisation has largely been neglected. Despite its potential significance, there is a notable scarcity of thorough scholarly research exploring the reasons behind employing specific visual design elements and principles in a robot's form factor. Additionally, studies that examine the impact of these visual design choices on human-robot interaction are almost non-existent.

This oversight in visual design personalisation is significant, especially considering the potential impact that visual aesthetics can have on user experience and engagement. While the field has made strides in developing robots that can adapt their behaviour based on user interactions, the same level of attention has not been extended to how robots look and the psychological and emotional effects their appearance can have on users. While there is acknowledgment of the impact of the visual design of a social robot and its impact on people's perceptions and interactions with robots (Deng et al., 2019; Dennler et al., 2023; Perugia et al., 2022), none go into the level of depth of the elements and principles of visual design as described previously in section 4.6. The lack of comprehensive research into visual design in social robotics suggests a gap in the understanding of how different design elements – such as colour, shape, size, and texture – contribute to users' perceptions, emotions, and behaviours when interacting with robots.

This research proposes that even minimal levels of personalisation in social robots can significantly enhance the quality and effectiveness of human-robot interaction. This hypothesis is supported by findings similar to those of the IKEA effect (Norton et al., 2012), which suggests that people tend to value objects more when they have personally contributed to their creation or assembly. This phenomenon underscores the importance of active engagement in shaping perceptions and value. In line with this, the study argues for a re-evaluation of the role of visual design in social robotics, advocating for its integration as a fundamental aspect of personalisation. The research does not treat visual design as merely an aesthetic consideration but as a crucial element that can deeply influence how individuals perceive and interact with robots.

This study focuses intensively on how different designs of robot screen eyes, a crucial component of a robot's visual interface, can significantly impact user perceptions and interaction behaviours. Previous research (Kalegina et al., 2018; Luria et al., 2018) has begun to explore the influence of a robot's eye design on people's perceptions and interactions. However, this study aims to go further, delving into the specific elements and principles of visual design that create particular perceptions using eye designs that are contextually rich and distinct, rather than generic. This detailed examination seeks to uncover how changes in the visual design of robot eyes can influence human-robot interaction.

5.5 Methodology

5.5.1 The Haru Design Space

The research presented here utilises the Haru research platform (Gomez et al., 2018), developed by the Honda Research Institute Japan (HRI-JP), as a basis for exploring personalised robot eye designs (Figure *53*). Haru is a table-top social robot distinguished by its unique eye display, which comprises two separate 3-inch LCD screens. Each screen is set within a rectangular frame that includes an addressable LED strip, adding to the robot's expressive capabilities. The design of Haru places significant emphasis on its eyes, which constitute about 44% of its overall body proportions. These eyes are mounted on a T-frame structure, representing the robot's head, which is then connected to a curved tube that functions as Haru's neck. This tube leads down to a semi-spherical dome base, forming the lower part of the robot's structure.

Figure 53. Haru Robot.

One of the key characteristics of Haru that distinguishes it from the current trend of human-like morphologies is its limited capacity for performing emotional gestures using its body. This design aspect makes Haru particularly well-suited for a study focused on the impact of personalised eye designs in human-robot interaction. Given that Haru's physical expressiveness is constrained, its visual design language heavily relies on eye-centric interactions.

To explore the impact of different visual styles on human-robot interaction, a small team of professional visual designers and animators was recruited to develop a diverse array of eye designs for the Haru robot. The team created six unique eye designs – Conservative, Dandelion, Sakura, Hiro, Bolts, and Mech – each based on different thematic briefs to ensure a wide spectrum of visual variety. This approach was designed to span a broad range of styles across Scott McCloud's Picture Plane, encompassing various degrees of realism, abstraction, and stylisation.

In addition to the distinct styles, nine different colour schemes (blue, brown, green, grey, orange, pink, purple, red, yellow) were applied to each eye design. This resulted in a comprehensive collection of 54 distinct eye variations, providing a rich dataset for investigating the effects of visual diversity on user interaction with Haru.

To further enhance the expressiveness of these eye designs, dynamic motion was integrated into each variant. This animation included standard idle movements such as gaze shifts and intermittent blinking, adding a layer of lifelike behaviour to the eyes. These subtle animations aimed to imbue each design with a sense of presence and responsiveness, enhancing the potential for emotional engagement with users.

The upcoming section of the study delves into the specific thematic briefs that guided the creation of each eye design. It also examines the particular segment of the design space each style occupies, offering insights into how variations in visual elements and principles influence user perceptions and interactions with Haru.

5.5.2 Conservative Eye

Figure 54. The Conservative Eye.

The development of the conservative eye (Figure *54*) was a direct response to the specific visual design expectations associated with the concept of social robots as explored earlier in Section 5.1. The prevalence of humanoid forms in social robot imagery served as the impetus for the creation of the conservative eye, with the primary goal being to instil a sense of familiarity in users. The intention behind this design was to make it effortless for individuals to connect with and feel at ease while engaging with Haru. The ultimate result is a design that strives for realism by closely mirroring the typical characteristics of the human eye.

The conservative eye features a series of concentric coloured circles to achieve its lifelike appearance. The innermost black circle mimics the appearance of a human pupil, while the middle-coloured circle serves as the representation of the iris. The thin outer white circle plays a crucial role in highlighting and providing visual separation from the black background, which is intended to function as the equivalent of the sclera in a human eye.

Human eyes traditionally feature a white sclera. However, adopting a white background for Haru's screen eyes would reveal the hardware limitations of its display. As illustrated in Figure 55, while Haru's eyes appear large due to their bevelled screen design, the actual functional screen size is much smaller than the perceived area. Using a white background would create a stark and visually disruptive contrast between the active display area and the smooth bevelled edges of Haru's hardware. To address this, the design prioritizes creating the illusion of an eye that extends seamlessly beyond the screen, favouring this visual continuity over an exact replication of the human eye.

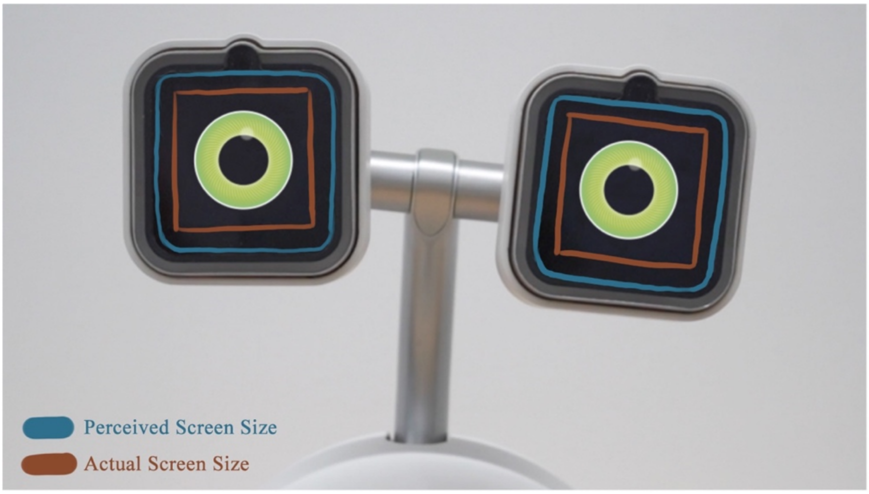

Figure 55. The blue outline represents Haru's perceived screen size. The red outline reveals the actual screen size.

To create the illusion of depth and dimension on Haru's otherwise flat screen, a coloured gradient is employed in the iris. In addition, a spiral texture is introduced to emulate the various iris patterns commonly found in human eyes.

In an effort to enhance visual interest in the conservative eye design, a small faded white circle is strategically positioned just above the pupil. This addition simulates an eye light or 'catchlight,' which represents reflections of light sources as bright spots within a person's eyes. In design, catchlights serve to infuse vitality, depth, and realism into the overall appearance of the eyes.

Finally, the conservative eye occupies a significant portion of Haru's screen eyes. This decision draws from extensive experience in the fields of design and animation, where characters often feature proportionally larger eye sizes. Such larger eyes facilitate improved expression and contribute to heightened visual appeal.

5.5.3 Dandelion Eye

Figure 56. The Dandelion Eye.

The development of the dandelion eye (Figure *56*) arose as a direct response to the perceived lack of visual diversity in contemporary social robot design. In an environment where rendered screen eyes offer almost limitless possibilities, it is a rarity to encounter eye designs that venture beyond the conventional human eye aesthetic. The objective was to tap into the rich tapestry of visual motifs found in nature and leverage the concept of pareidolia, which is the human tendency to perceive human-like faces in non-human objects. The final outcome was an eye design that embraced a more abstract and unconventional approach, drawing inspiration from the delicate white dandelion seeds.

The dandelion eye is characterised by a series of three concentric coloured circles, with two circles being explicitly drawn and one implied. The inner drawn black circle is crafted to resemble the pupil of a human eye, while the middle drawn coloured circle serves as the representation of the iris. These two circles constitute the core components of the eye design. The third circle, which is implied, is created through a succession of circles that uniformly encircle the main body of the eye. This implied circle is seamlessly integrated with the primary eye structure through a series of gradient lines that gradually fade to black, culminating in the distinctive dandelion design motif.

5.5.4 Sakura Eye

Figure 57. The Sakura Eye.

Expanding upon the floral motif, the sakura eye (Figure *57*) was crafted as a homage to Haru's Japanese heritage, drawing profound inspiration from the sakura cherry blossom – a quintessential symbol deeply rooted in Japanese culture. This design not only harmonises with the etymology of Haru's name, signifying spring in Japanese, a season intimately associated with the cherry blossom, but also embraces the symbolic depth embedded within this flower. The sakura eye design encapsulates profound themes of life's impermanence, renewal, and the fleeting beauty of existence. By doing so, it acknowledges and celebrates cultural identity while simultaneously embodying themes of unity and optimism. This artistic approach culminates in the creation of an abstract eye design, characterised by the unique and graceful shape of the sakura petal leaf.

The sakura eye design is distinguished by a series of two concentric circles, each contributing to the overall composition, and a collection of shapes that elegantly frame these central elements. The inner coloured circle, with careful attention to detail, replicates the appearance of the iris in a human eye, serving as the visual focal point of the design. The outer black circle, which represents the sclera, plays a strategic role in simplifying the visual complexity of the sakura eye design by providing a stark contrast that emphasises the vibrant iris. To further accentuate the significance of the iris, coloured lines gracefully encircle the black outer circle, creating a series of implied lines that artfully guide the viewer's attention towards the intricate details of the iris.

Surrounding these central circles are a series of petal-like shapes, crafted with a coloured gradient that seamlessly complements the sakura design motif. These petal shapes not only enhance the visual appeal of the eye but also evoke a profound sense of connection to the sakura cherry blossom. In essence, the sakura eye design is a harmonious blend of artistry and cultural symbolism, capturing the essence of Japan's rich heritage and the profound beauty of the sakura cherry blossom in an abstract and visually captivating form.

5.5.5 Hiro Eye

Haru was developed by the Honda Research Institute, Japan (HRI-JP) and the hiro eye (Figure *58*) serves to pay homage to Honda's distinguished role in automobile development. The hiro eye design is informed by the concept of pareidolia, the psychological phenomenon where human-like faces are perceived in inanimate objects. In the context of automobiles, this phenomenon is often evoked through the symmetrical layout of headlights and air intakes, which can imbue vehicles with varying facial expressions ranging from cheerful smiles to more aggressive demeanours. This approach culminates in the development of an abstract iconic eye design that draws inspiration from an amalgamation of different backlight designs found in some of Honda's most iconic car models.

Figure 58. The Hiro Eye.

The hiro eye design comprises three key elements, each contributing to its distinctive aesthetic. The inner black circle is crafted to closely mimic the appearance of the pupil in a human eye. Within this pupil, a small faded white circle is strategically placed, serving as an eye catchlight – a subtle touch that infuses vitality and depth into the overall presentation of the pupil, akin to the reflections of light sources in human eyes. The middle component of the hiro eye design is a white square that envelops the pupil, effectively serving as the sclera, providing a visually clear background for the eye's central feature. However, what truly defines the unique character of the hiro eye is the outer coloured curved quadrilateral that shapes the entirety of the eye. This element introduces a captivating striped horizontal pattern that alternates between two different saturations of the same hue. This pattern adds an element of dynamism and serves to complete the car backlight design motif. It pays homage to Honda's rich heritage in automotive design by drawing inspiration from the distinctive backlight patterns found in some of Honda's most iconic car models.

5.5.6 Bolts Eye

Figure 59. The Bolts Eye.

The aim of the bolts eye design (Figure *59*) was to fuse visual elements informed by the Victorian-era steampunk aesthetic – an artistic movement deeply rooted in industrial machinery, retro-futuristic themes, and often associated with early concepts of robotics. In steampunk culture, robots are typically amalgamations of gears, springs, and clockwork. Drawing on these characteristics, the design aims to incorporate key features of this stylistic movement such as gears, pistons, and complex clockwork mechanisms into the bolts eye design. This approach culminates in the development of an abstract iconic eye design that draws inspiration from the shape and intricate workings of an old vintage pocket watch.

The bolts eye design is characterised by two concentric circles, each playing a significant role in shaping its distinctive appearance. The inner coloured circle mimics the iris of a human eye, featuring gently curved faded white lines that serve as eye catchlights, infusing vitality into the overall presentation of the pupil. The outer grey circle that envelops the pupil is artfully shaped to resemble the silhouette of an antique pocket watch, and its metallic texture contributes to the overall notion of industrial machinery. Adorning this eye design are a series of bolts and screws, strategically placed to evoke the essence of steampunk aesthetics, ultimately completing the steampunk-inspired design motif.

5.5.7 Mech Eye

Figure 60. The Mech Eye.

The aim of the Mech eye (Figure *60*) was to preserve the humanoid visual design expectations of social robots, but to slightly deviate from the human form by incorporating more mechanical, machine-like features. This chunky eye was conceived as a harmonious blend of both humanistic and mechanical elements, yielding a more iconic representation of the human eye.

The chunky eye design comprises a single-coloured circle, crafted to emulate the appearance of the iris of a human eye. To introduce a touch of three-dimensional depth, a small drop shadow is strategically added. What sets the chunky eye apart from other designs is the incorporation of eyebrows. These eyebrows are constructed from three distinct machine-like components seamlessly conjoined by screw-like holes, forming rotational joints. The upper portions of the mechanical eyebrows are adorned with a lighter tint, while the lower sections feature a slight shade, creating a sense of depth and dimension within the eyebrows. Both the iris and the eyebrows are adorned with a circular metallic texture that further accentuates the mechanical aesthetic, completing the eye's overall machine-inspired motif.

5.6 Evaluation and Results

In order to enrich existing discourse on personalisation and how it can impact individual perceptions and behaviours during interactions with social robots, an extensive online questionnaire was conducted, encompassing a total of 54 unique eye variations as stimuli. The questionnaire was meticulously structured into three distinct phases, with each phase focusing on specific attributes and characteristics of the eye designs under examination. It is important to note that this research endeavour was conducted in strict compliance with ethical standards and was granted approval by the ethics committee at the University of Technology, Sydney, under the Ethics Code: ETH19-3968.

In the subsequent sections, we will provide a concise overview of the data collected during each phase of the questionnaire, accompanied by key statistical findings that shed light on the responses. The ensuing discussion will delve deeper into the emerging qualitative trends observed in the data, offering insights into the potential implications for the personalisation of human-robot interactions. In addition, we will explore relevant theoretical foundations that may help contextualise the observed outcomes and contribute to a more comprehensive understanding of the findings.

5.6.1 Demographics

The participants for this research study were recruited through the survey exchange platform Prolific (https://www.prolific.co), and a total of 100 individuals took part in the study. The participant demographics were diverse, with 49 identifying as female, 48 as male, and 3 as non-binary. The age distribution of participants was as follows: 40% were between 18–24 years, 38% were aged 25–34, and the remaining 22% fell into the age group over 35. Geographically, the study drew a substantial number of participants from various regions, with 37% from Mexico, 19% from South Africa, and 15% from the United Kingdom, among others.

In terms of ethnicity, the participants represented a wide range of backgrounds. A significant portion identified as Hispanic (40%), followed by Caucasian (31%), African (14%), Asian (7%), and South Asian (1%). Among those who identified as African, the majority identified as Black African (10%). This diversity in ethnic backgrounds contributed to a rich and varied participant pool.

It is noteworthy that a substantial majority of respondents (94%) did not have any professional or research affiliation within the field of social robotics. Those with some level of experience in this domain held diverse roles in sectors such as programming, social media, healthcare assistance, biomedical engineering, and business, highlighting the multidisciplinary nature of the study's participants.

Furthermore, the study revealed that a significant majority of participants (98%) did not possess a social robot. Among the few who did, one respondent mentioned acquiring the Misa Robot based on healthcare recommendations, while another indicated ownership of an Alexa smart speaker received as a gift. This distribution of ownership provided valuable insights into the participant pool's familiarity with social robots and technology in general.

5.6.2 Phase 1: Design

In the initial phase of the experiment, the primary objective was to evaluate the participants' responses to the six distinct eye designs presented, with an emphasis on design evaluation while controlling for colour preferences. All eye designs were consistently presented in the same colour during this phase, allowing for a focused assessment of the designs.

Participants were engaged in viewing a randomised sequence of videos, each featuring one of the six different eye designs. Subsequently, participants were asked to provide concise 1–2-word descriptions of their immediate emotional reactions to each design. Following this, participants were asked to rate their preferences for each design using a seven-point Likert scale, where 1 indicated a dislike and 7 indicated a like. Participants were also given the opportunity to provide additional comments.

The results of this phase are depicted in Figure *61* and indicated that the most favourably received eye designs were the conservative eye (29%) and the mech eye (25%). These two designs garnered the highest levels of positive responses. Following closely behind was the bolts eye design (16%), followed by the hiro eye design (11%) and the sakura eye design (11%). In contrast, the dandelion eye design received the lowest preference, with only 8% of participants expressing a positive response.

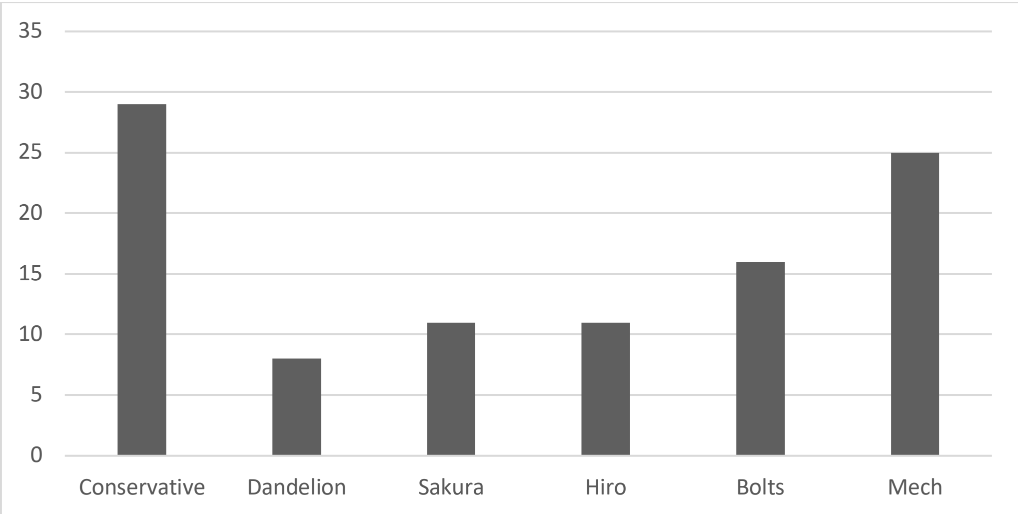

Figure 61. Overall favourite eye designs.

5.6.3 Phase 2: Colour

In the second phase of the experiment, the primary objective was to gauge participants' responses to different colour variations for each of the distinct eye designs. Participants were presented with a range of 9 diverse eye colours and were asked to select up to 3 of their most preferred eye colours for each of the presented eye designs. Furthermore, participants were invited to provide additional comments explaining their preferences for specific eye colours.

The outcomes of this phase revealed intriguing insights into the participants' colour preferences across all eye designs. Blue (21.2%) and green (17.4%) emerged as the most favoured eye colours, gaining the highest percentage of preferences across all designs. These colours appeared to resonate strongly with participants. Following closely behind were yellow (12.9%), pink (11.0%), grey (10.9%), and purple (9.3%), which were also relatively well-received. On the other hand, certain eye colours received comparatively lower preferences. Orange (7.6%), brown (5.7%), and red (4.0%) were the least popular choices among participants. The distribution of preferences for these eye colours is depicted in Figure *62*.

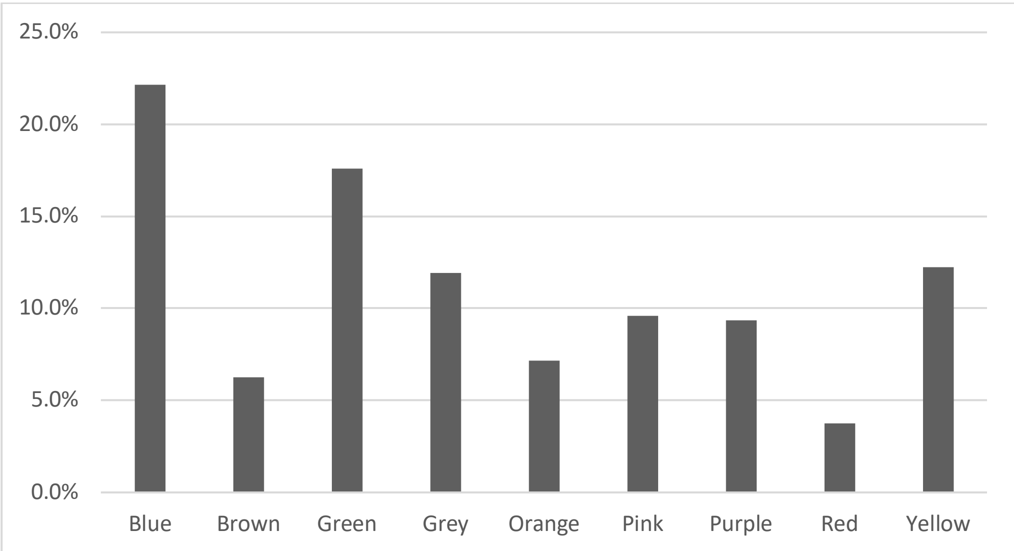

Figure 62. Overall favourite eye colours.

5.6.4 Phase 3: Design Context

In the third phase of the experiment, the aim was to assess the participants' preferences for various eye designs in different contextual situations while minimising potential biases related to colour preferences. All eye designs were presented in the same colour during this phase, with a focus on design evaluation.

Participants were presented with seven distinct contextual situations and were asked to select up to two eye designs they believed would be most appropriate for each scenario. Participants were also given the opportunity to provide additional comments explaining their choices. Figure *63* portrays the overall favourite eye designs in context.

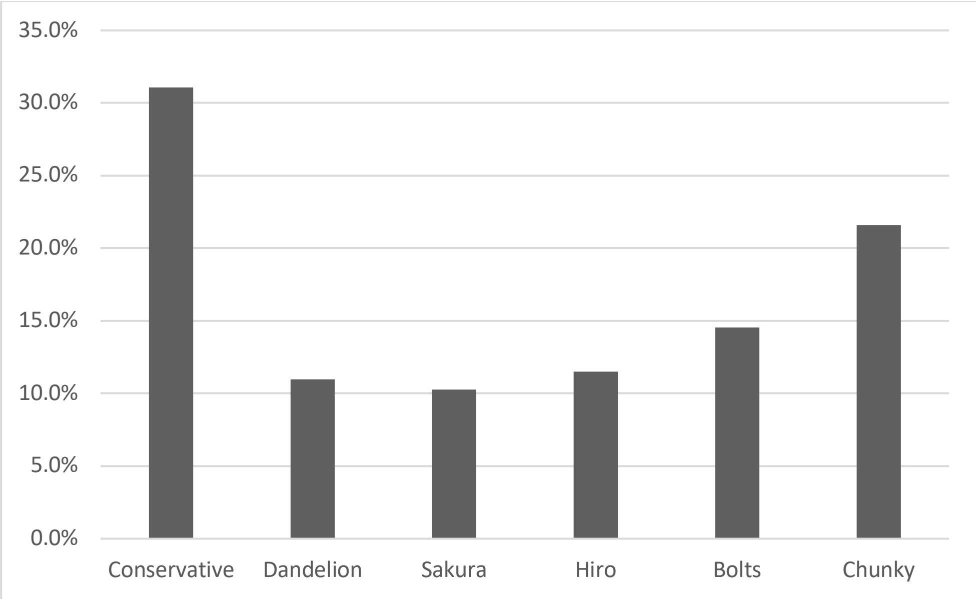

Figure 63. Overall favourite eye designs in content.

Home. In the context of a personal assistant at home, the conservative eye design (28.7%) and the mech eye design (25.2%) were the most favoured choices. These were followed by the bolts eye (15.0%) and the hiro eye (12.6%). The sakura eye (9.6%) and the dandelion eye (9.0%) received relatively lower preferences.

Office. For an office assistant in the workplace, the conservative eye design (35.6%) was the clear favourite, followed by the mech eye design (17.8%) and the bolts eye design (16.6%). The hiro eye design (12.3%) and the dandelion eye design (11.0%) also received significant consideration, while the sakura eye design (6.8%) was less favoured.

Emergency. In the event of a medical emergency at home, the conservative eye design (30.3%) was deemed most appropriate, followed by the mech eye design (23.9%) and the bolts eye design (19.4%). The dandelion eye design (10.3%), hiro eye design (9.7%), and the sakura eye design (6.5%) were less popular choices.

Hospital. If encountered by patients in a hospital setting, the conservative eye design (34.8%) was the most preferred, followed by the mech eye design (25.5%). The sakura eye design

(11.8%), bolts eye design (9.9%), hiro eye design (9.3%), and the dandelion eye design (8.7%) were less favoured.

School. In a primary school classroom with children aged 7–12, preferences for eye designs were more evenly distributed. The conservative eye design (23.3%) remained the most popular, followed by the sakura eye design (17.4%) and the mech eye design (17.4%). The dandelion eye design (14.5%), bolts eye design (14.0%), and the hiro eye design (13.4%) all received notable consideration.

Shops. When seeking directions in an unfamiliar mall from a robot shopping concierge, the conservative eye design (33.6%) was the most preferred, followed by the chunky eye design (21.5%) and the bolts eye design (15.4%). The dandelion eye design (12.1%), sakura eye design (8.7%), and the hiro eye design (8.7%) were less favoured.

Restaurant. In a local restaurant while placing an order with a robot waiter, the conservative eye design (32.0%) was the most popular choice. The mech eye design (20.3%) and the hiro eye design (14.4%) were also well-received. The bolts eye design (11.8%), dandelion eye design (11.1%), and the sakura eye design (10.5%) received comparatively lower preferences.

5.6.5 Phase 4: Colour Context

In the fourth phase of the experiment, the objective was to assess the participants' perceptions of which eye colours were most suitable for various contextual situations. To minimise potential biases related to eye designs, all eye colour variations were presented using the conservative eye, focusing exclusively on colour evaluation. Participants were presented with the same seven contextual situations as previously mentioned and asked to select up to three eye colours they believed would be most appropriate for each situation. In addition, participants had the opportunity to provide further comments explaining their choices for each contextual scenario. Figure *64* portrays the overall favourite eye designs in context.

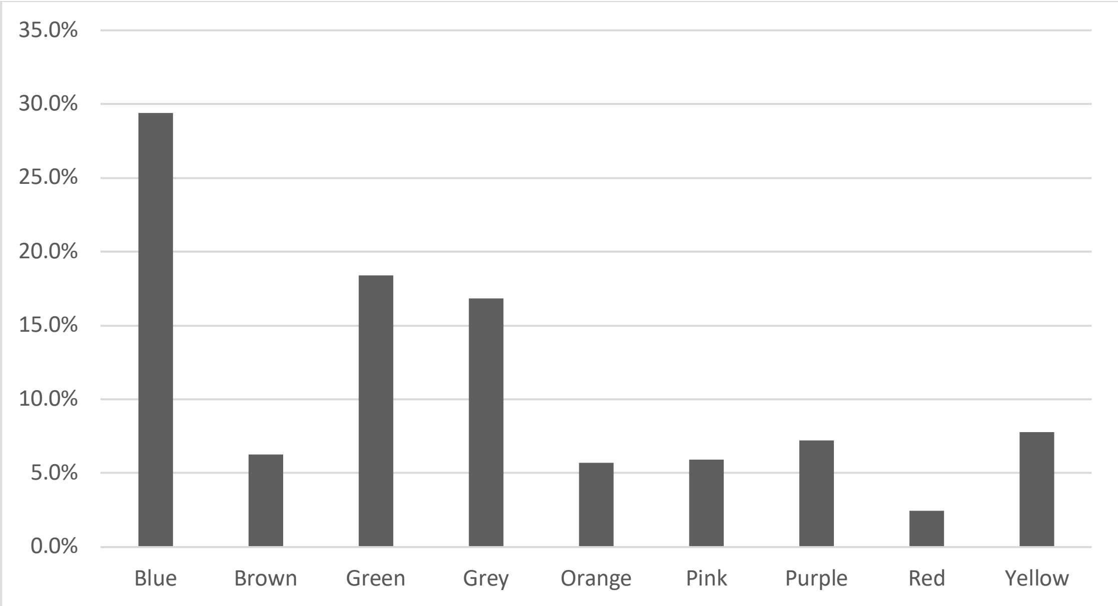

Figure 64. Overall favourite eye colours in content.

Home. In a home setting, blue eyes garnered the highest preference at 33.2%, followed by green at 18.2%, grey at 15.9%, and purple at 9.1%. Less popular choices included brown eyes at 5.5%, orange at 5.0%, pink at 5.0%, and red at 2.3%.

Office. Within an office context, blue eyes received the highest preference at 29.3%, followed by grey at 23.0%, and green at 19.4%. Yellow eyes were chosen by 8.6% of participants, while brown eyes received 7.7% of the votes. Purple eyes were less favoured at 5.0%, along with orange at 3.2%, pink at 2.3%, and red at 1.8%.

Emergency. In an emergency situation, blue eyes were favoured by 27.8% of participants, followed by green at 18.5%, and grey at 17.1%. Yellow eyes received 6.9% of the selections, followed closely by orange and pink at 6.5%. Brown and red eyes each garnered 6.0% of the preferences, while purple eyes were chosen by 4.6%.

Hospital. Within a hospital context, blue eyes were the preferred choice for 34.1% of participants, followed by green at 19.3%, and grey at 17.9%. Brown eyes received 7.2% of the votes, with purple eyes at 6.3%, and yellow eyes at 5.8%. The least popular choices were pink at 4.5%, orange at 3.1%, and red at 1.8%.

School. In a school setting, blue eyes were favoured by 24.1% of participants, followed by green at 15.2%, yellow at 13.9%, pink at 13.9%, and purple at 13.5%. Less popular choices included orange at 8.0%, grey at 5.1%, brown at 3.4%, and red at 3.0%.

Shops. As a shopping concierge, the most preferred eye colour was blue at 28.5%, followed by grey at 20.9%, and green at 17.5%. Yellow eyes received 8.9% of the selections, followed by orange at 7.2%, brown at 6.4%, purple at 6.0%, and pink at 4.3%. The least favoured choice was red eyes at 0.4%.

Restaurant. In the role of a restaurant waiter, blue eyes were the most favoured at 29.4%, followed by green at 21.1%, and grey at 18.4%. Brown eyes received 7.9% of the selections, with orange at 6.6%, purple at 5.7%, pink at 4.8%, and yellow at 4.0%. The least preferred choice was red eyes at 2.2%.

5.6.6 Phase 5: General Questions

The fifth phase of the experiment aimed at gaining a general understanding of robot eye design and personalisation. Participants were asked a series of open-ended questions about robot eye design and personalisation and were given the opportunity to provide further comments after each question. The questions were divided into three main topic areas: design, colour, and general questions.

5.6.6.1 Design

- Do you think the design of a robot's eyes would affect how you would interact with a social robot?
- Do you think it is important to have a selection of eyes to choose from so that you can personalise your social robot?
- Would you change the design of your robot's eyes on a regular basis?

- Do you think that the design of a robot's eyes should change in different situations or remain constant?

The survey results shed light on the participants' perspectives regarding the impact of robot eye design on their interactions with social robots. An overwhelming majority of the participants of 81% firmly believed that the design of robot eyes would indeed have a significant impact on their interactions with these machines. This finding underscores the importance of eye design as a crucial factor in shaping user perceptions and experiences with social robots.

Conversely, only a small minority of participants (8%) expressed the viewpoint that the design of robot eyes would have no effect on their interactions. In addition, 11% of participants remained undecided on the matter. These findings collectively highlight the broad consensus among participants regarding the significance of eye design in influencing their interactions with social robots.

Further reinforcing the importance of eye design customisation, 93% of participants emphasised the value of having a diverse range of eye designs available for personalising their interactions with social robots. This finding underscores the desire for customisation and individualisation in human-robot interactions, where participants value the ability to tailor the robot's appearance to their preferences and needs.

When considering the frequency of altering eye designs, it's notable that a significant minority of participants (23%) indicated a preference for making regular changes. In contrast, a larger majority of participants (52%), expressed a tendency to be less inclined to change eye designs regularly. The remaining 25% of participants were undecided on the matter. This divergence in preferences highlights the complexity of individual choices regarding the customisation and stability of eye designs.

Interestingly, despite the prevailing inclination against frequent changes in eye design, a substantial majority of participants (66%), maintained the belief that a robot's eye design should vary in different situations. This perspective suggests a nuanced approach to customisation, where participants see value in adapting the robot's appearance to suit specific contexts or tasks. In contrast, a large number of participants (34%) believed that the design should remain consistent, possibly reflecting a preference for continuity and familiarity in human-robot interactions.

5.6.6.2 Colour

- Do you think the colour of a social robot's eye would affect the way you would interact with it?
- Would you change the eye colour of your robot's eyes on a regular basis?
- Do you think the colour of a robot's eyes should change in different situations or remain consistent?

The survey results provide valuable insights into participants' perspectives regarding the impact of a social robot's eye colour on their interactions with these machines. A significant majority of participants (68%) believed that the colour of a social robot's eye would indeed have a notable impact on their interactions. This finding underscores the significance of eye colour as a factor that shapes users' perceptions and experiences when engaging with social robots.

Conversely, only a small number of participants (16%) expressed the viewpoint that the colour of a robot's eye would have no effect on their interactions. In addition, another 16% of participants remained undecided on the matter. These findings collectively highlight the general consensus among participants regarding the influence of eye colour on human-robot interactions.

When it comes to the frequency of changing eye colours, 36% of participants expressed a desire to alter the eye colour regularly. In contrast, a larger majority of participants (44%) indicated that they would be less inclined to change eye colours regularly. The remaining 20% of participants remained undecided on the matter. This divergence in preferences reflects the complexity of individual choices concerning the customisation and stability of eye colours in social robots.

Interestingly, despite the prevailing inclination against frequent changes in eye colour, a sizeable percentage of participants (68%) maintained the belief that a robot's eye colour should change in different situations. This perspective highlights the importance of adaptability and context-sensitivity in eye colour customisation, as participants see value in adjusting the robot's eye colour to suit specific contexts or tasks. In contrast, a significant minority of participants (32%) believed that eye colour should remain consistent, possibly reflecting a preference for continuity and uniformity in human-robot interactions.

5.6.6.3 General

Participants expressed a strong desire for personalisation in various aspects of social robots. The voice of the robot was the most commonly mentioned area for customisation, with 28.1% of participants supporting the option of personalisation. Following closely, 23.5% believed that the robot's personality should be customisable. Other aspects that participants considered important for personalisation included the robot's functionality (21.9%), size (14.5%), and construction material (12.0%).

5.7 A Nuanced Investigation into the Uncanny Valley

Upon initial examination of the data, it appears that the Uncanny Valley theory and the presumption that human-likeness is more intuitive holds promise for enhancing affinity in human-robot interaction. The conservative eye design, which was the most human-like and received a 29% preference rate among participants, aligns with the theory's suggestion that greater human likeness can lead to higher affinity. This design emerged as the most favoured, indicating a strong preference for human-like features. Conversely, the Mech eye, with a 25% preference rate, demonstrates that a balanced approach, incorporating both human-like and mechanical elements, can also achieve significant levels of affinity. This finding corresponds to the second highest peak in the Uncanny Valley curve, where a blend of human and non-human features is well-received. Designs that deviated more from human-like eyes, such as Bolts (16%), Sakura (11%), Hiro (11%), and Dandelion eye (8%), which bear minimal resemblance to human eyes, were less preferred. This observation appears to validate the central tenets of the Uncanny Valley theory, suggesting that designs too far removed from human likeness may not engender as much affinity.

However, when considering the data from a categorical analysis perspective, certain limitations of the Uncanny Valley theory become apparent. The combined preference rate for the less human-like eye designs – Bolts, Sakura, Hiro, and Dandelion – amounted to 46%, which presents a statistical contradiction to the theory. This cumulative preference indicates that a substantial portion of participants favoured designs with minimal human resemblance. This discrepancy suggests that factors other than human likeness play a significant role in participants' preferences. It implies that user evaluation criteria for robot eye designs might include additional dimensions beyond mere resemblance to human eyes. These could encompass aspects like artistic appeal, uniqueness, cultural relevance, or emotional resonance. This finding highlights the complexity of user preferences in human-robot interaction and points to the need for a more nuanced understanding of what drives user affinity in social robotics beyond the simplistic metric of human likeness.

The qualitative data from this study reveals that the effectiveness of a social robot's visual design is not solely dependent on human likeness, as presumed by the Uncanny Valley theory. Instead, the meanings participants attribute to the visual design are also of paramount importance. While a portion of participants did associate their preference for the conservative eye design with its human-like characteristics (17 mentions), a larger group (25 mentions) based their preference on aesthetic appeal, notably drawn to Haru's “cuteness”, an attribute that extends beyond simple human resemblance.

In addition, emotional attributes ascribed to Haru played a significant role in shaping participant preferences. There were 20 mentions that highlighted perceptions of Haru as friendly and innocent. This response might be linked to Haru's large eyes, an element of neotenisation and the baby schema, which were explored in subsection 4.4.2. Neotenisation refers to the retention of juvenile features in the adult form, and the baby schema encompasses a set of characteristics typically found in infants, like large eyes, that are universally perceived as cute and evoke nurturing responses. In the context of Haru, the large eyes might have elicited these instinctive reactions, leading participants to ascribe qualities like friendliness and innocence to the robot.

This observation underscores the importance of considering psychological principles and human innate responses in robot design. It suggests that the emotional impact of a robot's appearance can be just as crucial as its functional capabilities in determining the effectiveness of human-robot interaction. By integrating design elements that resonate on an emotional level, social robots can create more meaningful and positive interactions with users. This approach aligns with the broader goal of designing robots that are not only technologically sophisticated but also psychologically and emotionally attuned to human users.

This aspect of visual design highlights the limitations of the Uncanny Valley theory, which primarily focuses on human likeness as the central criterion for effective human-robot interaction. People's expectations, preferences, and comfort levels with robot designs are influenced by their unique backgrounds and experiences, which may lead them to find different styles more intuitive or appealing. In fact, an interesting observation in this study was the reaction of a specific subset of participants who explicitly cited human likeness as a deterrent in their preference for the conservative eye design, with 11 mentions noting this aspect. This response indicates that for some individuals, a high degree of human resemblance in a robot can actually be off-putting, contradicting the general assumption of the Uncanny Valley theory that greater human likeness equates to higher affinity.

This finding suggests that a one-size-fits-all approach in robot design, particularly one that prioritises human likeness, may not be universally effective. It underscores the need for a more nuanced and individualised approach in social robot design, one that considers a broader range of visual styles and interaction modalities. By acknowledging and accommodating the diverse preferences and perspectives of users, designers can find different ways to personalise social robots so that they better suit the varying needs and expectations of different individuals, ultimately enhancing the overall experience of human-robot interaction.

5.8 Frames of Understanding

To realign the balance between design elements and individual perceptions and experiences in social robotics, it is essential to explore the wide range of factors influencing how people interact with a robot's visual design. This approach is grounded in the design thinking principle of *frame creation* (Dorst, 2011). Frame creation involves a critical examination of the underlying assumptions, constraints, and perspectives that shape a field. In the context of social robotics, this means scrutinising the reasons behind users' diverse responses to different visual design elements.

By adopting this approach, social roboticists can delve deeper into understanding why participants ascribe particular meanings to different eye designs. This understanding is vital for moving beyond generic design solutions and towards more tailored and effective visual designs. It allows designers to identify and cater to the specific emotional and cognitive needs of different user groups, enhancing the robot's appeal and interactive quality.

The subsequent sections of this study will detail the various *frames* explored in this research, each representing a different perspective or set of considerations that influence user interaction with robot eye designs. These frames showcase the multitude of ways participants interpret and assign meaning to distinct eye designs. By highlighting this diversity, the study illuminates the rich tapestry of user experiences and preferences, underscoring the need for a more nuanced and user-centred approach in the visual design of social robots.

5.8.1 Media Influences

Media depictions in film, television, and video games significantly influence societal expectations and attitudes towards technology, including the collective cultural imagination of what a social robot should look like (Dourish & Bell, 2014). Often, these media representations serve as the public's introductory encounter with emerging technologies like robotics, shaping design decisions and user preferences across various social and cultural contexts.

The influence of media representations on the public perception of robots is profound and far-reaching. Frequent exposure to specific robot designs in the media creates a set of expectations or standards in the minds of the audience. For instance, when social robots are portrayed in the media with certain design features and personalities, these depictions can shape public expectations, leading people to anticipate similar traits in real-life robots (Dourish & Bell, 2014). This dynamic can lead to a feedback loop, where designers, aware of these media-induced expectations, may feel compelled to design robots that either align with or deliberately deviate from these perceptions to guide audience reactions in a particular direction.

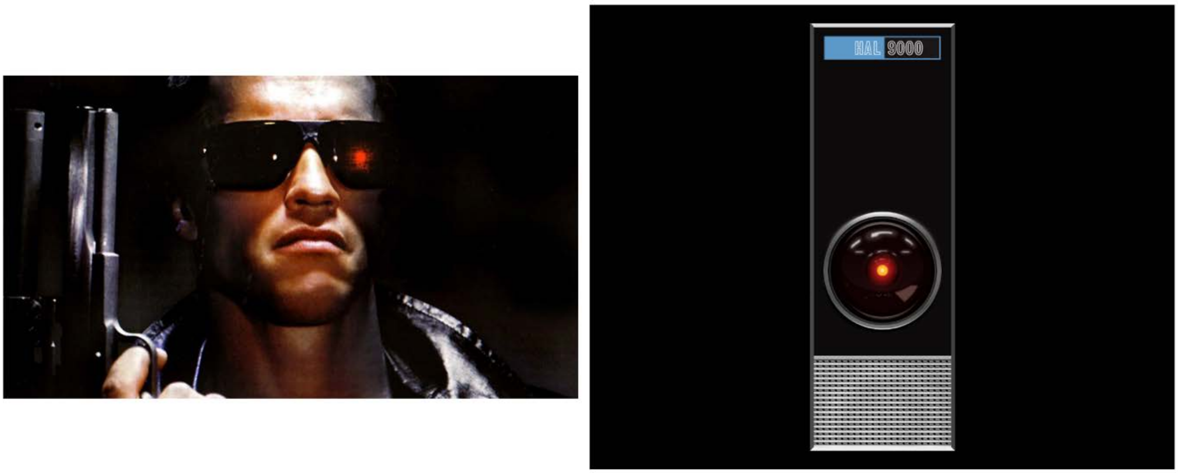

Figure 65. The Terminator (Cameron, 1984) and HAL (Kubrick, 1968) are robots of evil that feature red eyes.

A notable example of the influence of the media on robot design perceptions can be seen in the portrayal of robots in dystopian science fiction films. Classic examples include the Terminator (Figure *65* – left) from the *Terminator* series and HAL 9000 (Figure *65* – right) from *2001: A Space Odyssey*. In these narratives, robots often feature glowing red eyes, a design choice that symbolises malevolence or aggression (Kalegina et al., 2018; Veglahn, 1987). The Terminator, with its iconic, red-eyed gaze, embodies the archetype of a relentless and dangerous machine, while HAL 9000, uses a single, unblinking red eye to convey a sense of cold intelligence and potential menace. This recurring motif of red eyes in such influential films has established a cultural narrative that affects real-world perceptions and reactions to robot designs.

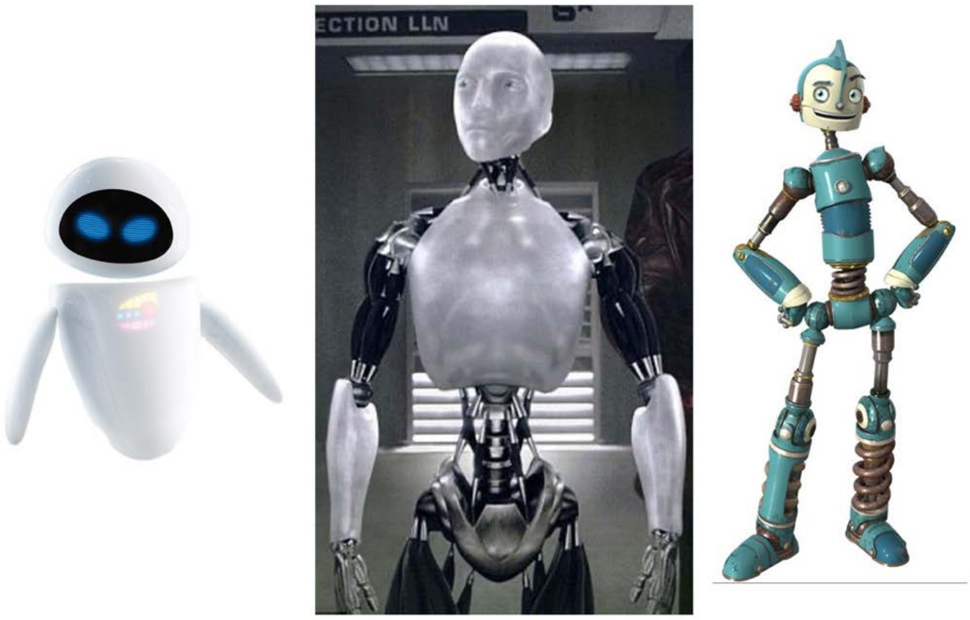

Figure 66. Eve (left – Stanton, 2008), Sonny (middle – Froyas, 2004), and Rodney (right – Wedge, 2005) are popular robots of good that feature blue eyes.

The impact of these media portrayals is evident in the findings of the current study, where red was the least favoured eye colour among participants, receiving only 4% of preferences. Participants frequently associated red eyes with negative attributes, describing them as uncomfortable (12 mentions), scary (7 mentions), dangerous (6 mentions), evil (6 mentions), and alarming (3 mentions). In contrast to this, the portrayal of characters with blue and green eyes in film and literature also seems to significantly shape societal preferences, particularly in the context of social robots (Brooks & Hébert, 2006; Caldas-Coulthard, 2003; K. Goldman, 2007). Eve (Figure *66* – left) from 2008 film *Wall-E*, Sonny (Figure *66* – middle) from the 2004 film *I, Robot*, and Rodney (Figure *66* – right) from the 2005 film *Robots,* are key characters in their respective films and utilise the blue colour as a motif for virtue, intelligence, or heroism. Like red eyes, this recurring motif of blue and green eyes has also established a cultural narrative that affects real-world perceptions and reactions to robot designs.

Applying these insights to the visual design of social robots, it becomes clear that the choice of eye colour can have a considerable impact on how a robot is perceived and interacted with.

The societal biases and associations with certain eye colours, as reflected in media portrayals and cultural narratives, influence user preferences and expectations. In this study, blue and green were the most popular eye colours, receiving 21.2% and 17.4% of preferences, respectively. This preference aligns with the positive attributes typically associated with these colours in cultural narratives. In addition to red (4.0%), other eye colours such as orange (7.6%) also ranked lower in preferences which may be the result of their close proximity to the colour red on the colour wheel. The comparatively lower preference for these colours might be influenced by cultural and media biases, or possibly due to their perceived lack of connection with the virtues or qualities often associated with blue and green eyes.

The observed preference for blue and green eyes in the survey, despite the majority of the world's population having brown eyes, raises intriguing questions about the influence of media and cultural representation on aesthetic choices. The survey, which included a significant proportion of Hispanic participants (40%)—a demographic known for predominantly having brown eyes—revealed that brown eyes were one of the least preferred colours, with only a 5.7% preference rate (as portrayed in Figure *67*). This outcome could be attributed to the impact of media and popular culture, especially from the pre-1990s era when blue-eyed Caucasian actors were prominently featured (Hunt et al., 2023). Such consistent exposure may have ingrained a preference for these eye colours in viewers.

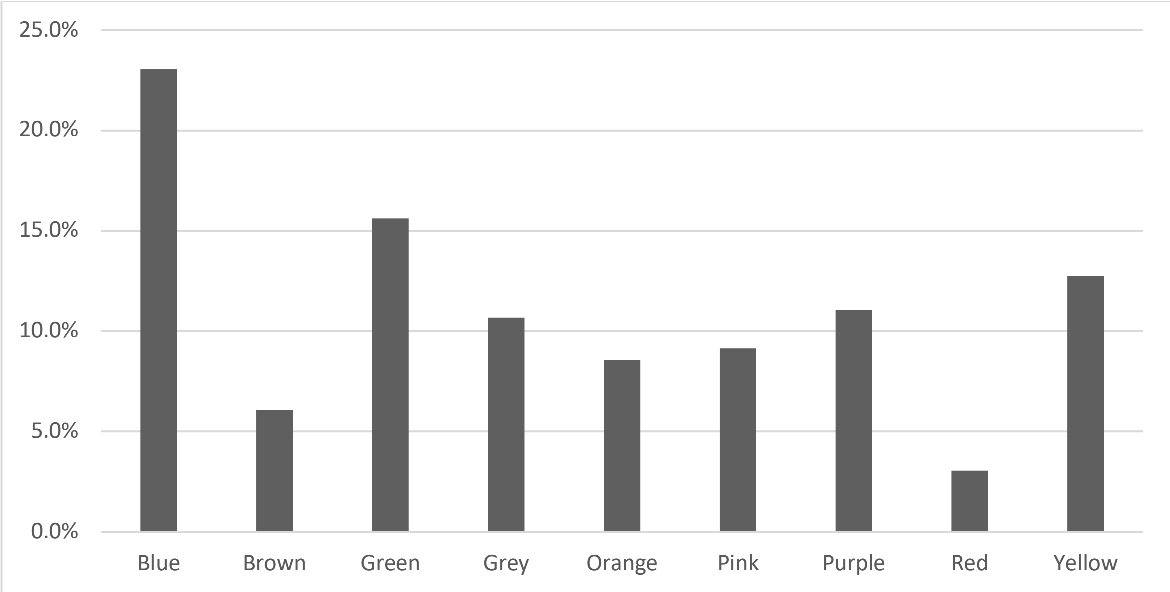

Figure 67. Hispanic overall eye colour preferences.

The colour of blue and green eyes in media has often carried positive connotations, aligning with attributes such as attractiveness, trustworthiness, or heroism. This portrayal may have subconsciously influenced individuals who grew up with such media representations. In literature and film, these colours have often been romanticised, with blue eyes linked to depth and calmness, and green eyes to mystery or enigma. This romanticisation may contribute to their desirability in social robot design. In contrast, the historical context of racism in Hollywood, tied to colonialism, often relegated people of colour, especially those with darker skin, to villainous roles, reinforcing negative stereotypes (Hunt et al., 2023). This may lead to subconscious biases against darker eye colours, impacting design preferences for social robots. The "Blue Eyes/Brown Eyes" conducted by Jane Elliott (2016), where participants were treated preferentially or discriminatorily based on their eye colour, demonstrated how such physical attributes can influence social hierarchies and individual self-esteem, demonstrated how eye colour can influence social hierarchies and self-esteem, revealing deep-seated biases and stereotypes related to eye colour.

Furthermore, the survey results, showing a notable preference for blue and green eyes among a significant number of Caucasian participants (31%), could be reflective of a desire for self-representation in social robot design. This inclination towards certain eye colours is not merely a matter of aesthetic preference but also a search for familiarity and identification. The dataset reinforces this notion, with 19 participants specifically highlighting the human-like qualities of blue and green eyes. Comments such as "Blue is a calming colour that evokes a sense of comfort and safety," and "Green eyes are more natural looking like the human eye," illustrate a perceived connection between these colours and human characteristics.

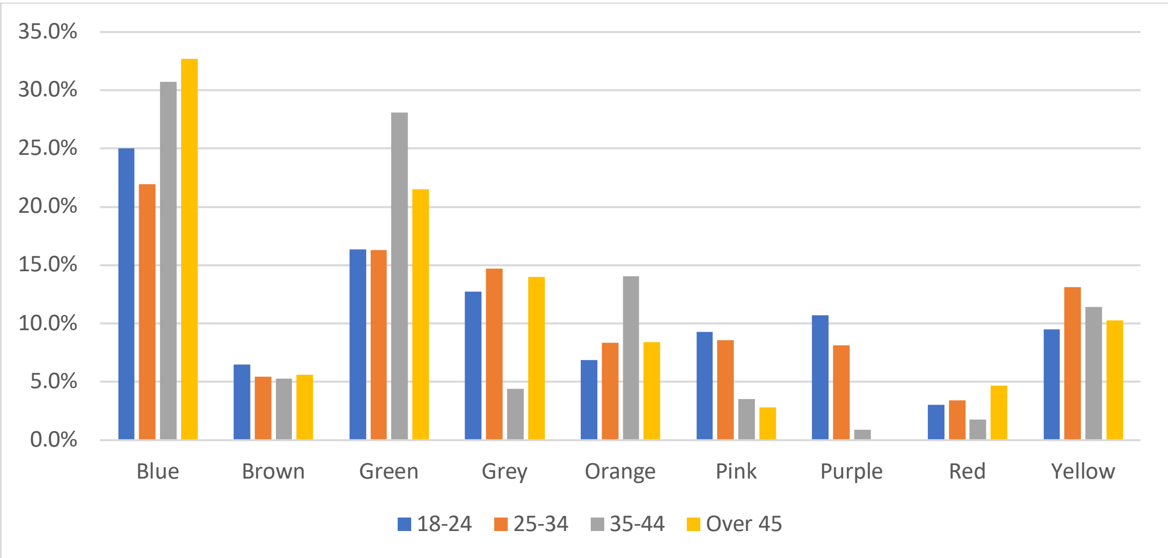

Figure 68. Age group overall colour preferences.

The recent shifts in societal norms and media representation, as evidenced by the Hollywood Diversity Report (2023)., offer profound insights into the changing landscape of preferences, particularly in the context of social robotics. This study's data (as portrayed in Figure *68*) reveals that older age groups, particularly those aged 35-44 and over 45, tend to favour traditional eye colours like blue (30.7% and 32.7%, respectively) and green (28.1% and 21.5%). In contrast, younger cohorts aged 18-24 and 25-34 show a lower preference for these colours (25.1% and 21.9% for blue, and 16.3% each for green). This divergence in preferences is a reflection of the broader societal shift towards embracing diversity, influenced by the increasing presence of ethnically diverse lead actors in media – from 9.1% in 2013-2014 to 35.9% in 2021-2022.

As younger generations are exposed to a more inclusive and diverse range of representations in media, their aesthetic preferences are expanding beyond conventional norms. This evolution is crucial for the field of social robot design. It signifies a shift in what individuals find relatable or desirable in robotic companions (Hunt et al., 2023). This change in perception necessitates a move away from the traditional focus on blue and green eyes towards a more inclusive range of options. By incorporating a broader spectrum of eye colours in social robots, including more commonly occurring hues like brown, designers can better reflect the true diversity of the global population.

Finally, the preference for blue and green eyes in both Hollywood and this study points to an intriguing phenomenon of over-representation, where these less common eye colours are given disproportionate prominence. It has been has estimated that approximately 70-80% of the world's popular have brown eyes in comparison to blue with only 8-10% and green with only 2% (M. Edwards et al., 2016; Gudgel, 2023; Katsara & Nothnagel, 2019; Mackey, 2022). Despite being relatively rare in the global population, blue and green eyes have been consistently idealised and magnified in media, lending them a sense of novelty and rarity. This over-representation can shape perceptions and preferences, leading to a heightened attraction to these colours.

Incorporating a variety of eye colours in social robot design is not only about aesthetic diversity but also about challenging and broadening the existing norms and preferences shaped by media representation. By offering eye colours that mirror the true diversity of the human population, designers can counter the skewed representation in media and contribute to a more inclusive and realistic portrayal of beauty and individuality. This commitment to diversity in design resonates with a growing societal awareness and demand for representation and inclusivity, aligning with ethical and responsible design practices.

5.8.2 Branding and Marketing Influences

The marketing and branding strategies of major tech companies play a pivotal role in shaping public preferences, extending to aspects like robotic eye colour (DeSantis, 2023). Companies such as Apple and Uber utilise minimalist monochrome colour schemes in their branding, which are often associated with luxury and sophistication. Conversely, brands like Android and Spotify opt for green, a colour typically linked to innovation and growth. These strategic colour choices, consistently reinforced through marketing campaigns and user interfaces, not only assist in brand differentiation but also subtly influence consumer preferences and perceptions.

In the realm of social robotics, these branding influences can be particularly significant. The consistent exposure to certain colour schemes in tech products and advertising can create subconscious associations and preferences in consumers' minds (Caivano & Lopez, 2007; Grimes & Doole, 1998; Page et al., 2012). For instance, the heavy use of blue and green in tech branding might lead consumers to associate these colours with modernity, reliability, and innovation. Similarly, the monochrome palettes of luxury brands could evoke perceptions of elegance and high quality. This phenomenon extends beyond mere colour preference; it influences the overall style and aesthetic that consumers find appealing. For example, the sleek, minimalist design favoured by certain high-end brands might lead to a preference for robots with a similar aesthetic. In contrast, the vibrant and dynamic colour schemes of more playful brands could make consumers more receptive to robots with a similar lively design.

The influence of branding and marketing on consumer preferences could have influenced eye colour preferences in this study. The most preferred colours were blue (22.2%), green (17.6%), and grey (11.9%), which may be attributed to their frequent use in tech industry branding. This study's findings underscore the importance for designers and researchers in social robotics to take into account the broader branding influences when selecting eye colours for consumer-oriented robots. Choosing popular colour schemes from the tech industry can certainly boost the marketability and user acceptance of social robots. However, this strategy requires careful consideration to ensure that the robots remain accessible and appealing across diverse cultural backgrounds and preferences. In aligning with specific colour schemes associated with well-known tech brands, it is crucial to recognise that this choice may also inadvertently align the robot with the values and ideas represented by these companies. Each brand carries a set of associations and connotations in the public's mind, shaped by the company's history, marketing strategies, and public perception (Otto et al., 2011).

Therefore, when integrating popular colour schemes and design aesthetics from established brands, designers should be aware of the implicit messages and values they might be conveying. It is important to ensure that these choices do not conflict with the intended purpose, ethos, or user demographic of the social robot. Moreover, a reliance on existing brand colours should not overshadow the need for originality and creativity in design, nor should it limit the scope for representing a diverse array of cultural values and ideas. By carefully considering these aspects, designers can create social robots that are not only in line with current market trends but also embody a broader range of values and appeal to a diverse spectrum of users. This approach will contribute to the development of social robots that are technologically advanced, culturally sensitive, and inclusive, reflecting a variety of perspectives and experiences.

5.8.3 Gender Impacts

The influence of traditional gender norms and socially constructed ideals on aesthetic preferences is a nuanced and complex aspect of design that can significantly shape perceptions of social robots. These norms, which have historically dictated specific aesthetic preferences and perceptions in various domains—such as associating suits with men and dresses with women—extend their reach into the realm of social robotics, influencing perceptions of gender through the robots' visual design. In the context of this study, these gendered perceptions and expectations have manifested in the preferences in the eye designs of social robots.

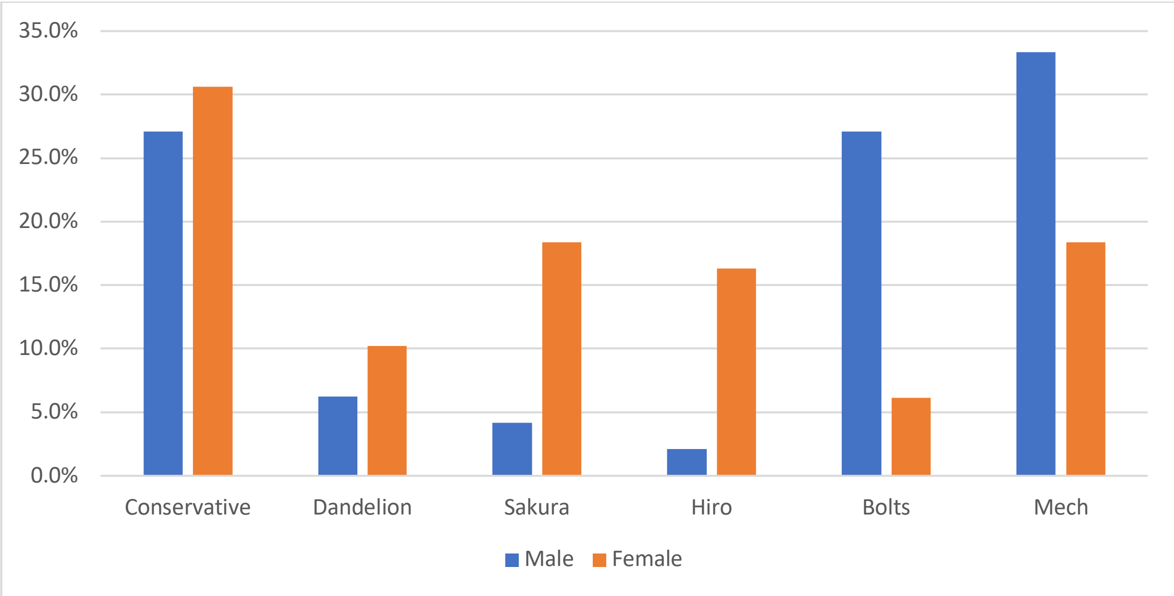

Figure 69. Gender overall design preferences.

The disparity in preferences for the Sakura Eye design between females and males in social robots is a striking example of how gender norms and personal aesthetics can significantly influence design choices. This difference is highlighted by the data (as portrayed in Figure *69*), showing that 18.4% of females preferred the Sakura Eye design, while only 4.2% of males did. The attraction of women to this particular design was predominantly rooted in its flower-themed aesthetic. This theme, mentioned six times, underscores a broader cultural association that often links women with nature and beauty (Mann, 1998). Beyond the fondness for floral motifs, women also emphasised the overall aesthetic appeal and beauty of the Sakura Eye design. This aspect of their preference, mentioned three times, reflects a tendency among women in this study to value the visual appeal and distinctiveness in design. Descriptions of the design as "eye-catching, innovative, cute, and beautiful" indicate a deep appreciation for designs that are not only aesthetically pleasing but also unique and engaging.

The critical response of men to the Sakura Eye design was primarily due to the lack of resemblance to the human eye, a sentiment mentioned five times. This perspective likely stems from traditional masculine values that often prioritise functionality, realism, and practicality over purely aesthetic considerations. Such values are ingrained in many societal norms, where men are often expected to focus on utility and directness (Form & McMillen, 1983). This idea is emphasised by a preference for simplicity and minimalism in the design which two participants described the Sakura eye as too 'childish' and 'over decorated'. There also seems to be an associated expectation in what a social robot should look like among males with three participants stating that the Sakura eye did not align well with the robot's intended objectives or its overall design which could reflect men's tendency towards a more utilitarian approach to technology. The contrast in responses between men and women to the Sakura Eye design illustrates the deep-rooted influence of gender norms on perceptions and preferences, especially in the realm of technology and design. While women were drawn to the aesthetic appeal and uniqueness of the design, men prioritised functionality, realism, and alignment with the robot's overall objectives.

This gender-based divergence in design preferences was not just limited to the Sakura Eye but was also evident in responses to other designs like the Bolts and Mech eyes. The Bolts Eye design, characterised by its mechanical, retro-futuristic aesthetic, was notably more popular among male participants (as portrayed in Figure *71*), with 27.1% preferring this design compared to only 6.1% of female participants. Similarly, the Mech eye design, which heavily incorporates machine-inspired design motifs, garnered significantly more preference among male participants (33.3%) than female participants (18.4%). These statistics reveal a consistent pattern where men tend to favour designs that emphasise technological aspects and futuristic elements, while women are more inclined towards designs that are emotionally resonant and aesthetically pleasing.

This divergence in design preferences reflects broader societal trends and cultural narratives that shape gender roles and expectations. The challenge for social roboticists lies in navigating these gender-based preferences while avoiding the reinforcement of stereotypical gender norms. A nuanced understanding of these preferences can help in creating designs that are inclusive and appealing to a broad spectrum of users. By acknowledging and thoughtfully considering the impact of gender norms on design preferences, roboticists can strive to create social robots that transcend traditional stereotypes and appeal to diverse user groups. Moreover, the evolving nature of gender norms and the increasing recognition of non-binary and fluid gender identities add another layer of complexity to the issue. This evolving landscape necessitates a dynamic and inclusive approach to social robot visual design that accommodates a wide range of preferences and identities. In summary, the consideration of gender norms and ideals in social robot design is crucial for ensuring that these technologies are inclusive, appealing, and effective for all users, regardless of their gender identity.

5.8.4 Cultural Impacts

In the study comparing the preferences of Hispanic and Caucasian participants, there are notable differences in the popularity of various social robot eye designs between the two groups (as portrayed in Figure *70*). Among Hispanic participants, who numbered 40 in total, the Mech Eye Design emerged as the most popular choice, with 40% preferring this style. This was followed by the Bolts Eye Design, which was chosen by 30% of the participants, and the Conservative Eye Design, preferred by 15%. In contrast, the group of 31 Caucasian participants showed a distinct preference pattern. The Conservative Eye Design was the clear favourite, with 51.6% of Caucasians choosing this style. The Mech Eye Design was the second choice for this group, preferred by 19.3%, and the Hiro Eye Design was the third most popular, selected by 16.1%. These preferences illustrate differing aesthetic values and design priorities between Hispanic and Caucasian participants in the realm of social robot eye design.

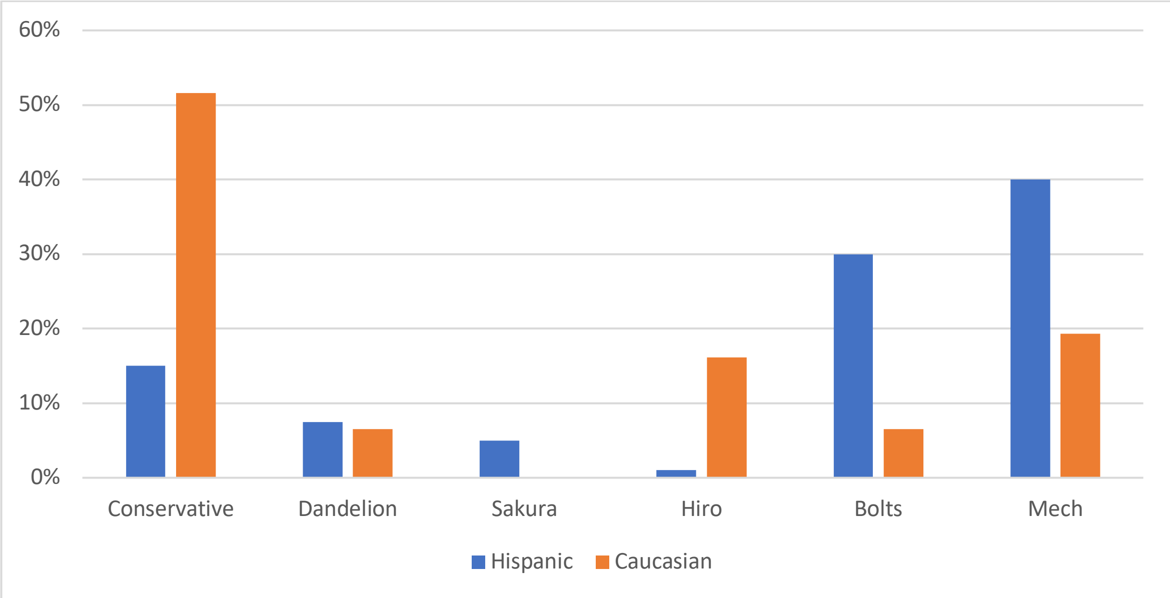

Figure 70. Hispanic and Caucasian overall design preferences.

Hispanic participants exhibited a strong inclination towards futurism and technology, evident in their preference for robot eye designs that prominently feature a robotic aesthetic. The popularity of the Bolts eye design among Hispanic participants, with seven mentioning its appeal, underscores this trend. Their comments often emphasised the importance of the eyes having a distinctly robotic and artificial appearance. Statements like "I like that it's a very robotic design" and "A robot needs to have artificial looking eyes" reflect a clear preference for designs that highlight the robot's non-human nature. In addition, the fusion of futuristic and retro elements in the Bolts eye design resonated with these participants, as indicated by comments such as "It feels futuristic but at the same time retro because we can see the screws on the eyes" and "I like futuristic designs." This preference suggests a keen enthusiasm for embracing new technologies and a future-oriented mindset, which is reflected in their aesthetic choices for social robots.

The findings from this study regarding the Hispanic participants' preferences in robot design reveal a nuanced balance between a distinctly robotic aesthetic and an appreciation for human-like qualities. This dual preference is exemplified in their fondness for the Mech eye design, a trend that emerged clearly from the responses of fourteen participants. The Mech eye design's capacity to replicate human emotions and expressions was highly regarded, a feature largely attributed to the inclusion of an eyebrow. This addition was seen as a key factor in enhancing the design's expressiveness and relatability. Participants' comments, such as "He looks more expressive like a human" and "It gives human vibes; it can replicate more emotions by having eyebrows," underscore their appreciation for designs that imbue robots with human-like expressiveness.

Furthermore, the role of the eyebrow in the Mech eye design was not only about replicating human expressions but also about adding a deeper layer of personality to the robot. This aspect was highlighted by seven participants who saw the eyebrows as crucial in giving the robot a more defined personality and enhancing its expressiveness. Statements like "I like it better just for the eyebrows, gives it more personality" and "The eyebrows might help it convey more emotion" reflect an appreciation for design elements that contribute to a robot's perceived character and emotional range.

This blend of preferences for both robotic and human-like elements in design illustrates a complex aesthetic sensibility among Hispanic participants. They value the clear, futuristic robotic identity, yet also seek elements that offer emotional resonance and expressive capabilities akin to humans hence the popularity of the Mech and Bolts eye designs. This duality in design preferences suggests a desire for social robots that are technologically advanced and distinctively robotic, yet capable of engaging in a human-like, emotionally expressive manner. This is in stark contrast with Caucasian participants who had a different emphasis on different aspects of a social robot’s design.

There was a pronounced preference among Caucasian participants (as portrayed in Figure *72*) for the Conservative Eye Design, which aligns with a broader cultural trend among these participants towards realism and human likeness. This preference was evident as 51.6% of participants gravitated towards the Conservative eye design a design which closely mimics real human eyes. This sentiment was mentioned 6 times, with comments like "It's closest to the real eye" and "Out of the 6 designs, this design looks the closest to the human eye, for me". Such a choice reflects a cultural inclination towards designs that resonate with natural, familiar forms, suggesting a comfort with and desire for realism in technology.

In addition to their preference for lifelike designs, Caucasian participants also valued simplicity and clarity in the robot's eye designs. Their inclination towards designs that were straightforward and devoid of unnecessary embellishments indicates an appreciation for minimalism. This was evident in the comments of five participants noting how they appreciated the straightforwardness of the design as reflected in remarks such as "simple, straight to the point, does the job" and "it is simple, without unnecessary frills, the look seems sincere". This preference for a clear, uncluttered aesthetic suggests a desire for designs that are easy to interpret and interact with, without the distraction of overly complex or ornate features.

In the study, the Caucasian participants' preferences for social robot eye designs revealed a significant emphasis on emotional connection, which was closely tied to the *lifelikeness* of the robots. This preference for human likeness in the design was a key factor in establishing a sense of connection and relatability between the participants and the robot. Seven participants specifically mentioned the importance of lifelikeness, with statements like "This one seems the most life like, which I feel I will have more of an emotional connection to" and "Makes the robot seem more lifelike and feels like they are looking at you". These comments highlight the significance they placed on realism as a means of fostering a deeper emotional bond with the robot.

This emphasis on human likeness and emotional connection contrasts with the preferences of the Hispanic participants, who showed a greater inclination towards futuristic and distinctly robotic designs. While Hispanic participants appreciated elements that combined human-like expressiveness with robotic characteristics, Caucasian participants demonstrated a stronger preference for designs that closely mimicked human eyes and conveyed a sense of life and warmth.

These cultural differences in design preferences underscore the importance of considering the diverse aesthetic values and emotional expectations of different user groups in the field of social robotics. Understanding and catering to these differences is crucial for creating social robots that are not only technologically advanced but also culturally attuned and emotionally resonant with their intended users.

5.8.5 Situational Contexts

Design preferences are significantly influenced by the context in which a specific design is used reflecting the dynamic nature of human interaction. Take, for instance, the design of wristwatches. An adventurer or athlete might prefer a rugged, durable watch with features like water resistance, a robust build, and a digital interface for easy readability and functionality during outdoor activities. In contrast, a business professional attending formal events might opt for a sleek, classic analogue watch, valuing elegance and minimalism over rugged functionality. These contrasting preferences highlight how different environments and use cases shape the desired attributes and aesthetics of a product (Goedhart, 2020; McCracken & Roth, 1989). Recognising these distinctions is crucial for designers, as it allows them to tailor their designs to meet the unique demands and expectations of diverse user groups, ensuring relevance and appeal across various situational contexts. In this study, participant perceptions and expectations have similarly influenced their preferences for specific eye designs in various situational contexts. The data reveals a distinct pattern where the choice of eye design for social robots varied depending on the intended use or environment.

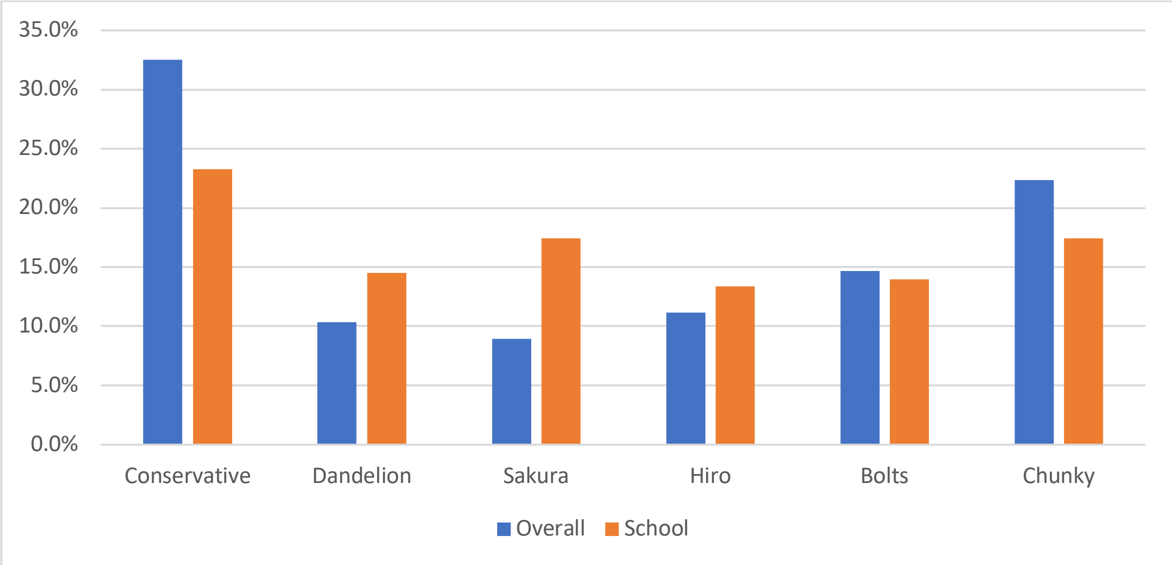

Figure 71. Overall and school context design preferences.

The data from this study reveals a compelling insight into how situational contexts, such as a school environment with children aged 6-12, can significantly influence design preferences for social robots. In most situations, the Conservative and Mech eye designs were predominantly preferred, with averages of 32.5% and 22.4% respectively (as portrayed in Figure *71*), indicating a general inclination towards designs that embody human likeness or a balanced mechanical aesthetic. However, in the context of a classroom with young children, there was a notable shift in preferences with a more even distribution across various eye designs, especially those that deviated from human-like appearances. The Dandelion eye (14.5%), Sakura eye (17.4%), Hiro eye (13.4%), and Bolts eye (14.0%) designs received considerably higher preference rates compared to other contexts. This indicates a greater openness to eye designs that are less human-like and more playful or abstract, aligning with the imaginative and diverse interests of children. Conversely, the preferences for the more human-like Conservative eye and the balanced Mech eye designs dropped to 23.3% and 17.4% respectively in the school context.

This even distribution suggests that in an educational environment, especially one catering to younger children, there is a greater openness to diverse and potentially more playful or imaginative eye designs. For instance, a key finding from the data is the paramount importance of designs that resonate with children's interests. With 12 mentions emphasising the need for playful, fun, and creative elements, it's clear that participants believe these attributes are crucial to effectively engage young learners. Statements like "I think kids would respond to the more playful shapes in these designs" and "the children would love these" reflect a consensus that the robot's appearance should be captivating and engaging, fostering a positive and interactive learning environment.

Equally important is the perception of friendliness and approachability in the robot's design, highlighted in 9 mentions. The participants expressed a clear preference for eye designs that convey warmth and welcome, as seen in comments such as "they seem friendly and happy" and "friendly and welcoming." This preference underscores the belief that for a robot to be effective in a classroom, it must be perceived as a benevolent and accessible presence, capable of fostering a sense of safety and comfort among young students.

Preferences for eye designs also reveal key insights into the importance of engagement, suitability, and visual interest in educational settings (Boyatzis & Varghese, 1994; Zentner, 2001). The potential of certain eye designs to attract and sustain students' attention was noted six times, highlighting the need for interactive and visually stimulating features to maintain engagement and active participation in learning. Additionally, the suitability of these designs for children was a significant consideration, with five mentions emphasising the need for non-threatening, age-appropriate designs, indicating a keen awareness of aligning the robot's appearance with the developmental level and sensibilities of young learners. Lastly, the unique visual appeal of the designs was valued, with four mentions pointing to the importance of distinctiveness and visual interest in maintaining children's attention. Phrases like "The rotation circle would undoubtedly pique children's interest" and "Children like cool shapes" underscore the desire for designs that are not only functional but also engaging and visually appealing, demonstrating the importance of considering these elements when designing social robots for educational purposes.

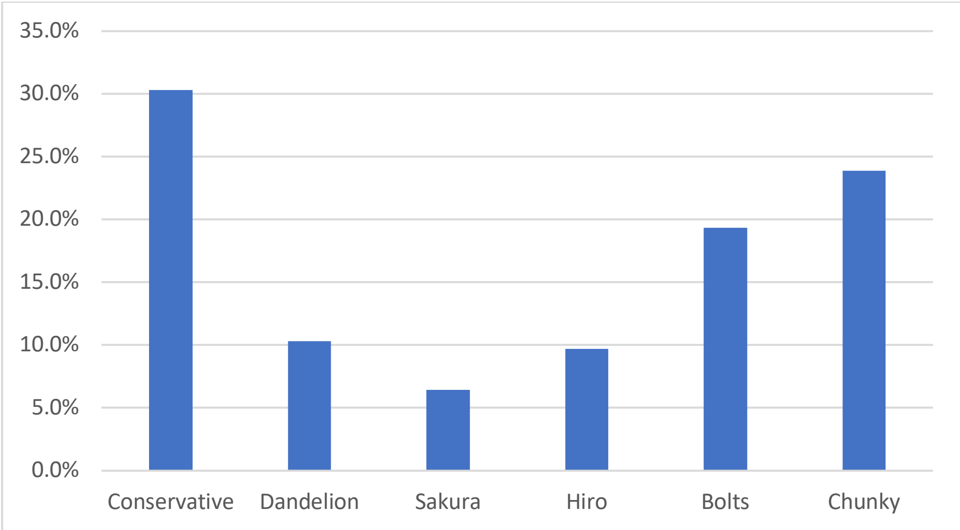

Figure 72. Participant preferences in a medical emergency context.

While design preferences in most situations tend to favour conservative and mechanical designs, it remains crucial to consider individuals' perceptions of various situations. For instance, in the context of a medical emergency (as portrayed in Figure *72*) the majority of participants gravitated towards the conservative eye design, with 30.3% expressing a preference for this style, largely due to its resemblance to real human eyes. This inclination towards a more familiar and comforting design was explicitly mentioned in 12 comments. Such a choice reflects a desire for familiarity and normality in high-stress situations like medical emergencies, where reducing stress and discomfort for patients is crucial. Statements such as "In these serious situations, I'd like to have an eye design that looks relatively normal" and "closest to real eyes" highlight this preference for a reassuring and unobtrusive design. Additionally, the suitability of the design in the unique context of a medical emergency was a significant consideration, as noted in 6 comments. Participants sought designs that were appropriate and non-distracting, underscoring the importance of context in influencing design choices. Comments like "It looks appropriate for that context" and "The 'medical emergency' aspect might make it less essential for the eyes to appear human. So, I chose the cleanest designs instead" emphasise the need for a design that blends seamlessly into the medical setting.

However, the sakura eye design, while the least preferred overall in an emergency situation, drew specific praise from some participants for its calming, natural aesthetic. Four respondents specifically mentioned the therapeutic effect of its floral motif in the tense atmosphere of a medical emergency, suggesting a broader appreciation for designs that evoke natural beauty and tranquillity. These participants viewed the sakura eye as a source of comfort and positivity, a sentiment encapsulated in phrases like "The flowers are calming and are a reminder of health" and "happy face because it's a place where people are sad”. This data demonstrates that while there is a general preference for more conventional designs in high-stress environments, there is also a recognition of the emotional impact of more artistic and naturalistic elements. The sakura eye's ability to provide a sense of safety, comfort, and optimism in a medical setting, despite being less conventionally realistic, highlights the diverse ways in which design can influence mood and morale. This insight is critical for designers, emphasising the importance of considering individual perceptions in a given situation, especially in contexts as sensitive as healthcare.

5.8.6 Visual Context

While this study primarily focuses on the visual design of robot eyes, it is essential to recognise their visual relationship with adjacent design elements. The broader aesthetic context, including the robot's facial contours, material textures, and other features, plays a significant role in influencing how an eye design is perceived. The interaction between these elements shapes the overall visual impact of the robot and can significantly alter the interpretation of individual design components, such as the eyes (Brommer, 2011; Field, 2018; Itten, 1970; Kress &

Leeuwen, 1996). For instance, an eye design that seems friendly and approachable in isolation might project a different image when integrated into the robot's overall head or body design. The robot's facial shape, the materials used in its construction, and the placement of the eyes in relation to other features can all influence how the expressiveness or emotion of the eyes is perceived. A design that appears friendly might lose some of its warmth if placed on a robot with a sharp, angular face. Conversely, the same eye design might be enhanced and appear even more approachable on a robot with a soft, rounded facial structure. This interplay of design elements highlights the importance of a holistic approach in the field of social robotics. Designers and researchers must be aware of how various visual components interact and complement each other. The overall aesthetic appeal and effectiveness of a robot are not just the sum of its individual parts but also the result of their synergistic interaction.

The role of contrast in shaping colour preferences for robot eyes, as observed in this study, can be connected to broader principles of contrast and attraction in human perception, similar to the use of makeup to accentuate facial features (Granger, 1955; Itten, 1970; Webster, 1996). The study's low preference rate for brown eyes, which was only 6%, can be largely attributed to the poor contrast between the brown iris and the black sclera. Participants frequently described the brown hue as dull, a sentiment expressed 13 times. Across all age groups and ethnicities, there was a noticeable preference for eye colours with high colour contrast, such as blue and green. This preference aligns with fundamental human attractions to colour contrasts, a concept that can be paralleled with the use of makeup.

The interplay between makeup application and the aesthetics of robot eye design underscores a fundamental principle of human perception: our inherent attraction to contrast. This inclination, deeply rooted in our evolutionary biology, shapes our aesthetic choices and preferences (Field, 2018, p. 20; Itten, 1970; A. L. Jones et al., 2018; Russell et al., 2019). In makeup, contrast is used to accentuate features, making them more noticeable and engaging.

For example, eyeliner and mascara deepen the contrast between the iris and sclera against the skin, highlighting the eyes (as portrayed in Figure *73*). This principle is mirrored in the preference for high-contrast eye colours in social robot design, where stark contrasts between the iris and sclera can make robot eyes appear more distinct and expressive.

Figure 73. Eyes with mascara creates more contrast in comparison to the eye without (Sharma, 2015).

Traditionally, makeup techniques have focused on creating contrast and depth on fair skin, often employing light and shadow to achieve noticeable effects (Jha, 2016). However, these methods may not be as effective for darker skin tones, where contrasts can appear unnatural or subdued. For darker skin, makeup artists often employ a range of colours to complement and highlight natural tones, rather than relying on stark contrasts (as portrayed in Figure *74*). This principle finds a parallel in the design of robot eyes. In the study, participants frequently perceived brown eyes as 'dull', a sentiment that may stem from inadequate contrast between the brown iris and the black sclera. This lack of contrast diminishes the eyes' vibrancy and engagement, mirroring the challenges of makeup application on darker skin. Addressing this in social robot design necessitates a thoughtful selection of colours for the eyes, particularly darker hues. This could involve integrating different colours within the eye design to create contrast, especially against a dark background. Such a strategy ensures that all eye colours, including darker ones, are presented in a manner that maximises their expressiveness and appeal.

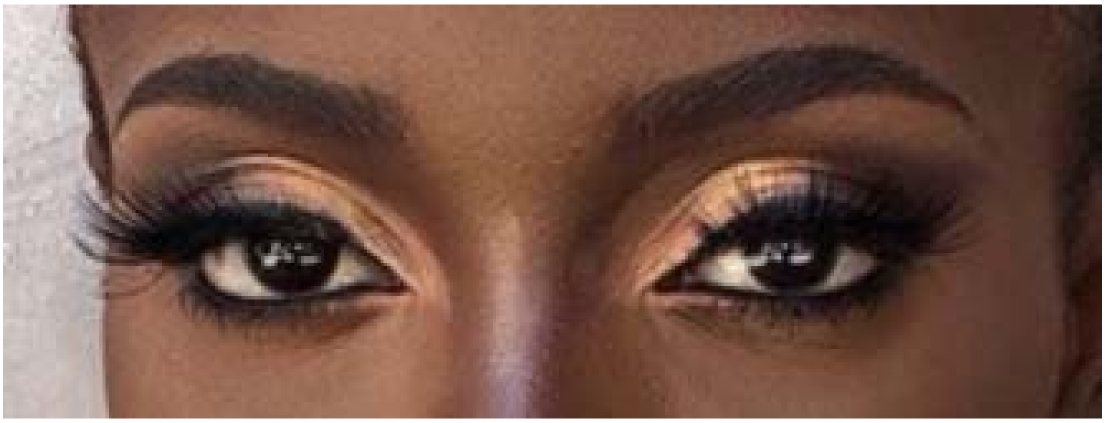

Figure 74. Highlighting the eyes with colours on darker skin tones (Forbes, 2020).

The choice of a black background for the sclera in Haru's design was influenced by specific hardware constraints (Galindo et al., 2022; Gomez et al., 2018). The design aimed to create the illusion of larger eye dimensions, a key aspect of Haru's visual appeal. However, using a white sclera would have compromised this effect. It would have revealed the smaller and non-bevelled screen on which the eyes were displayed, creating a contrasting angular frame within Haru's bevelled hardware design. This discrepancy could have disrupted the seamless appearance that the design intended to achieve. While the black sclera effectively facilitated the illusion of larger eyes, it also introduced a challenge in terms of colour contrast, particularly for certain iris colours like brown (as portrayed in Figure *75*). The reduced contrast between the brown iris and the black sclera diminished the vibrancy and visibility of the brown colour, leading to perceptions of the brown eyes as less appealing (Granger, 1955; Itten, 1970; Webster, 1996). This suggests that had a white sclera been used, the colour preferences among participants might have been different. This indicates the potential for design adjustments to influence user preferences and points to the importance of considering how each design decision might interact with others to create the final visual effect.

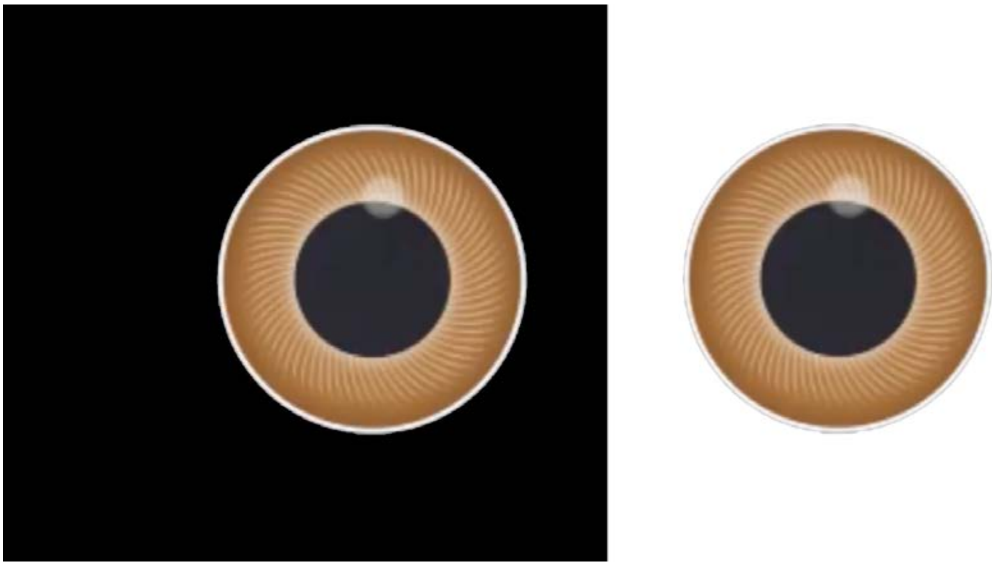

Figure 75. Differences in colour contrast of a brown pupil against a black and white sclera.

In addition to colour contrasts, the hardware limitations in Haru's hardware design also led to an unintentional association with a well-known film and media trope, *the darkness gazes back* (TV Tropes, 2019). This trope typically involves a menacing entity hidden in the shadows, revealed only by the sudden appearance of eyes (as portrayed in Figure *76*). The use of a black background for the sclera, while intended to hide hardware constraints and to create the illusion of larger eye dimensions, inadvertently aligned with this trope. The dark sclera surrounding the robot's eyes could give the impression of eyes materialising from the shadows, a visual effect often used to portray something sinister or threatening. This association with *the darkness gazes back* trope likely influenced how some participants perceived the conservative eye design in Haru leading to characterisations such as *scary*, as noted four times, and *angry*, mentioned three times. Such responses demonstrate how certain visual elements in robot design can evoke specific cultural or media references, which in turn shape user perception and reactions.

Figure 76. Team Avatar up against the sinister darkness (DiMartino & Konietzko, 2005).

Another impact of visual context was the observed preference for grey eye colours in this study, which can be attributed to principles of Gestalt psychology. Gestalt psychology emphasises the human tendency to perceive visual elements as part of a larger, cohesive whole. This psychological framework suggests that people have an inherent preference for designs that appear unified and harmonious (Granger, 1955). In the case of Haru, the robot's design features a predominantly white exterior with grey accents. This colour scheme likely influenced the preference for grey eye colours, as it aligns with the Gestalt principle of visual coherence. The grey eyes complement Haru's overall colour palette, creating a sense of unity and cohesiveness in the robot's design (as portrayed in Figure *77*). This preference was reflected in the responses of several participants, with 19 mentions highlighting how selecting grey eyes contributed to achieving a visually coherent perception of the robot.

Figure 77. The colour of robots is grey.

These findings underscore the importance of considering interdependent visual factors in robot design. The hardware limitation of a black sclera, while seemingly a minor detail, can significantly affect design and colour preferences as well as the overall perception of the robot. Designers need to be mindful of how individual design elements interact with each other within the broader aesthetic context of the robot.

5.8.7 Temporal Events

Temporal events can have a profound impact on the criteria used to assess the effectiveness of a particular design. These events can range from global cultural shifts to technological advancements and individual experiences (Dalsgaard, 2014; Dixon, 2020; Dourish & Bell, 2014).

- **Cultural Shifts**: Societal values and norms are constantly evolving. For example, a design that may have been considered avant-garde or appealing in one era might be viewed as outdated or less appropriate in another, as public tastes, and cultural sensibilities change. In the context of social robotics, designs that were once seen as futuristic and innovative might now be perceived as clichéd or overused.

- **Technological Advances**: As technology progresses, new possibilities for design and functionality emerge. What was once the pinnacle of technological achievement can quickly become obsolete. In robotics, advancements in materials, sensors, and artificial intelligence continuously redefine what is possible, thereby changing the benchmarks for what is considered state-of-the-art or effective in design.
- **Personal Experiences**: Individual experiences with technology can greatly influence expectations and preferences. For instance, a person who has grown accustomed to the sleek, minimalist design of modern smartphones might prefer social robots with a similar aesthetic. Conversely, someone who has had a negative experience with a particular type of technology may be biased against similar designs in the future.

These temporal factors suggest that design cannot be static; it needs to be dynamic and adaptable (Dalsgaard, 2014; Dixon, 2020; Dourish & Bell, 2014). What is appealing and effective at one point in time may not hold the same appeal later due to these evolving cultural, technological, and experiential contexts. A notable example of a piece of design that had its meaning and significance changed following a major event is the design of the World Trade Centre Twin Towers in New York City (Wallerstein, 2001). Prior to the tragic events of 11 September 2001, the Twin Towers were celebrated as an architectural marvel and a symbol of financial power and innovation. Their unique design, featuring two massive, identical buildings, was iconic and instantly recognisable around the world. However, after the September 11 attacks, the perception and significance of such architectural design shifted dramatically becoming inextricably linked to the tragedy and loss of that day. The tragic event led to a revaluation of architectural priorities and design strategies, with a newfound focus on creating structures that were not only visually impressive but also resilient and safer for occupants. This example illustrates how major events can profoundly alter the perception and relevance of a design.

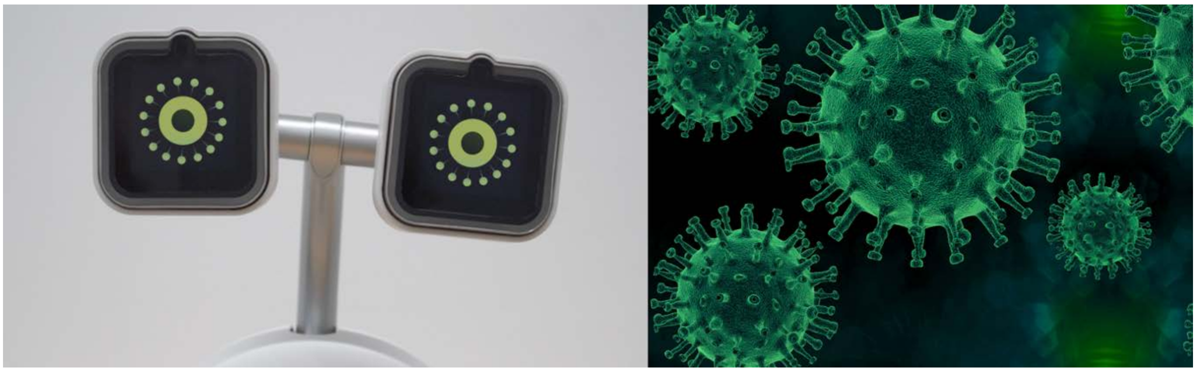

Figure 78. The dandelion eye (left) and the Covid-19 virus (right – Fairs, 2020) look strikingly similar.

The influence of temporal events on social robot design perception is vividly illustrated in the changing attitudes towards the dandelion eye design in this study. Initially, when the design was created in 2017, it was well-received, with no association to viral imagery. However, as the Covid-19 pandemic emerged and became a global crisis, perceptions dramatically shifted. The dandelion eye design began to be associated with the Covid-19 virus, as mentioned by participants 16 times. As portrayed in Figure *78*, this association likely stems from the pandemic's widespread impact and the visually striking representations of the virus that became ubiquitous in media coverage (Fairs, 2020). Consequently, the design, which had no previous negative connotations, suddenly became the least preferred among participants due to its resemblance to the virus. The change in perception of the dandelion eye design exemplifies how external events can profoundly alter the interpretation and acceptance of a design.

Such temporal shifts highlight the importance of personalisation in social robots. By allowing individual users to customise aspects of a social robot's design, such as its eye colour or other visual features, the robot can remain relevant and appealing to individuals despite broader societal changes. In addition to this, incorporating personalisation features into social robots caters to the diverse preferences and needs of users, enabling these robots to serve a wide range of different individuals

5.8.8 Shifting Perceptions

The recognition that individual preferences are fluid and can evolve over time is crucial, especially in the context of social robotics. Preferences may quickly shift as individuals acquire new knowledge or undergo different experiences, influencing their initial choices and expectations, ultimately leading to entirely different selections and outlooks (Dalsgaard, 2014; Dixon, 2020; Dourish & Bell, 2014). This adaptability underscores the importance of designing social robots that can accommodate the dynamic nature of human preferences. The study's survey design, which included questions about the desire for a variety of eye designs or colours, illustrates this point well. Despite a clear initial preference for blue and green conservative and mech eyes, the findings revealed a broader desire among participants for the option to choose from a diverse selection of eye designs and colours. This suggests that while individuals may have a current preference, they also value the flexibility to alter their choices as their perceptions or circumstances change.

The survey results indicate a strong belief among participants that the design and colour of a robot's eyes can significantly impact their interactions with the robot. Specifically, 81% of participants believed that the eye design would affect their interaction with a social robot, while 68% felt that the eye colour would have an influence. Furthermore, an overwhelming 93% of participants expressed a desire for choice in the visual design of their social robot, highlighting the importance of customisation and personalisation.

There is an indication that if participants were to retake the survey, or if they were initially prompted with these questions about personalisation at the beginning of the survey and how they personalise everyday technological devices such as their smartphones, the results might differ. By the end of the survey, participants had become more informed about the possibilities in social robot design and what they could expect or desire in terms of customisation. This increased awareness about the potential for personalising social robots could lead to different preferences and expectations.

The evolving nature of preferences in social robot design suggests that as social robots become more familiar and their capabilities expand, user expectations and desires may also change. This underscores the importance of ongoing user education and engagement in the field of social robotics. Keeping users informed about the evolving capabilities of social robots and the options available for customisation can empower them to make choices that more closely align with their individual needs and preferences. This approach is crucial for ensuring that social robots remain relevant, appealing, and effective as tools for interaction and assistance in a variety of settings.

5.8.9 Agency and Choice

The survey results, where participants predominantly selected a few specific eye designs and colours for the social robot but later expressed a desire for a broader range of choices, exemplify the Paradox of Choice in consumer behaviour. This term, popularised by psychologist Barry Schwartz (2004), refers to a situation where individuals believe they prefer many options, but when faced with a large array, they tend to choose from a smaller, more familiar set. This paradox highlights a common dilemma in decision-making: while people appreciate having numerous options, they often find it less stressful and easier to select from a limited range.

In this survey, the initial gravitation towards a limited set of eye designs and colours could be attributed to the comfort of familiarity or the overwhelming nature of too many choices. However, the expressed desire for a broader array of options at the survey's end suggests a deeper psychological need. This juxtaposition suggests that while participants may not have expressed an immediate desire to deviate from their initial selections, the act of choosing from a broader array resonates with their intrinsic need for control and the ability to tailor their technological experiences. The desire for choice transcends the mere availability of options, embodying a craving for empowerment and personal agency. This insight underscores the importance of offering choice in design, not as a means to overwhelm, but as a pathway to enhance user engagement and satisfaction by affirming their autonomy and preferences (Saffar, 2019; Story et al., 1998).

Providing the option to choose different eye designs or colours for a social robot offers users a sense of personal agency and individuality, allowing them to align the robot more closely with their personal identity and preferences (Pereboom, 2014; Schwartz, 2004). This aspect of personalisation taps into a fundamental human behaviour: the desire to exert control over one's environment and tools, especially in technologies that play a social or companion role in intimate personal spaces such as the home. Therefore, incorporating user choice in the design of social robots extends beyond aesthetic appeal; it also addresses the human need for self-expression and agency. By enabling users to personalise their robots, designers can enhance the user experience, fostering a deeper connection between the user and the robot. Such an approach not only increases the robot's engagement and appeal but also strengthens the user's sense of autonomy and control, which are vital for the acceptance and success of social robots.

5.8.10 Methodological Considerations

The format of the study, whether conducted in-person or online, plays a significant role in shaping participant perceptions of a robot's visual design. In-person interactions allow for a more comprehensive, multi-sensory experience, providing participants with a fuller context for evaluating the robot's eye design (Bainbridge et al., 2011; D. David et al., 2022; Gou et al., 2021). In contrast, online formats, such as questionnaires accompanied by videos, are limited to two-dimensional representations, focusing mainly on framing and composition. These differences in presentation can lead to different interpretations of the same design elements.

Given that this study was conducted online, the way Haru was presented in the videos became critically important. Presenting a full body shot of Haru would have given participants a holistic view of the robot, placing the eye designs within the context of its overall design. However, this approach posed a challenge: the eyes, being a key focus of the study, might have appeared too small or less detailed for participants accessing the questionnaire on smartphones. To navigate this challenge, the study used an initial full body shot followed by a cropped close-up of the eyes. This method aimed to provide both context and detail.

The chosen strategy of using a close-up shot in the video presentation inadvertently introduced an additional variable that significantly influenced participant perceptions in this study. The cropped close-up of Haru's eyes created a downward-sloping curve in the video frame (as portrayed with blue markings in Figure *79*). This visual detail was interpreted by many participants as an expression of sadness, a perception mentioned 53 times across various eye designs. Such a framing, while intended to provide a detailed view of the eyes, unexpectedly imparted an emotional tone to the images that participants evaluated, and which could have potentially impacted their preferences for certain eye designs or colours.

Figure 79. Unintentional framing of Haru's eyes on the video made Haru look sad to many participants as indicated by the blue markings.

This outcome highlights the complexities involved in conducting research on visual design elements, especially in an online format. The way visual information is presented can significantly affect how it is perceived and interpreted. For designers and researchers in social robotics, this underscores the importance of carefully considering the presentation format and framing when conducting studies on robot design, especially when dealing with subtle and nuanced elements like eye design. It also illustrates the need for a robust methodology that accounts for the potential influence of presentation style on participant perceptions, ensuring that the data collected accurately reflects the participants' responses to the design elements themselves, rather than the framing or context in which they are presented.

5.8.11 Other Impacts

This study's exploration of specific frames in social robot design indeed opens the door to a vast array of potential frames that could be studied to understand the multifaceted perceptions and interactions with social robots. The selection and depth of these frames should be guided by the intended use case of the robot, ensuring that the design is not only effective but also diverse, equitable, and inclusive.

One such frame that warrants exploration is accessibility, particularly how individuals with sensory impairments might interact with and perceive various visual design elements of social robots. This aspect is crucial for creating inclusive designs that accommodate a wide range of users with diverse needs. For instance, considering how colour contrasts in robot eyes might be perceived by individuals with colour vision deficiencies, or how the design might communicate non-verbally in a way that is clear and understandable to someone with a visual impairment, are essential considerations. These accessibility considerations are not just about compliance with standards but are integral to creating truly user-centred designs that cater to all potential users.

Furthermore, long-term engagement studies present another valuable frame of reference. Such studies could reveal how sustained interactions with social robots might alter human perceptions and preferences over time. For instance, initial reactions to a robot's eye design might evolve as users become more accustomed to or develop a deeper understanding of the robot's functionalities and capabilities. Understanding these dynamic changes in perception is vital for designing robots that remain effective, appealing, and relevant to users in the long run.

5.9 Subtle Personalisations Framework

The quest for a universally optimal aesthetic design, which accommodates every individual's unique criteria for evaluating a social robot's effectiveness, is impractical. This study highlights the substantial impact that even subtle customisations can have on the success of human-robot interactions for a diverse range of individuals. These personalisations enable users to actively engage in the interaction process, allowing them to imbue the robot's visual design with their own interpretations and preferences.

A significant finding of this study is the overwhelming preference for personalisation in the visual design of social robots. With 93% of participants desiring a choice in the visual design of their robot and 81% acknowledging that the design of a robot's eyes would impact their interactions, it is clear that offering options for specific design elements facilitates more meaningful interactions. This choice not only caters to individual preferences but also fosters a sense of ownership among users, a crucial component of the aesthetic experience.

Subtle personalisations, though individually minor, can cumulatively transform the uniqueness and relatability of social robots without necessitating significant engineering modifications. This concept emphasises the power of integrating various personalisable attributes—ranging from eye shape and colour to more nuanced aspects like the personality reflected through eye movement. Beyond the visual elements, personalisation can extend to the robot's voice, the sounds it produces, its gestures, and even its movement patterns, all of which contribute to its perceived character and personality. For instance, eye colour alone offers a simple yet impactful means of customisation, allowing users to select hues that resonate with them personally. When combined with the choice of eye shape, this can significantly alter the robot's facial dynamics and expressiveness. Further adding layers of personalisation, the robot's voice, and the sounds it emits can be tailored to match the user's preferences, enhancing the emotional connection and communication effectiveness. Moreover, the subtlety of personalisation extends to the robot's physical appearance, such as its colour and material, and even to its movement style and gestures, each reflecting different facets of personality and function. This approach to design ensures that individual preferences are catered to without impacting the underlying engineering or the robot's form factor.

Such a framework for subtle personalisation acknowledges the diverse preferences of users, offering them the autonomy to mix and match features to their liking. A user might opt for just a single modification, like eye colour, or combine several elements, such as eye colour, voice, gestures, and material, to achieve a deeper level of personalisation. This flexibility underscores the idea that even small adjustments, when aggregated, can lead to substantial personalisation of a robot, significantly enhancing the user experience and emotional engagement without necessitating changes to the robot's core engineering. Incorporating these options from the beginning of the design phase, with an interdisciplinary team, ensures that robots can be easily personalised, fostering a more inclusive, engaging, and individualised approach to social robot design.

Expanding upon this, the approach to design incorporates a crucial ethical dimension, challenging and shifting societal norms and expectations by broadening the spectrum of personalisation to include diverse representations. For instance, while the stereotypical white robot with blue eyes might dominate current perceptions, providing options for different eye colours, such as brown, allows for representation that mirrors the diversity of the human population. This aspect of design not only gives users more choice but also confronts and potentially alters entrenched societal preferences shaped by media and popular culture. By including a variety of personalisation options that extend beyond the mainstream, designers can help shift the demand towards a more inclusive representation of social robots. This responsibility towards ethical design and representation underscores the importance of offering a wide range of personalisation options from the outset, ensuring social robots can reflect and respect the diversity of their users. Such an approach not only enhances the individual user experience but also contributes to a broader cultural shift towards embracing diversity and equity in technology.

In a technological environment that often favours one-size-fits-all solutions, prioritising efficiency and standardisation, this study advocates for a re-evaluation of design priorities, posing a critical question: should the emphasis be on simplifying the design process for developers, or on enhancing the interaction quality for users? The introduction of Subtle Personalisations, though potentially increasing the complexity and time required for the design phase, underscores the value of prioritising individual interactions. This approach demands a shift towards interdisciplinary collaboration early in the design process, integrating insights from experts in the fields of psychology, design, animation, and social sciences. While this interdisciplinary scholarship might initially seem to slow down the development process, it is essential for creating robots that are more aligned with human emotional and social needs. The study highlights the importance of considering individual preferences and the complex dynamics of human-robot interactions from the outset, suggesting that a deeper, more nuanced understanding of these aspects can lead to more meaningful and effective technology solutions. By shifting the focus from a uniform design approach to an interdisciplinary approach that embraces customisation and personal expression, roboticists can create social robots that are not only technologically sophisticated but also contextually appropriate, emotionally resonant, diverse, and inclusive.

Chapter 6: The Movement Design of Social Robots

6.1 Introduction

In 1944, psychologists Fritz Heider and Marianne Simmel conducted a landmark investigation which delved into the fascinating phenomenon of how individuals perceive and assign motives to simple geometric shapes in motion (as portrayed in Figure *80*). The study consisted of an experiment where participants were presented with animations featuring shapes engaged in movements reminiscent of human actions, such as chasing or interacting with each other. What emerged from this experiment was a striking revelation about human cognition: observers instinctively imbued these abstract figures with intentions, emotions, and purpose. This pioneering research unveiled the profound impact of motion on our perception, demonstrating our inclination to anthropomorphise inanimate objects.

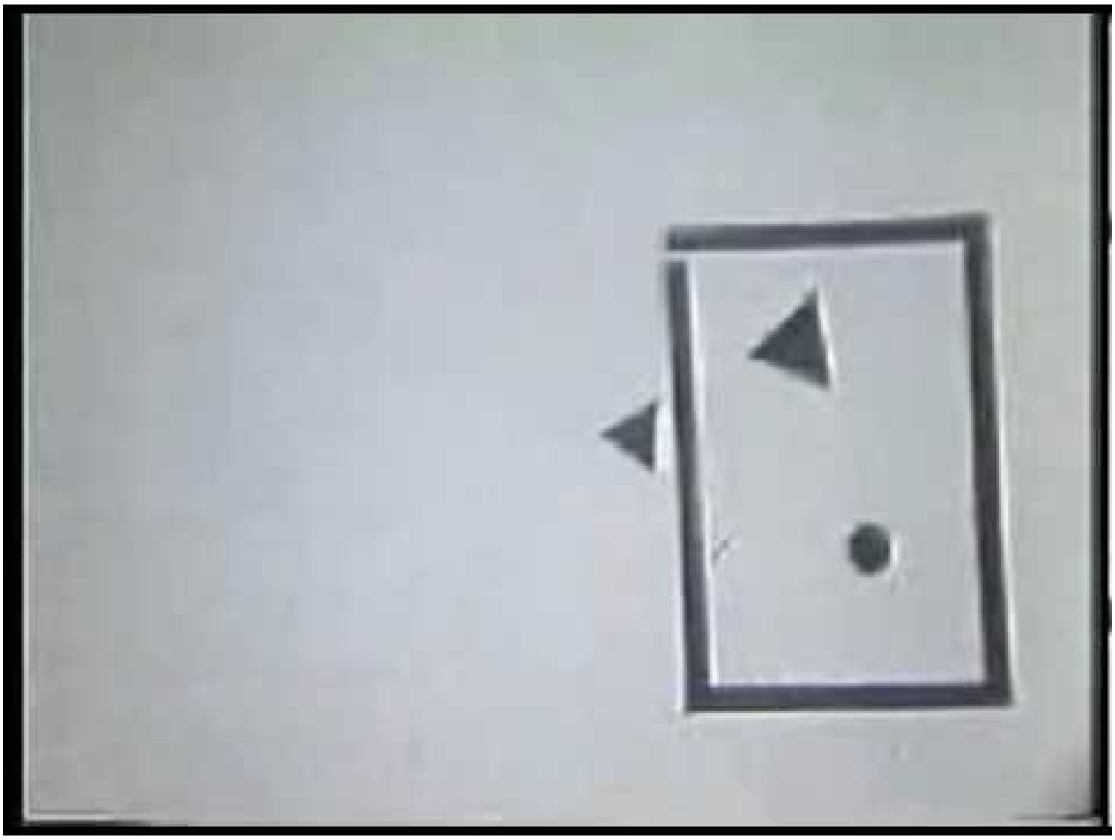

Figure 80. A screenshot of the animated simple geometric shapes in motion (Heider & Simmel, 1944).

The human tendency to anthropomorphise even the simplest of moving shapes and machines along various channels of social expression demonstrates the crucial role that movement plays in the dynamics of human social interaction (Heider & Simmel, 1944). Humans are visual creatures, and the visual communication channel that movement provides plays an essential role in how humans will interact with social robots. With up to 30% of the neurons in the cerebral cortex of the brain devoted explicitly to visual processing, as compared to 8% for touch, and 3% for hearing (Denys et al., 2004; Essen & Drury, 1997) it remains without a doubt that movement plays an important role in human communication.

Despite this, many current day social robots still exhibit *janky* bodily movements characterised by their slow, crude and unreliable quality. This issue has risen from a techno-centric design approach where the subtleties and expressiveness of motion are often overlooked in favour of functionality and efficiency (Chandrasekhar & Ghosh, 2001; Dorst, 2011; Peltu et al., 2008; Šabanović, 2010). For social robots to truly integrate into our daily lives – in homes, offices, schools, or public spaces – their movements need to be more than just mechanically efficient. They need to expressively convey the robot's purpose, intent, state, mood, personality, and responsiveness for effective and intuitive human-robot interaction (Hoffman & Ju, 2014).

This chapter delves into the study of gestures in the movement design of social robots, analysed through the lens of an animator. It focuses on integrating key principles from animation to demonstrate how refined, considered gestural movements for embodied mediums can significantly enhance human-robot interaction. This shift is essential to foster a deeper and more intuitive connection between humans and robots, paving the way for social robots to be perceived not just as tools, but as companions capable of nuanced and meaningful interaction.

6.2 Gestural Studies

Gestures are a form of non-verbal communication in which bodily actions are used to express and convey messages (Elsaesser, 2014; Goldin-Meadow & Alibali, 2013; Kendon, 2004; McNeill, 1992). These movements, often performed with the hands, arms, face, or body, do not rely on spoken words but instead use physical expressions to communicate a variety of intentions and emotions. Gestures can range from simple actions like nodding the head to indicate agreement or waving a hand to say goodbye, to more complex series of movements that can express a wide array of feelings and concepts. They serve as a critical component of human communication, adding depth and nuance to our interactions by providing visual cues that enhance understanding and connection.

Gestures represent a form of communication intricately linked with language, a connection rooted in the brain's inclination towards visual comprehension and learning (Damasio, 1999). Gestures are not mere accompaniments to verbal communication; they are integral to it, enhancing over 90% of spoken utterances by providing visual context (Nobe, 2000). For instance, a person may use a horizontal hand gesture above their head to indicate someone's height, while a simple thumbs-up or thumbs-down gesture can convey approval or disapproval without the need for spoken words. These gestures act as a visual counterpart to spoken language, allowing listeners to swiftly grasp and mentally visualise the speaker's intended message, providing insight into their mental representation (Kendon, 1980; McNeill, 1992).

The second channel of communication offered by gestures significantly enhances human communication comprehension, particularly when verbal language is ambiguous, misinterpreted, or when language proficiency is limited (Goldin-Meadow & Alibali, 2013). In cross-cultural contexts where language barriers exist, gestures become crucial in understanding each other's intentions. In fact, repeated comprehension failures often lead to more frequent and intense gesturing (Chawla & Krauss, 1994; Morsella & Krauss, 2004). For instance, an individual seeking direction to an airport in a foreign country may employ manual gestures to depict a person boarding an aircraft. In cases where the listener does not grasp the intended meaning, the speaker may proceed to extend their arms horizontally simulating aeroplane wings to provide additional clarification. These instances underscore the value of gestures as an auxiliary communication medium that can significantly enhance language, especially in situations of mutual misunderstanding.

Moreover, psychologist McNeill (2008) notes a *dynamic dimension* of language, highlighting that gestures do not simply mirror thoughts but also actively contribute to the formulation of thoughts and speech. This dual function of gestures as a language feature not only enriches the communicative process but also offers a secondary channel for conveying new and unique ideas. For instance, picture a scenario in which a speaker wants to convey the concept of *unity* within a language that lacks a specific term for this state of togetherness. The speaker might use a gesture involving interlocking fingers from both hands, symbolising the coming together of individuals in harmony. Another example can be seen in conveying the notion of *embracing change* by using gestures that depict open arms and a welcoming stance, symbolising acceptance and adaptation to new circumstances. As noted by linguists Hockett and Hockett (1960), gestures enable the expression of concepts in a manner that remains comprehensible within the language framework, thereby broadening the scope of human interaction and understanding.

In addition to this, gesture can impact the interpretation of what is being said in speech, informing observers about a person's internal intentions, goals, and emotional states (Leeuwen, 2021). This process of comprehension goes beyond the symbolic representation of gestures; it involves an in-depth understanding of the psychological motivations and emotional nuances behind each movement. For example, consider a situation where a speaker is discussing a challenging personal experience. While speaking, they unconsciously clench their fists and then slowly release them. These subtle hand movements can convey suppressed frustration and the gradual release of tension, providing listeners with valuable insights into the speaker's emotional state. Another example may involve a scenario where a speaker is discussing their excitement about an upcoming vacation. As they speak, they use expansive arm gestures and an enthusiastic facial expression, effectively conveying their anticipation and positive emotional state. Such gestures communicate a wealth of information about an individual's intentions and emotions, making them an essential component of human communication (Elsaesser, 2014; Goldin-Meadow & Alibali, 2013; Kendon, 2004; McNeill, 1992). This deeper understanding of gestures highlights their significance in human expression and interaction, revealing the layers of meaning and emotion that are communicated through even the simplest of movements.

The field of animation possesses a uniquely profound understanding of the impact of gestural movement, surpassing other design mediums in this regard. Animators meticulously craft each movement to convey specific emotions, intentions, and character traits (Hooks, 2017; Thomas & Johnston, 1995; R. Williams, 2012). Through the deliberate manipulation of timing, rhythm, and flow, guided by The Twelve Principles of Animation, animators breathe life into characters, making them expressive and relatable. They recognise that movement is not just a means to an end but a vital aspect of character building. Animators focus on the subtle movements even between gestures, ensuring that they contribute to the believability and depth of the character they are trying to convey.

An animator's deep understanding of the significance of gesture highlights the potential of applying animation principles to the design of social robots, where the nuanced use of gestural movements can greatly enhance the robot's effective ability to communicate and interact with humans. This exploration is crucial for understanding how to design robot movements that are able to convey intentions, goals, and emotional intent in a manner that is effective, coherent, and relatable to humans in specific contexts.

6.3 The Current State of Social Robot Movement Design

Just as humans interpret each other's intentions, goals, and emotions through gestural cues, the perception of social robots is significantly influenced by their movements (Ekman & Friesen, 1975; Heider & Simmel, 1944; Kendon, 2004; Rimé et al., 1985). Various studies have highlighted the impact of movement in human-robot interaction. For instance, research has shown that varying the speed of a robot's movements in different proximities can affect the levels of trust it elicits from humans (MacArthur et al., 2017). In addition, the adoption of different body postures by robots has been found to influence the overall mood and quality of interactions (Xu et al., 2015). These studies underscore the critical role of movement design in social robots, emphasising the need for the thoughtful consideration of how movement patterns can improve and deepen interactions between humans and robots. Understanding and applying these nuances in movement design is essential for creating social robots that can effectively and intuitively engage with individuals in a variety of different contexts.

The current landscape of social robot design, heavily influenced by a techno-centric approach, tends to prioritise efficiency and technical functionality, often at the cost of nuanced gestural communication (Hoffman & Ju, 2014; Knight & Simmons, 2014, 2015, 2015). This focus on practical capabilities, such as task performance, frequently overlooks how different cultural contexts and individuals might interpret and react to a robot's movements. As a result, there is a notable gap in appreciating the potential of gestural movements to enrich human-robot interactions and individual user experiences. This oversight underscores the need for a shift in design philosophy, and an interdisciplinary approach that balances functional efficiency with a deeper understanding of gestural communication. By integrating culturally and socially sensitive gestural movements, social robots can become more than just functionally efficient machines; they can evolve into empathetic and engaging companions, better aligned with ethical and cultural standards and capable of fostering positive, respectful interactions with individual users.

The next section of this thesis will delve into the prevailing movement paradigms that have been shaped by the techno-centric discourse. It will examine how these paradigms have influenced the development of social robot movement design and their impact on human-robot interaction. By exploring these paradigms, the following section aims to highlight the limitations of current movement design approaches and the potential benefits of integrating an animator's perspective to the nuanced realm of the gestural communication of social robots.

6.4 Existing Approaches in Social Robot Movement

Similar to the visual design of social robots, as discussed previously in Section 4.5, the landscape of social robot movement design is also largely the result of processes that emphasise the engineering design values of functionality and efficiency over the hedonic and social. This has also resulted in design processes that have divided social robot movement design into two distinct separate phases where engineers are tasked with solving practical or functional related problems first and designers are relegated to work on aesthetic elements of emotional and intentional gestural expressions second (Hoffman & Ju, 2014; Mital et al., 2014; Nelson & Stolterman, 2014).

The following subsection describes three approaches to social robot movement design that have resulted from the dichotomy of these two phases and aims to discuss how each approach has contributed to the current landscape of social robot movement design.

6.4.1 The Pragmatic Approach: The Robot Dance

Echoing the utilitarian ethos in the visual design of social robots, as outlined in Section 4.5.1, a pragmatic approach to movement design similarly anchors itself in the philosophy of the robot as a functional tool (Hoffman & Ju, 2014; Knight & Simmons, 2014, 2015, 2015). Within this paradigm, the primary motivators for crafting robot movement are functionality and efficiency. Movements derived from this pragmatic perspective tend to be mechanical and abrupt, characterised by stilted, goal-directed transitions from one pose to another (P. Edwards, 2014; Vox, 2016). Such movements are emblematic of industrial robotic arms like the Arduino robotic arm, designed for manual labour tasks. The objective here is to efficiently optimise for the process of developing functional robot movements.

In the pragmatic approach, gestural studies and the nuanced interpretation of emotions and meanings behind movements are often relegated to secondary importance. This trend is evident in the social robot design literature, where discussions on gestures and their significance are noticeably sparse (Hegel et al., 2011; Hoffman & Ju, 2014; Knight & Simmons, 2014; LC et al., 2021; Peña & Tanaka, 2018; Stock-Homburg, 2022; Young et al., 2009). This approach typically results in social robots, like Baxter (Figure *81* – left) and PR-2 (Figure *81* – right), that resemble an assemblage of industrial robot arms with a tablet screen for facial interactions. Instead of movements, these designs focus on achieving specific poses to communicate intent relying on databases of static poses such as the Facial Action Coding System **(**FACS) (Bittermann et al., 2007; Ekman & Friesen, 1975; Kühnlenz et al., 2010; Menne et al., 2016) or the Body Action and Posture Coding System (BAP) (Dael et al., 2012; Embgen et al., 2012; Filntisis et al., 2019; Huis In 't Veld et al., 2014). Utilising these expression frameworks, the emphasis lies in orchestrating the robot's transition from one expressive posture to the next, often neglecting the nuances of transitional movement. Consequently, these movements tend to appear binary and linear, emerging from isolated joints without considering the fluidity or expressiveness essential in human-like gestural communication.

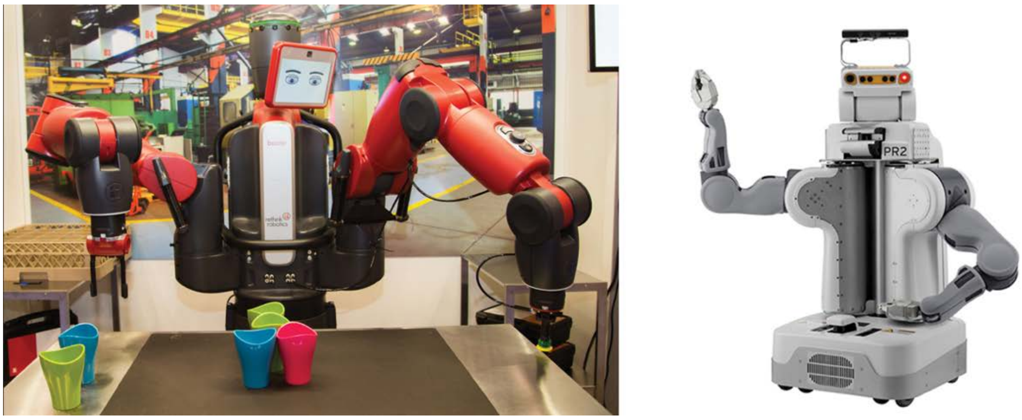

Figure 81. Baxter Robot (left – Rethink Robotics, 2011) and PR2 Robot (right – Willow Garage, 2010) are robots designed with the pragmatic approach in mind.

In human communication, movement patterns and transitions between poses carry significant communicative value, conveying aspects of a person's character or emotional state. Gestural studies expert Adam Kendon (2004) emphasises that these subtleties in movement reveal much about an individual's internal state. For example, the manner in which a person opens a door – slowly and with little energy, suggesting tiredness or sadness, versus energetically and forcefully, indicating excitement or impatience – provides insights into their inner emotions, motivations, and intentions. The pragmatic approach in social robot design often neglects these nuances and such oversights can limit the effectiveness of social robots in cooperative interactions and compromise individual safety, particularly in high-stress situations that require subtle communication cues. By neglecting the intricacies of gestural movement, the pragmatic approach fails to tap into the potential of robots to engage with humans in a more intuitive and meaningful manner.

Ironically, in certain contexts people do enjoy this style of mechanical movement as a form of performance, mimicry or parody. The dance style known as 'The Robot', also referred to as 'the mannequin' or 'the dancing machine', is an illusionary street dance that aims to imitate the movements of a robot or mannequin (P. Edwards, 2014; Vox, 2016). This dance style emerged in the early twentieth century, a period marked by the increasing presence of robots in popular culture and a time when society was grappling with the uncertainties brought about by rapid technological innovations. Mimes like Robert Shields and Lorene Yarnell in the 1970s effectively used robotic movements in their performances to tell stories or evoke specific emotions and thoughts about the increasingly technological age. Their work paved the way for other artists, including Don Campbell, Charles Washington, Bill Williams, and, most notably, Michael Jackson (as portrayed in Figure *82*) in the 1980s, who incorporated these robotic movements into music, giving rise to the *robot* dance as it is known today.

Figure 82. Michael Jackson performing the robot dance (CBS, 1974).

The intrigue surrounding the emulation of machine-like behaviour by humans originates from the dexterity and bodily awareness necessary to authentically reproduce intricate and isolated robotic motions. As defined in the Collins English Dictionary (2022), referring to someone as a machine in certain contexts can be considered a compliment, implying their exceptional skill in a particular activity and their ability to tirelessly perform with consistent machine-like precision. This fascination finds expression in Moravec's Paradox, as explored in Section 1.3, which states that tasks that are difficult for humans are often easy for computers and robots, while tasks that are easy for humans are quite challenging for computers and robots to perform. Moravec's Paradox hints towards the limitations of the human machine metaphor, particularly when it extends to the social and communicative aspects of human behaviour. For example, while it may commend the technical prowess and repetitive efficiency of an individual in work related contexts, it can be considered an insult in social contexts carrying connotations of being programmed, emotionless, and lacking in empathy. This understanding is particularly relevant in the context of social robotics, where the challenge lies not just in achieving mechanical efficiency but also in designing robots that can navigate and respond to the complexities of human emotions and social cues.

While there may be novelty in having robots perform actions in a distinctly robotic manner, such mechanical movements might not be sustainable in long-term human-robot interactions, especially in intimate or personal settings where meaningful gestural expression is more valued (Elsaesser, 2014). The challenge lies in designing robots that not only perform tasks efficiently but also communicate and interact with humans in ways that are contextually appropriate, emotionally resonant, and safe.

6.4.2 The Mimetic Approach: Hyper-Realism

The mimetic approach in social robot movement design is rooted in the philosophy of realism, aiming to replicate human gestures as faithfully and accurately as possible (Freedman, 2012;

M. A. Harrison & Hall, 2010; Menache, 2011; Mori, 1970; Nair, 2011; Sloan, 2012). The fundamental idea is that human-like movements in social robots will make the interpretation and comprehension of a robot's communicative interface more intuitive for human interaction. This approach has been realised through motion-capture technology and 3D animation, a process where live human motion is recorded, converted into mathematical models, and then used to create a three-dimensional representation of movement (Freedman, 2012; Menache, 2011). These recorded movements are then tagged with emotional markers and categorised for various use cases, forming a comprehensive expression library. The development of these gesture libraries are then informed by interdisciplinary research in biology, psychology, and the social sciences, ensuring that the robot's movements are not only realistic but also contextually appropriate (Bhatia et al., 2022; Perre et al., 2015; Tuyen et al., 2018; Zhang et al., 2020).

The pursuit of lifelike movement in social robots raises profound philosophical questions, particularly in the realms of aesthetics and emotional expression, as explored through Mori's *Uncanny Valley* Theory (1970), previously discussed in Section 1.2 and illustrated in Figure 9. However, in the context of moving robots, the peaks and troughs of the *Uncanny Valley* affinity curve become even more pronounced. Consider, for example, the lifeless body of a deceased human lying motionless on the ground in contrast to a zombie – a supposedly deceased corpse in motion. In this scenario, an element of stillness coexists with animation, creating a wild paradoxical juxtaposition in expectations that further heightens the uncanny effect.

The psychological basis of the Uncanny Valley theory is rooted in the ambiguous feelings of strangeness and familiarity and was conceptualised by German psychiatrist Ernst Jentch (1997) in his original essay titled "On the Psychology of the Uncanny" in 1906, which was then famously critiqued and further elaborated upon by Austrian neurologist and psychoanalyst Sigmund Freud (1919) in his essay "The Uncanny" in 1919. What they both observed was that the unsettling effect arose from the difficulty in discerning what is real and what is not, breaking expectations and leading to a sense of vagueness and confusion. For example, consider encountering a lifelike portrait painting where the subject's eyes appear to follow you as you move around the room. Despite knowing it is just a painting, the eerie sense of being watched can induce a feeling of the uncanny due to the ambiguous boundary between the static artwork and perceived animation. In the context of human interaction, think about a scenario where you meet someone who bears an uncanny resemblance to a long-lost friend or relative, both in appearance and mannerisms. Despite knowing it is not the same person, the uncanny likeness can create a sense of unease due to the blurred boundary between the familiar and unfamiliar. This feeling of uncertainty is what makes interactions emotionally unintuitive as it becomes difficult to ascertain what is the true nature of the surrounding environment or the interaction (Damasio, 2006; Kahneman, 2011).

A key problem with the mimetic approach is that robots are not humans. On a philosophical level, no matter how close roboticists get to creating human-like social robots with human-like gestural expressions, the robot will always be a robot (Turing, 2016). On a biomechanical level, robots and humans will always have different base kinematic and dynamic structures (Ferrari et al., 2016). And on a biological level, the robot does not innately share the grounded history of human evolutionary communication methods, such as empathic perspective taking, that have allowed for human survival over the last 5–7 million years (Smith, 2006; Wall, 2008). Perceptually speaking, regardless of the degree of realism achieved in these movements, the very fact that these robots are not actually human will always elicit some sort of uncanny response. Therefore, it is clear that the mimetic approach still requires some sort of intervention in-between the motion-capture of real-life movement data and the translation of that movement onto the social robot.

This idea of translation has been a point of contention in the animation industry for a long time dating back to the inception of motion-capture technology starting with rotoscoping by Max Fleischer in 1915, and evolving with advancements in computer-generated imagery, high-fidelity rendering, and motion-capture technology. It is a method of animation that has often attracted significant criticism. For instance, Disney's film *Snow White and the Seven Dwarfs* (1938) was criticised as being a "badly drawn attempt at realism" and an "anatomic automaton" with "staccato movements" that negatively impacted the art form (Menache, 2011). This was also the case with more recent motion-capture films that feature hyper-realistic aesthetics, such as *Final Fantasy: The Spirits Within* (2001), *The Polar Express* (2004), *Tin Tin* (2011), *Cats* (2019), and *The Lion King* (2019) as portrayed in Figure *83*. These films have been described as initially captivating but ultimately uncanny, revealing a "coldness in the eyes" and a "mechanical quality in the movements" leading to them being perceived as "dead-eyed", "lifeless", and "frighteningly realistic" (Freedman, 2012).

Figure 83. Aki (left – Sakaguchi, 2001), Know-it-all (middle – Zemeckis, 2004), and Tintin (right – Spiegel, 2011) are examples of film characters designed with the mimetic approach in mind.

Jerome Cheng (2016), a renowned visual effects supervisor and director, highlighted the limitations of motion-capture in accurately conveying human expressions in embodied animated mediums. In an interview with Variety, Cheng described the motion-capture data as resembling a "flapping puppet," lacking in volume and depth, especially in facial expressions like squinting or pursing the lips (Figure *84*). The data provides timing cues but fails to capture the extent of movement. Cheng explained the necessity for animators to interpret these cues, often modifying or disregarding the raw data to achieve the desired effect. He cited his experience with *Beowulf* (2007), where a team of over 60 animators worked for a year to refine every frame of the movie, underlining that there was not a single frame that did not require an animator's touch (Debruge, 2006). The need for this translation in the animation medium arises from the fact that, similar to social robots, animated characters are also non-human embodied mediums and, as such, necessitate distinct methods of abstracting, interpreting, and refining captured movements for effective emotional expression.

Figure 84. The level of detail captured in the facial expressions of actors in Beowulf still required intervention by an animator to achieve the perception of realistic expressive motion (Zemeckis, 2007).

The animator's methods for abstracting, interpreting, and refining captured movements are distilled into the 12 Principles of Animation. These principles serve as guidelines that underscore the importance of clear, expressive, and nuanced interpretations of movement, ensuring that animated characters not only exhibit movement that is grounded in realistic human communication methods, but also effectively convey emotions and intentions in a manner that is appropriate for the visual design of an animated character (Bishko, 2007; Rooij, 2019; Thomas & Johnston, 1995; R. Williams, 2012). In short, the key is not necessarily towards the strict adherence of realistic movement patterns, but rather towards movement patterns that are *perceptually* realistic (Hooks, 2017; Thomas & Johnston, 1995).

In the realm of social robot design, the mimetic approach frequently overlooks the essential layer of translation required when integrating human-like movements into these robots. For instance, the direct application of motion-captured eye gestures, such as saccades, onto a social robot may result in an excessive degree of eye movement. This occurs due to the disparities in physical attributes between the human body and the robot body, potentially intensifying these eye movements and causing disruptions in human-robot interactions (Stix, 2008). The incorporation of a movement translation layer, facilitates a more deliberate utilisation of such movements, aligning them more appropriately with the capabilities of the visual design of the robot.

6.4.3 The Stylised Approach: Caricatured Movement

These principles, developed since the 1930s by numerous Disney animators through experimentation and reflective practice were formally articulated by Ollie Johnston and Frank Thomas in their seminal 1981 book, *The Illusion of Life*, and later revised in their 1995 edition. These principles provide basic guidelines for producing the illusion of life in characters by adhering to the fundamental laws of physics while dealing with more abstract issues such as visual design, emotional timing and character appeal.

The stylized approach to social robot movement design draws heavily from the 12 Principles of Animation. These principles were first articulated by Ollie Johnston and Frank Thomas in their seminal book *The Illusion of Life* (1981) and later revised in the 1995 edition. Originally developed by Disney animators through decades of trial, error, and experimentation since the 1930s, the principles emerged from careful observation of motion on-screen and a focus on what aspects of animated movement enhanced the believability of characters. Rooted in over a century of collective experience and expertise, these principles continue to serve as the foundation for capturing the spirit of iconic animated characters to life such as Bugs Bunny, Wile E. Coyote, Gerald McBoing-Boing, Roadrunner, Ren & Stimpy, Fred Flintstone, Scooby Doo, and Mickey Mouse from renowned production studios such as Warner Brothers, UPA Studio, Hanna Barbera, and Disney. In this approach, social robot movements are crafted with bold and exaggerated gestures, deliberately transcending the boundaries of physical realism (as portrayed in Figure *85*). This deliberate departure from realism is an artistic choice that allows for a heightened freedom in movement that better enables expressions of emotional intent in the robot medium with the aim to parallel the emotional resonance and expressiveness commonly found in animated characters in film.

Figure 85. Jerry coming to an extreme abrupt stop (Hanna Barbera, 2001).

Exaggeration is a key component of the stylised approach and is an important principle of animation. It is the idea of making the essence of an action more readable and convincing so that it clearly connects with people – an expressive performance of reality (Thomas & Johnston, 1995; R. Williams, 2012) or, as famous Disney Animator Ollie Johnston aptly describes, "reality plus" (Freedman, 2012). Johnston noted that if a particular movement is meant to convey sadness, make the movement even sadder; bright, make it brighter; worried, more worried; wild, make it wilder (Thomas & Johnston, 1995). By amplifying certain gestures or features, designers can create robots that communicate more clearly and dynamically, making interactions more intuitive and enjoyable.

In social robot movement design, this amplification of gestures using The Twelve Principles of Animation typically results in a highly caricatured, playful, and imaginative aesthetic with the aim of prioritising expressiveness and emotional clarity over the strict adherence to human-like accuracy (Hooks, 2017; Thomas & Johnston, 1995; R. Williams, 2012). The intention of this approach is to allow for more approachable and easily interpretable robots for human-robot interaction, fostering endearing qualities that enhance user engagement. By applying these principles to movement design, this approach not only makes interactions with social robots more intuitive and enjoyable but also encourages creative design possibilities. The stylised approach offers designers the freedom to explore beyond the constraints of realism, enabling them to craft unique and dynamic interactive experiences with social robots (Breemen, 2004; Ribeiro & Paiva, 2012; Schulz et al., 2019; Takayama et al., 2011). This approach broadens the scope of social robot design, inviting a spectrum of imaginative and emotionally resonant designs that can appeal to diverse user groups and enrich the human-robot interaction experience.

While the stylised approach makes it possible to transcend the confines of realism, it also raises a notable concern when applied without due consideration for context and character. This approach often entails the blind application of The Twelve Principles of Animation, neglecting the unique character and the interaction context of the robot. It is not uncommon for roboticists to employ The Twelve Principles of Animation primarily for its stylistic aesthetic appeal and the meanings such animated movements might bring to the interaction, which can lead to the risk of adopting stereotypical movement patterns (Bishko, 2007, 2014a).

A prime example of such stereotypical movement is what is referred to as the *cartoony style* (Bishko, 2007, 2014a). This style is characterised by the depiction of characters within dramatic contexts, with bodily actions portrayed in a zany, comedic manner. It often results from the indiscriminate application of animation principles solely as a matter of functionality, without the deliberate crafting of movement to establish distinct characterisations and styles (Bishko, 2007, 2014a). When robot movement is divorced from emotional expression, these principles may be reduced to a formulaic approach aimed at efficiency creating functional motion that *just works*.

This tendency is also susceptible in animation education, where fundamental exercises like animating a bouncing ball or a waving flag often teach the principles primarily from a functional perspective. At the early stages of learning animation, an emphasis on functional aspects is essential, as without proper function, expressive intent can be challenging to achieve. However, it is crucial to define expressive goals before diving into animation, as a well-defined intent for emotional expression often guides and enhances the functional aspects. This is where animators can draw from the craft of acting to gain valuable tools for clarifying intent before becoming entangled in the intricacies of frame-by-frame animation (Bishko, 2007, 2014a).

Ironically, some social roboticists intentionally incorporate stereotypical movements into their designs, drawing inspiration from the familiar, enjoyable, and entertaining characters found in animated media – a style often associated with *fun* and *comedic* elements. However, this approach often overlooks the core elements that initially made these characters emotionally resonant and popular, namely, their unique characterisations and expressive qualities. In reality, what truly sets these animated characters apart is their ability to convey distinct personalities and emotions through their movements and actions. In fact, the way in which a character is animated can also tell us something about the character or the universe in which they occupy.

Figure 86. The various spider people hailing from different dimensions each retaining their unique visual and movement aesthetic (Ramsey, Persichetti & Rothman, 2018).

A recent example of this phenomenon is found in the 2018 film *Spider-Man: Into the Spider-Verse* (as portrayed in Figure *86*), which boldly introduced a variety of animation styles to differentiate the diverse *spider people* hailing from various dimensions. The animation for each character serves as a visual manifestation of their unique backgrounds and personalities. For instance, Miles Morales, the film's central character, exudes the vibrant energy of urban street art, with his fluid, graffiti-inspired movements. By contrast, Peni Parker's animation style draws heavy inspiration from Japanese anime, emphasizing her futuristic and mecha-themed persona. In contrast, Spider-Man Noir's animation movements are a study in deliberate, meticulously executed actions, further underscored by unique cinematic camera angles, such as low shots, dramatic close-ups, and dynamic framing, which contribute to the noir ambiance and complement the character's brooding demeanour. Peter Porker, humorously known as Spider-Ham, adopts a classic and whimsical animation style, marked by exaggerated movements that aptly capture his comedic essence. Remarkably, the animation style of Peter Porker maintains its original animation frame rate from its Hanna-Barbera era, typically ranging from 8 to 12 frames per second. This unique feature sets Spider-Ham apart, particularly when juxtaposed against the other spider people animated at the contemporary standard of 24 frames per second. In each case, the animated movement harmoniously aligns with the distinct personality of the characters, enhancing their depth and acting as a powerful storytelling tool, offering viewers immediate visual cues about the spider people's origins and experiences. Ultimately, it is the synergy between character development, emotional depth, and their well-suited movement styles that captivates audiences and fosters a lasting connection with these iconic characters.

Without careful consideration of characterisation, expression, intention and context, the stylised approach can lead to movement patterns that may not be effective or appropriate in various human-robot interaction scenarios. Take, for instance, a social robot employing a highly stylised cartoony approach to movement during a therapy session for individuals with autism. In such a sensitive therapeutic context, where predictability and gradual engagement are vital, the stylised approach might create confusion or distress for the interacting individual. Social roboticists need to be mindful that while a stylised approach can be visually engaging and comedically entertaining, it should be employed with clear intent and an understanding of the specific interaction context to ensure effective and meaningful human-robot interactions (Bishko, 2007; Hooks, 2017; Thomas & Johnston, 1995; R. Williams, 2012).

6.4.4 Critiquing Current Approaches to Social Robot Visual Design

Human social interaction is a multifaceted and intricately interconnected system influenced by biological, societal, and cultural factors. It underscores the significance of movement design in facilitating effective human-robot interaction. The inherent human tendency to anthropomorphise even simple moving shapes (Heider & Simmel, 1944), as discussed in section 6.1, underscores this point. This natural inclination to imbue robots with human-like characteristics based on their movement patterns necessitates a meticulous and nuanced approach to crafting these movements. Such an approach should encompass not only the functional aspects of a robot's movements but also the manner in which these movements are perceived and understood by humans within diverse social and cultural contexts (Galindo et al., 2022; Hoffman & Ju, 2014; Knight & Simmons, 2014, 2015; Leeuwen, 2021). By adopting such an approach, roboticists can cultivate more captivating, empathetic, and affective interactions between humans and robots, thereby enriching the overall human-robot interaction experience and fostering greater acceptance of social robots in everyday life.

The existing paradigms of pragmatic, mimetic, and stylised approaches each offer distinct perspectives on how to approach social robot movement design but fall short in fully encompassing key aspects of human communication, including subtlety, contextual awareness, and emotional expression. The pragmatic approach, though useful, has its deficiencies as it predominantly relies on static emotional expressions. In doing so, it overlooks the nuanced communicative value embedded in the transitional movements between these static poses. These transitional movements have the potential to convey intricate facets of an individual's character or emotional state, often missed by a rigid reliance on predefined poses. On the other hand, the mimetic approach, which strives for realism by replicating human-like movements, encounters a notable challenge. It tends to neglect the pivotal layer of translation required when integrating human-like movements into robots that fundamentally lack human attributes. While aiming for authenticity, this approach can sometimes fail to account for the essential differences between human and robotic anatomy and physiology, potentially leading to incongruities in movement interpretation. Conversely, the stylised approach, which seeks inspiration from the movement styles of popular animated characters, offers a unique perspective. However, this approach overlooks critical factors intrinsic to the social robot itself, including character representation, expression, intention, and contextual awareness. In some cases, the pursuit of a particular movement style may overshadow the robot's individual characteristics and its adaptability to various social contexts.

Individually, each of these approaches falls short in capturing the true essence of effective movement design which is the robot's ability to convey expressiveness. The formidable challenge lies in amalgamating elements from these paradigms in an interdisciplinary manner to formulate a comprehensive approach that fully encompasses the subtleties, contextual understanding, and emotional depth intrinsic to human communication. Simultaneously, this approach must also acknowledge and accommodate the unique attributes and capabilities of social robots across a spectrum of social contexts. By pursuing this strategy, designers can facilitate the creation of interactions that are more intuitive, captivating, and profound. This ensures that social robots can effectively communicate and resonate with human users through a movement design that better aligns with a social robot's communication channels.

Of all the current approaches, the stylised approach emerges as the most promising step towards realising a fully integrated interdisciplinary approach to social robot movement design. This approach champions the integration of animation expertise, within the domain of social robot design – a trend gaining recognition for its potential to nurture empathy and establish emotional connections through the artful execution of gestural performances. Numerous studies have underscored the intrinsic value of leveraging the 12 Principles of Animation to augment the emotional expressiveness of robots (Breemen, 2004; Lacey & Caudwell, 2018; Rett, 2009; Rett & Dias, 2007; Saldien et al., 2014). However, in reviewing the literature from the field (Burton et al., 2016; McColl & Nejat, 2014; Paiva et al., 2014; Ribeiro & Paiva, 2012; Schulz et al., 2019; Venture & Kulić, 2019), roboticists lean towards a less than holistic approach in their understanding and application of the underlying principles of movement, often cherry picking the salient ideas from research literature from design and performing arts disciplines and shoehorning them into their own existing movement frameworks. For example, rarely do social roboticists apply the full breadth of the 12 Principles of Animation. In a systematic literature review of 106 articles using the 12 Principles of Animation as the basis for robot gestural movement, it was reported that only 18 studies utilised more than one animation principle at a time (Schulz et al., 2019).

The application of the 12 Principles of Animation in social robot design is often constrained by a segmented and goal-oriented development process, heavily influenced by a techno-centric approach. This process, explored in Section 4.3 and Section 6.3, splits the design process into two distinct stages: engineers first address practical or functional problems, and then designers focus on the aesthetic aspects of emotional and intentional gestures (Hoffman & Ju, 2014; Mital et al., 2014; Nelson & Stolterman, 2014). Though intended to make development more efficient, this approach inadvertently limits true interdisciplinary collaboration. As a result, there is a tendency to adopt a mimetic approach when utilising the 12 Principles of Animation, where social roboticists often emulate specific movement styles from popular animated cartoons. While this method is efficient, it often overlooks the deeper complexities needed for a thorough understanding of communication and gesture through the embodied medium of the social robot.

The proper integration of the 12 Principles of Animation in social robot design faces challenges due to the inherent nature of animation as a discipline, which is characterised by a reflective and iterative process, often yielding tacit knowledge. This tacit knowledge emerges from the animator's experience and is not easily transferable through literature, which tends to provide descriptive rather than explicit measurable guidance (Argyris & Schon, 1974; Schön, 1983, 1987, 1995). Consequently, this tacit knowledge poses a challenge for fields attempting to fully utilise these principles, as this approach requires direct experience in observing and abstracting real-world movement, exaggerating underlying motivations, and then translating these transformed movements through the medium's unique communicative channels. This profound level of understanding and application, deeply entrenched in the experience and intuition of animators and performance artists, creates a barrier to its comprehensive adoption in disciplines like social robotics, where such nuanced, intuitive knowledge is less common.

The implementation of animation principles in social robot design demands a sophisticated interdisciplinary approach that extends beyond simple mimicry of movement patterns. Such an approach requires comprehensive interdisciplinary collaboration to develop a well-rounded understanding of communication and gesture in the design of robot movements. Given the reliance on tacit knowledge in this field, it is essential to involve animation experts from the beginning. This collaboration helps avoid misinterpretations and errors in translating literature, ensuring the principles are applied with an understanding of intention and context. This joint effort is crucial in crafting movement and gestural expressions specifically suited to social robots, yet still pertinent to the nuances of human communication. By integrating this expertise from the outset of the design process, rather than as an afterthought, social roboticists can develop more effective and intuitive human-robot interactions, leveraging the nuanced expressivity and communicative potential of gesture and movement.

The forthcoming section addresses the challenges of interdisciplinary collaboration and aims to guide social roboticists towards the 12 Principles of Animation, demonstrating how these principles can enrich the design of social robot movements. It highlights the unique contributions that animators can make to robotics, focusing on their expertise in creating expressive and engaging movements. The section seeks to translate these skills to enhance social robotics effectively. By exploring the relevance and application of each principle within the context of robot design, it illustrates how collectively, these principles can enhance a robot's capability to communicate and interact with humans more naturally and intuitively. This examination is designed to deepen the integration of animation principles in social robotics, thereby fostering more effective and empathetic human-robot interactions.

6.5 The Twelve Principles of Animation

The evolution of animated movement at the Disney studio during the 1930s was pivotal to the formalisation of believable and authentic movement parameters (Hooks, 2017; Thomas & Johnston, 1995; R. Williams, 2012). During this era, a core team of animators began to experiment with animated movement. The findings of these parameters were formalised by Frank Thomas and Ollie Johnston in The Illusion of Life: Disney Animation (1995). Walt Disney pushed the animators to develop their skills and create a more physically believable animated world. Gradually, a terminology, or language of animated movement evolved, which became known as the 12 Principles of Animation.

Given the success of animated films such as *Astro Boy* (1968), *The Iron Giant* (1999) *Wall-E* (2008), and *Big Hero 6* (2014), films which all feature robots as main characters, animation has significant potential in creating robot behaviours that look and feel believable. However, in reviewing the literature, the application of animation expertise in robotics has only just begun to scratch the surface. A major barrier hindering the broader utilisation of animation principles in robotics is the fact that they constitute tacit knowledge acquired by animators through experiential learning and reflective practice. To bridge this gap, the upcoming section will detail each of the 12 Principles of Animation, explore their impact on gestural expression, and then apply these principles to the context of social robot design. It is important to note that the principles of *appeal* and *solid drawing* have been excluded from this discussion as they do not directly pertain to movement.

6.5.1 Squash and Stretch

Figure 87. The principle of squash and stretch (Thomas & Johnston, 1995).

The principle of *squash and stretch* pertains to the inherent elastic properties of objects or characters and how external forces like gravity impact their shape (Thomas & Johnston, 1995; R. Williams, 2012). Its primary objective is to imbue objects with a sense of weight and flexibility, accentuating their speed and momentum (Bishko, 2014b). This effect is achieved through the deformation of objects, either through elongation or compression. The most common application of squash and stretch in animation aligns with the laws of physics. For example, a bouncing ball gradually stretches at its fastest point of trajectories (as illustrated in frames 5, 7, and 8, and again in frames 12, 14, and 15 in Figure 87) and squashes upon impact with the ground (as illustrated in frames 6 and 13 in Figure 87). However, squash and stretch can also mirror the emotional states of characters or objects. In the case of a bouncing ball, it may exhibit squash and stretch either due to the physical demands of its weight and material or due to its enthusiastic desire to bounce (Thesen, 2020).

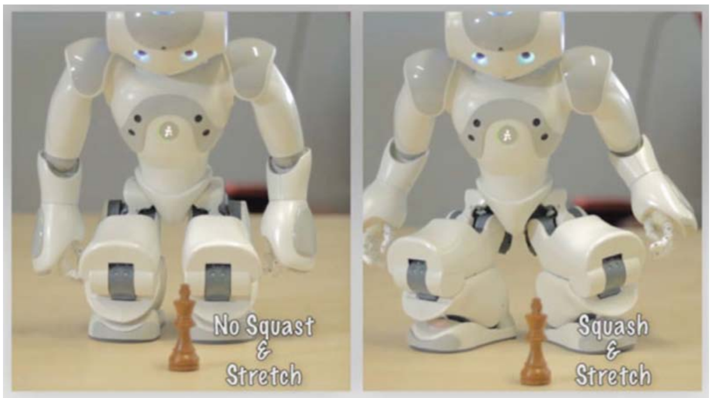

Figure 88. The Nao Robot achieving the principle of squash and stretch by using a more horizontal stance (Paiva, Leite & Ribeiro, 2014).

In the context of social robot design, squash and stretch could refer to the elongation and squashing of a robot's physical exterior. However, beyond physical design considerations, it is also feasible to achieve a squash and stretch effect through the utilisation of specific poses and body movements (Ribeiro & Paiva, 2020). For instance, the Nao robot can create the illusion of squash and stretch by extending its arms and legs outward just before executing an upward motion (as portrayed in Figure *88*). Another illustrative case is seen in the design of the JIBO robot (as portrayed in Figure *89*), where the perception of squash and stretch was achieved by positioning the robot's degrees of freedom at slanted angles (Robotics Business Review, 2015).

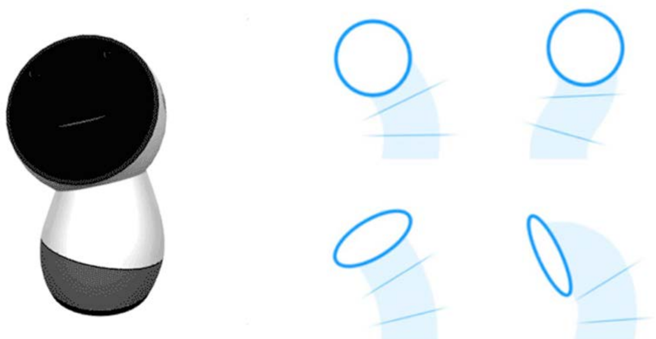

Figure 89. The JIBO Robot achieving squash and stretch through two slanted joints off axis from each other (Robotics Business Review, 2015).

6.5.2 Anticipation

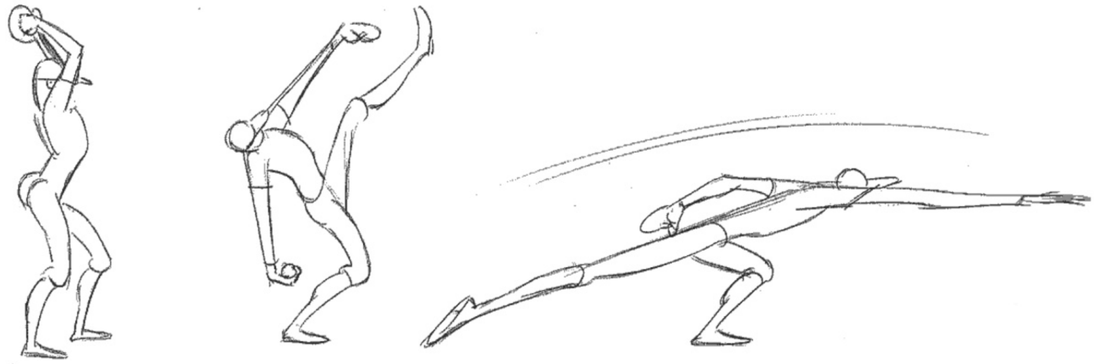

Figure 90. The principle of anticipation (Thomas & Johnston, 1995).

Anticipation describes the way a character prepares for an action (Thomas & Johnston, 1995; R. Williams, 2012). The purpose of this principle is to telegraph one's intention to act so that the resulting action is clear and understandable. This is accomplished by initiating a movement in the opposite direction prior to the primary action. Similar to the squash and stretch principle, the most prevalent application of anticipation is rooted in the principles of physics. For instance, in the act of throwing a ball, an individual will initially move backwards and pull the ball behind their head before swinging their arm out in front of them to release the ball (as portrayed by the middle illustration in Figure *90*). Beyond physics, anticipation can also signify a shift in cognitive or emotional processes (Thomas & Johnston, 1995; Williams, 2012). Emotional or mental anticipation deals with the preparation of a character's thought, an emotional action, reaction, or change. This form of anticipation is subtle and may manifest as simple actions such as a character making eye contact with an object of interest before taking action or blinking their eyes in response to a new thought (as portrayed in the second illustration in Figure *91*).

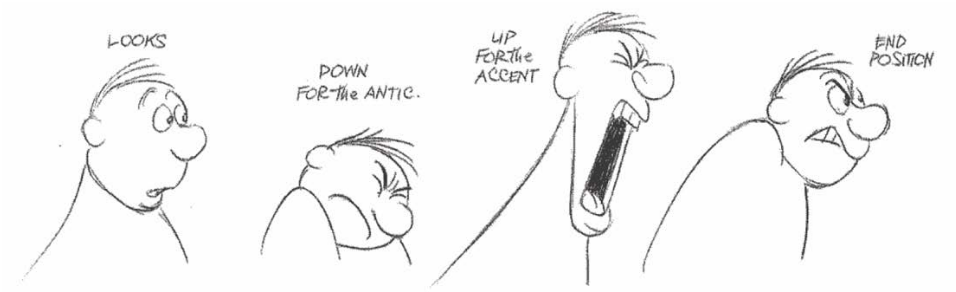

Figure 91. A blink used as part of the anticipation pose to transition the expression from neutral to anger (Thomas & Johnston, 1995).

In social robot design, anticipation can help people understand what a robot is going to do and so help with a robot's readability and understandability. For example, in an on-location user evaluation study exploring the use of a fully autonomous tour guide robot, it was noted that the robot would get stuck at the intersection of busy walkways due to its safety collision detection system (Karreman et al., 2015). It was noted that the use of a short physical anticipatory movement backwards prior to moving forward, could provide enough information to signal surrounding people the robot's intent to move forward.

6.5.3 Staging

Staging encompasses the deliberate design and sequential arrangement of a pose or a series of poses to ensure that the actions within a scene are conveyed with absolute clarity and without ambiguity (Thomas & Johnston, 1995; R. Williams, 2012). Staging takes into consideration various facets of filmmaking, including the performances of on-screen characters, the timing of actions, the spatial arrangement of on-screen activities within the composition, and the camera's position and angle. For instance, situating the central subject of a scene in close proximity to a background character in motion can result in visual confusion, making it challenging for the audience to discern the focal point. To address staging challenges, several techniques can be applied. These include repositioning the camera to bring the central subject into the foreground of the composition, utilising bokeh (background blur) to naturally guide the viewer's focus, or highlighting the main character by posing them to dominate the compositional space. This approach ensures the viewer's attention is first drawn to the most prominent element, such as the main character, before naturally shifting to smaller details like secondary characters or text (as shown in Figure 92).

Figure 92. Illustration of famous Disney animator Milt Kahl telling off his student Richard Williams (Thomas & Johnston, 1995).

Staging goes beyond compositional techniques, encompassing character animations and the clear portrayal of a character's intent in a compelling and understandable way. For instance, in Figure 93, where a character is depicted lifting a rock, the sequence is thoughtfully staged to convey both process and intent. The character doesn't immediately bend down to pick up the rock. Instead, it begins by looking at the rock, visually signalling its intention to interact with it. The character examines the rock from various angles, searching for an ideal grip. This is followed by an anticipation pose, where the character stretches upward before bending down to lift the rock. The subsequent struggle to lift the rock is animated to emphasize its weight, before the character ultimately succeeds in hoisting it. This deliberate sequence not only clearly communicates the character's intent but also adds richness to the scene, highlighting details such as the rock’s heaviness and the character’s intense focus and determination to lift it. These elements enhance both the narrative and the emotional engagement of the audience.

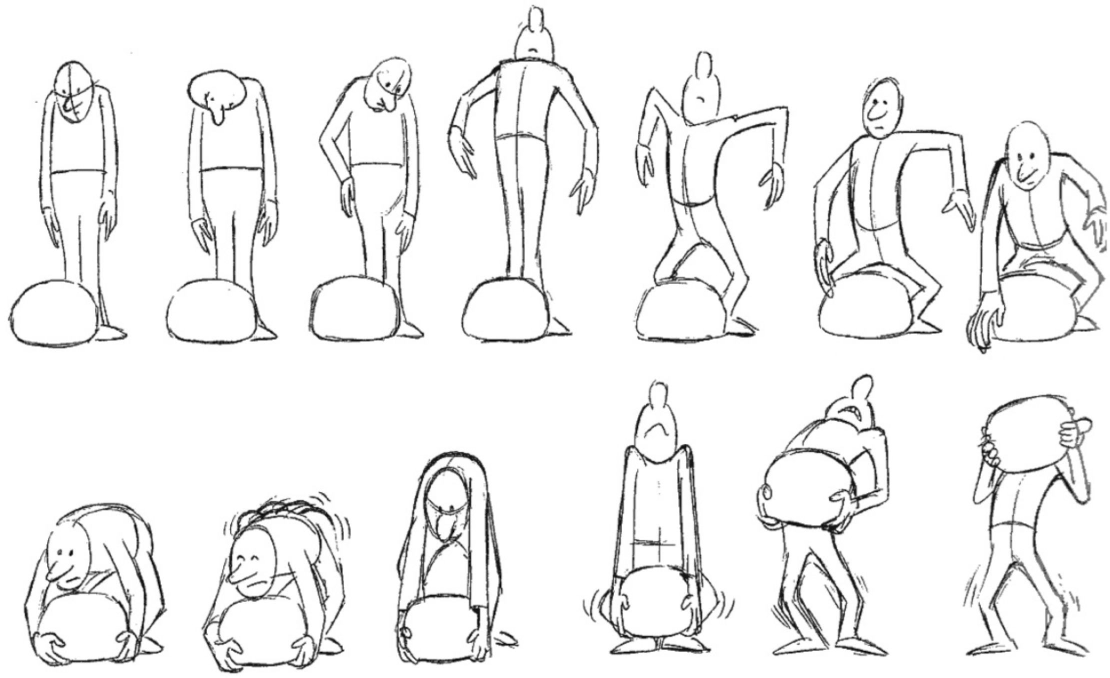

Figure 93. Staging of a character lifting a rock (Thomas & Johnston, 1995).

In the context of social robot design, staging pertains to the presentation of the robot's intentions (Ribeiro & Paiva, 2012). Staging distinguishes itself from anticipation as anticipation concerns the immediate preparatory movements for a robot's upcoming action, whereas staging encompasses the entire sequence of actions performed by a robot that conveys the purpose behind the action. Take, for example, a scenario where a robot is tasked with handing an item to a human (as portrayed in Figure *94*). Here, the sequence involves the robot first orienting its gaze towards the item, indicating its next action, then picking up the item, and finally turning to the human to complete the handover. This sequence of looking at the item before proceeding with the pickup and handover demonstrates staging in action, setting the stage for the robot’s interaction with the human, making the robot's actions more understandable and purposeful to the human observer.

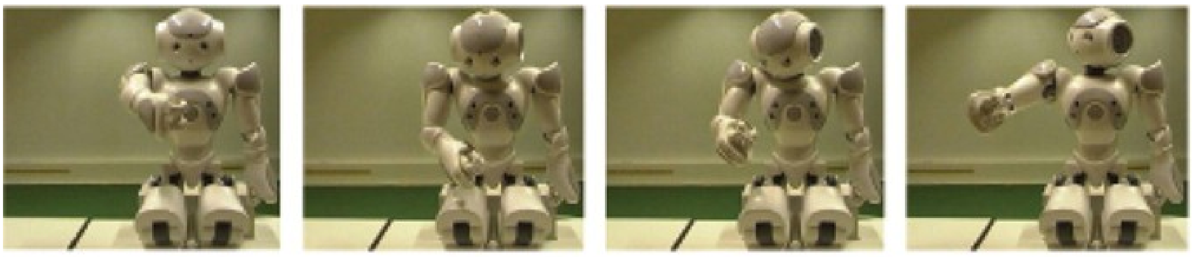

Figure 94. Staging sequence of a social robot handing an object to someone (Schillaci, Hafner & Hara, 2016).

6.5.4 Straight-Ahead Action and Pose-to-Pose

Straight-ahead action and *pose-to-pose* represent two distinct animation workflow methods utilised to achieve loose or controlled outcomes, respectively. Straight-ahead action involves creating animation by drawing each frame individually in a sequential order without predetermined endpoints for the action. This approach is typically employed for dynamic, spontaneous movements, where unpredictability is a key element, such as animating waves crashing onto a beach or flames flickering in a firepit. In contrast, pose-to-pose animation (as portrayed in Figure *95*) involves establishing the initial and final frames of an action and then interpolating the intermediate frames of extreme and breakdown poses to complete the motion. Pose-to-pose animation provides animators with greater control over the timing of specific actions, making it suitable for scenarios where precise synchronisation is desired, such as characters dancing in sync with specific beats of music or reacting to particular events or interactions within a scene.

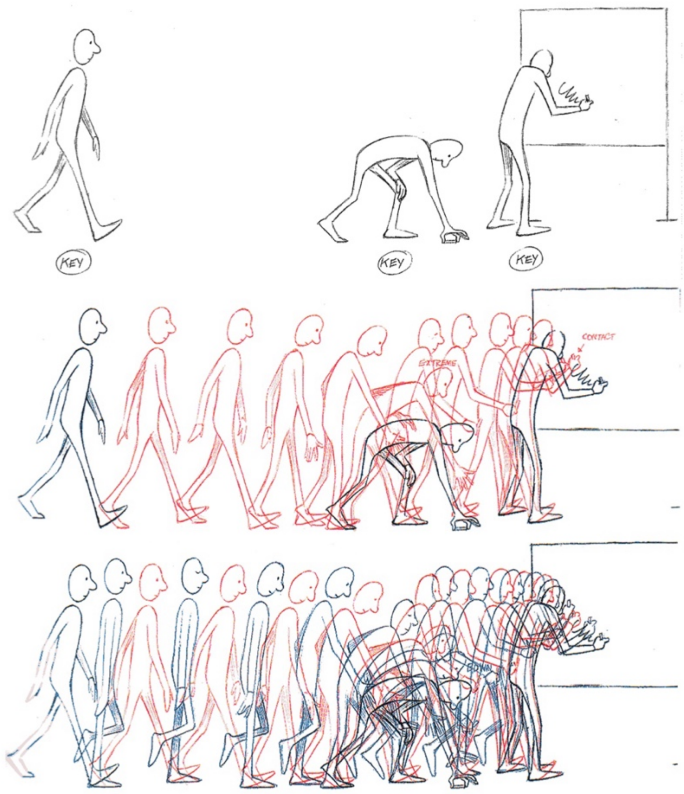

Figure 95. Illustrated example of pose-to-pose animation. Key frames are established as the main beats of the action with extreme poses in red which further break down the pose into import contact points, and breakdown poses in blue to further flesh out the action sequence (Thomas & Johnston, 1995).

In social robots, this principle pertains to the various techniques employed for generating robot movement (Ribeiro & Paiva, 2020). A motion sequence that has been previously animated and stored in a gesture library, then played back as-is, can be likened to pose-to-pose animation. This method is prevalent in robot animation but lacks interactivity, as the trajectories are replayed exactly as originally generated. Conversely, a motion sequence that is generated procedurally utilising pre-configured motion frameworks is akin to straight-ahead action animation. This approach introduces the potential for dynamic interactivity and responsiveness. However, an effective approach to human-robot interaction necessitates the integration of both modes of motion generation within a comprehensive motion framework (Ribeiro & Paiva, 2020).

6.5.5 Follow-Through and Overlapping Action

Follow-through and *overlapping action* refers to the distinctive, wave-like progression that continues at the end of one movement onto another (Thomas & Johnston, 1995; Williams, 2012). The primary objective of this principle is to create the illusion that a specific movement adheres to the principles of physics, particularly the concept of inertia. The follow-through and overlapping action principle accomplishes this by extending a particular movement slightly beyond its intended end position and then retracting it back to its original ending position. Notable instances of this principle in practice include the undulating motion of a waving flag or the delayed, reactive movement of a character's hat flaps as they move up and down (Figure *96)*.

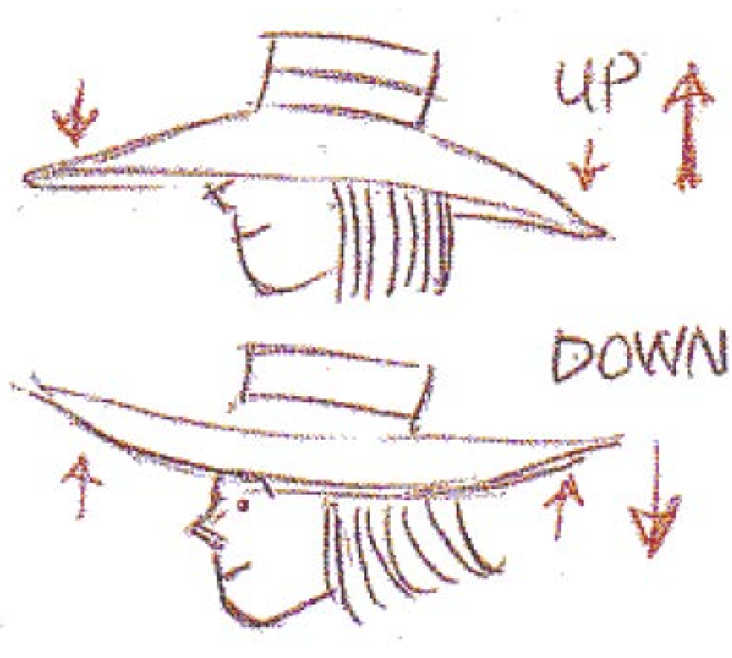

Figure 96. The delayed movement of a person's hat as a character moves up and down (Thomas & Johnston, 1995).

In social robots, the principle of follow-through and overlapping action plays a pivotal role in considering the balance and coordination of movements, particularly in scenarios involving close human-robot interactions (Ribeiro & Paiva, 2020). This principle becomes instrumental in distinguishing between successive actions performed by the robot. To elaborate, envision a social robot assisting a person in a caregiving context. When transitioning from helping the person to stand up to guiding them towards a different location, the robot employs follow-through and overlapping action by smoothly concluding the initial movement before initiating the subsequent one. This deliberate pause and graceful conclusion serve as visual cues, delineating the end of one action and the commencement of the next. Such clarity in movement sequencing not only enhances the overall safety of interactions but also contributes to the user's understanding of the robot's intentions and actions. This meticulous orchestration of actions in social robot design ensures that the robot's movements are not only functional but also perceptually intuitive, fostering a sense of trust and cooperation between the robot and its human users.

6.5.6 Slow In and Slow Out

The principle of slow in and slow out refers to the gradual acceleration and deceleration of motion, a concept in animation used to create lifelike and natural movement by easing into and out of motion trajectories (as illustrated in Figure 97). This principle stands in stark contrast to stop and start movement, which lacks these transitional nuances. Stop and start motion is abrupt, rigid, jerky, and constant, often perceived as mechanical or crude, making it less effective in fostering intuitive or engaging interactions. Organic movement rarely follows a uniform rate of acceleration or deceleration. Instead, it transitions fluidly, and slow in and slow out replicate this by smoothing the initiation and termination of motion. While slow in is sometimes mistaken for anticipation and slow out for follow-through or overlap, their distinct purpose is to ensure seamless movement transitions rather than extend the duration of an action.

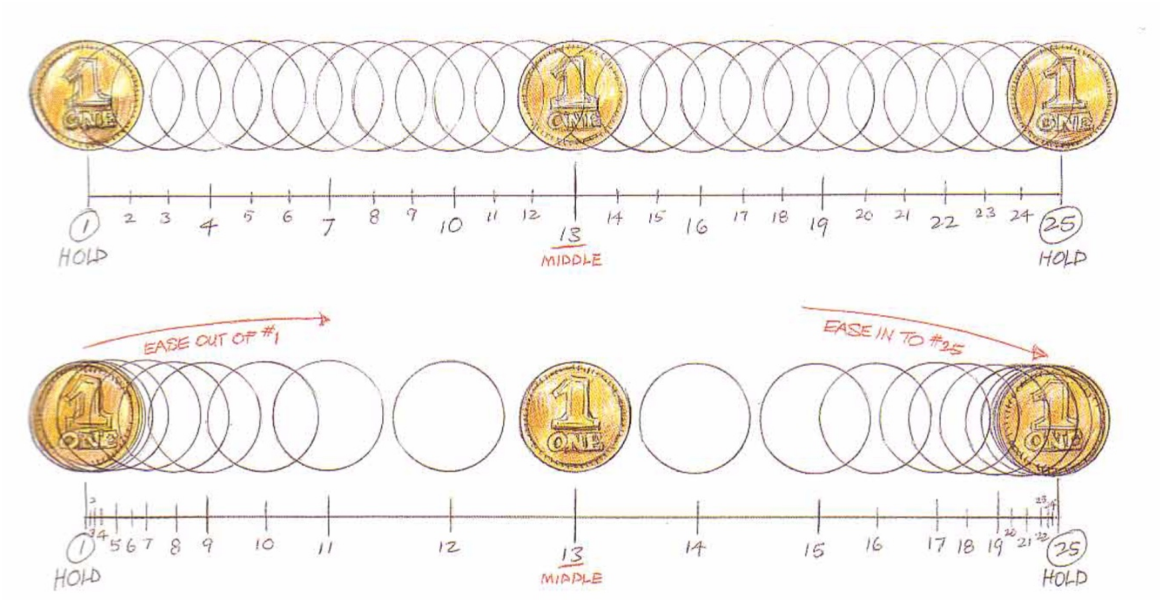

Figure 97. Top illustration demonstrates a coin moving from left to right with no slow in and slow out. The bottom illustration demonstrates the same movement but with slow in and slow out (Thomas & Johnston, 1995).

In social robot design, embracing slow in and slow out over stop and start motion is essential to achieving lifelike and relatable behaviours. Smoothly transitioning into and out of motions enhances the robot's organic and intuitive feel, making human-robot interactions more engaging. Conversely, stop/start movement disrupts the flow of interaction, creating a jarring, mechanical impression that hinders user experience. By adopting the principles of slow in and slow out, social robots can mimic the fluidity and naturalness of organic motion, significantly improving how they are perceived and interacted with.

6.5.7 Arcs

The principle of arcs refers to the inherent nature of movement in the organic world. Very few organisms or objects are capable of executing perfectly straight-line motions with absolute precision. Instead, the majority of organic life, including humans and animals, exhibit a characteristic pattern of movement known as an arched trajectory. This fundamental concept underscores the aim of the principle of arcs in animation, which is to replicate the organic and lifelike quality of motion. Consider, for instance, the arc trajectory of a person walking (as portrayed in Figure 98) where the swinging motion of the arms and legs follows curved, pendulum-like paths rather than rigid, straight lines. This natural arched trajectory not only conveys a sense of balance and fluidity but also enhances the believability and reliability of the movement.

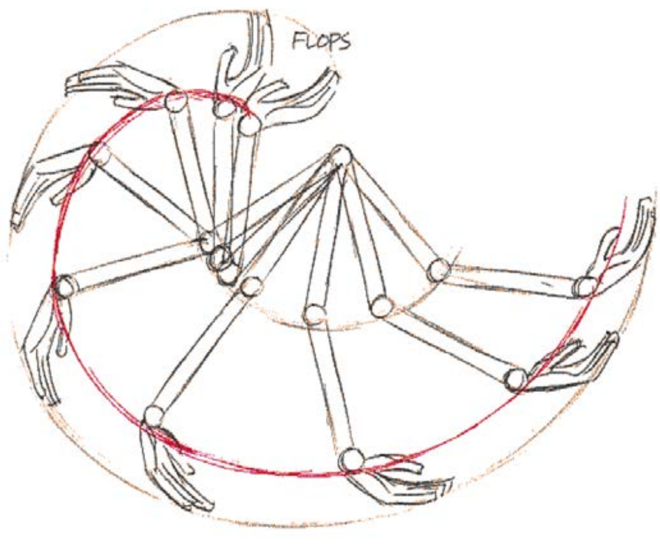

Figure 98. The arc trajectory of a backwards swinging arm from the elbow, wrist, and tips of the finger (Thomas & Johnston, 1995).

Much like the animated characters seeking to emulate the lifelike quality of motion, social robots benefit from embracing this principle to create movements that resonate with humans. The inherent tendency of organic life to move in arched trajectories is deeply ingrained in our perceptual experience. Therefore, when designing the movements of social robots, replicating these natural arcs can play a pivotal role in making their actions appear more relatable and intuitive to human observers. Whether it is the graceful sweep of an arm or the gentle swaying of a robotic body, incorporating the principle of arcs fosters a sense of organic movement, ultimately enhancing the robot's ability to interact with humans in a manner that feels inherently familiar.

6.5.8 Secondary Action

Secondary actions in animation are used to complement or enhance the primary action, adding depth and nuance to a character’s performance. For instance, a startled character rising to their feet in shock might simultaneously shake their head in disbelief (as illustrated in frames 5 to 10 in Figure 99), or a flustered individual may pause to adjust their glasses in an attempt to regain composure. In these examples, the head shaking and glasses adjustment are considered secondary actions. It is important to ensure that secondary actions remain subordinate to the primary action. This balance prevents them from overshadowing or complicating the main focus, which could result in poorly staged scenes that confuse viewers. When executed effectively, secondary actions enrich the narrative, enhance the scene’s clarity, and add dimension to a character’s personality, making their reactions more relatable and engaging.

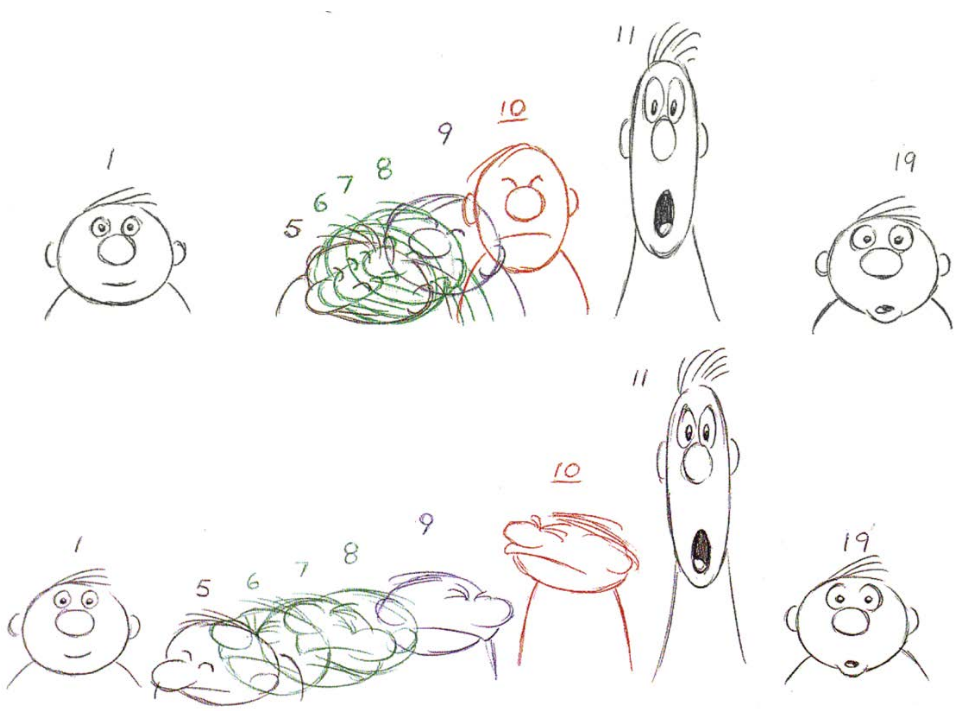

Figure 99. The top illustration depicts a character transitioning into a shocked expression. In contrast, the bottom illustration shows a similar transition but incorporates the secondary action of the character shaking its head side to side as it moves into the shocked expression (Thomas & Johnston, 1995).

Just as animated characters utilise secondary actions to complement or emphasise the primary action, social robots can leverage this principle to enhance their interactions with humans. For instance, imagine a social robot assisting a person in a crowded environment. While its primary action may involve guiding the person through the crowd, the robot can employ secondary actions such as subtly adjusting its position to ensure the person's safety or conveying reassurance through calm facial expressions. These secondary actions remain subordinate to the primary task, preventing any conflict or confusion. In addition, in a caregiving scenario, a robot assisting an elderly individual with mobility may incorporate secondary actions like adjusting its pace to match the person's comfort level or providing verbal encouragement, adding depth and warmth to the interaction. In essence, secondary actions in robot movement design serve as a means to enrich the overall experience, conveying nuance and enhancing the personality of the robot character.

6.5.9 Timing

The principle of timing encompasses a broad spectrum of factors, including the velocity, acceleration, deceleration, and overall duration of an action. Timing also extends to transitions between poses or movements, the speed of reactions, and the interaction between characters, making it an essential element in animation and social robot design. The primary objective of this principle is to illustrate how the allocation and coordination of time in specific actions significantly influence the perceived quality and expressiveness of movement.

In social robot design, timing plays a critical role in shaping the character and perception of robotic movements. For instance, swift timing in a robot’s actions may convey a sense of excitement or nervousness, while deliberate, slower timing can impart an impression of relaxation or lethargy. These nuances enable robots to communicate emotional states and attitudes effectively. Consider a robot assisting a child in a playful activity: engaging in swift and lively movements could project enthusiasm and excitement, enhancing the interaction’s energy and fun. Conversely, in a caregiving scenario with an elderly individual, slower, more deliberate timing could communicate calmness and reassurance, fostering a sense of comfort and non-intrusiveness.

Additionally, timing influences how a robot transitions between different movements or poses, which can enhance fluidity and naturalness. The speed of a robot's reactions also impacts its perceived responsiveness and attentiveness in interactions. For example, a robot that quickly reacts to a user's input feels engaged and dynamic, while slower reactions might convey a sense of contemplation or caution. Furthermore, timing in multi-robot or human-robot interactions determines the rhythm and coordination between participants, further enriching the relational dynamic.

All in all, timing facilitates the expression of a robot's intentions, emotional states, and interactive capabilities, making it a powerful tool for designing relatable, emotionally resonant, and engaging social robots.

6.5.10 Exaggeration

As discussed in Section 6.3.3, exaggeration involves the deliberate amplification of specific attributes or movements within a character, achieved through a broader range of motion than would naturally occur. The primary goal of exaggeration is to enhance the clarity and emotional resonance of an action by making it more pronounced and impactful. This is accomplished through the integration of multiple animation principles working together to heighten the overall effect.

As depicted previously in Figure 88, Jerry's abrupt stop upon seeing Tweety point a gun at him showcases the use of exaggeration to convey sheer shock. The sudden halt in Jerry's movement emphasizes the immediacy of the danger, with his face registering the alarm while the rest of his body collapses into a squashed, accordion-like shape. This follow-through and overlapping action heighten the comedic effect, reinforcing how utterly unprepared Jerry was for Tweety to wield such a weapon. Additionally, the exaggerated stretch of Jerry's shocked expression amplifies the emotional impact, making his surprise unmistakable. In this example, the principle of exaggeration works in harmony with other animation techniques to intensify the character's reaction and the scene's overall impact.

In social robot design, the principle of exaggeration is essential for enhancing the clarity and impact of robotic actions by amplifying specific movements, making them more engaging and easily understood. The application of exaggeration varies depending on the robot's purpose or the context of interaction. For example, in tasks requiring instructional precision, such as demonstrating slow and deliberate movements in a laboratory setting, a robot might exaggerate its motions by significantly slowing its timing and incorporating pronounced slow in and slow out transitions. These techniques emphasize caution and accuracy, creating a sense of careful intent. Conversely, in playful or social scenarios, exaggerated gestures—such as rapid arm waves or bouncing motions—achieved through shorter timing and wider arcs can convey enthusiasm and approachability, encouraging users to interact.

This deliberate use of exaggeration differs from the stylized approach to robot movement discussed in subsection 6.4.3, where exaggeration is often applied for dramatic or comedic purposes. Instead, here it serves as a functional tool to improve the clarity and effectiveness of robot interactions, ensuring that movements not only fulfill their practical purposes but also resonate emotionally and intuitively with users.

6.6 Conclusion

The human tendency to anthropomorphise even the simplest of moving shapes and machines along various channels of social expression (Heider & Simmel, 1944) means that how a robot moves can dramatically affect the perception of a robot's role, personality, and interactive capabilities. Despite this fact, social robots today still exhibit slow, crude, janky, and unnatural bodily movements as a result of pragmatic and mimetic approaches in social robot movement design, which still place a larger emphasis on the concerns of functionality and efficiency over the meaning and perception behind the movement. If social robots are to become a part of our everyday living, it is important that we design robots with movements that best express the robot's purpose, intent, state, mood, personality, attention, responsiveness, intelligence, and capabilities (Hoffman & Ju, 2014).

The stylised approach to social robot movement, while holding significant promise in addressing various concerns, is intricately linked to tacit knowledge deeply embedded within certain fields. This chapter offers a concise overview of the fundamental concepts and principles from the discipline of animation, which are critical to this approach. However, it is imperative that roboticists collaborate closely with experts from these disciplines, who possess specialist skills in conveying meaning and emotion through physical, embodied gestures. Such collaboration is crucial because the way people interpret and understand movement profoundly influences their interaction with their environment. The expertise of animators and other specialists in gestural expression can provide invaluable insights into how movements can be perceived as expressive, meaningful, or even empathetic. This understanding is not just theoretical but experiential and intuitive, developed through years of practice and reflection in their respective fields.

As a result, while roboticists can gain a foundational understanding of how to achieve somewhat effective movement in the embodied medium of social robots, the nuanced application of these principles requires a deeper engagement with the tacit knowledge that animators hold. This involves not just the mechanical replication of movements but understanding the subtleties of how movements can convey character, emotions, intentions, and personality. By working alongside these experts, roboticists can learn to create social robots that not only perform functional tasks but also interact with humans in a manner that is naturally intuitive and emotionally resonant. This can lead to a new level of sophistication in social robot design, where robots are not just tools but entities that can engage with humans on a more personal and emotional level, enhancing the overall quality of human-robot interactions.

The next chapter will focus on deepening the integration of social robot movement design using the principles of animation. It will introduce a movement design framework that carefully considers the nuances, context, and emotional depth of human communication, while also considering the specific characteristics and abilities of a social robot's form. This framework is geared towards directing emotional expression through the physical embodiment of a social robot, aiming to create more nuanced and emotionally resonant interactions.

Chapter 7: The LMA12-O Framework for Emotional Robot Eye Gestures

7.1 Introduction

Humans are experts in human social interaction and if technology adheres to human social expectations, then people are more likely to find the interaction enjoyable, feel empowered, and feel competent (Reeves & Nass, 1996). As a result, social robots are increasingly incorporating interfaces that mimic human facial features in order to establish agency, personality traits and communicate intent (Kalegina et al., 2018). Of those incorporated facial features, the eyes play a significant role in how social robots are perceived by humans. With up to 43.4% of human attention during social interactions explicitly devoted to the eyes (Janik et al., 1978), the eyes have the ability to communicate much about an individual's emotional state (Ekman & Friesen, 1975).

In order to achieve expressive robot eye gestures and bypass the current technical challenges of mechanically actuated eyes, a large number of social robots feature anthropomorphised eyes that are rendered on a screen (Kalegina et al., 2018). This has enabled flexibility in the design and animation of eye gestures ranging from the more human-like, such as FURo-D (Figure *100* – left), the iconic, such as Zenbo (Figure *100* – middle), and abstract, such as JIBO (Figure *100* – right). However, despite the creative freedom and the potential emotional expression these screens have provided, we argue that to date there has been no consistent and articulate system for designing affective emotional eye gestures in anthropomorphised social robots. As a result, many roboticists look towards replicating human eye movements such as attentional eye gaze, saccades, blinking frequency and emotional eye poses (Ruhland et al., 2015). However, this approach overlooks the fact that robots are not biologically built in the same way as humans and do not possess the same intricacy of human facial expressiveness. The mismatch between the anthropomorphised appearance of robots and realistic human-like eye movements creates eye gestures that often fail to effectively communicate emotional intent.

Figure 100. Furo-D (left – Robots.nu, 2017), Zenbo (middle – ASUS 2016), and JIBO (right – JIBO Inc, 2016) are robots with screen faces that allow for creative freedom in its visual designs.

To realise the full emotional and expressive capabilities of an anthropomorphised social robot's eyes, we propose that it is the design of the eye gestures themselves, the manner in which the eye moves from one position to the next, that plays a key role in expressing emotional intent. The prototype system we have designed challenges robot eye gesture systems based on realistic human eye movement and creates a consistent and articulate system that increases the expressive communication potential of a robot's eyes.

7.2 Background

This study incorporated an interdisciplinary research team of computer scientists and professional animators with the aim of devising a unique, articulate, and transferable framework for maximising the potential of affective emotional expression in robot eye gestures. It combines research findings from a range of disciplines – oculesics (O), Laban Movement Analysis (LMA) and The Twelve Principles of Animation (12PA) – in order to create the unique prototype framework LMA12-O. The following section briefly describes the premise of each discipline's component of study and their application to the field of robotics.

7.2.1 Oculesics

Oculesics, an interdisciplinary field of study focusing on eye gestures within human communication, integrates perspectives from psychology, neuroscience, and the social sciences. This field plays a crucial role in understanding how subtle variations in eye movements, eyelid positions, and gaze direction contribute to non-verbal communication, particularly in expressing emotions (Sullivan, 2009). By analysing these nuances, oculesics provides a comprehensive framework for designing eye gesture systems in robots. The understanding derived from oculesics is crucial for developing robotic eyes that effectively mimic the intricate and nuanced expressions of human eyes, a concept detailed earlier in subsection 6.4.2. For instance, in human interactions, a slight change in eye contact duration or the frequency of blinking can convey a range of emotions, from interest and agreement to discomfort or deceit. Similarly, the direction and intensity of the gaze can indicate focus, curiosity, or social cues like acknowledgment and invitation (Kendon, 2004; Langton et al., 2000; Murch, 2001).

A comprehensive literature review by Ruhland et al. (2015) details various robot eye gesture models used in social robots. These models encompass a diverse array of both high and low-level considerations. The low-level elements of eye animation include saccades (quick, simultaneous movements of both eyes in the same direction), vestibulo-ocular reflex (eye movements that stabilise images on the retina during head movement), smooth pursuit (the eyes' ability to smoothly follow a moving object), vergence (simultaneous movement of both eyes in opposite directions to obtain or maintain single binocular vision), eyelid movement, pupil dilation and contraction, and combined eye-head movements. On the other hand, the high-level aspects of eye gesture behaviour focus on using the eyes to initiate interactions and direct attention, thereby mediating conversations. This includes shared attention and gaze cueing, which are pivotal in non-verbal communication and social bonding. Additionally, these high-level models enable robots to indicate thought processes and express a range of emotions through eye movements, further enhancing their interactive capabilities. These comprehensive models aim to closely replicate the complex movements and expressions of human eyes. By doing so, they significantly improve the ability of robots to engage in natural, intuitive non-verbal communication. The integration of oculesics into social robots plays a crucial role in making their interactions more relatable and human-like, thereby enhancing the overall effectiveness of human-robot interaction.

Despite the extensive physiological data provided by oculesics, models based solely on this discipline often fall short in practical application, largely due to the uncanny valley effect (Mori, 1970) as explored previously in subsection 6.4.2. This effect arises when the direct translation of human movements to robotic mediums results in a somewhat eerie or unsettling appearance. For instance, an anthropomorphic robot mimicking the blinking frequency of a normal human may appear unnatural or nonsensical (Murch, 2001). This issue stems from the fact that the human eye is composed of numerous intricate muscles, a level of complexity that is difficult to replicate in the simplified designs of anthropomorphic, abstract, and sometimes even hyper-realistic robotic eyes. The discrepancy between the detailed nature of human eyes and the limitations of robotic eye designs highlights the need for a more guided and nuanced approach to the translation and abstraction of eye movements for social robots. This approach must consider not only the physiological aspects of human eye movements but also the constraints and capabilities of robotic systems, striving to achieve a balance that avoids the uncanny valley while still conveying realistic and relatable expressions. This necessitates a framework that can adapt human eye gestures to the unique context of robotics, ensuring that these gestures are both technically feasible and emotionally effective.

7.2.2 Twelve Principles of Animation

Rooted in a rich history spanning 140 years, animation has continually focused on the depiction of emotional body gestures in physical mediums. This vast experience has culminated in the formulation of The Twelve Principles of Animation (12PA) and was explored extensively in Section 6.5. Formally articulated by Disney animators Ollie Johnston and Frank Thomas in their seminal 1981 book, The Illusion of Life, and later revised in the 1995 edition, the 12PA distil key insights from the field of animation and serve as a foundational framework within the discipline.

These principles provide a qualitative and adaptable framework, aligning with the fundamental laws of physics while also addressing more abstract aspects such as design, emotional timing, and character appeal (Ribeiro & Paiva, 2020). The 12PA are instrumental in guiding animators to create movements that are not only physically plausible but also emotionally resonant and visually appealing. This framework offers a valuable resource for translating the nuances of animated gestures into other mediums, such as social robotics, where the portrayal of emotion and character is important for affective human-robot interaction.

The Twelve Principles of Animation (12PA) have seen only limited application in the development of emotional eye gestures in social robotics. The systematic literature review of animation techniques in human-robot interaction (HRI) by Schulz et al. (2019) indicates that the use of the 12PA in this field has been either limited or applied in isolation. A major factor contributing to the limited use of the 12PA is that it predominantly consists of tacit knowledge (Argyris & Schon, 1974; Hooks, 2017; Schön, 1983, 1987, 1995; Thomas & Johnston, 1995), which animators develop through hands-on experience and reflective practice. This type of knowledge, as discussed in subsection 6.4.3, is inherently challenging to transfer to disciplines outside of animation due to its implicit and experiential nature.

This challenge of transferring such experiential knowledge to the domain of social robotics significantly hampers the broader application of the 12PA. Given their potential in enhancing emotional expression, the development a consistent framework for applying the 12PA in social robotics could be highly beneficial. Such a framework would provide structured guidance on integrating these principles into robot design, helping to bridge the gap between the art of animation and the science of robotics. This would enable the creation of social robots with more nuanced, expressive, and emotionally resonant gestures, particularly in the context of eye movements.

7.2.3 Laban Movement Analysis

Laban Movement Analysis (LMA) is an intricate framework that meticulously dissects the core elements of movement patterns that was conceptualised in the 1920s by Rudolf Laban, a distinguished Hungarian dance artist and theorist. Laban, in collaboration with his students and associates, developed this framework into a refined and adaptable movement language. LMA provides a structured and measurable method for describing human body movements, with a particular emphasis on those expressing emotion. This framework utilises a well-defined language for the documentation, visualisation, and interpretation of movements driven by emotional motivation (Bishko, 2014b; Knight & Simmons, 2014, 2015; Laban & Lange, 1975).

A pivotal strength of Laban Movement Analysis (LMA) lies in its graphical representation of movement similar to musical notation (as portrayed in Figure *101*), which plays a crucial role in discerning and analysing the patterns, constellations, and rhythms inherent in movement phrasing (Guest, 2013). LMA achieves this through a detailed set of parameters that extensively outline both the form and execution of bodily movements. These parameters are organised into four primary categories, known as the Four Laban Categories of Movement: body, space, shape, and effort. Each category offers a unique lens for examining different facets of movement, thereby providing a comprehensive, multi-dimensional perspective. The upcoming section will offer a concise description of these four Laban categories, shedding light on their individual contribution to the analysis and understanding of movement, and by extension, their application in fields such as dance, therapy, and human-robot interaction.

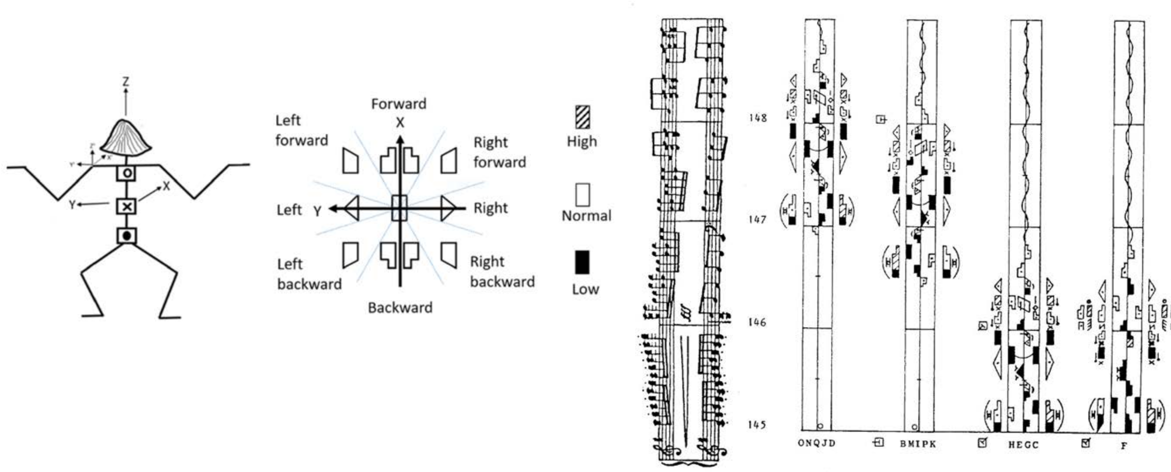

Figure 101. Laban notation which features a notation language similar to music notation (Guest, 2013).

7.2.3.1 Body

The body category in Laban Movement Analysis delves into the structural elements of bodily motion, focusing on how the body moves as a cohesive unit (Bishko, 2014b; Knight & Simmons, 2014, 2015; Laban & Lange, 1975). It scrutinises which body parts are active or stationary, the way movement flows from one part to another, how the body's kinetic chains are organised and coordinated, and the postural habits influencing gestural expression. This category essentially addresses the functional and biomechanical aspects of movement.

Within the body category, specific parameters are employed to evaluate the ease and fluidity present in the body during movement. These parameters are critical in understanding how the body functions as a conduit for genuine expression. In essence, the body acts as the physical embodiment of internal states or intentions. By analysing movement through this lens, one gains a comprehensive understanding of how physical actions are both constructed and perceived.

Consider the same example of a human performing a jump. The body category would examine how the legs initiate and drive the movement, the role of the arms in balancing or adding momentum, the spinal alignment during the jump, and how the feet position themselves for landing. It would also assess the fluidity and coordination of these actions, providing insight into the efficiency and expressiveness of the jump as a whole. This analysis offers a deeper appreciation of the body's role in conveying intent and emotion through movement.

7.2.3.2 Effort

Effort, in Laban Movement Analysis, reflects the inner attitude expressed through movement, describing the dynamic qualities of how energy is utilised in motion (Bishko, 2014b; Knight & Simmons, 2014, 2015; Laban & Lange, 1975). This category comprises four factors: weight, space, time, and flow, each exhibiting qualities that fluctuate along a continuum. Qualities like light, indirect, sustained, and free are considered indulgent or accepting, whereas strong, direct, sudden, and bound are seen as resisting or fighting.

Weight relates to how one senses and adjusts to gravity, defining the force needed to move a body part as either heavy or light. Light movements are executed effortlessly, while heavy movements require significant force.

Space concerns spatial awareness and orientation. It reflects how a person interacts with the space around them, indicating movement intention. Movements can be direct, aiming for a target in a linear fashion, or indirect, which are more unfocused and flexible.

Time pertains to the timing of an action, measuring the duration of a movement as either sudden or sustained. Sudden movements are quick and abrupt, while sustained movements are gradual and prolonged.

Flow assesses the level of control in a movement, categorising movements as either bound or free. Bound movements, performed close to the body, offer greater control and precision, whereas free movements, executed further from the body, allow for more expansive actions.

For example, in the act of jumping, the *effort* factors play a crucial role. The *weight* factor is evident in the force used to push off the ground (heavy) and land softly (light). The *space* factor is observed in the direct path the body takes as it moves upwards. The *time* factor is seen in the sudden exertion of the jump and the sustained descent. Finally, the *flow* factor can be seen in the controlled, bound nature of the movement as the body maintains balance and coordination throughout the jump.

7.2.3.3 Space

Laban Movement Analysis closely examines how movement interacts with and is influenced by the spatial environment (Bishko, 2014b; Knight & Simmons, 2014, 2015; Laban & Lange, 1975). The space category specifically focuses on the mover's engagement with their three-dimensional surroundings, encompassing spatial dynamics such as pulls and counter-tensions that either stabilise or mobilise the body.

Central to this category is the concept of the kinesphere, defined as the reach space or the area within which the body can move. This spatial range is not fixed; rather, it varies based on the individual's movements. Laban observed that individuals create complex spatial patterns in their movements. These patterns can be one-dimensional, two-dimensional (planar), or three-dimensional, often taking the form of various polyhedral shapes like octahedrons, cubes, icosahedrons, and dodecahedrons.

This geometrical aspect of Laban Movement Analysis is fundamental to Laban's philosophy that inner intention and emotions are expressed through a reciprocal relationship between the self and the environment, facilitated by movement (Bishko, 2014b, 2014a). For example, a dancer might extend their arms outward, expanding their kinesphere and engaging with the space in a way that expresses openness or dominance. Conversely, a more contained movement, with limbs close to the body, might convey introspection or reservation, reflecting a different spatial relationship and intention.

In essence, the space category in Laban Movement Analysis provides a lens to understand how movements are not just confined to the body but extend into and interact with the surrounding space, reflecting deeper aspects of the individual's intentions and emotional states.

7.2.3.4 Shape

The shape category in Laban Movement Analysis focuses on the transformation of the body's shape over time, both in relation to the individual and their interaction with the environment. This category examines how body shapes evolve, reflecting the individual's feelings about themselves and their relationship with their surroundings (Bishko, 2014b; Knight & Simmons, 2014, 2015; Laban & Lange, 1975).

Shape change can begin internally, with adjustments in the body's own structure, such as shifting inner volumes or transitioning from one shape to another. These internal shifts often express the individual's feelings or attitudes about themselves. Alternatively, shape change can occur in response to the environment, with the body's form moulding to reflect the individual's attitude or relationship to their surroundings.

In motion, the body is in a constant state of flux, either opening up through extension or closing in through flexion. The ongoing process of these shape changes forms a pattern of either opening or closing, creating a directional relationship with the environment. This interaction can manifest in various ways, such as rising and sinking, which relate to vertical shifts, spreading and enclosing, which involve expansion or contraction, and advancing and retreating that indicate forward or backward movements.

For instance, in a dance performance, a dancer might exhibit shape changes that convey specific emotions or tell a story. A dancer opening their arms wide and lifting their face upwards could be expressing joy or openness (spreading and rising), whereas a dancer curling inward with arms crossed might indicate sadness or defensiveness (enclosing and sinking). These shape changes are not just physical movements but are expressive tools that communicate an array of emotions and intentions, deeply intertwined with the individual's interaction with their environment.

Laban Movement Analysis has proven to be immensely valuable, transcending its initial applications in dance to contribute to diverse fields such as cognitive science, psychoanalysis, athletics, and performing arts and has also started to see application in the field of human-robot interaction to enhance the emotional expressiveness of basic, arbitrary robot body movements (Burton et al., 2016; Knight & Simmons, 2014, 2015; Rett, 2009; Samadani et al., 2013, 2013). These applications have predominantly been in the context of humanoid robots. However, there have been limited instances where LMA has been utilised for non-humanoid robotic forms, and even fewer where the methods have been communicated in a manner that is easily transferable to other contexts or robot designs. Notably, to the best of our knowledge, there are no existing studies that have specifically applied LMA to the development or refinement of eye gestures in robots. This represents a significant gap in the research, considering the potential for LMA to contribute to more nuanced and emotionally resonant eye movements in social robots.

7.2.4 Analysing Oculesics, 12PA and LMA

In analysing the disciplines of oculesics, The Twelve Principles of Animation (12PA), and Laban Movement Analysis (LMA), it becomes clear that each framework is not wholly sufficient in isolation for the comprehensive development of emotionally motivated eye gestures in robotics. Oculesics, aiming for realism by mimicking human-like eye movements, often overlooks the crucial translation process required when applying human-like movements to robots. This gap can lead to issues related to the Uncanny Valley, where robots with overly human-like features can be perceived as unsettling. The 12PA, while offering a stylistic approach to movements suitable for the embodied design of a social robot, faces limitations due to its basis in tacit knowledge. Therefore, applying these principles in robotics can be challenging, as roboticists often requires more measurable and concrete directives. Conversely, LMA offers specific quantitative measures for movements to attain particular effects. However, its application in social robotics has largely been limited to humanoid robots. This is primarily because LMA's most common use cases have traditionally been in dance and acting, where the focus is on the full range of human bodily movements.

However, the strengths of these fields lie in their areas of intersection and overlap. By integrating the insights and methodologies from each of these disciplines, a more effective and systematic approach can be formulated for communicating a robot's emotional intent through meticulously designed eye gestures. This combined approach can potentially address the limitations of each individual framework, leading to more nuanced and expressive interactions in social robotics. The following section will detail the research process that led to the development of the LMA12-O framework, showcasing how the integration of these diverse yet complementary fields can enhance the design and functionality of robotic eye gestures.

7.3 Methodology

This study introduces a novel methodology that synthesises the principles of oculesics, Laban Movement Analysis (LMA), and The Twelve Principles of Animation (12PA) into a unified prototype framework, termed LMA12-O. The primary objective of LMA12-O is to establish systematic guidelines for crafting emotionally motivated eye gestures in anthropomorphised social robots. This is achieved by:

- Utilising the oculesics framework to define the embodied eye's core movement capabilities for expressing emotional intent.

- Applying the qualitative framework of 12PA to enhance eye movement capabilities by applying specific principles of movement that enhance the perception of emotional expression.
- Incorporating the quantitative framework of LMA to define how and where the eye should move to achieve specific displays of emotional intent.

Figure 102. The Haru Social Robot.

To evaluate the effectiveness of the LMA12-O framework, this study used Haru (as portrayed in Figure *102*), a table-top social robot with screen-rendered eyes, as its research platform (Gomez et al., 2018). Haru's design is particularly limited in expressing emotional body gestures, which makes it an ideal candidate for this study, as its primary mode of emotional communication is through its eyes. The selection of Haru was strategic due to its conventional eye design, which allows for the findings and applications derived from this study to be easily translated to other anthropomorphised robot eye designs. This focus on Haru's eye expressions provided a clear and specific context to test and demonstrate the practical application and impact of the LMA12-O framework in enhancing the robot's capability to convey emotions more effectively and naturally through eye gestures.

7.3.1 Defining Eye Movement Capabilities Using Oculesics

The initial phase of implementing the LMA12-O framework involved defining the movement capabilities of the robot's eyes. Drawing from the principles outlined in oculesics literature, the core movement capabilities essential for conveying emotional eye gestures were identified. This step was crucial as it helped to constrain the potentially limitless range of movements possible with a screen-rendered eye, setting specific and consistent movement parameters.

To practically implement these capabilities, 3D animation software was utilised to construct and rig the eyes. Rigging is a process where movement capabilities are not only defined but also assigned measurable and manipulable values. This approach ensures that each eye movement is both controlled and replicable, essential for consistent emotional expression.

The movement capabilities were then articulated as variables, each with arguments that describe the extent and purpose of each movement. Importantly, the values assigned to these movements are represented as percentages of a potential movement, rather than fixed, absolute values. This is because the actual range of motion and the specific values would vary depending on the particular robotic platform the framework is applied to, such as the motion range of Haru's screen-rendered eyes. This flexible approach allows for the LMA12-O framework to be adapted to different robot models with varying eye design and movement capabilities.

The following subsections will briefly outline the core movement capabilities essential for conveying emotional eye gestures.

7.3.1.1 Eye Movement

Movement, particularly in the context of eye gestures, is fundamental to human interaction as it enables others to discern the direction of one’s gaze. This aspect of communication is facilitated by human physiological features, notably the distinct contrast between the white sclera and the dark pupil. Factors like the location to which someone directs their gaze, the speed of their eye movements, and the duration for which they hold their gaze in a particular position, provide important cues about their emotional intent (Argyle & Dean, 1965).

For instance, intense and prolonged eye contact can often be perceived as an expression of anger. This is because in many social contexts, holding someone's gaze for an extended period can be seen as confrontational or aggressive. Conversely, frequently averted gaze might be interpreted as a sign of distraction, discomfort, submissiveness, or even dishonesty, as averted eyes are often associated with lying in some cultural contexts. Understanding these nuanced connotations of eye movements is crucial in replicating human-like emotional expressions in social robots. By incorporating these subtleties into a robot's eye movements, it becomes possible to create more natural, intuitive, and emotionally resonant interactions.

In defining the movement capabilities for the robot's eyes in this study, a specific variable structure was used: *eyeMovement(x1, y1, x2, y2, t)*. Here, the arguments within this variable play distinct roles in determining the eye's motion:

- *(x1, y1)* represent the starting positional coordinates of the eye. These coordinates determine the initial point from which the eye movement will commence.
- *(x2, y2)* are the ending positional coordinates, indicating where the eye movement will conclude. This defines the final point in the eye's trajectory.
- t stands for the time required for the eye to move from the start position *(x1, y1)* to the end position *(x2, y2)*. This parameter is crucial as it controls the speed of the eye movement, which can significantly impact the perception of emotional intent.

Figure *103* provides a visual representation of this variable, illustrating how these coordinates and time factors are utilised to create specific eye movements.

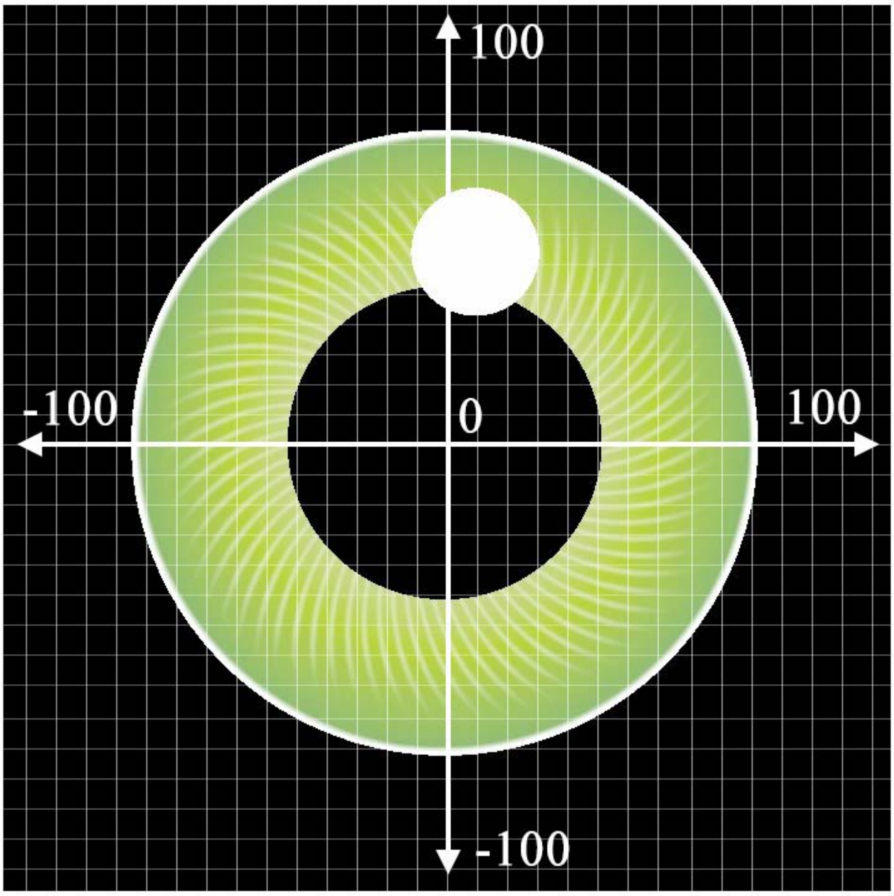

Figure 103. Visualisation of the eye movement parameter.

7.3.1.2 Pupil Size

The size of the pupil, which is controlled by the body's autonomic nervous system, plays a significant role in non-verbal communication, particularly in conveying emotional states. Human physiology facilitates this interaction through the expansion and contraction of the pupil in response to various stimuli and emotional conditions. The dynamics of pupil size and the rate at which it changes can provide insightful cues about a person's emotional state (Hess, 1965).

For instance, a rapid contraction of the pupil can indicate surprise. This is because pupil size can react reflexively to sudden changes in light, but also to emotional responses. Similarly, pupil dilation is often associated with increased interest or arousal; the pupils may dilate in response to something that the individual finds emotionally stimulating or engaging (Hess, 1965).

The movement capabilities for the eye's pupils were defined using the variable: *pupilSize(p1, p2, t)*. The arguments for this variable are as follows:

- p*1* refers to the starting size of the pupil, establishing the initial diameter before any change.
- *p2* is the ending size of the pupil, indicating how much the pupil will expand or contract.
- *t* represents the time taken for the pupil to change from its starting size *p1* to its ending size *p2*.

Figure *104* provides a visualisation of this variable, demonstrating the application of these parameters in simulating pupil size changes.

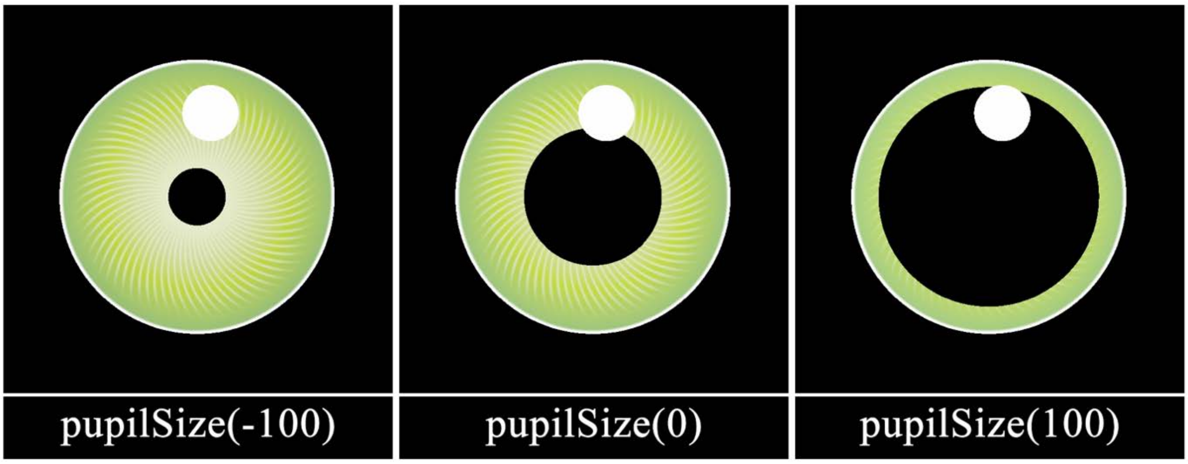

Figure 104. Visualisation of the eye pupil parameter.

7.3.1.3 Eye Shape

The shape of the eye is significantly influenced by the intensity of a person's emotional state. Human physiology facilitates this form of non-verbal communication through the tensing or relaxing of the muscles surrounding the eyes, leading to various eye shapes. The degree of muscle tension and the duration for which these muscles are held in a particular state can provide important cues about a person's emotional intent. For instance, when the facial muscles around the eyes lack tension, it can lead to a drooping eye shape, which is often associated with sadness. This understanding of how eye shape correlates with emotions is pivotal in replicating human-like expressions in social robots, enabling them to convey emotions more effectively through subtle changes in eye shape (James, 1922; Kret, 2015; Murube, 2009).

The movement capabilities for the eye's shape were defined using the variable: *eyeLidCurve(e1, e2, t)*. The arguments for this variable are structured as follows:

- *e1* refers to the starting position of the eyelid, indicating its initial curvature or opening.
- *e2* is the ending position of the eyelid, showing how much the eyelid will move, altering the eye's shape.
- *t* represents the time it takes for the eyelid to transition from its starting position e1 to its end position *e2*.

Figure *105* offers a visualisation of this variable, illustrating the range and dynamics of eyelid movements used to simulate different eye shapes.

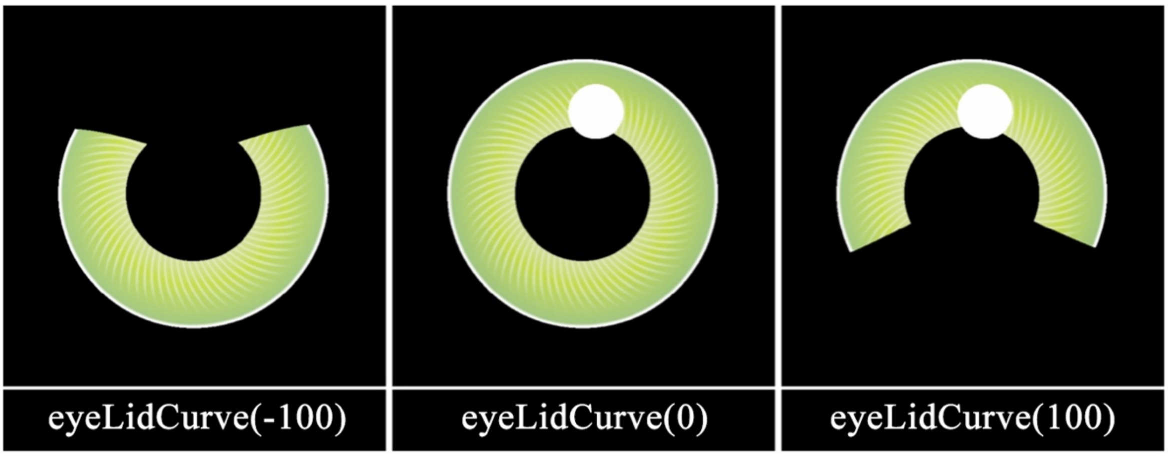

Figure 105. Visualisation of the eye lid curve parameter.

7.3.1.4 Blinking

The act of blinking is a key indicator of emotional processing. This physiological response involves the periodic raising and lowering of the top and bottom eyelids. The characteristics of blinking, such as the speed at which it is executed, the duration of each blink, and the frequency or variability in blinking patterns, are indicative of emotional states (Stern et al., 1994). For instance, a quick succession of three blinks within a short timeframe can signal surprise. Understanding these nuances in blinking patterns is essential for interpreting emotional cues and can provide valuable insights into a person's feelings and reactions.

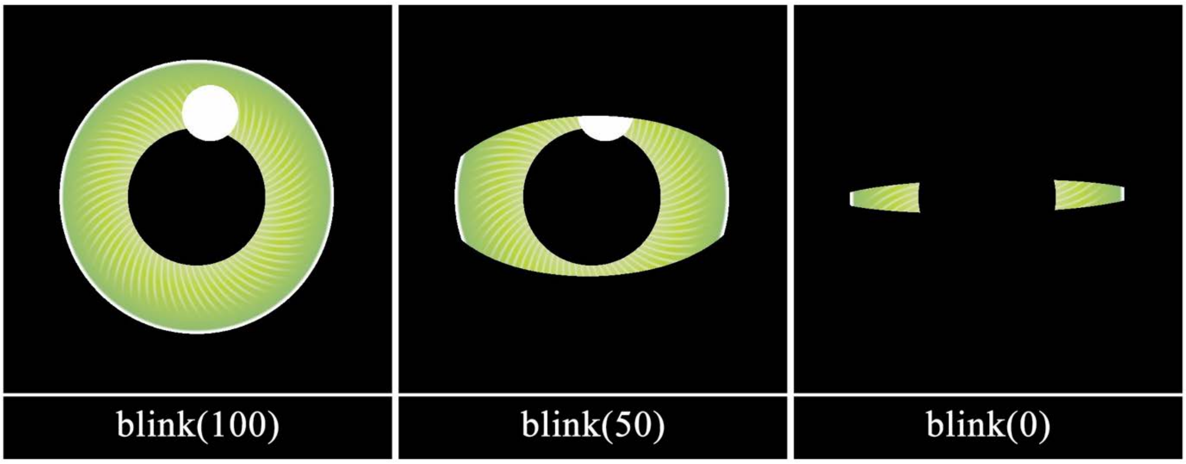

Figure 106. Visualisation of the blink parameter.

The movement capabilities for blinking were defined using the variable: *blink(b1, b2, t)*. The components of this variable are as follows:

- *b1* refers to the starting position of the blink. This position indicates the initial state of the eyelids before the blink begins.
- *b2* denotes the ending position of the blink, determining how the eyelids will be positioned at the end of the blinking motion.
- *t* represents the time it takes for the blink to occur, from the starting position *b1* to the ending position *b2*.

Figure *106* offers a visualisation of this variable, illustrating how the parameters are used to simulate the blinking action.

7.3.2 Applying 12PA to the Existing Eye Movement Capabilities

As noted in subsection 7.2.4, relying solely on oculesics is insufficient for effectively translating emotional human eye gestures to more simplified designs of anthropomorphic and abstract robot eyes. This is primarily due to the intrinsic differences between the complex movements of human eyes and the mechanical constraints of robotic eyes. However, The Twelve Principles of Animation (12PA) framework excels in adapting real-world observed movements to inorganic mediums, such as animations or robotic movements.

Based on this understanding, it was hypothesised that integrating 12PA with oculesics could yield an embodied eye in a robot that is capable of expressing a wide range of nuanced emotional gestures, perceptible and relatable to humans. This combination aims to leverage the strengths of both frameworks: the detailed study of human eye behaviour in oculesics and 12PA's expertise in adapting these behaviours as expressive movements for non-organic forms. The resulting synergy is expected to enhance the robot's ability to communicate emotionally through eye gestures, providing a richer and more diverse set of expressive possibilities.

The initial phase of applying the LMA12-O framework involved simplifying The Twelve Principles of Animation (12PA), as not all principles are necessary for creating affective eye gestures. Notable principles were intentionally omitted as they were less relevant or already integrated into the framework's design. Notably, the principle of secondary action was excluded. This principle typically pertains to movements that occur in conjunction with other body parts, which is less applicable in the context of focusing solely on eye gestures in robots. In addition, the principles of straight-ahead action and pose-to-pose were not included. These principles refer specifically to methods of animation which is what the LMA12-O framework inherently incorporates through its structured approach to designing and animating eye gestures.

The focus was on selecting a subset of principles that are specifically relevant to movement, to enhance the expressiveness of the robot's eye gestures. The chosen principles included:

- Squash and Stretch
- Arcs
- Staging
- Slow In/Slow Out
- Anticipation
- Follow-Through and Overlap
- Timing
- Exaggeration

The selected principles from The Twelve Principles of Animation (12PA) were then incorporated as additional movement capabilities and arguments in the design of the eye rig. This integration aimed at enriching the core movements underlying eye gestures, enhancing their potential to be more perceptually expressive and emotionally affective. Table *1* presents a comprehensive summary of all the manipulable parameters resulting from the integration of the 12PA.

The following section provides an overview of how the combined application of the 12PA and oculesics can enrich the range and subtlety of the eye gestures, contributing to a more nuanced and emotionally resonant robotic eye movement system.

Table 1. All manipulable parameters resulting from the integration of the 12 Principles of Animation with Oculesics.

Arguments	Definition
Eye Movement	((x1, y1), (x2, y2), t)
Pupil Size	(p1, p2, t)
Eye Lid Curve	(e1, e2, t)
Blink	(b1, b2, t)
Squash and Stretch	(sns)
Arcs	(arc)
Staging	(stg)
Slow In and Out	(sio)
Anticipation	(ant)
Follow Through and Overlap	(fto)

7.3.2.1 Squash and Stretch

The *squash and stretch* principle in animation is designed to impart a sense of weight and flexibility to objects by emphasising changes in speed and momentum. This is achieved through the deformation of objects, either by elongating or compressing them. In the context of designing the eye rig, this principle was incorporated to enhance the expressiveness of the eye's movements.

The movement capability for the eye's squash and stretch was defined using the variable: *squashAndStretch(sns)*. Figure *107* provides a visualisation of this variable, illustrating how the squash and stretch parameter is used to elongate or compress the eye shape. The values of this variable determine the squash and stretch of the eye’s shape:

- *(sns=0)* indicates minimal deformation in the eye's movements, meaning the eyes retain their shape without significant elongation or compression.
- *(sns=100)* represents a large amount of deformation, allowing for more exaggerated changes in the eye's shape, thereby providing a greater sense of dynamism and expressiveness.

This variable allows for a range of deformation, from subtle to highly exaggerated, enabling the eyes to convey a wide array of emotional expressions and intensities. The application of the *squash and stretch* principle to the eyes enhances their ability to mimic the nuances of human-like expressions, making the interactions with the robot more engaging and lifelike.

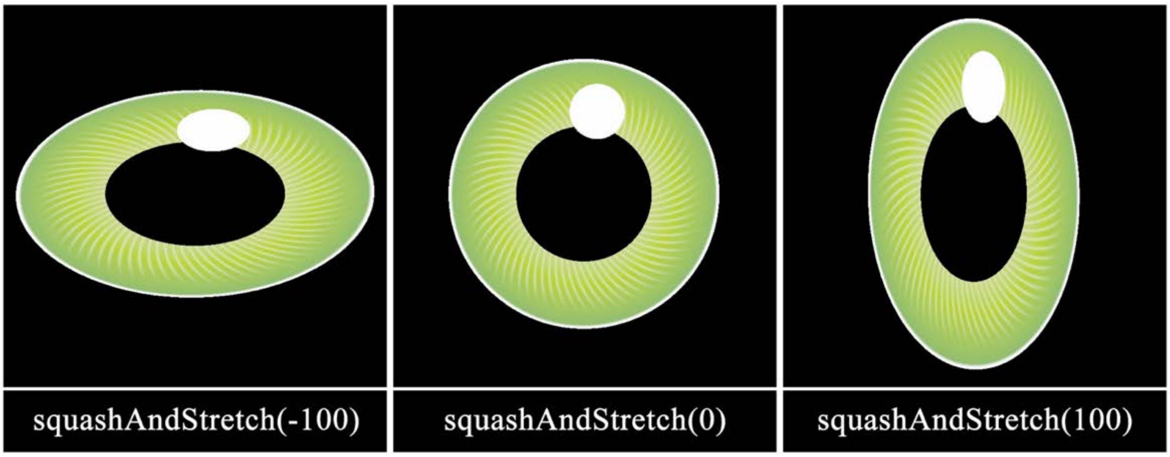

Figure 107. Visualisation of the squash and stretch parameter.

7.3.2.2 Arcs

The Arc principle is based on the observation that most organic life moves in an arched trajectory, contributing to natural and lifelike movement. In the context of robotic eye movements, this principle is utilised to add a curved trajectory, enhancing the fluidity and natural feel of eye gestures. The Arc principle functions as an additional argument within the Eye Movement variable, modifying the path along which the eye moves from its start position to its end position.

The movement capabilities for the eye's arc were defined using the variable: *arc(arc).* Figure *108* provides a visualisation of this variable, illustrating how the arc parameter is used to determine the curvature of the eye’s movement path. The values of this variable determine the curvature of the eye's movement path:

- *(arc=-100)* indicates a deep upward curvature of the eye's movement path.

- *(arc=0)* signifies no curvature in the eye's movement path, resulting in a straight-line movement.
- *(arc=100)* indicates a deep low downward curvature of the eye's movement path.

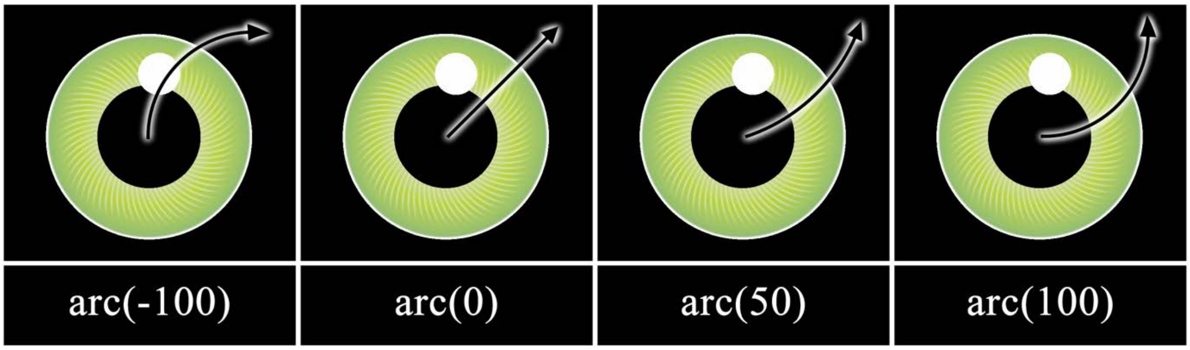

Figure 108. Visualisation of the arc parameter.

7.3.2.3 Staging

The *staging* principle in animation is about presenting a movement in a way that its intention is unmistakably clear. This can be achieved through various means, such as the pose and placement of a character, the use of light and shadow, or the angle and position of elements within a scene. In the context of robotic eye movement, the *staging* principle is applied to define the extent to which the eye can move within a defined space.

The movement capabilities for the eye's staging were defined using the variable: *staging(stg)*. Figure *109* provides a visualisation of this variable, illustrating the space in which the eye has to move within a set defined space. This variable determines the range of movement allowed for the eye:

- *(stg=0)* implies a restriction in the space within which the eye can move. This setting limits the eye's range of motion, making the movements more confined.
- *(stg=100)* indicates that there are no restrictions on the eye's range or frequency of movements. The eye is free to move extensively within the available space, allowing for a wide range of expressive gestures.

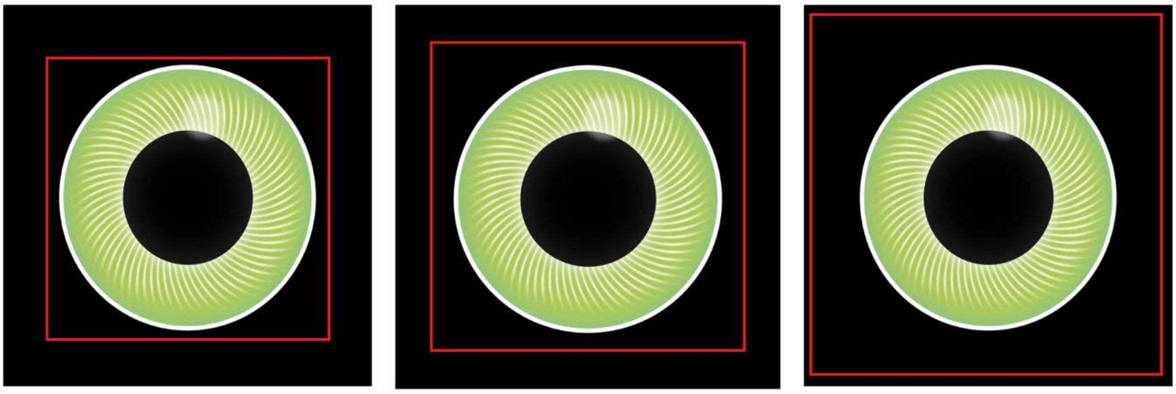

Figure 109. Visualisation of the staging parameter.

7.3.2.4 Slow In/Out

The Slow In/Slow Out principle in animation is centred on replicating the natural variation in acceleration and deceleration observed in organic movement. This principle adds a sense of realism to movement by gradually easing into or out of movement trajectories, avoiding uniformly paced motions that can appear mechanical.

In the context of robotic eye movements, the Slow In/Slow Out principle was applied to modulate how the eye eases into or out of its movement trajectory. Adjusting the slowInAndOut parameter allows for a finer simulation of the natural variances in speed typical of human eye movements, contributing to the overall lifelike quality of the robot's eye gestures. Figure *110* provides a visual representation of how different values of the sio parameter affect the pacing and fluidity of the eye's movement. The movement capabilities for this aspect of the eye's motion were defined using the variable: *slowInAndOut(sio).* This variable determines the pacing of the eye's movement:

- *sio=-100* defines eye movement that significantly slows into its main movement trajectory.
- *sio=0* sets the eye movement to a linear motion, meaning the eye moves at a constant speed from start to finish, without easing in or out.

- *sio=100* defines eye movement that significantly slows out of its main movement trajectory.

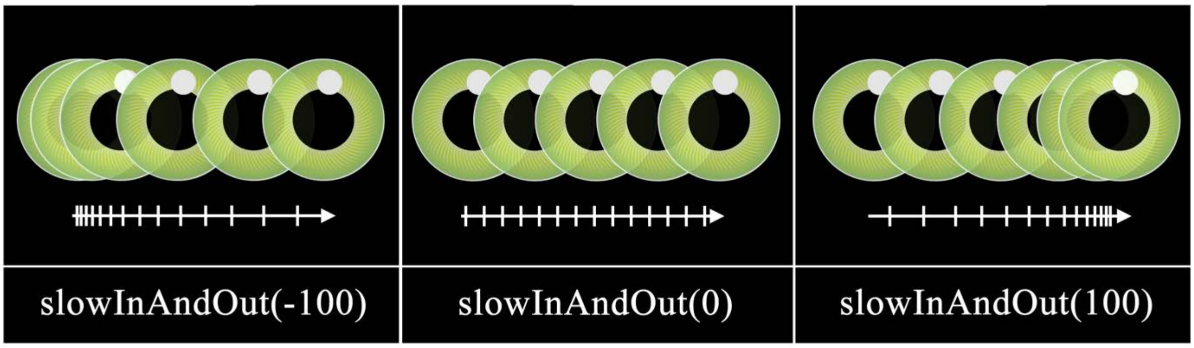

Figure 110. Visualisation of the slow in and slow out parameter.

7.3.2.5 Anticipation

The Anticipation principle in animation is crucial for conveying a character's intention before the main action occurs, making the action clear and understandable. It typically involves a preparatory movement in the opposite direction of the main action, setting the stage for what is to come. This principle is particularly effective in telegraphing actions, enhancing the clarity and impact of the movement.

In the context of robotic eye gestures, the Anticipation principle was applied to indicate how far and for how long a preparatory movement occurs before the main eye action. The movement capabilities for the eye's anticipation were defined using the variable: *anticipation(ant).* This variable determines the extent of the anticipatory action:

- *ant=0* signifies a minimal amount of distance and time for the anticipating action. This setting results in a subtle preparatory movement, which may be more suitable for smaller, less dramatic eye gestures.
- ant=100 indicates a significant amount of distance and time for the anticipating action. This allows for a more pronounced and noticeable preparatory movement, enhancing the expressiveness and impact of the eye gesture.

Figure *111* in the study offers a visual representation illustrating the impact of different values of the anticipation *(ant)* parameter on the eye's movements. It presents Movement 1 as the anticipatory movement, preceding the main action, and Movement 2 as the intended movement trajectory. The figure also demonstrates that as the *ant* value increases, the amount of backward movement becomes more pronounced.

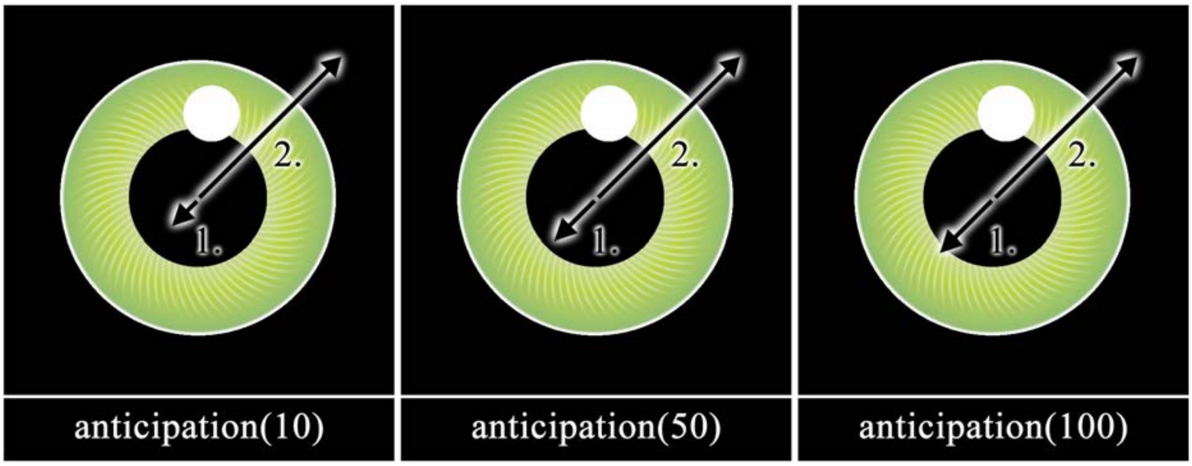

Figure 111. Visualisation of the anticipation parameter.

7.3.2.6 Follow-Through and Overlap

The Follow-Through principle in animation is designed to convey the impression that a movement is adhering to the laws of physics, particularly inertia. It does this by extending a movement slightly beyond its intended end position and then settling back to its final pose. This principle adds a sense of realism and continuity to the motion.

In the development of robotic eye gestures, the Follow-Through principle was applied to determine the extent and duration of the movement that occurs after the main action. The movement capabilities for the eye's follow-through were defined using the variable: *followThroughAndOverlap(fto)*. This variable dictates the nature of the follow-through action:

- *fto=0* signifies that the follow-through movement is of shorter length and duration. This results in a more restrained and subtle extension beyond the main movement.

- *fto=100* indicates that the follow-through movement is of longer length and duration, providing a more pronounced and extended motion past the main action.

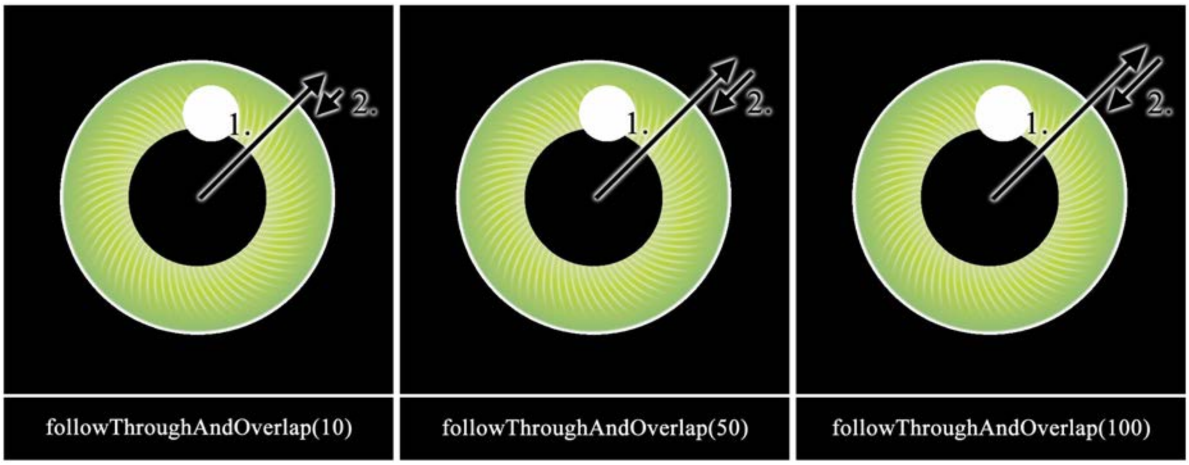

Figure 112. Visualisation of the follow-through and overlap parameter.

Figure *112* provides a clear illustration of how changing the *followThroughAndOverlap(fto)* parameter influences the eye's movements. It depicts Movement 1 as the initial movement of the eye, and Movement 2 as an extension of this motion beyond its intended endpoint before it settles into its final position. The figure also demonstrates that as the fto value increases, the displacement in Movement 2 becomes more pronounced, further extending the motion past the endpoint.

7.3.2.7 Timing

The principle of *timing* in animation plays a crucial role in defining the perceived quality of a movement. It emphasises how the duration allocated to a particular action can significantly influence its perception. For instance, an action that unfolds slowly over a longer duration might be seen as deliberate or careful, while a quicker action might be perceived as sudden or erratic. This principle is fundamental in animation because it underscores that all movements occur within the dimension of time.

In the context of robotic eye movements, the principle of *timing* is integral to every movement capability. Each eye movement defined in the framework includes a timing component, denoted as *timing(t)*. This variable determines the duration of each eye gesture, thereby influencing how the movement is perceived in terms of speed and fluidity.

Timing is an intrinsic part of each movement variable and has been implicitly present in the earlier discussion of eye movement capabilities. By carefully adjusting the timing parameter for each eye movement, a wide range of emotional expressions can be effectively communicated, from subtle and gentle to quick and intense.

7.3.2.8 Exaggeration

The principle of Exaggeration in the context of The Twelve Principles of Animation (12PA) is about amplifying certain aspects of a movement to make its essence more apparent and engaging. Exaggeration works by either intensifying or diminishing the application of each principle of animation, thereby enhancing the overall expression and readability of the action. For instance, to emphasise the slowness and sadness in a character's movement, one might exaggerate by making the movement even slower. This deliberate alteration helps to highlight the emotional state being conveyed, making it more discernible and impactful to the audience.

In the realm of robotic eye movements, the principle of Exaggeration is intrinsically woven into every movement variable. It plays a crucial role in adjusting the intensity and scale of each eye gesture, ensuring that the essence of the intended emotional expression is clear and convincing. By carefully modulating the degree of exaggeration, robotic eye gestures can range from subtle and nuanced to more pronounced and intense. This flexibility is key to enhancing the robot's ability to communicate a wide spectrum of emotions, facilitating a more dynamic and engaging interaction with human observers.

7.3.3 LMA12-O - Applying LMA to 12PA and Oculesics

As noted in Section 2 of the study, the individual use of The Twelve Principles of Animation (12PA) and oculesics presents certain limitations in providing a detailed, systematic approach for directing eye movements to convey specific emotional intentions in robotics. Each framework, while robust in their own domain, do not fully address the nuances required for creating emotionally expressive eye gestures in robots.

However, the amalgamation of Laban Movement Analysis (LMA) with 12PA and oculesics, as explored in the preceding sections, offers a promising solution. This integration can lead to the establishment of explicit, actionable guidelines for emotional robotic eye gestures. More specifically, LMA contributes its quantitative analysis, allowing for the precise measurement and replication of movements. When combined with the qualitative insights from 12PA – focused on enhancing the aesthetic and expressive quality of movements – and the emphasis of oculesics on realistic human eye behaviours, a more comprehensive and effective framework for robotic eye gestures emerges.

This synergistic approach enables the creation of a system that is not only grounded in the principles of human eye movements and animation but also adaptable to the mechanical constraints and capabilities of robots. By applying this integrated framework, roboticists can develop eye gestures that are emotionally resonant, contextually appropriate, and perceptually effective. Such a system has the potential to be transferable across different robotic platforms, allowing for a wide range of robots to engage in more nuanced, expressive, and emotionally intelligent interactions.

In adopting a method akin to the streamlining of The Twelve Principles of Animation (12PA) for eye gestures, the categories of Laban Movement Analysis (LMA) were also tailored to align with the specific requirements of robotic eye gestures more aptly. It was recognised that not all

LMA categories are directly applicable to the subtleties of eye movements, or their aspects are already encompassed within the movement capabilities outlined by oculesics and the 12PA. A key example is the LMA category of *body*, which primarily deals with which body parts are in motion. This aspect is effectively covered by the eye movement capabilities already defined by oculesics, as it pertains to the structural elements and the movement dynamics of the eyes. Similarly, the LMA category of *shape*, which focuses on how movement relates to its contextual situation, moves beyond the scope of this study.

A focused subset of Laban Movement Analysis (LMA) categories was identified for their significant impact on directing and shaping eye movements to express specific emotional intentions. The selected categories, *shape* and *effort*, and their respective sub-categories – including shape, weight, time, flow, outward, approach, and verticality – were chosen for their relevance to eye movement dynamics.

To effectively integrate these selected LMA categories with The Twelve Principles of Animation (12PA), a detailed mapping process was conducted. This involved correlating the properties of the *shape* and *effort* categories from LMA with corresponding principles from the 12PA. The mapping was based on the interrelationships between these categories and principles, as well as the equivalency of key concepts.

Table 2. A Summary of the mapping between the selected Laban Movement Analysis (LMA) categories and The Twelve Principles of Animation (12PA).

12PA	Effort				Shape		
	Space	Weight	Time	Flow	Outward	Approach	Verticality
Squash and Stretch		✓		✓			
Anticipation		✓		✓			
Staging				✓	✓	✓	✓
Follow Through		✓		✓			
Slow In/Out		✓		✓			
Arc	✓			✓			
Timing				✓			
Exaggeration	✓	✓	✓	✓	✓	✓	✓

Table *2* presents a thorough summary of the mapping between the selected Laban Movement Analysis (LMA) categories and The Twelve Principles of Animation (12PA). This table details the correlation between the properties of the *shape* and *effort* categories from LMA and the various principles from the 12PA. This mapping is instrumental in streamlining the process of designing emotionally expressive eye gestures for robots. It ensures that the movements are not only technically sound but also deeply rooted in the artistic and expressive principles of animation, as well as the detailed analysis of human movement provided by LMA. This integrated approach offers a more systematic and theoretically grounded method for developing robotic eye gestures. By aligning the movement principles from both animation and human movement analysis, the framework enhances the robot's ability to convey emotions through eye movements.

In the process of mapping the key concepts between Laban Movement Analysis (LMA) and The Twelve Principles of Animation (12PA), it was observed that certain concepts from each framework have a universal impact across all principles. Specifically, the category of *Flow* from LMA and the principle of *Exaggeration* from 12PA were found to be applicable to every principle in their respective frameworks.

As explored in subsection 7.3.2.8 and supported by Knight and Simmons (2014) and Bishiko (2014b, 2014a), the principle of Exaggeration in 12PA acts as a control variable that influences all other principles. It determines the extent to which each principle is applied, such as the level of anticipation or the degree of an arc. Since Exaggeration affects the intensity and scale of all principles, it naturally extends to all categories of LMA, influencing how each movement is expressed.

Similarly, in LMA, the concept of *Flow* permeates all aspects of movement. Flow determines the continuity or interruption of movements, making it a fundamental element that influences how each LMA category is executed. Consequently, the concept of Flow is seen to correspond to every principle in the 12PA. This mapping underscores the interconnectedness of these frameworks and highlights the importance of considering both the flow of movement and the degree of exaggeration when designing emotionally expressive eye gestures for robots.

After successfully mapping the key concepts between Laban Movement Analysis (LMA) and The Twelve Principles of Animation (12PA), LMA was utilised to gauge the extent to which each principle from 12PA was required to achieve the varying degrees, or opposing polarities, of each LMA category. This approach led to the formulation of a set of rules that offer a consistent foundation for realising the distinct movement polarities described within each LMA category. The upcoming subsection will delve into these rules in greater detail, examining how they influence expressive robot eye movement.

7.3.3.1 Space Rule (Direct/Indirect)

The space rule focuses on the intention behind a movement, distinguishing movements as either direct or indirect based on their nature and purpose. In this context direct movements are goal-oriented and efficient, aimed at moving from one point to another in the most straightforward and quickest way possible. These movements are characterised by their clear, purposeful trajectory. Indirect movements, in contrast, are more unfocused and adaptable. They lack a straight-line path and are more about exploration and flexibility in movement rather than reaching a specific target efficiently.

Within The Twelve Principles of Animation (12PA), the principle of *Arc* is closely related to this concept in the Laban Movement Analysis (LMA) sub-category. The Arc principle in animation emphasises natural, curved paths of motion, rather than rigid, linear trajectories. To implement this in the design of robotic eye movements:

- For direct movements, the eyes should employ 'arc(0)'. This setting suggests a minimal curvature in the movement path, rendering the eye gesture more direct and targeted.
- For indirect movements, the eyes should use 'arc(100)'. This maximises the curvature in the movement path, leading to a more fluid and less direct eye gesture.

7.3.3.2 Weight Rule (Heavy/Light)

The weight rule focuses on the amount of force required for a particular movement, categorising it as either heavy or light based on the principles of Laban Movement Analysis (LMA). Light movements are those that can be executed with minimal effort. They are typically quick, fluid, and require little force. Heavy movements, in contrast, require a considerable amount of force and effort. They are often slower and more deliberate.

In the realm of The Twelve Principles of Animation (12PA), several principles correspond to this LMA sub-category, particularly in terms of how movement is executed in relation to force. These principles include Squash and Stretch, Anticipation, Follow-Through, and Slow In/Slow Out. To apply this to robotic eye movements:

- For heavy movements, the eyes should be configured with settings that emphasise the effort and force in the movement. This includes using '*squashAndStretch(0)*', *'anticipation(100)'*, *'followThroughAndOverlap(100)'*, and *'slowInOut(100)'*. These settings collectively contribute to a more pronounced, forceful, and deliberate movement.

- For light movements, the settings of these principles are inverted to reflect the ease and minimal effort required. This would typically involve less squash and stretch, minimal anticipation and follow-through, and quicker movement transitions.

7.3.3.3 Time Rule (Sudden/Sustained)

This rule focuses on the temporal aspect of movement, determining how long it takes to perform a specific action. It categorises movements as either sudden or sustained, based on their duration. Sudden movements are characterised by their quickness and abrupt nature. They happen rapidly and are typically brief. Sustained movements, on the other hand, are more gradual and prolonged. They unfold over a longer period, emphasising a slower pace.

In the framework of The Twelve Principles of Animation (12PA), the principle of *timing* closely aligns with this sub-category of Laban Movement Analysis (LMA). Timing in animation is crucial in determining the perceived speed and rhythm of a movement. To apply this rule to robotic eye movements:

- To achieve sudden movements, the timing should be set to *short*. This setting ensures that the eye movements are executed quickly and abruptly, conveying a sense of immediacy or surprise.
- For sustained movements, the timing should be set to *long*. This allows the eye movements to occur more slowly and deliberately, often used to convey emotions like contemplation, sadness, or calmness.

7.3.3.4 Flow (bound/free)

This rule relates to the degree of control exerted over a specific movement, categorising it as either bound or free according to Laban Movement Analysis (LMA). Bound movements are those that are performed close to the body, facilitating greater control and precision. These movements are typically more contained and deliberate. Free movements, in contrast, occur further away from the body, allowing for more expansive and open types of gestures. These movements are less constrained and often more fluid.

In The Twelve Principles of Animation (12PA), the principle of *Exaggeration* aligns with this LMA sub-category. Exaggeration in animation involves enhancing or reducing certain aspects of a movement to achieve the desired effect. Applying this to robotic eye movements:

- To achieve bound movements, the range of the eye gestures should be limited. This means the movements should be subtle and controlled, reflecting a more restrained emotional expression or a focused gaze.
- For free movements, the eye gestures should be allowed a wider range of movement. This would enable the eyes to express more open and expansive emotions, such as surprise or excitement, through broader and more exaggerated gestures.

7.3.3.5 Outwards Rule (Spreading/Enclosing)

This rule focuses on determining whether a movement is characterised by expansion or contraction. It categorises movements as either spreading or enclosing, based on their spatial dynamics. Spreading movements start from within the body and move outward. These gestures give an impression of expansion and openness, as if reaching out or embracing the space around. Enclosing movements, conversely, begin away from the body and move inward. They convey a sense of contraction or closing in, as if drawing back or protecting oneself.

In The Twelve Principles of Animation (12PA), the principle of *staging* is the equivalent concept for this sub-category of Laban Movement Analysis (LMA). Staging in animation involves the placement and presentation of characters or elements in a way that clearly communicates the intent or mood of the scene. Applying this to robotic eye movements:

- To achieve spreading movements, the staging should be set to *large*. This setting allows the eye movements to cover a broader area, creating a sense of expansion and engagement with the environment.
- For enclosing movements, the staging should be set to *small*. This restricts the range of the eye movements, making them more focused and contained, suggesting introspection or caution.

7.3.3.6 Approach Rule (Advancing/Retreating)

This rule focuses on creating movements that convey a sense of advancing or retreating. It categorises movements based on their directional quality. Advancing movements are characterised by their forward motion, giving the impression of moving towards something or someone. These movements are typically assertive and can indicate engagement or interest. Retreating movements, on the other hand, are defined by a backward motion, suggesting a movement away from something or someone. These movements often convey withdrawal, caution, or disengagement.

In The Twelve Principles of Animation (12PA), the principle of *staging* corresponds to this Laban Movement Analysis (LMA) sub-category. Staging in animation involves the strategic placement and presentation of elements to clearly communicate the narrative or emotional context. Applying this rule to robotic eye movements:

- To create the effect of advancing movements, the staging should be set to *large*. This setting allows for more pronounced eye movements, indicating forward engagement or interest.
- For retreating movements, the staging should be set to *small*. This limits the extent of the eye movements, suggesting a more reserved or cautious expression.

7.3.3.7 Verticality Rule (Rising/Sinking)

This rule is designed to facilitate upward or downward movements as part of the Laban Movement Analysis (LMA) shape category, specifically focusing on verticality. It categorises movements based on their vertical direction. Rising movements are those that move upwards, conveying a sense of elevation or ascent. These movements often suggest optimism, alertness, or an upward focus. Sinking movements, in contrast, move downwards, indicating a descent or lowering. These can convey feelings of relaxation, sadness, or a downward focus.

In The Twelve Principles of Animation (12PA), the principle of *staging* serves as the equivalent concept for this LMA sub-category. Staging in animation is about the strategic placement and presentation of elements to communicate the intended narrative or emotional context effectively. To apply this to robotic eye movements:

- To create upward movements, the staging should be set to *high*. This setting allows the eyes to move in an upward direction, giving the impression of looking up or elevating the gaze.
- For downward movements, the staging should be set to *low*. This results in a downward trajectory of the eye movements, as if the gaze is being lowered.

By adjusting the staging parameter in this way, the LMA12-O framework enables the design of eye gestures that move vertically, either upwards or downwards. This control over the vertical aspect of eye movements is crucial for accurately conveying a range of emotional expressions and intentions, from attentiveness and curiosity to contemplation and disengagement.

7.3.4 Creating Emotional Eye Gestures Using LMA12-O

With the establishment of the LMA12-O rules, the next crucial step involved associating these rules with specific emotions to create a guideline for animating emotionally expressive eye gestures. Seven emotions were selected: happiness, sadness, anger, fear, surprise, curiosity, and shyness.

To accurately assign a specific LMA12-O rule polarity to each emotion, a thorough cross-reference was made with multiple Laban Movement Analysis research studies (Camurri et al., 2003; Roether et al., 2009; Shafir et al., 2016). This process ensured that each emotion was linked to the most appropriate and expressive movement characteristics as defined in the LMA12-O framework. Table *3* in the study provides a summary of these emotions along with their corresponding LMA12-O rule polarities.

Table 3. Summary of the expression of emotions and their corresponding LMA12-O rule polarities

Emotion	Space	Weight	Time	Flow	Outward	Approach	Verticality
Happy	Indirect	Light	Sudden	Free	Spreading	Advancing	Rising
Sad	Indirect	Heavy	Sustained	Free	Enclosing	Retreating	Sinking
Angry	Direct	Heavy	Sustained	Bounded	Spreading	Advancing	Centred
Fear	Direct	Light	Sudden	Bounded	Enclosing	Retreating	Centred
Surprise	Direct	Light	Sudden	Bounded	Spreading	Retreating	Centred
Curious	Indirect	Light	Sustained	Free	Spreading	Advancing	Rising
Shy	Indirect	Light	Sustained	Bounded	Enclosing	Retreating	Sinking

These associations between the polarities of the LMA12-O rules and specific emotions then served as a foundational guide for animating the eye gestures. By following these guidelines, the eye movements of the robot can be animated to reflect the intended emotional state more accurately and expressively, enhancing the robot's ability to communicate and interact in a more nuanced and emotionally resonant manner that best aligns with the social robot's form factor.

7.4 Evaluation

To assess the effectiveness of the LMA12-O framework, an online questionnaire was implemented. This survey aimed to evaluate how accurately and effectively the animated eye gestures, created using the LMA12-O framework, conveyed a range of emotions. A total of seven emotions were selected for this purpose: happiness, sadness, anger, fear, surprise, shyness, and curiosity. For each of these emotions, three distinct variations of eye gestures were animated, resulting in a total of 21 different emotional expressions. These variations were subtly different from each other, featuring subtle adjustments in one or more of the eye movement capabilities defined in the LMA12-O framework. For instance, in one variation of the angry eye gesture it featured the maximum level of anticipation 100, in another variation it featured 95, and in another 90. These nuanced differences in the animations were designed to gauge a spectrum of emotional expressions by making slight changes in the eye movement parameters. Links to videos of these emotional expressions can be found in Appendix B.

In the experiment designed to evaluate the LMA12-O framework, participants were shown a randomised series of videos featuring Haru, the social robot, performing various emotional eye gestures. After watching each video, participants were asked to identify the emotion Haru was expressing from a set of multiple-choice options. The options included happiness, sadness, anger, fear, surprise, curiosity, and shyness. This approach aligns with the research by Ekman and Friesen (1975), suggesting that humans recognise a specific set of universal emotions.

To further gauge the accuracy of emotional interpretation, participants were also asked to rate their confidence in their chosen answer on a scale from 1 to 5, with 1 being unsure and 5 being very confident. This confidence rating aimed to capture the clarity and recognisability of each emotional expression as conveyed through Haru's eye gestures. In addition, at the end of the assessment of each emotion, the participants were given the opportunity to provide comments. These comments could offer qualitative insights into their perceptions, any challenges they faced in recognising the emotion, or suggestions for improvement. This comprehensive feedback was then invaluable for refining the LMA12-O framework, ensuring that the robotic eye gestures are both accurate in representing the emotions and easily interpretable by human users.

The participants in the study were sourced through Prolific, an online survey exchange service. The study comprised 100 participants, with a gender distribution of 64 females, 33 males, and 3 identifying as non-binary. The age range of the participants was predominantly young adults, with 71% falling within the 18-25 age bracket and 24% in the 25-35 age range. Only a small proportion, 5%, were over the age of 35.

The participant pool was geographically diverse, including individuals from various regions around the world. A significant portion of participants, 28%, were from Australia, followed by 15% from the United States and 14% from the United Kingdom. The study also had participants from Eastern Europe, Asia, and the Middle East, contributing to a broad international representation. This diverse sample provided a wide-ranging perspective on the perception and interpretation of emotional expressions through robotic eye gestures, enhancing the validity and applicability of the study's findings across different cultural contexts.

7.5 Results and Discussion

As indicated in Figure *113* of the study, participants demonstrated varying levels of accuracy in recognising different emotional eye gestures animated using the LMA12-O framework. The results summarised by their mean (M) percentage and standard deviation (SD), were as follows:

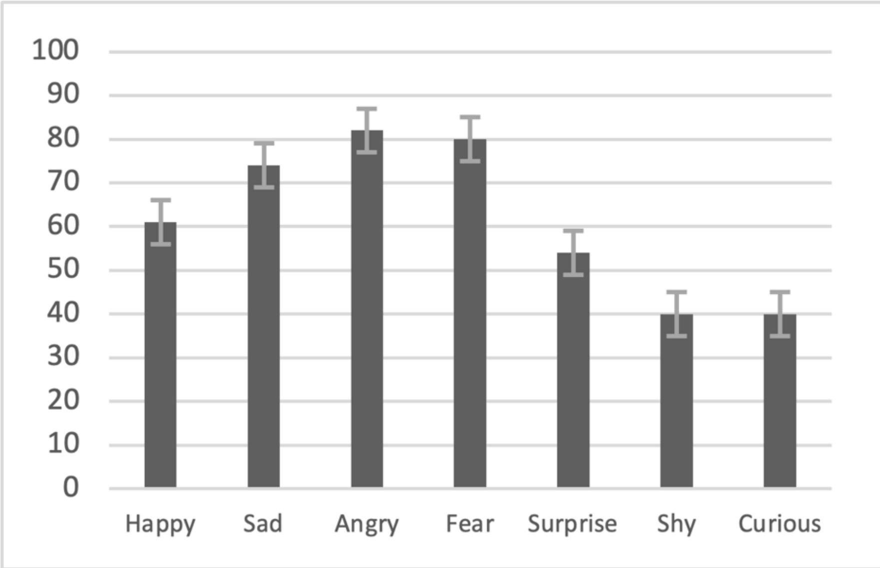

Figure 113. Recognition rates of emotional eye gestures using the LMA12-O framework.

- Angry was recognised with a high degree of accuracy (M = 82%, SD = 4.16%).
- Fear was also accurately recognised (M = 80%, SD = 4.36%).
- Sad had a notably lower recognition rate (M = 4%, SD = 5%).
- Happy was moderately well recognised (M = 61%, SD = 12.5%).
- Surprise had a recognition rate of (M = 54%, SD = 2.65%).
- Curious (M = 40%, SD = 2.65%) and Shy (M = 40%, SD = 5.29%) were less accurately recognised.

Confidence ratings were high for the eye gestures representing anger, fear, and sadness. However, there was some confusion about the gestures for surprise and happiness. The participants also faced challenges in recognising the eye gestures for curiosity and shyness, which was reflected in the lower confidence ratings for these emotions.

Considering that the LMA12-O framework is still in a prototype phase, some degree of variability in recognition rates was anticipated. The subsequent section of the study aims to delve into the reasons behind the lower recognition rates for certain emotions and proposes potential enhancements and modifications for future iterations of the framework. These adjustments could help in improving the accuracy and perceptual clarity of the emotional eye gestures, thereby enhancing the overall effectiveness of the LMA12-O framework in conveying a broader range of emotions.

7.5.1 Emotions are Context Dependent

The reduced recognition rates for emotions like shyness and curiosity stem largely from their reliance on situational context for accurate identification. In cases of perceived shyness, observers frequently misinterpreted the downward movement of the eyes as a sign of focusing on a nearby object, rather than as an indicator of shyness. Similarly, in instances of surprise, the rapid and vibrant eye movements were often confused with expressions of happiness. This tendency to misconstrue emotional cues suggests that participants were inclined to form narratives or scenarios involving Haru, the subject of observation, to justify their interpretations. Such a pattern of interpretation underscores the findings in current emotion research, particularly the theory that emotional expressions are not isolated phenomena but are deeply intertwined with and influenced by the environmental and situational context in which they occur (Bishko, 2014a). This perspective highlights the complexity of emotional recognition and the significant role of contextual factors in shaping our understanding of emotional expressions.

A notable limitation of this research lies in the fact that the interactions with the social robot were exclusively conducted in a laboratory setting, utilising pre-recorded videos. This methodological approach, while practical, introduces several potential constraints. The primary concern is the reduction in ecological validity, which refers to the extent to which the findings can be generalised to real-world settings (Zaga et al., 2017). Laboratory conditions often fail to replicate the complexities and unpredictability of real-life environments, which can significantly impact the interaction dynamics between humans and robots.

Furthermore, the use of pre-recorded videos may lead to a diminished sense of immersion for the participants. Immersion is crucial in studies involving human-robot interaction as it influences the participants' engagement and emotional involvement with the robot. A lack of immersive experience can create a disconnect between the participant and the robot, potentially skewing the perception and interpretation of the robot's emotional expressions.

Furthermore, this limited interaction scenario may affect the participants' perceptions of the robot's physical embodiment. Physical embodiment plays a critical role in how humans interpret and relate to robots, particularly in the context of emotional expression (Schilbach et al., 2013). In a more naturalistic setting, participants might perceive and respond to the robot's physical presence and emotional cues differently. As a result, the restricted laboratory setup and reliance on video-based interactions may not fully capture the nuances of human responses to a physically present social robot, which is essential for understanding the dynamics of human-robot emotional interaction.

In subsequent versions of the LMA12-O framework, addressing these contextual variations can be achieved by situating the social robot in the environment of its intended application, establishing specific scenarios corresponding to each emotion, and carrying out user testing in person.

7.5.2 Complex Emotions

The lower recognition rates for the eye gestures for curiosity and shyness can be attributed to the nuanced nature of these emotions of these emotions, as they are often composed of a blend of different emotional states. This multifaceted nature poses a challenge for accurate recognition. For instance, several participants pointed out that the eye movements associated with curiosity bore a resemblance to expressions of surprise. This similarity was particularly noted in the consecutive, unbounded dilations of the pupils, a characteristic commonly associated with surprise. In addition, the rising vertical movement and the effortless, unrestricted flow of the eye gestures were likened to expressions of happiness, further complicating the task of distinguishing curiosity from other emotions.

In the case of shyness, similar complexities were observed. Some participants identified a connection between the eye gestures for shyness and those for fear. This connection was primarily seen in the constrained and retreating movement of the eye, a typical response in fearful expressions. Furthermore, the suddenness of the eye movements in shyness was also found to be reminiscent of surprise, adding another layer of emotional overlap.

This finding aligns with existing research in the field of human emotional expression and recognition, which suggests that emotions are not always singular or isolated experiences. Instead, as demonstrated in various studies, emotions frequently occur in close temporal succession, overlapping to create more complex emotional states (Shaver et al., 1987).

In social robotics, most studies on emotional expression rely on the Ekman emotions framework, which conceptualizes emotions as discrete, isolated categories such as happiness, sadness, or anger. This framework has gained popularity in the field due to its simplicity and ease of replication, particularly its focus on clear and distinct facial expressions that can be analysed in detail. However, the Ekman framework is based on static images of facial expressions at their most defined state, overlooking the sequential movements that lead to and evolve from these emotions. By neglecting the dynamic transitions between emotional states, this framework fails to account for the contextual nuances and interplay of more complex emotions.

While the Ekman framework has been foundational, it oversimplifies the multifaceted and fluid nature of human emotional experiences, treating them as static rather than evolving processes. In reality, emotional expressions involve a dynamic interplay where one emotion can lead into another, creating a nuanced and sequential emotional experience. For instance, anger may transition into sadness or relief, depending on the context, and such transitions often occur naturally and continuously. This complexity suggests a performative element, where the expression of one emotion may set the stage for the emergence of another, influenced by changing stimuli or internal states.

However, the current prototype of the LMA12-O framework lacks the capability to fully account for this dynamism and sequential nature of emotional expressions. To enhance its effectiveness, future iterations should incorporate elements that go beyond static emotional states, enabling the recognition and representation of the transitions and interplay between emotions. This would allow for a more nuanced and realistic approach to emotional expression in social robots, bridging the gap between static models like Ekman's emotions framework and the fluidity and context-dependent emotional dynamics of real-world interactions.

7.5.3 Asymmetrical Eyelid Expressions

One limitation of this study was the lack of consideration for asymmetry in eyelid movements, which may have contributed to the lower recognition rates for more complex emotions such as curiosity and shyness. Asymmetry plays a vital role in human facial expressions, as our faces are naturally asymmetrical, and emotions are often communicated through subtle imbalances in movement and positioning. For example, a raised eyebrow on one side, combined with a slight downward tilt of the opposite eyelid, can convey curiosity, while uneven eyelid closure or a slight squint might suggest skepticism or hesitation. These asymmetrical features add layers of depth and complexity to nonverbal communication, making expressions feel more authentic and relatable to human observers.

Future iterations of the LMA12-O framework will address this limitation by exploring how asymmetry can enhance the expressive capabilities and dynamic range of social robot eyes.

This will involve testing various degrees of asymmetry in eyelid positioning and movement, as well as designing asymmetrical gestures that better replicate the subtleties of more complex emotional states. By incorporating asymmetry, social robots could convey a wider array of nuanced emotions, enabling them to adapt to diverse social scenarios and fostering more relatable and intuitive interactions.

In addition to improving emotional recognition, incorporating asymmetry could make robot expressions feel more lifelike and engaging. Human observers often subconsciously associate symmetry with artificiality and asymmetry with naturalness, as real-world expressions are rarely perfectly balanced. Moreover, asymmetry could allow social robots to adapt more effectively to different social scenarios by conveying a wider range of emotions, ultimately fostering more intuitive more relatable human-robot interactions.

7.5.4 Anthropomorphised and Real-World Eye Gestures

The lower recognition rates for emotions such as happiness and surprise in the study can be attributed to the unique strategy employed: combining realistic human eye gestures with anthropomorphised robot eye expressions. This approach was designed to capitalise on a social robot's ability to express emotional intent by incorporating stylised, metaphorical eye expressions commonly found in various forms of visual media.

Specifically, the study utilised metonymic eye tropes (TV Tropes, 2023), which are symbolic visual cues that represent certain emotions or states of mind. For instance, spiral wingding eyes (as portrayed in Figure *114*) used to denote confusion. These spirals are a visual shorthand commonly seen in cartoons and graphic art, where they replace the pupils to indicate a state of dizziness or bewilderment. Similarly, *manpu* eyes, a distinctive feature in Japanese anime and manga, were employed to represent a range of emotions such as nervousness, embarrassment, or excitement. Metonymic tropes are used extensively in these mediums to convey emotions in a visually striking and immediately recognisable manner.

Figure 114. Spiral winding metonymy eye gesture that signals confusion (Sakura, 1990).

While Haru's eye gestures conformed to the movement profiles designated for happiness and surprise in the LMA12-O framework, certain variations of these specific emotions were animated in a style more similar to metonymic eye tropes. For example, happiness and surprise were both depicted using a unique bouncing eye gesture, a stylistic choice that diverged from the conventional, realistic eye movements assigned to other emotional expressions. This contrast in animation styles may have contributed to a break in user expectations. Participants engaging with Haru had likely acclimatised to the more lifelike eye movements representing other emotions. When confronted with the exaggerated, trope-based animations for happiness and surprise, their ability to accurately recognise these emotions might have been compromised. The abrupt shift from realistic to stylised animation could create a cognitive dissonance, as the participants' established understanding of the robot's communication style was suddenly altered.

The lower recognition rates for happiness and surprise, as a result, highlight a crucial aspect of designing emotional expressions in social robots: consistency in communication style. While the use of stylised, metaphorical expressions can be engaging and expressive, it is essential to balance these with the user's expectations and familiarity with such expressions.

Despite this, the use of these metonymic eye gestures in a social robot presents a novel way of communicating emotional states. However, it also introduces a level of abstraction that may not be immediately intuitive to all users, especially those not familiar with these visual tropes. This finding highlights the need for careful consideration of the audience's familiarity and comfort with certain gestural communication styles. It points to a broader challenge in the field of human-robot interaction: balancing the expressiveness and relatability of robots with the diverse interpretive frameworks of different user groups.

In response to this insight, future iterations of the LMA12-O framework will focus on creating a more cohesive and consistent approach in animating emotional expressions. This could involve a more integrated blend of realistic and stylised gestures or clearer distinction between the two styles to minimise confusion.

7.5.5 Variations in Emotional Eye Gestures

In the study involving variations of emotional eye gestures, the participants' interpretations revealed intriguing insights into the subtleties of emotional recognition. When slight alterations were made to eye movement characteristics associated with certain emotions, the participants often inferred different emotions than those intended. For instance, enhancing elements of anticipation in the eye gestures meant to convey anger led some participants to perceive sadness. This misinterpretation could be due to the shared characteristics between the expressions of anticipation and certain aspects of sadness, such as a thoughtful or reflective gaze. Similarly, an increased focus on the timing of pupil contraction in the fear expression was occasionally misread as anger by participants. This confusion might stem from the common intensity found in both fear and anger expressions, where rapid pupil movements can signify heightened emotional states. This was also the case with the recognition of happiness which was notably associated with the use of *squash and stretch* techniques in the eye gestures. This animation principle, often used to convey elasticity and liveliness, seemed to effectively communicate the dynamic and joyful nature of happiness.

These findings resonate with current research on complex emotions, which suggests that micro-expressions, or subtle facial movements, can introduce ambiguity in the process of emotional recognition. The nuanced nature of these micro-expressions means that small changes can significantly alter the perceived emotion. This complexity in emotional recognition highlights an opportunity for future iterations of the LMA12-O framework to consider incorporating blended emotional expressions. This approach could allow for a more nuanced and accurate representation of human emotions, reflecting the real-world complexity of emotional experiences.

7.6 Conclusion

This chapter presents a novel prototype framework, named LMA12-O, designed for generating emotional eye gestures in social robots. This framework is underpinned by interdisciplinary research involving Laban Movement Analysis (LMA), the 12 Principles of Animation (12PA), and oculesics (O), integrating insights from movement theory, animation, and the study of eye behaviour. The study demonstrated that the LMA12-O framework is generally effective in conveying emotional intent in anthropomorphised social robots.

Looking forward, future versions of the LMA12-O framework have the potential to evolve into a consistent and robust method for generating emotional expressions. The aim is to capture the intricacies and nuances of emotional expression more comprehensively. This includes a deeper exploration of context, where the environment and situational factors are taken into account to enhance the relevance and accuracy of the emotional expressions. Furthermore, the framework could be expanded to represent complex emotions more effectively. These are emotions that are either blends of primary emotions or those that do not fall neatly into conventional emotional categories. Another aspect for future enhancement is the representation of emotional intensity. This involves not just identifying the type of emotion but also its strength and subtlety, which can significantly influence how an emotion is perceived and responded to. Finally, the incorporation of metonymic eye gestures, which use symbolic or culturally informed visual cues to convey emotions, offers a promising avenue for making emotional expressions in social robots more diverse and relatable. While this introduces challenges in terms of universal recognition and interpretation, it also opens up possibilities for more expressive and culturally resonant emotional communication.

In summary, the LMA12-O framework represents a significant step forward in the field of social robotics, with the potential to become a seminal tool in the nuanced articulation of emotional expression. By continuously refining and expanding upon its foundational concepts, it could greatly enhance the way social robots interact and engage with humans on an emotional level.

A version of this study was published in the 2018 ACM/IEEE International Conference on Robot and Human Interactive Communication (RO-MAN 2022).

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Chapter 8: Reflections and Contributions

8.1 Introduction

To conclude, this thesis has thoroughly investigated the integration of design and animation principles into the field of social robotics, aiming to enhance human-robot interaction through culturally sensitive, empathetic, and contextually relevant approaches. The study has challenged the prevailing techno-centric discourse and the siloed nature of current social robot design, advocating for interdisciplinary collaboration that extends beyond design and animation to include insights from history, philosophy, psychology, and the social sciences.

The fieldwork, findings, and analyses presented in this study offer new perspectives and integrative approaches, highlighting the potential of diverse academic disciplines in enriching social robot design. Reflecting on the initial objectives, the research studies, and findings, this thesis underscores the profound impact that such a holistic interdisciplinary approach can have on the future development of social robots where technical functionality is harmoniously blended with thoughtful consideration of individual experiences and societal dynamics, paving the way for more meaningful and effective human-robot interactions in the near future.

8.2 Summary of Findings

This thesis began with a comprehensive examination of the robotics field, tracing its evolution from a pragmatic and functional orientation to a more hedonic and social one. Despite this progression, a noticeable gap was identified in the discourse surrounding the social aspects of social robot design. To address this, the chapter delved into the potential of leveraging animation design expertise. It highlighted the interwoven history of animation, its significant impact on the collective cultural imagination, and how this influence has shaped the development of real-world social robots. This exploration aimed to shed light on how animation design principles and practices could be effectively integrated into social robot design, filling existing gaps and enhancing the social and interactive capabilities of these robots.

Chapter 2 focused on the prevalence of the techno-centric discourse, exploring how this perspective led to a widespread misconception about the role of designers in social robot design. This misunderstanding positioned design primarily as a tool for aesthetic enhancement, emphasising the visual beauty of a robot's exterior. The chapter sought to clarify the multifaceted role of design in social robotics, beginning with foundational definitions. It explored the connection between design and ecological psychology through the notion of affordances and highlighted the necessity for interdisciplinary contributions in social robot design through the concept of framing. The section then critiqued existing design frameworks in social robotics, arguing that an imbalanced emphasis on techno-centric discourse and a singular focus on efficiency and standardisation had led to stagnation in social robot development. The chapter concluded by emphasising the need for a theoretical framework that could rebalance design values, as well as a methodology that could accommodate the wider perspectives of a variety of different design disciplines.

Chapter 3 articulated a theoretical framework and methodology aimed at rectifying the limitations inherent in techno-centric design approaches. The chapter began by describing the philosophy of Deweyan Pragmatism as the core theoretical framework for this thesis and discussed its ontological relationship with design discourse. Following this, the chapter introduced design thinking as an epistemological methodology, serving as a pragmatic framework for examining a diverse array of design perspectives. This was then supported by the Universal Design Principles as a guiding framework towards accessible, inclusive, and user-friendly social robots. The purpose of integrating these frameworks was to pave a way for social robots to become more than just functional machines, but also intuitive, empathetic companions that could enrich the lives of as many people as possible. The chapter concluded by describing the specific methods that were used as well as important ethical research considerations.

Chapter 4 sought to highlight the critical role of visual design in social robotics through the concept of visual social semiotics. The chapter began by exploring the lack of visual diversity in social robot design and how it could lead to the reinforcement of existing harmful stereotypes within the context of human social interactions. It then explored the existing design approaches which led to these stereotypes and advocated for an approach that considered all visual design elements and principles and the semiotics associated with their cultural and social use, as well as its technical requirements. Acknowledging the field's limited grasp of visual design principles, the chapter concluded by offering a primer on the fundamental elements and principles of visual design and how they could affect individual semiotic interpretations and meanings.

Chapter 5 was a case study that aimed to substantiate personalisation as a means for overcoming the Uncanny Valley theory in social robot visual design. The study underscored the potency of personalisation in social robot design by illustrating how even subtle visual adjustments could significantly influence individual perceptions. This concept was explored through the lens of Deweyan Pragmatism, particularly John Dewey's notion of *art as experience*, and Scott McCloud's concept of *the picture plane*. The investigation focused on the personalisation of a singular design element, namely, the robot's eyes. Participants were asked to rate and comment on a total of 54 different eye variations, encompassing six distinct eye designs, each with 9 different eye colour options. Contrary to the Uncanny Valley theory, a qualitative examination of the data unveiled that the primary determinant of a social robot's visual design effectiveness was not its degree of *human likeness*. Instead, it was the individual perceived meanings attributed to the visual designs that played a pivotal role in shaping participant perceptions.

Chapter 6 aimed to emphasise the importance of movement design in social robotics through the examination of gestures in human communication. The chapter delved into an analysis of the current state of social robot movement design, addressing the prevailing stereotype that characterised robot movement as slow, crude, and janky. The chapter then engaged in a critical analysis of the current design processes, such as the pragmatic, mimetic, and expressive approach, and design concepts, such as the Uncanny Valley, which had contributed to this stereotype. It highlighted that the principal driver behind the Uncanny Valley theory was not the social robot's inability to replicate human-like movement faithfully but rather the creation of any movement lacking motivation, intentionality, and contextual reference. Once again introducing the Deweyan Pragmatic notion of *art as experience* in conjunction with Leslie Bishiko's work on *The Uses and Abuses of Cartoon Style in Animation*, the chapter advocated for the development of a movement design framework that not only took into account human gestural expression but also movement that considered the context of human-robot interaction.

Chapter 7 was a case study that aimed to discuss the design and evaluation of the prototype LMA12-O framework for the purpose of maximising the emotive communication potential of expressive eye gestures in social robots. The LMA12-O framework was a methodology that synthesised the existing movement frameworks of Laban Movement Analysis (LMA), the 12 Principles of Animation (12PA), and oculesics (O) to create a new movement framework. This framework allowed for the development of different gestural expressions and styles unique to the design of a particular social robot but still situated and grounded within the context of human communication. The results of initial user testing showed LMA12-O to be effective in designing affective emotional eye gestures in the test robot, with important considerations for future iterations of this framework. While the LMA12-O framework was limited to eye gestures, it was built to be applicable to other areas or body parts of a social robot's visual design.

8.3 Contributions to Knowledge

8.3.1 Deweyan Pragmatism as a wholistic theoretical framework for addressing techno-centrism in social robot design

This thesis contributes significantly to the field of social robot design by introducing Deweyan Pragmatism as a comprehensive theoretical framework to address the prevailing issue of techno-centrism. Deweyan Pragmatism, with its emphasis on experience, interaction, and continuous adaptation, provides a much-needed holistic perspective to the design of social robots. This approach challenges the conventional techno-centric focus which predominantly emphasises technical and functional aspects, often neglecting the broader social, cultural, and ethical implications of robot design.

By applying Deweyan Pragmatism, this research has demonstrated the importance of considering a robot's design from a more inclusive and human-centric perspective. It underscores the need for social robots to be not just functionally efficient but also contextually relevant, culturally sensitive, and empathetic to individual human experiences. This approach facilitates the creation of robots that are capable of meaningful and responsible interactions in diverse social settings.

Furthermore, the thesis highlights how Deweyan Pragmatism encourages interdisciplinary collaboration, bringing together insights from fields such as design, animation, psychology, and the social sciences. This integrative approach enriches the design process, allowing for more nuanced and empathetic social robots that can adapt to and resonate with a wide range of human emotions and social contexts, and paves the way for more responsible and inclusive approaches in the development of social robots.

8.3.2 'Subtle Personalisations' as a visual design framework for fostering social robots that are not just technically proficient but also socially responsible, culturally sensitive, and ethically grounded

This thesis also makes a marked contribution to the field of social robot design by introducing Subtle Personalisations as a novel visual design framework. This approach marks a pivotal shift from focusing solely on technical proficiency to fostering social robots that are socially responsible, culturally sensitive, and ethically grounded. The Subtle Personalisations framework emphasises the importance of nuanced, individual design customisations that profoundly influence people's perceptions and interactions with social robots.

By applying the Deweyan Pragmatic concept of *art as experience* this research challenges the entrenched beliefs in social robot design regarding an *optimal* universal visual aesthetic. It argues that such a narrow focus on human likeness and a simplistic balance between realism and abstraction leads to a homogenised and limited design scope. In contrast, the thesis advocates for a spectrum of interactive and adaptable designs that cater to the diverse aesthetic experiences and preferences of individual users. This approach embodies a more inclusive and holistic perspective in social robot design, acknowledging the rich variety of human experiences and aesthetic values.

The framework of Subtle Personalisations not only augments the functional and emotional appeal of social robots but also brings cultural, social, and ethical considerations to the forefront of design. Incorporating examples like the ability for users to choose among a variety of eye designs, colours, and even personality traits through gestures and movements, the thesis illustrates how these seemingly small customisations can collectively create a significantly personalised robot. This approach allows for a spectrum of personalisation, where users can select just one attribute or a combination of different attributes to match their preferences, thus not impacting the engineering or the fundamental form of the robot. By prioritising these dimensions, the thesis promotes a more empathetic, responsible, and culturally sensitive approach to social robot design. It advocates for the creation of social robots that effectively serve their intended purposes while being respectful and mindful of the diverse needs and values of different users, with a particular focus on enhancing the human experience at the core of design. This paradigm shift in design philosophy is instrumental in facilitating more profound and responsible human-robot interactions, showcasing how even minimal personalisations, when aggregated, can lead to substantial enhancements in robot personalisation, thereby enriching the user's emotional connection and engagement with the robot.

8.3.3 'LMA12-O' as a movement design framework for fostering different gestural expressions and styles unique to the design of a particular social robot but still situated and grounded within the context of human communication

This thesis introduces LMA12-O as a movement design framework, specifically crafted to enhance the field of social robot design. This framework represents a significant advancement in fostering diverse gestural expressions and styles that are uniquely tailored to the design of a specific social robot, while remaining deeply rooted and coherent within the context of human communication.

The LMA12-O framework synergises insights from the Laban Movement Analysis (LMA), a renowned method for interpreting and documenting human movement, with the foundational 12 Principles of Animation. This integration creates a comprehensive set of guidelines that inform the development of social robot movements that can not only perform tasks efficiently but also engage in expressive and intuitive interactions with humans. The framework ensures that each robot's gestural language is not just mechanically accurate but also emotionally and contextually resonant, bridging the gap between technical functionality and human relatability.

In addition, the LMA12-O framework is designed to be adaptable across various robot designs, allowing for the creation of gestural expressions that are specific to each robot's unique form and intended function. This adaptability enables designers to craft movements that are not only expressive but also coherent with the robot's physical design and intended use cases.

The LMA12-O movement design framework represents a significant contribution to the field of social robot design. It offers a novel approach to creating robots with nuanced, expressive, and contextually grounded movements, thereby elevating the standard for human-robot interaction, and paving the way for more advanced and empathetic social robots in the future.

8.4 Implications for Social Robot Design

8.4.1 Advancement in Human-Robot Interaction

This research marks a significant advancement in human-robot interaction by integrating animation principles, pioneering design frameworks like Subtle Personalisations and LMA12-O, and the philosophical underpinnings of Deweyan Pragmatism. The application of these concepts has the potential to develop socially intelligent robots that interact with humans in more empathetic and meaningful ways. By fostering deeper connections that go beyond traditional technological interactions, this approach enriches the user experience. Deweyan Pragmatism in particular, emphasises the importance of experience, interaction, and continuous learning in design, which contributes to making social robots more relatable, adaptable, and effective in diverse human-centric environments. This holistic approach aligns with the pragmatic philosophy of considering the broader context and the dynamic nature of human experiences in social robot design.

8.4.2 Emphasis on Cultural and Ethical Considerations

This study underscores the importance of cultural sensitivity and ethical considerations in social robot design, closely aligned with the Universal Design Principles. By focusing on these crucial aspects, the research facilitates the development of socially responsible robots that are attuned to the diverse spectrum of human experience. This approach promotes inclusivity and mitigates potential biases in robot design, ensuring that the robots are not only technically proficient but also ethically and culturally considerate. The incorporation of Universal Design Principles further strengthens this approach, as it emphasises the creation of robots that are accessible and usable by all people, regardless of age, ability, or other factors. This conscientious approach to design is essential in ensuring that social robots are developed in a way that respects and understands the varied needs and values of different communities, thereby fostering ethical compliance and broader acceptance.

8.4.3 Interdisciplinary Collaboration from the Beginning

This thesis emphasises the critical importance of interdisciplinary collaboration from the beginning of the design phase in creating social robots. By drawing upon a wide array of expertise from fields such as animation, psychology, design, and robotics, this approach ensures that social robots are developed with a comprehensive understanding of the intricate dynamics of human-robot interactions. Engaging diverse disciplines early in the design process enriches the development of social robots with nuanced insights, making them technically sophisticated while being socially and emotionally attuned for its intended use cases. This proactive collaboration contrasts with the traditional method of integrating these insights later in the development process, which can, ironically, be less efficient and less effective in achieving a robot's social and emotional potential. By prioritising interdisciplinary input from the beginning, the design of social robots becomes a holistic endeavour, leading to innovations that are contextually situated and emotionally resonant. This methodology not only optimises the integration of robots into human settings but also paves the way for future advancements in social robotics by establishing a model for how varied expertise from the beginning of the design process can collectively enhance the empathetic and interactive capabilities of robots.

8.4.4 Forges New Pathways for Design and Animation Studies

This research forges new pathways in design and animation studies by integrating principles of animation and Laban Movement Analysis into the realm of social robot design. This novel approach can have a profound impact on both design and animation education and professional practices. It enables social roboticists to appreciate the significant impact of design and animation expertise in their field, highlighting the nuanced ways in which design and animation principles can enhance robot functionality and human interaction. Simultaneously, it encourages designers to recognise how their skills and knowledge can be applied in previously unexplored domains like robotics. This interdisciplinary fusion not only broadens the scope of design and animation studies but also enriches the field of social robotics, fostering a deeper understanding of how aesthetic, kinaesthetic, and emotional factors intertwine in the creation of engaging and effective robots. This contribution extends the dialogue between design, animation, and technology, setting a precedent for future collaborations and innovations in these intertwined fields.

8.4.5 Practical and Societal Applications

The outcomes of this thesis have far-reaching implications for the practical implementation of not just social robots but also technology in general across multiple sectors, including healthcare, education, and customer service. The incorporation of design and animation principles that emphasise human emotions and cultural contexts ensures that social robots can be integrated into society more effectively. This approach not only increases the practical utility of these robots but also improves their acceptance and relatability among diverse user groups. By creating robots that are not only functionally proficient but also empathetically attuned to human needs, this research contributes to a future where social robots can significantly enhance various aspects of daily life, from assisting in healthcare settings to enriching educational experiences and improving customer interactions. The emphasis on cultural sensitivity and ethical considerations further ensures that these robots are designed with a deep understanding of the societal impact they carry, paving the way for a more harmonious and beneficial coexistence between humans and robots.

8.4.6 Implications on the Broader Technological Landscape

This thesis elucidates findings with profound implications, extending beyond the domain of social robotics to encompass the entire technological sphere. It delves into the ramifications of a techno-centric discourse, which has shaped the development of technology and led to prevalent social, cultural, and ethical challenges encountered today. While the thesis is centered on social robot design, the principles it explores—rooted in Deweyan Pragmatism, Design Thinking, Universal Design Principles, Gibsonian Affordances, Design Frames, and Interdisciplinary scholarship—are universally applicable across technological development. These principles provide a framework for considering human emotions, cultural contexts, and ethical considerations, proposing a paradigm shift towards a more empathetic approach in technology development.

The research argues for a departure from solely efficiency-driven technology to innovations that are deeply empathetic and culturally responsive, embodying a vision for the future where technology enriches human life in multifaceted ways. This involves not only enhancing day-to-day functionality but also fostering stronger human connections and promoting diversity and inclusivity. By advocating for an interdisciplinary development process that is informed by a broad spectrum of human experiences and values, this thesis lays the groundwork for creating more ethical and socially responsible technological solutions. This approach champions a future where technology and humans coexist in a more balanced and mutually beneficial relationship, underpinned by a commitment to enhancing the collective well-being and fostering a deeper understanding of technology's role in society.

8.5 Challenges and Limitations of This Research

This research, spanning 2018–2023, faced significant challenges due to two major global events: the Covid-19 pandemic and the 2022 Global Silicon Chip Shortage as stated in the front matter of this thesis. The pandemic's lockdowns hindered direct observational studies of human interactions with social robots, particularly with the Haru robot, a central element of this thesis. Haru's reliance on specialist support from international entities, including Honda Research Institute, Japan (HRI-JP), Service Robotics Lab at Universidad Pablo de Olavide in Spain, and IDMind Living Robots in Portugal, became impractical due to travel and logistical constraints. Plans to focus on thesis writing in 2020–2021 and user testing in 2022 were disrupted by the prolonged silicon chip shortage, leading to a pivot towards online questionnaires and video recordings of Haru for data consistency. The pandemic also affected daily PhD activities, with limited campus access in Sydney, loss of workspace, restricted resource availability, and delays in literature and equipment access due to disrupted global supply chains. These circumstances necessitated a dynamic and adaptive approach to research, underscoring the resilience and flexibility in maintaining the study's relevance and applicability in the field of social robot design, despite the unprecedented global turbulence during this period.

8.6 Recommendations for Future Research

The field of social robot design is evolving rapidly, driven by interdisciplinary insights and technological advancements. While the current research has made significant strides, there is a constant need for further exploration to address emerging challenges and harness new opportunities. This section outlines key recommendations for future research in social robot visual and movement design.

8.6.1 Real-World User Testing

In future research, it is crucial to expand the scope of user testing environments for social robots. Moving beyond laboratory settings, these studies should incorporate real-world environments like homes, schools, and public spaces. This approach will provide essential insights into the practical application and social integration of social robots. Testing in a variety of real-world scenarios will reveal unique interaction dynamics and help gauge acceptance levels in different social contexts. This step is vital for understanding how social robots function in everyday settings, responding to the diverse needs and behaviours of users in their natural environments.

8.6.2 Evaluating 'Subtle Personalisations' With Different Parts of a Robot's Visual Design

Future research should expand upon the 'Subtle Personalizations' framework by examining the impact of personalization across various elements of social robots. This includes exploring how features such as facial expressions, body language, voice, and interactive capabilities can be tailored to suit the diverse preferences and contexts of individual users. A key area for development is the design of robot eyes, where testing should incorporate a more nuanced progression from lifelike to abstract forms. This could involve evaluating consistent structural designs while experimenting with the inclusion or exclusion of specific design elements, such as eyebrows or eyelids, to better understand their effects on user perception.

To address this, future studies should embrace a broader range of eye designs, spanning from hyper-realistic to minimalist abstract forms. This approach would enable researchers to assess how different visual design choices affect user perceptions, emotional engagement, and the overall quality of human-robot interaction. Such experimentation would provide deeper insights into how eye design can shape the robot's personality and relatability.

Moreover, personalization efforts should go beyond visual features. Customizing attributes like gestures, material textures, and vocal characteristics could significantly enhance a robot's relatability and user acceptance. Investigating how these elements interact and collectively influence the robot's impression on users is crucial for refining design strategies.

It is also essential that future research includes a broader demographic sampling to better align with the intended use cases of social robots, particularly in contexts like elderly care. The current research's limitations resulted in generalizing respondents over 35 as a single group, which does not reflect the nuanced needs and preferences of older adults. Future surveys should aim to include targeted demographics or age-specific groups to explore how personalization strategies can be tailored for a wider range of different user populations and applications.

Ultimately, a comprehensive and integrated approach to personalization will foster more intuitive and meaningful human-robot interactions while ensuring that social robots are designed with greater cultural and emotional sensitivity.

8.6.3 Evaluating LMA-12-O in Other Social Robots

In future research, it is essential to thoroughly evaluate the practical application and impact of the LMA12-O framework across different social robot designs. This evaluation should include comparative studies that examine various movement design strategies within this framework. Such research would provide valuable feedback on how effectively these strategies are implemented in real-world applications. By comparing different approaches, researchers can refine and enhance the effectiveness of the LMA12-O framework, ensuring it meets the dynamic needs of human-robot interaction in various contexts.

8.6.4 Further Emphasis on the Social and Cultural Considerations of a Social Robot's Visual and Movement Design

Future research should place greater emphasis on understanding and addressing the ethical and social implications associated with the visual and movement design of social robots. This exploration should encompass a range of concerns, including the potential impact of social robots on employment, privacy issues, emotional dependency, and their integration into society. Such research is critical for developing robots that are not only technically proficient but also socially responsible and ethically sound. Investigating these areas will contribute to a more holistic approach to social robot design, ensuring that these technological advancements align with societal values and ethical standards. This comprehensive perspective is crucial for fostering trust and the acceptance of social robots as they become more prevalent in various aspects of human life.

8.6.5 Exploring the Longitudinal Evolution of Human-Robot Interactions

Future research should prioritise longitudinal studies to gain a deeper understanding of how interactions with social robots evolve over time. Long-term observation is key to comprehending the lasting impact of design choices and the adaptability of social robots to the dynamic needs and environments of human users. Such studies could reveal insights into how initial perceptions and interactions with social robots might shift as individuals become more accustomed to their presence and functionality. This approach is particularly significant in examining the sustainability of design elements and the enduring effectiveness of robots in various social settings. Additionally, understanding how a person's intentions and attitudes towards social robots change over time can provide valuable feedback for future design enhancements, ensuring that social robots remain relevant and beneficial in long-term human contexts.

8.7 The Future of Social Robot Design is Interdisciplinary

When I embarked on my PhD journey in 2017, my background in social robots was non-existent. I had just completed a Bachelor of Design in Animation and a Bachelor of Arts in International Studies, majoring in Japanese, in 2016. My academic and professional history had no apparent connection to robotics; I lacked experience in engineering and programming. Despite being granted the opportunity to delve into social robotics, it is fair to say that I was initially doubtful about my abilities and the potential contributions I could make to the field of human-robot interaction. Identifying primarily as an animator, my aspirations were originally aligned with creating short films, contributing to major Hollywood studio productions, and possibly sharing my creations on YouTube. And yet, here I was an animator in the middle of a field dominated by engineers and computer scientists. This isn't to imply that I completely doubted my ability to contribute to this field; rather, it was challenging for me to envision the significant impact my expertise in animation could have in the realm of human-robot interaction.

During the initial phase of my PhD, I encountered significant challenges, primarily due to the transition from a predominantly practical field to a highly academic one. Adapting to the intensive readings and writings required was a formidable task. This challenge was further intensified by an amazing opportunity to intern at the Honda Research Institute, Japan (HRI-JP) with Chief Scientist Randy Gomez in 2018. With merely a year and a half of research experience under my belt, I began to experience the pangs of imposter syndrome. In an environment predominantly occupied by engineers and computer scientists, my role as an animator often seemed out of place. Anecdotally, my colleagues did not fully grasp the value an animator could bring to their field, making my experience there quite daunting. The occasional quip questioning my presence was not uncommon adding to the sense of alienation.

Despite these obstacles, my time in Japan was not without its merits. It was there that I discovered Laban Movement Analysis, which led to the conceptualisation of combining it with the Twelve Principles of Animation and oculesics, culminating in the creation of the LMA12-O framework. Even with this significant contribution, I often felt that my efforts were inadequate. I struggled with understanding why the LMA12-O framework was effective; I knew it worked and that I had chanced upon something intriguing, but the underlying reasons for its success remained elusive.

It was only during specific milestones in my PhD journey that my role as an animator in the field of human-robot interaction began to feel significant. A pivotal moment came when my supervisor Deborah Szapiro recommended attending a series of research development lectures by Dr. Lien Pham, a Senior Lecturer at the Graduate Research School at University of Technology, Sydney. These lectures introduced me to the philosophy of education, igniting a newfound passion for philosophy. This experience transformed my academic discourse and deepened my understanding of epistemology – the study of knowledge and its acquisition. It was a transformative period where I began to see myself not just as an animator, but as a true scholar and researcher.

My perception of this field expanded significantly when my supervisor, Associate Professor Bert Bongers, introduced me to Gibsonian Affordances and the principles of ecological psychology. Delving into these concepts deepened my understanding of how we perceive and interact with our environment. This exploration of philosophy, psychology, biology, and design, unveiled the complex interplay between our actions and the surrounding world, enlightening me to the profound impact design can have on our environment and us.

However, the most defining moment occurred after Deborah Szapiro, directed me to a journal article titled *Resistance is Futile: Reading Science Fiction Alongside Ubiquitous Computing* by computer scientist Paul Dourish and cultural anthropologist Genevieve Bell. This paper was a revelation. It synthesised philosophy, design, ecological psychology, biology, art, ethics, engineering, computer science, and human-robot interaction into a cohesive whole. It was through this article that I fully recognised the profound influence of animators. It underscored the power of imagination and creativity in shaping our technological future.

This realisation was not just an academic awakening; it was also an emotional anchor. It provided the reassurance and validation I needed whenever I encountered sceptical remarks about my place in the field of robotics. It was the moment when everything my supervisors had been teaching me merged into a clear, coherent understanding of my role and potential in this inherently interdisciplinary landscape.

What I want to emphasise with my journey is that my contributions to the field of human-robot interaction are important precisely because they stem from a foundation of interdisciplinary scholarship. I am convinced that without my slow, meandering, almost random exploration across various fields, such as social robotics, human-robot interaction, human-computer interaction, philosophy, psychology, sociology, biology, ethics, design, art, and animation, the contributions made in this thesis would not have been possible.

I have observed with certainty that the periods when I encountered roadblocks in my research were those times when I focused too narrowly on the field of social robotics. When my approach became overly techno-centric, and I sought solutions solely within the confines of robotics, then my progress stalled. In contrast, the breakthroughs and answers I sought often emerged when I ventured into entirely different areas of study. This pattern underscored the value and necessity of a broad, interdisciplinary perspective in human-robot interaction research. The insights gained from these diverse disciplines not only enriched my understanding but also equipped me with unique tools and perspectives that were pivotal in advancing my work in human-robot interaction.

At the onset of my PhD, I predominantly identified as an animator, confining myself within that specific role. This self-imposed limitation was, I believe, the root of the struggles I faced during the initial year and a half of my PhD journey. I had a narrow perception of the capabilities inherent in my skill set and struggled to recognise the unique perspective that my background as an animator could bring to diverse fields of study, particularly in relation to human-robot interaction and social robot design research.

As I progressed through my PhD, I began to gradually shed this singular identity of just being an animator. My engagement with complex and varied topics, such as Deweyan Pragmatism, Affordances, Ecological Psychology, Design Thinking, The Universal Design Principles, and Aesthetics, facilitated a transformation in my self-perception. I started to embrace my intrinsic qualities as a designer – someone who is passionate about exploring new concepts and understanding how these ideas weave into the broader tapestry of my own knowledge tree.

This evolution in my identity was profound. No longer was I merely an animator; I had grown into a multifaceted scholar with a rich blend of roles. I had become a philosopher, delving into the depths of human thought; a psychologist, exploring the intricacies of the human mind; a sociologist, examining the complexities of social interactions; a biologist, understanding the principles of life; an ethicist, contemplating moral implications; a designer, crafting meaningful experiences; an artist, expressing creativity; and still, an animator, bringing stories to life. This diverse amalgamation of roles not only enriched my personal growth but also significantly enhanced my contributions to the field of human-robot interaction.

Societal structure, particularly after the Industrial Revolution, has indeed gravitated towards fostering deep, specialist knowledge, possibly at the expense of broader, interdisciplinary innovation. Specialist expertise is undeniably valuable, and those who excel in their specific fields should undoubtedly have the freedom to delve deeply into their areas of interest. However, as technology continues to advance and becomes more entwined with our daily lives, especially with the emergence of social robots capable of altering not just our physical environment but also the very fabric of human communication, it is crucial that we avoid confining ourselves to a singular knowledge base.

In the context of such rapidly evolving technological landscapes, where the boundaries between different fields of study are increasingly blurred, embracing a more fluid and expansive approach to learning becomes essential. There's a growing need for meaningful interdisciplinary collaborations that challenge our perspectives and open up new avenues for exploration and understanding. It is about recognising the value and insights that these diverse perspectives bring.

By fostering a culture of openness and curiosity, where individuals are encouraged to step beyond their comfort zones and engage with a range of disciplines, we can cultivate a more holistic and nuanced understanding of the world. This approach is particularly relevant in human-robot interaction, where the integration of perspectives from psychology, sociology, ethics, design, art, animation, and technology is critical for developing systems that are not only technically advanced but also socially positive and ethically responsible. It is this blend of diverse knowledge and skills that will drive innovation and enable us to navigate the complexities of human-robot interaction and our increasingly interconnected world.

Figure 115. The author interacting with the Haru Social Robot (UTS 2020).

I would like to offer a final reflection to my peers in the animation community. My hope is that my research inspires you to look beyond the traditional boundaries of the screen and explore the varied ways your experience can contribute to the evolving fields of science and technology

(Figure *115*). Your skillsets, though it may not be immediately apparent, are immensely valuable and needed in these areas.

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Figure 21 (left bottom). Mayfield Robotics. (2017). *Kuri Robot* [Link].

Figure 21 (middle top). (2008). Wall-E [Link]

Figure 21 (middle bottom). Sony. (2017). *AIBO Robot* [Link].

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Figure 24 (left). Luvozo. (2017). *SAM Robot* [Link].

Figure 24 (middle). Rethink Robotics. (2015). *Sawyer Robot* [Link].

Figure 24 (right). Hiroshi Ishiguro Laboratories. (2020). *Alter 3 Robot* [Link].

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Figure 28 (left). Engineered Arts. (2014). *RoboThespian* [Link].

Figure 28 (right). Robotics and Innovation Lab. (2019). *Stevie II Robot* [Link].

Figure 29. Boston Dynamics. (2016). *Spot Robot* [Link].

Figure 30 (left). Genly Inc. (2012). *Line of action on actors posing* [Link].

Figure 30 (middle) Engineered Arts. (2014). *RoboThespian* [Link].

Figure 30 (right). Robotics and Innovation Lab. (2019). *Stevie II Robot* [Link].

Figure 31 (left). MIT Mechanical Engineering. (2024). *Pick and place with precision* [Link].

Figure 31 (right). Florida Atlantic University. (2017). *Bioengineered robotic hand with its own nervous system will sense touch* [Link].

Figure 32 (left). Tempest, M. (2014). *Magic Robot – The Illusion of the Thinking Machine* [Link].

Figure 32 (right). Shadow Robot (2015). *Shadow Robot Hand on Baxter Integration – Ball Demo* [Link].

Figure 33 (left). Kamayashi, S. (2007). *Kobian is surprised* [Link].

Figure 33 (right). Softbank Robotics (2008). *The sixth generation of Nao* [Link].

Figure 34. Motonari, T. (2015). *Paro interacting with elderly in dementia care* [Link].

Figure 35. FCS Art Blog. (2016). *The use of positive and negative space in a frame.* [Link].

Figure 36 (left). Robelf. (2019). *Robelf* [Link].

Figure 36 (right). Morby, A. (2017). *ElliQ Robot* [Link].

Figure 37. Hall, E. T. (1990). *The Hidden Dimension*. Anchor.

Figure 38. Robelf. (2019). *Robelf* [Link].

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Figure 40 (left). LuxAI. (2017). *QTRobot* [Link].

Figure 40 (right). Blue Frog Robotics. (2014). *BUDDY Robot* [Link].

Figure 41. Rethink Robotics. (2011). *Baxter Robot* [Link].

Figure 42. Bird, B. (1999). *The Iron Giant in a low angle shot* [Link].

Figure 43. Taniguchi, G. (2006). *Lelouch with large eyes and small eyes* [Link].

Figure 44. O'Connor, B. (2016). *Atlas Robot* [Link].

Figure 45. Sony. (2017). *AIBO Robot* [Link].

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Figure 48. White, N. (1987). *The Helpless Robot* [Link].

Figure 49. Penny, S. (2006). *Petite Mal* [Link].

Figure 50. Velonaki, M. (2003). *Fish-Bird* [Link].

Figure 51. Marynowsky, M. (2009). *The Hosts* [Link].

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Figure 65 (left). Cameron, J. (1984). *The Terminator* [Link].

Figure 65 (right). Kubrick, S. (1968). *HAL9000* [Link].

Figure 66 (left). Stanton, A. (2008). *Eve* [Link].

Figure 66 (middle). Froyas, A. (2004). *Sonny Robot* [Link].

Figure 66 (right). Wedge, C. (2005). *Rodney Copperbottom* [Link].

Figure 73. Sharma, B. P. (2015). *Eyes with and without mascara* [Link].

Figure 74. Forbes, C. (2020). *Highlighting the eyes with colours on darker skin tones* [Link].

Figure 76. DiMartino, M. D., & Konietzko, B. (2005). *The avatar team looking at the darkness gazes back.* [Link].

Figure 78. Fairs, M. (2020, May 14). *Covid-19 Links were designed to create "feeling of alarm" says CDC illustrator*. Dezeen. [Link].

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Figure 81 (left). Rethink Robotics. (2011). *Baxter Robot* [Link].

Figure 81 (right). Willow Garage. (2010). *PR2 Robot* [Link].

Figure 82. CBS. (1974). *Michael Jackson doing the robot dance* [Link].

Figure 83 (left). Sakaguchi, H. (2001). *Aki Ross* [Link].

Figure 83 (middle). Zemeckis, R. (2004). *Know-it-all* [Link].

Figure 83 (right). Spiegel, S. (2011). *Tintin* [Link].

Figure 84. Zemeckis, R. (2007). *Motion capture used in Beowulf* [Link].

Figure 85. Hanna Barbera. (2001). *Jerry coming to an extreme abrupt stop* [Link].

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Figure 100 (middle). ASUS. (2016). *Zenbo* [Link].

Figure 100 (right). JIBO Inc. (2016). *JIBO Robot* [Link].

Figure 101. Guest, A. H. (2013). *Labanotation: The system of analyzing and recording movement*. Routledge.

Figure 114. Sakura, M. (1990). *Chibi Maruko Chan in a daze* [Link].

Figure 115. UTS. (2020). *Haru interacts with PhD candidate Kerl Galindo, a graduate of the Bachelor of Design in Animation at UTS* [Link].

Appendix

Appendix A: LMA12-O Video Links

Note. All links direct to UTS OneDrive.

Emotion	Variation	Link
Happy	1	haru_happy_01.mp4
Happy	2	haru_happy_02.mp4
Happy	3	haru_happy_03.mp4
Sad	1	haru_sad_01.mp4
Sad	2	haru_sad_02.mp4
Sad	3	haru_sad_03.mp4
Angry	1	haru_angry_01.mp4
Angry	2	haru_angry_02.mp4
Angry	3	haru_angry_03.mp4
Fear	1	haru_fear_01.mp4
Fear	2	haru_fear_02.mp4
Fear	3	haru_fear_03.mp4
Surprise	1	haru_surprise_01.mp4
Surprise	2	haru_surprise_02.mp4
Surprise	3	haru_surprise_03.mp4
Shy	1	haru_shy_01.mp4
Shy	2	haru_shy_02.mp4
Shy	3	haru_shy_03.mp4
Curious	1	haru_curious_01.mp4
Curious	2	haru_curious_02.mp4
Curious	3	haru_curious_03.mp4