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Exploration of Moving Things in the Home

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Abstract

One question we ask ourselves as we age is, "who will help us when we get older and need extra help?"

A natural answer to this question has, in the past, been younger members of the family or nurses and other members of the healthcare system. Future demographics of at least Europe and North America, however, highlight a trend that there will be a larger proportion of older, retired people than younger who can take care of them. This could mean that when an older person is in need of help, there is nobody to provide it.

One possible solution is to use information and communication technology to help older people maintain their independence and live at home longer. There are many ways this can be achieved. This Ph.D. dissertation focuses on having a mobile robot in the home that can monitor the vital signs of a person and potentially contact experts in event of a problem.

A robot in the home opens many areas of research. This dissertation, however, focuses on two areas. The first area we examine is the privacy issues of a robot in the home. Many of the technology solutions require collecting and processing data about the home residents. How can we examine and discuss the privacy issues related to a robot in the home? What trade-offs must we take into consideration when a robot is in the home environment?

The other area we examine is robot movement in the home, how a robot should move, and how it affects people's interaction with a robot. Can other disciplines, such as film animation, help make a robot move in ways that will lead to a better interaction?

Investigations into these aspects resulted in the four papers that are presented in this dissertation. It also resulted in the following additional contributions of: (*1*) a framework, with sample dilemmas, for examining privacy issues in a home environment with a robot. (*2*) a review of the use of animation techniques in human-robot interaction user studies, (*3*) an examination of one of the principles of animation and how it can be applied to a robot, (*4*) a way of examining and categorizing movement between a human and a robot in the home, and (*5*) an evaluation of how applying this principle to a robot's movement affects people's perception of the robot.

The contributions provide items that should be considered when one is creating a robot for the home. Examining the potential privacy boundaries that must be negotiated when a robot is in the home can lead to privacy-preserving robots. In addition, using animation techniques to move a robot may help in people feeling safer around a robot, and this can make robots easier to interact with in the home or anywhere we encounter them. These contributions can lead to safe and trustworthy human-robot interaction with older people in the home.

Contents

List of Papers

Paper 1

Schulz, T., Herstad, J., & Holone, H. (2018, July 15). Privacy at Home: An Inquiry into Sensors and Robots for the Stay at Home Elderly. In *Human Aspects of IT for the Aged Population. Applications in Health, Assistance, and Entertainment* (pp. 377–394). International Conference on Human Aspects of IT for the Aged Population. doi:10.1007/978-3-319-92037-5_28.

Paper 2

Schulz, T., Torresen, J., & Herstad, J. (2019). Animation Techniques in Human-Robot Interaction User Studies: A Systematic Literature Review. *ACM Trans. Hum.-Robot Interact.*, *8*(2). doi:10.1145/3317325.

Paper 3

Schulz, T., Herstad, J., & Torresen, J. (2018a). Classifying Human and Robot Movement at Home and Implementing Robot Movement Using the Slow In, Slow Out Animation Principle. *International Journal on Advances in Intelligent Systems*, *11*, 234–244. Retrieved January 16, 2019, from http://www.iariajournals.org/intelligent_systems/tocv11n34.html.

Paper 4

Schulz, T., Holthaus, P., Amirabdollahian, F., Koay, K. L., Torresen, J., & Herstad, J. (2019, October). Differences of Human Perceptions of a Robot Moving using Linear or Slow in, Slow out Velocity Profiles When Performing a Cleaning Task. In *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. 2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN). doi:10.1109/RO-MAN46459.2019.8956355.

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Preface

I have two memories that may explain my pursuit of this Ph.D. The first memory is from when I first thought about getting a Ph.D. in computer science. It was in the fall of 1997. I had started at Concordia College in Moorhead, Minnesota. I was sitting in the infamous Room 226 in the Ivers Science Building, and I had just read an article from the ACM arguing that getting a Ph.D. was the thing to do. The additional years of study would be over quickly and Ph.D. students were paid for their work. It may have been a desperate plea from universities losing students to what would later be called the "dot-com bubble", but this resonated with me. For some reason I had decided in that room, talking with fellow students, that I would get this Ph.D.

The second memory is a conversation I had with my mother on an occasion of my parents visiting Norway. She suggested that I get a dog. I felt that cooping up a dog in a small apartment for the good part of a day was cruel. But a *robot* dog, like the Aibo (Figure 1), wasn't a problem. I began looking for a used Aibo that evening. I could tell by mother's rolled eyes that I had missed her point.

FIGURE 1: The Aibo 210 that I eventually purchased.

It may have taken longer than I thought, and the path was more twisted than expected. But it appears that I'm reaching that goal. I'm pleased that I could combine several of my interests (robots, animation, and privacy) into an intense period of study. Conventional wisdom states that one should try to research something that piques your interest to maintain motivation. Yet I suspect it is seldom that interests can line up so well.

Acknowledgments

Research is rarely a solitary endeavor. There were many fellow researchers, co-authors, and well wishers that provided support and assistance along the way. I doubt I can name everyone, but I will attempt to describe them here. I'll start with those closest to the research and move outward.

Crafting focused research from different fields for a Ph.D. requires guidance. I was fortunate to have wise and experienced guidance from my main supervisor Jo Herstad and my second advisor Jim Tørresen. Jo and Jim provided perspective from the fields of human-computer interaction and robotics and provided opportunities for exploration and valuable feedback to my research. Their advice improved the quality of the research and kept my explorations largely on track.

Spanning out from this are the people from the MECS project. They provided a welcoming environment for discussing research and allowed a sharing of activities and research. Diana Saplacan and Rebekka Soma were essential in their efforts on the different activities at Kampen Omsorg+, and providing feedback on several articles. Weria Khaskar and Md. Zia Uddin provided valuable insights into the working of robots and sensors that increased my understanding and led to better articles on these subjects. A special thanks to MECS partner Kampen Omsorg+, its past leader Marit Müller Nilssen, and its current leader Sol Gangsaas. Kampen Omsorg+ were gracious enough to let us work with their employees and residents. I am grateful for the time these people granted to us, their assistance in activities, and the insight that they provided.

Moving out from the researchers that were part of MECS, the Design of Information Systems group (or Design group) and the Digitalization and Entrepreneurship group (or DIGENT group) also provided useful insight and guidance on research, plus sharing experiences from Ph.D. and university life. These includes my fellow Ph.D. candidates outside of MECS: Alice Frantz Schneider, Andrea Gasparini, Ines Junge, Johanne Svanes Oskarsen, Jorunn Børsting, Klaudia Carcani, Sumit Pandey, and Swati Srivastava and the permanent staff: Tone Bratteteig, Gisle Hannemyr, Svein Anton Hovde, Suhas Govind Joshi, Guri Birgitte Verne, Alma Leora Culén, and Maja Van Der Velden.

Moving beyond the University, thanks go to the Research Council of Norway for providing the funding for the MECS project. They also provided extra funding that allowed me to travel to England to conduct research there. This Ph.D. would not have been possible without their support. Thanks also to the Norwegian Computing Center (*Norsk Regnesentral*) that provided a leave of absence for doing the Ph.D. and a safe harbor for return. Knowing that one has a place of future employment when the funding for a Ph.D. is over reduces stress considerably.

Part of my research happened at the University of Hertfordshire. Patrick Holthaus, Farshid Amirabdollahian, and Kheng Lee Koay from the Computer Science group provided extensive help in providing suggestions for the experiment, where and how to recruit participants, and help in the running the experiment. A special thank you also to Frank

Foerester, Silvia Moros, Alessandra Rossi, Marcus Scheunemann, and all the others in Hatfield for making me feel welcome and providing a tour of Ph.D. and researcher life in Hertfordshire.

Thanks to the "trial disputation" committee of Petter Nielsen and Kai Olav Ellefsen. They provided valuable feedback that improved the final dissertation.

Alan Becker gave me permission to use screen grabs from his series on the 12 Principles of Animation. These images improved my introduction on the subject in the second chapter and were much better than what my drawing skills could produce in the time I had before the deadline. I can recommend checking out Alan Becker's YouTube channels and tutorials.

Alisdair Grahmn-Brown provided proof-reading and copy-editing that substantially improved the final draft of the dissertation.

Outside of the people directly connected to the dissertation, I'd like to thank my Mom and Dad—Kyle and Tom Schulz—and my brothers—Tanner and Thad Schulz—for support and good thoughts during my research. Even though they are far away, I'm glad for their support. I also appreciated timely and sagely advice from Jasmin Blanchette.

Finally, I would like to thank my wife Anne Jeanette Sylta. Jeanette was by my side from the start of this Ph.D. She provided constant support through times of contemplation, long evenings, and weekends. She helped put things in perspective, took up extra slack on the home front, and provided motivation to finish. I'm glad we made it here together.

Part I

Thesis Summary

1 *Introduction*

> **Fry**: Wait! You're the only friend I have!
> **Bender**: You really want a robot for a friend?
> **Fry**: Yeah, ever since I was six.
>
> *Futurama*, Season 1, Episode 1: "Space Pilot 3000"

A possible future scenario that we are often presented with is one in which *robots* move around and help us in our homes. A robot here refers to a physical object that interacts with the physical environment, either on its own or via a person, to accomplish a task. The physical form is important for this definition of the robot. For the purposes of this dissertation, software programs, or algorithms on their own (for example, a "chatbot" or a trading algorithm) are not considered to be robots.[1]

Siciliano and Khatib (2016) document how the idea of robots has been around for centuries with references in Greek myths (3500 BCE) to the Babylonian water clock (1400 BCE) to inventions of Al-Jazari (1200 CE) and Leonardo di Vinci (1500 CE). This is long before the word "robot" was used by Čapek in his 1920 play *R.U.R.* in which he depicted robots aiding us in all sorts of tasks (Čapek, 1920). The robots in Čapek's play are, however, created chemically and are more human-like than the mechanical automatons we normally associate with robots.

Today, robots assist people in different ways and in different environments. For example, a robot can assemble items in a factory, perform demolition disposals, or travel into areas that are dangerous for people such as zones of high radiation or even other planets. In the future, robots may provide assistance when a person is not available. The research problem of this dissertation is to add a robot to a home environment. The robot will help people to live independently at home longer by being less dependent on care givers.

Unfortunately, the *home environment* is an area where robots have been less successful. The home environment or home context includes the people, pets, locations, and other things that we find in the home (Figure 1.1 provides an example). People often feel safe at home. The home context provides a place of familiarity where people can be themselves, relax, and keep their secrets, passions, messes, and personal information safe. Though a home environment feels safe and familiar to the home's residents, each home is varied and not a controlled environment. This is especially true when compared to other contexts such

1. The question of what is and is not a robot may seem straightforward. There, however, appears to be room for ambiguity. For example, Norman (2005b) argues that appliances like dish-washing machines and microwaves are robots, but others (myself included) disagree since they do not move or interact with the environment. There is also a recorded dispute over whether a machine gun is a robot (Hodgman & Thorn, 2010).

as work places or public spaces. The home's varied and complex environment means that we may find robot vacuum cleaners or robot lawn mowers in some homes, but no robot butlers or robot housekeepers.

FIGURE 1.1: Example of an apartment in Kampen Omsorg+ in which a robot vacuum cleaner has been installed.

There are many aspects that can be examined in bringing a robot into a home environment. This dissertation will examine two. The first aspect is privacy for the home residents when a robot is in the home. Robots typically have a number of types of sensors that gather different types of information. It is important to understand the data that is collected and how this interacts with humans. It is also import to understand that residents do not wish to share all their information with a robot and its potential controllers. These privacy boundaries must therefore be negotiated. Finding a way to identify, model, and address these privacy concerns can make the robot easier to have in the home.

The second aspect looks at how robots move in the home. Traditional control techniques make a robot move in a slow, mechanical way. But what happens when a robot moves in a more lively way? How does this affect people's perception of the robot? There are many ways robot movement can be achieved. One way is to draw inspiration from the world of animated film. Animation has been making drawings of objects easier to relate to and understand for generations of people watching films. Animation techniques are also now part of computer graphics and of user interfaces for computers, mobile devices, and other technology (Chang & Ungar, 1993; Lasseter, 1987). One could, in fact, argue that animation and computer graphics play a major role in modern, live action blockbuster films. Animation techniques could therefore be used to make robots move in a smoother and more natural way, which could help make robots easier to interact with in our homes or anywhere we encounter them.

Before looking further at these topics, let us first examine the context where this research begins. This can help clarify the motivation and aim of this work.

1.1 Motivation & aim

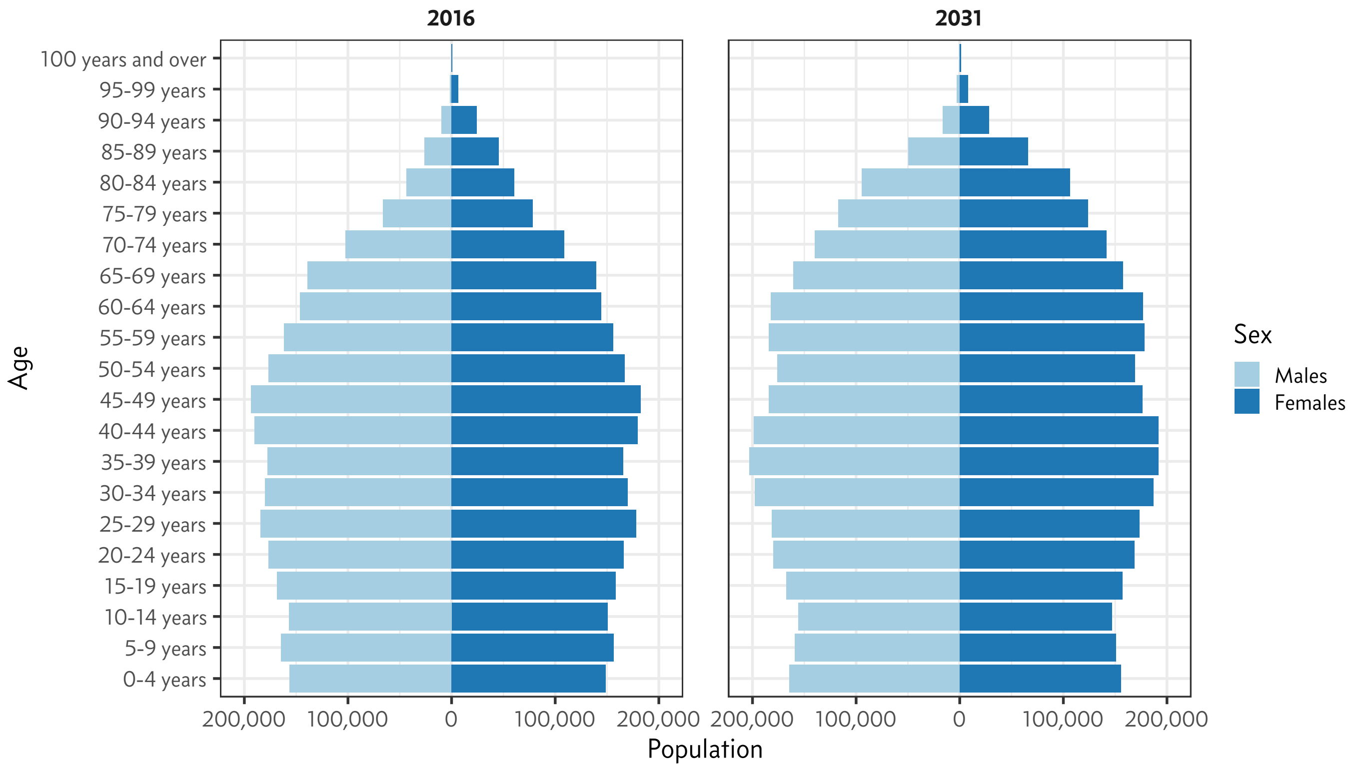


FIGURE 1.2: Population pyramids of the Norwegian population in 2016 and projections for 15 years into the future (2031). The 2031 charts show a bulge for people over 60 years, indicating a smaller ratio younger individuals to older individuals when compared to 2016. Source: Statistics Norway. Projections based on Main alternative (MMMM).

We start by examining the research problem and context for the dissertation. Then, we introduce the Multimodal Elderly Care System research project, the project that this dissertation is a part of. Finally, we will examine my research activities inside the project.

1.1.1 *The research problem*

A rapidly approaching issue in Norway and many other countries is *eldrebølgen*[2]. The literal translation of this into English is *senior wave*. This is the concept that the number of older, retired people (hereafter referred to as older people) compared to the number of working people is increasing (Figure 1.2) and is projected to keep increasing (United Nations, Department of Economic and Social Affairs, Population Division, 2017). Based on data from Figure 1.2 (Leknes, Løkken, Syse, & Tønnessen, 2018), there were around four (4.005) people aged 15 to 64 for every one person aged 65 and older in 2016. In 2031, there will be *under three* (2.986) people aged 15 to 64 for every one person aged 65 and older. Older people may therefore face a shortage of human caregivers, unless immigration provides additional caregivers or increases the efficiency of overall health and self-care increases. The lack of congregate living facility availability and older people not wishing to move into these facilities and live collectively, will mean that older people will have to live independently at home longer, possibly aided by new technology. This wave will eventually peak and the ratio will return to historical values. In the meantime, society needs to address this issue.

2. This research was carried out in Norway. There are therefore words for concepts with no direct equivalent in English. Where there is no good translation, the original Norwegian word is used, but quickly explained.

This independence at home also means that people must live safely at home. For example, residents may handle many tasks on their own, but may need occasional reminders for things such as taking medicine, eating a meal, or turning off a stove burner. People may trip and fall and not manage to get up on their own. Lying on the ground for hours may also complicate the fall's injuries. Technology could help by watching over residents, their schedules, and the items in the home. They could also notify others if something happens, bringing timely help to the home in the case of an emergency situation. Combining these technologies with artificial intelligence may even make it possible to predict a possible event, such as a fall, before it happens. This type of technology is called *welfare technology* (Norwegian: *velferdsteknologi*).

1.1.2 *The Multimodal Elderly Care System*

This dissertation is part of the Multimodal Elderly Care System (MECS) research project. MECS examines how newer technologies can help older people live independently longer at home, the project is aiming to develop additional welfare technology that can assist those with health-related issues to live longer at home. The project focuses on robots and sensors that can help monitor the older person staying at home, predict any issues, and contact others where appropriate. Robots were selected as they may be easier to relate to than cameras and other sensors that would be installed throughout the house and monitor older people in every part of their home. A robot may detect a problem earlier when the person needs help, (e.g., where the person is in danger of falling), and perhaps even intervene. Robots may also provide a better metaphor for older people with regard to collecting data and maintaining privacy than a house in which many built in sensors are installed. For example, instead of moving to rooms with no sensors, it might be possible for older people living at home to ask a robot, and by extension all its on-board sensors, to leave the room to give them privacy (T. Schulz & Herstad, 2018).

MECS is not the only project that has examined the use of technology to help people live independently at home longer. The European Commission has funded many research projects focusing on this issue, several have involved robots. Some examples of these projects include: ACCOMPANY, which included testing robots with older people in a home-like setting called Robot House (Amirabdollahian et al., 2013); MARIO, which was aimed at having a robot assist people with dementia (Felzmann, Murphy, Casey, & Beyan, 2015); and ExCITE (Cesta, Cortellessa, Orlandini, & Tiberio, 2016), which used a robot for *telepresence*, that is providing the feeling of presence, of caregivers, friends, and relatives in the home of older people.

MECS examines the issue of older people living independently at home longer in the Norwegian context and is based on the multidisciplinary work of user-centered design, robotics, and sensor experts. The users were the residents of Kampen Omsorg+, an independent living facility in Oslo. Kampen Omsorg+ provides a café and common areas for different activities. The residents, however, have their own apartments (Figure 1.1) and live their own lives. The residents' experiences and opinions helped inform our requirements and the design of a solution for the project.

1.1.3 Research work in MECS

The overarching aim of this dissertation is to create a robot that can help older people live safely and independently at home. This research began by examining the privacy issues associated with having a robot in the home. This concern is reflected in previous projects in which the focus was on trust in devices and accessibility for future security technology (Fritsch, Groven, & Schulz, 2012; T. Schulz & Fritsch, 2014). If robots are to be an easier metaphor for understanding data collection, we needed to understand the privacy issues they raise. We used the concept of privacy as a boundary as originally presented by Altman (1975). The concept is based on the idea that a person has personal information and erects a boundary to limit access to that information.

Others may, however, gain access to this information by negotiating the boundaries with the person concerned. This concept of a privacy boundary was developed into a framework for examining network privacy issues in computer-supported cooperative work in the workplace. We applied this boundary framework to a new arena, a robot helping older people in a home environment. This work was documented in Paper 1. The papers will be introduced in Section 1.3.

Other areas of interest were robot movement when interacting with people, and how humans infer a great deal about a situation or a condition from how other people, animals, and objects move. How could robot movement contribute to this? In human-computer interaction (HCI), practitioners have used animation techniques to ease the interaction with and understanding of graphical user interfaces (Hudson & Stasko, 1993). This led us to examine applying animation techniques to robots and the effect of this.

Human-robot interaction (HRI) was something that was completely new to me at the start of this part of the research. I only knew about the basics of animation. The first step was therefore to examine the animation techniques and robots, to determine whether there was any overlap between the two, what this overlap was, whether any research had been carried out in this area previously, and the results of this work. Early in the history of animation, the *twelve principles of animation* evolved and are still influential today. It has been suggested that these principles can be an inspiration for robot motion (van Breemen, 2004b). Cataloging the use of animation techniques and robots therefore became a major task in this work and the literature search therefore morphed into a systematic literature review. The final result of this review formed Paper 2 in this dissertation, and represents a foundation for future work.

Researchers met with the residents at Kampen Omsorg+ and ran activities to help establish a set of robot requirements. These activities included a focus group that discussed robot appearance and what should happen when encountering a robot moving in a home environment (Figure 1.3). This included an experiment in which residents encountered robots that were programmed with different ways of moving, an extended vacuum cleaner robot stay in resident's apartments, and a workshop on the appearance and construction materials of robots in the home. These activities led to other research findings that are not covered in this dissertation (Bråthen, Maartmann-Moe, & Schulz, 2019; Newaz & Saplacan, 2018; Soma, Dønnem Søyseth, Søyland, & Schulz, 2018). These activities also provided the opportunity to explore some ideas about movement between a person and a robot. This exploration led to a classification system of the types of movement of

FIGURE 1.3: Focus group at Kampen Omsorg+ where the topic included robot appearance and if a robot should give way when encountering a person in a hallway.

a person or a robot—movement around a room, or just movement of parts of the body—and linked this to other familiar phenomena that we encounter in the world.

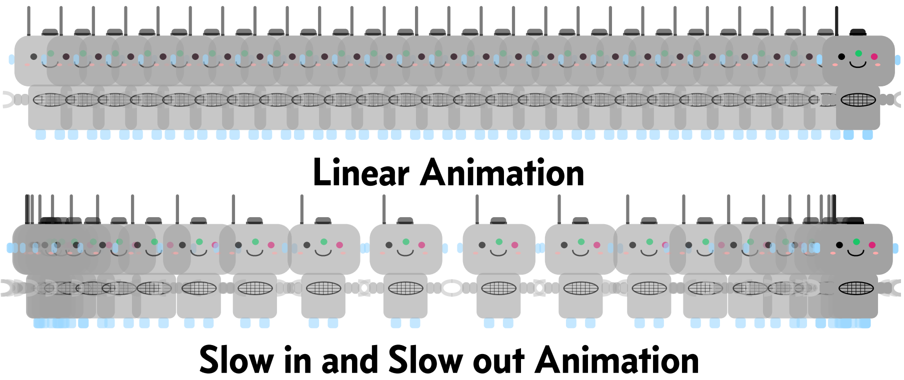


FIGURE 1.4: An illustration of a robot that moves using a linear animation (*top*) and a robot that moves using a slow out start and a slow in stop (*bottom*).

After the literature review was completed, we focused our examination on just one of the animation principles, *slow in and slow out*. This principle is also called *easing*, which is the idea that motion initially starts out slowly (easing out), gradually increasing to its full speed, then moving slowly in (easing in) to a stop (Figure 1.4). The everyday environment is full of this phenomenon. But robots are often propelled at constant speed without any easing. Our examination focused on a Turtlebot3 (Figure 1.5) and the *velocity profiles* of robots. Velocity profiles describe how a robot's speed changes over time. The Turtlebot3 used a linear profile, which has little of the slow in and slow out effect. An algorithm was therefore devised that added more of a curve to the

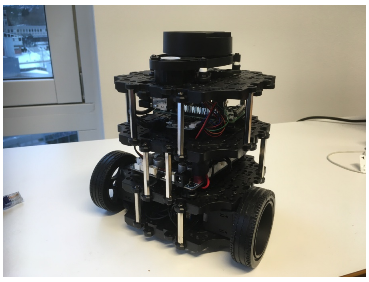


FIGURE 1.5: The Turtlebot3, "burger" variant.

robot's acceleration and deceleration, leading the robot to move more in accordance with the slow in and slow out principle (Figure 1.6). This also gave me the opportunity to appreciate some of the development challenges involved in working with robots. This algorithm and the above classification became Paper 3.

The next step was to explore how much just one principle could affect a person's perception of a robot. This part of the research was carried out in cooperation with the University of Hertfordshire. We, with the Hertfordshire group, ran a user study in their Robot House facilities using a Fetch robot (Figure 1.7). The study looked at how a person perceived a robot when working with the robot on a task. The experiment generated unexpected results and provided information about what might and might not work and about possible ways forward for future research. The study and results are cataloged in Paper 4.

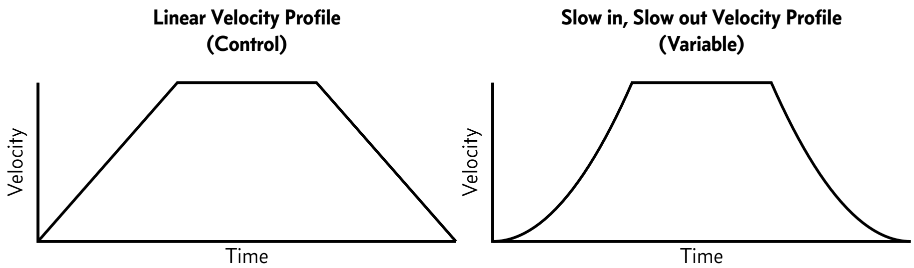


FIGURE 1.6: A comparison of the linear velocity curve (*left*) and a slow in, slow out velocity curve (*right*).

FIGURE 1.7: The Fetch robot used in the University of Hertfordshire's Robot House study.

1.2 Research Questions

The aim and motivation helped form the research questions that guided the Ph.D. research. The questions and their sub-questions are presented below.

RQ1. What are the privacy implications of having a robot in the home?

- RQ1.1. How can we examine and discuss privacy issues associated with having a robot in the home?
- RQ1.2. What privacy issues and trade-offs must we be aware of when having a robot in the home environment?

RQ2. How does the use of animation techniques to move robots affect people's interaction with robots in a home environment?

- RQ2.1. In what ways can a robot's movements be used to make it easier to relate to the robot and, by extension, make it easier to have in the home?

RQ2.2. How can an animation principle be applied to robot motion?

RQ2.3. How does the use of animation techniques affect people's perceptions of robot motion?

Complete and final answers to Ph.D. research questions are not always forthcoming. Such questions do, however, help define the contributions arising from the research.

1.3 Contributions

This is a *kappa* or paper-based dissertation. The first set of contributions are therefore the papers that are included in the dissertation. Longer introductions to each paper are given in Chapter 4. We, however, present the titles and their venue here:

Paper 1 "Privacy at Home: An Inquiry into Sensors and Robots for the Stay at Home Elderly". Published in *Human Aspects of IT for the Aged Population. Applications in Health, Assistance, and Entertainment*, which is part of 2018 International Conference on Human Aspects of IT for the Aged Population.

Paper 2 "Animation Techniques in Human-Robot Interaction User Studies: A Systematic Literature Review". Published in the *ACM Trans. Hum.-Robot Interact.*, Volume 8, Issue 2, Article 12.

Paper 3 "Classifying Human and Robot Movement at Home and Implementing Robot Movement Using the Slow In, Slow Out Animation Principle". Published in *International Journal on Advances in Intelligent Systems*, Volume 11, Issues 3 & 4.

Paper 4 "Differences of Human Perceptions of a Robot Moving Using Linear or Slow in, Slow out Velocity Profiles When Performing a Cleaning Task". Published in the proceedings of *2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)* in New Delhi, India.

Each paper should answer one or more of the research questions presented in Section 1.2. The breakdown between papers and research questions is given in Table 1.1.

Below are listed other contributions.

TABLE 1.1: Breakdown of research questions addressed by paper.

Paper	Knowledge for Research Questions
Paper 1	RQ1.1., RQ1.2.
Paper 2	RQ2.1., RQ2.2., RQ2.3.
Paper 3	RQ2.1., RQ2.2.
Paper 4	RQ2.1. RQ2.2., RQ2.3.

1. A *framework* for examining privacy issues in a home environment in which there is a robot. This boundary framework is based on the boundary framework of Palen and Dourish (2003). It helped us create and examine scenarios and the issues that arise, and classify them into well-defined groups. Such example scenarios in the form of dilemmas can be used in other design work. The framework is ready for further exploitation. For example, the framework could help lawyers, developers, and researchers examine the compliance issues present when designing a robot that is to comply with the European General Data Protection Directive (GDPR) (The European Union, 2016). This contribution is documented in Paper 1.

2. A *literature review* of HRI user studies that incorporated animation technique. Researchers, designers, and practitioners who aim to use animation techniques to achieve better interaction between humans and robots, should be aware of research previously carried out in the area. Animation techniques have been used in a number of studies. Conversations have also shown interest in these areas across a wide and diverse group, particularly in the design area. The literature review provides an introduction to the area, some terminology from animation (e.g., the twelve principles of animation), a snapshot of the research previously carried out and how it was evaluated, and future areas of exploration. This contribution is documented in Paper 2.

3. An *examination* of one the principles of animation (slow in and slow out) and how it relates to the movement of a robot. This includes an *implementation* of a slow in and slow out velocity profile on wheeled robots. This contribution is documented in Paper 3.

4. A *categorization* of movement between a human and a robot in the home using phenomenology. The categories can aid the discussions of researchers who are exploring robot movement in the home and can serve as a springboard for the creation of a more advanced classification framework. This contribution is documented in Paper 3.

5. An *evaluation* of the differences between people's perceptions of slow in and slow out and their perceptions of regular linear acceleration applied to a task in a home environment. This study did not find a pronounced effect. The items evaluated may therefore have been too broad. The study, however, shows how other events in the environment (i.e., breakdown situations) may interact with perceptions. It also points to areas where studies that focus more on one topic, such as safety, may uncover interesting results. This contribution is documented in Paper 4.

Contributions in computer science can be divided into two categories: *practical* and *theoretical*. Practical contributions are specific and can be applied by researchers and practitioners to solve or understand a specific problem. Theoretical contributions contribute to the theory of the discipline (such as HRI and HCI) or generate knowledge for the community in general. Some contributions fall into both categories. Table 1.2 lists the contributions of this dissertation, the paper where the contribution may be found, and the category of the contribution.

Contribution	**Paper**	**Practical**	**Theoretical**
Contribution 1.	Paper 1	⋆	⋆
Contribution 2.	Paper 2	⋆	⋆
Contribution 3.	Paper 3	⋆	
Contribution 4.	Paper 3		⋆
Contribution 5.	Paper 4	⋆	⋆

TABLE 1.2: Contributions by paper, stars indicating the contribution category.

1.4 Structure of the dissertation

The dissertation is divided into two parts. Part I provides a summary and the extended context of the papers in Part II. Part I chapters should be read in numerical order. Part II chapters can be read in any order.

This chapter, Chapter 1, states the overarching aim and motivation of the research and a provides a summary of the contributions.

Chapter 2 provides the background for the dissertation and attempts to place the research in the context of the fields of research.

Chapter 3 details the methods and methodology used in the dissertation. It also documents some project activities. Only some of the activities were included in the papers in this dissertation. All activities, however, helped form the research of other papers.

Chapter 4 provides a summary and motivation for each of the four papers included in this dissertation.

Chapter 5 discusses the papers, their contributions, and some ethical considerations.

Chapter 6 provides a final summary and possibilities for future work. It ends Part I.

Part II reprints each of the four papers, each in a separate chapter.

2 *Background & Field of Research*

> Although the objective of the Trukese navigator is clear from the outset, his actual course is contingent on unique circumstance that he cannot anticipate in advance.
>
> Lucy Suchman
> *Human-machine Reconfigurations: Plans and Situated Actions*, Second Edition, p. 25

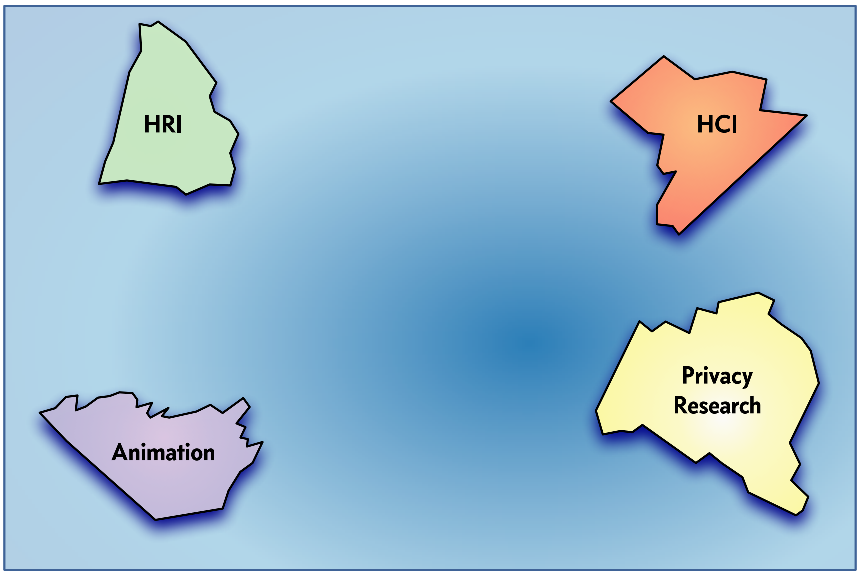


FIGURE 2.1: The metaphorical islands of research that the dissertation's research is placed in.

MECS is a multidisciplinary project. This, however, leads to the question of which disciplines are included in this multidisciplinary approach? This project is an information and communication technology (ICT) project, which implies that it is a computer science project. But there are many fields within computer science. The different fields of computer science can be envisaged as islands in an archipelago, connect by the bridges and ferries between them.[1] This chapter aims to determine which island or islands are the home bases for this research and which islands we travel between (Figure 2.1).

We start this journey by covering human-computer interaction (HCI) and human-robot interaction (HRI). This dissertation, however, also includes animation techniques and privacy. We therefore briefly explore these areas and build a connection between them and their use in HCI and HRI. This examination ultimately covers parts of previous research carried out in these areas.

1. This metaphor was introduced to me by Dag Svanæs at the NordiCHI 2018 doctoral consortium. Like all metaphors, it can help us understand an idea, but we should not let it override where it no longer makes sense. For example, it fails to acknowledge overlap within sub-fields. But it works well in situating one's work.

2.1 Human-Computer Interaction

Human-computer interaction (HCI) is a combination of a number of different disciplines. Authors have put together chronologies for HCI, but these chronologies all differ slightly. The interpretation presented here is informed by Dix, Finlay, Abowd, and Beale (2004); Shneiderman and Plaisant (2004); and Mackenzie (2013).

HCI has its roots in *human factors* (also called *ergonomics*) research. Human factors research is broadly concerned with human capacities, performance, and limits. This research is being used to create and ensure that systems are efficient, safe, and comfortable for humans. Office workers may be familiar with ergonomic office chairs, adjustable desks, and ergonomic keyboards. Ergonomic chairs help workers maintain their posture when working, so reducing back pain or other injures. The height of adjustable desks can be adjusted to allow workers to stand or sit when working. Finally, ergonomic keyboards are designed to ensure people place their hands correctly on the keys, resulting in less pain over the long term and reduces the risk of other repetitive strain injuries.[2] The human factors associated with how people worked with computers also began to be examined as computer operation became less of a specialized profession and began to enter the ordinary workplace.

2. It is possible to use a regular keyboard, desk, and chair over long periods of time with no injury. But it requires vigilance to hold your hands correctly, maintain your workspace at a correct height, take breaks to get up and move around, and otherwise maintain a good posture when sitting. Ergonomics products are designed to make this easier.

The field of *information science* at the same time became interested in how people used computers. Information science looks at presenting information in a way that makes it easily understood by the people using it. A computer's primary task is to process and output information. Studying how this computer-processed information is presented to humans therefore seems a natural topic for information science.

The final HCI root is computer science and system designers. Computers ultimately would be used by people who were not computer experts. Creating systems that could be used by non-experts therefore became more important. This is where HCI found its home. HCI became an area of study in the early 1980s and has remained specialization area in the other disciplines.

HCI has no official date of birth. Mackenzie, however, ties the birth of HCI to the Association of Computing Machinery's (ACM) creation of a special interest group in computer-human interaction (SIGCHI) and this group's first conference in 1983 (Mackenzie, 2013). 1983 was also the year when the book *The Psychology of Human-Computer Interaction* was first published. It was written by Card, Newell, and Moran, and was an attempt to create an applied psychology for those working with computers. The authors' goal when writing the book was to create models of how humans work with computers and use these models as guidance when creating software. Card et al. used ideas from psychology such as Fitts's law for selecting an item (Fitts, 1954) and Hick's law for making choices (Hick, 1952). The book also chronicled concepts such as Goals, Operators, Methods, and Selectors (GOMS) and the keystroke-level model (KLM) (Card, Moran, & Newell, 1980).[3]

3. Incidentally, my background in computer science and programming drew me to this branch of HCI. Earlier, I had read Raskin's *The Humane Interface: New Directions for Designing Interactive Systems* (2000) and was excited by the work of Card et al. (1983) who created models of interaction. I used this as the basis for my master thesis (T. W. Schulz, 2008).

Bødker (2006) has divided the history of HCI into metaphorical waves (Figure 2.2). She described the beginning of HCI as the *first wave*. HCI grew quickly beyond this first wave of examining one person and a computer. As networking technology became more prevalent, research was directed at how computers could support people working together to accomplish a task. This became the research area of computer-supported cooperative work (CSCW). How computers and technology can affect entire organizations (Information Systems) also evolved as a further area of study. This development also led to new ways of looking at HCI, knowledge from different areas being drawn on and new methods such as user-centered design and participatory design being used to create systems. This era was the *second wave* of HCI. We will explore these methods and areas of knowledge more in Section 3.1.

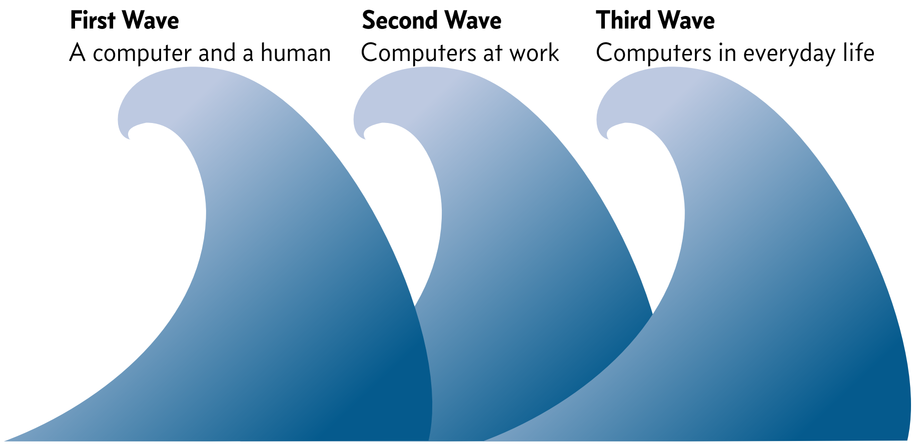


FIGURE 2.2: The three metaphorical waves of HCI. The first wave of HCI research looked at the interaction between a computer and a human; the second wave looked at the interaction between computers and people in the workplace; the third wave looks at the interaction between people and computers in many parts of everyday life.

Bødker (2015) asserts that we have entered a *third wave* of HCI in which technology has moved outside of the workplace and into homes and many people's everyday lives. Mobile telephone use, mobile phone applications, video games, "smart" televisions, and websites are all now a part of HCI. One could argue that robots are also on this list of technologies. Not just computer scientists are interested in HCI, but also psychologists, graphic designers, technical writers, anthropologists and sociologists (Dix et al., 2004). An increase in the range of uses of HCI therefore also require the expertise of policy analysts, economists, lawyers, privacy advocates, and experts in ethics (Shneiderman & Plaisant, 2004). No one can become an expert in all these areas and methods. A team of experts that can work together is therefore necessary. HCI research can therefore introduce new designs or new ways of interaction (Campatelli & Mehic, 2018; Takehara, Murata, & Yoshikawa, 2018), models of interaction (Card et al., 1983; John, Prevas, Salvucci, & Koedinger, 2004), theories of interactions (Bødker, 2006; Harrison & Dourish, 1996), or a mix of these.

2.2 Human-Robot Interaction

Human-robot interaction (HRI), like HCI, has its origin in the coming together of a number of different fields to examine how a technology and humans interact. HRI resulted from the bringing together of researchers from artificial intelligence, robotics, cognitive science, human factors, natural language, psychology, and HCI. The summary presented here is based on a classification by Thrun (2004) and a larger survey by Goodrich and Schultz (2008) that is intended to introduce people to the discipline.

There have, based on the definition in Chapter 1, been robots throughout the twentieth century. Scholtz (2003) states that the origins of HRI is in the teleoperation of robots by humans in factories. The field of HRI research did not, however, emerge until the 1990s. This emergence can be marked by the creation of several robotics conferences starting with the IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN) in 1992 (Goodrich & Schultz, 2008), which is still held today. Other robotics and artificial intelligence conferences at this time held workshops or sessions that focused on HRI.

A number of conferences and events began to appear at the beginning of the 2000s that only looked at HRI. One of the larger conferences was the ACM International Conference on Human-Robot Interaction. This conference started in 2006 as a venue for the multidisciplinary work in HRI. It was, in the following year, co-sponsored by ACM SIGCHI, ACM Special Interest Group on Artificial Intelligence, and the IEEE Robotics and Automation Society (RAS), with technical sponsorship from the Association for the Advancement of Artificial Intelligence (AAAI), the Human Factors and Ergonomics Society, and the IEEE systems, man, and cybernetics society. Collaborations with the three main sponsors and AAAI has continued in succeeding conferences including the 2019 conference.

HRI defines interaction as the communication between a robot and a person. This interaction can be split into two categories: (*a*) Remote (or indirect) interaction, where the person interacts with a device at a distance from the robot and the information flow is normally one way; that is, the robot provides sensor information and the human may provide control information. (*b*) Proxemic (or direct) interaction, where the person interacts with a nearby robot and information flow is bidirectional; that is, both humans and robots exchange information (Thrun, 2004). A very broad interpretation of interaction could, of course, also include programmers among those involved in HRI (Goodrich & Schultz, 2008).

There are different ways of classifying robots. Thrun (2004) attempted to classify by differentiating between industrial robots (robots in industrial settings such as factories and warehouses), professional service robots (robots that provide service in hospitals or dangerous environments), and personal service robots (robots used in domestic settings). Goodrich and Schultz (2008) rejected classifying robots by where they are used and instead focused on the roles a robot can take in interaction and the different areas of application. Roles are based on a classification by Scholtz (2003): (*a*) supervisor, (*b*) operator, (*c*) mechanic, (*d*) peer, and (*e*) bystander. Goodrich and Schultz add (*f*) mentor to this.

Robots play these roles in different HRI application areas including (*1*) Search and Rescue—where robots are used to find and rescue people after a disaster, especially in urban environments. (*2*) Assistive and educational robotics—where robots help in a workplace, at a school, a teaching context, or in a home environment. The MECS project is under this application area. (*3*) Entertainment—robots engage people to entertain them, for example, a robot as part of a movie or a museum tour guide robot. (*4*) Military and police—teleoperated robots that help with tasks such as demolitions disposal. (*5*) Space exploration—robots that travel to other planets or other parts of space and report findings to scientists. (*6*) Unmanned air vehicles and unmanned underwater vehicles—teleoperated robots that explore the air and underwater.

Goodrich and Schultz in addition described a number of accepted practices in HRI research (examples in parenthesis): (*a*) including experts from multiple disciplines (Hoffman & Ju, 2014), (*b*) creating real systems (Breazeal, 2002), (*c*) conducting experiments blending simulation and physical robots (Saerbeck & Bartneck, 2010), (*d*) establishing standards and common metrics (Bartneck, Kulić, Croft, & Zoghbi, 2009), and (*e*) longitudinal studies (Cesta et al., 2016).

Dautenhahn (2018) has also challenged researchers to test robots in real-world contexts, such as a home or work environment, and not through using a video or in labs. She and the University of Hertfordshire have led this work by creating a living room environment for conducting studies (Dautenhahn et al., 2005) and, later, a complete furnished house (Lehmann, Saez-Pons, Syrdal, & Dautenhahn, 2015; Salem, Lakatos, Amirabdollahian, & Dautenhahn, 2015; Syrdal, Dautenhahn, Koay, & Ho, 2014). Other researchers have sent robots out to travel around their university's buildings and interact with staff (Knight, Veloso, & Simmons, 2015).

A number of these practices can be seen in the dissertation papers. Paper 3 suggests how to create a system, Paper 4 is an experiment of the system using a real robot in a home and the common metric of the Godspeed questionnaire, and Paper 2 can be seen as being an attempt to build knowledge that can help in future standards and metrics. All the papers are co-authored with researchers from different areas of computer science.

2.3 Privacy research

Privacy research is linked to security research. It is not so much an island, but a continent that includes law, mathematics, statistics, and computer science. The research into privacy research, even where we limit ourselves to the computer science side (information security), includes research on networking systems using different algorithms (Abie et al., 2010, 1 & 2; Hamdi & Abie, 2014), modeling the trust between people and systems (Fritsch et al., 2012; Leister & Schulz, 2012), systems for managing ones identity (Røssvoll & Fritsch, 2013; T. Schulz & Fritsch, 2014), and privacy (Zibuschka, Fritsch, Radmacher, Scherner, & Rannenberg, 2007).

The main area of focus in our work is, however, the privacy issues that can arise for people in a home. Privacy is, however, an intuitive concept. It is frequently discussed, but is rarely defined. Privacy has been discussed in the computer science world in terms of, for example, (Crabtree, Tolmie, & Knight, 2017): (*a*) control; (*b*) boundary; (*c*) contextual integrity; (*d*) paradox, trade-off, and concern; and (*e*) protective measure.

The control frame is normally attributed to Westin (1967). In this, privacy is framed in terms of a person who controls the flow of personal information to those who need to receive it. We can see this control frame in many of the privacy policies we encounter on the web in Europe. It can, however, be difficult to identify all personal data and control its flow, particularly when we take into consideration all the ways we are monitored in everyday life.

An alternative frame could be the boundary frame. This frame is taken from Altman (1975) who presents privacy in terms of a person who creates a boundary between that person's personal information and others. Access to the personal information is negotiated between that person and the party who whishes to access it. This provides a more complete picture of dealing with privacy policies on the web and negotiating what data is available and how it can be used.

Nissenbaum (2004) frames privacy as contextual integrity. Personal information can, in this approach, flow to different recipients. But what data is transferred and to who is dependent on the norms for the context. One could argue that this is comparable with negotiating a boundary, the difference between the two being here that the norms for the context enforce additional requirements. Others have used contextual integrity to show that the concept of privacy can evolve with the norms of society and that privacy is not solely about the individual, but also about relationships with others (Ess & Fossheim, 2013)

Privacy can also be seen to contain paradoxes. For example, people may care about privacy, but in practice do not do much to protect it (Hart, 2019). Privacy can also be raised as a concern in the development of a technology. For example, Zibuschka et al. (2007) presented the privacy issues that can emerge from using location-based services and how privacy can be protected. Those who create or support a technology will often discuss the trade-off between the benefits of using a technology (for example, social networks or payment systems) versus the technology's personal information requirement and the potential harm access to this can lead to.

Finally, privacy can be framed as being a protective to counter attackers who want to access your personal information. This frame is often used when discussing information technology and the ability of this to store a diverse range of information without us being aware of this (Bellotti & Sellen, 1993). The concept of *privacy by design*, in which privacy is taken into consideration right from the start of the development of an artifact or a service (Langheinrich, 2001), is also framed as a defense against the misuse of data.

Each of these frames are useful in different contexts. This dissertation uses the boundary framing from Altman (1975) in Paper 1 to explore privacy. This frame allowed us to make use of the boundary framework of Palen and Dourish (2003) that specifies three boundaries: (*a*) the disclosure boundary, (*b*) the identity boundary, and (*c*) the temporal boundary.

The disclosure boundary denotes the boundary for the things that we disclose about ourselves. This is probably closest to the idea of a person controlling the information and deciding when this information is disclosed. Creating a résumé for a job or wearing a t-shirt for a rock band can be examples of disclosing information through this boundary.

The identity boundary can represent the role that a person plays in specific situations. Sometimes a person is an employee. At other times the same person may have a role of coach, fan, friend, sibling, and spouse. Each of these roles involves different tasks. These roles, however, also involve different sets of information that are to be kept private and are to be shared.

The final boundary is the temporal boundary. This boundary denotes how information that is collected and stored over time can result in private information acquisition. For example, insurance companies may not be interested in someone driving without a seatbelt once, but would be very interested in a person that drove without a seatbelt repeatedly.

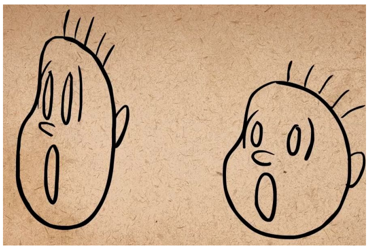


FIGURE 2.3: *Squash & Stretch*: A face stretching vs. a non-stretched face (Image courtesy: Becker, 2017).

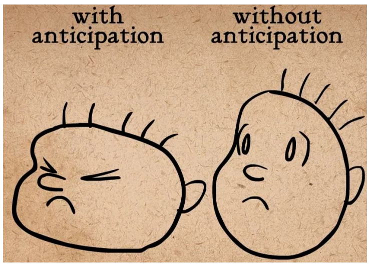


FIGURE 2.4: *Anticipation*: A face squashing in anticipation of being surprised (i.e., before Figure 2.3) vs. a face not squashing in anticipation (Image courtesy: Becker, 2017).

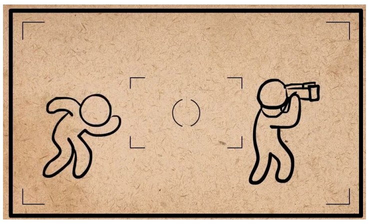


FIGURE 2.5: *Staging*: The position of the camera helps tell the story (Image courtesy: Becker, 2017).

These boundaries have been used in a number of case studies of shared calendars, family intercoms, ID badges, mobile phones, and instant messages to illustrate *genres of disclosure*. Genres of disclosure is a term to show that the disclosure boundary, the identity boundary, temporal boundary, social arrangements, and technical arrangements all interact with each other when negotiating privacy. They cannot be resolved independently. Palen and Dourish's framework reveals privacy concerns and shows where protective measures can be deployed. The boundary framework's identity and temporal boundaries can also be applied to finding additional contexts for disclosing data.

Some technology enthusiasts may hope that privacy can be protected purely through a technological solution (Levine, 2019). There is, however, also a legal dimension to privacy. Data capturing is only one aspect of privacy. What happens to the data and who owns the data are also important aspects. In Europe, the General Data Protection Directive (The European Union, 2016) contains regulations on the handling of data and on informing people about how their data is being used. The question of legal compliance and data protection (beyond how data is collected and used in research) is ignored in papers that focus on technology. This is also true for Paper 1. But we want to highlight that an approach that includes technology *and* law is needed to answer privacy questions.

2.4 Animation & the 12 principles of animation

Animation is an art form with a long tradition in films and other media. It is, in essence, an optical illusion; images changing quickly enough to be perceived as motion. Animation, unlike HCI and HRI, has a history of over 100 years. Many people are familiar with *flip books* a series of images that are flipped through quickly to give the illusion of movement. Devices such as the *phnakistoscope* and the *zoetrope* used a series of images of a motion on a sheet that, as it was rotated, depicted the motion (Williams, 2009). These devices were available in the 1800s. In the 1900s, animated short films such as *Gertie the Dinosaur* (McCay, 1914) showed the potential for animation. This and many of the earliest animated short films or cartoons are now in the public domain and easily available for viewing.

Many are interested in the animated films themselves. The interest in this dissertation, however, lies in what makes animated motion appear as it does. The style of the animation of the early films is primitive in relation to modern tastes.The style's evolution is traceable through changes in technology, audience understanding and expectations, and the techniques developed by the animators. Thomas and Johnston (1995) documented the methods animators at Walt Disney Studios used when creating their animations. Over time, the animators found a few methods that "... seemed to produce a predictable result," (Thomas & Johnston, 1995, p. 47). These methods were dubbed the *fundamental principles of animation* by the artists, and are taught to new animators (Williams, 2009).

These principles have never been examined scientifically. They have, however, been used in many financially successful animated films. Papers 2 and 3 review these principles, but an expanded treatment is given below.

Squash and Stretch Characters and objects should squash and stretch throughout an action. But they should not completely lose their shape. For example, a ball deforms, squashes, as it hits the floor and stretches as it reaches the top of the bounce before gravity pulls it down again (Figure 2.3).

Anticipation Major action should be telegraphed. Examples of this include reaching backwards before throwing an object, having an arm moving up before reaching down into a pocket, or a face compressing before reacting to a surprise (Figure 2.4).

Staging This principle is more about how a scene is presented to an audience than character animation. An action should be clear to the audience. For example, the audience should understand an action by only viewing it in silhouette, or a character is placed on the far side of a scene to give the audience the clue that something is entering on the other side (Figure 2.5).

Straight Ahead Action and Pose to Pose This principle relates to the drawing of an action. Straight ahead drawing is where the drawing of the action is begun and continued until the action is completed. Pose to pose drawing, however, sets a number of specific poses that are to occur in an action (Figure 2.6). These are

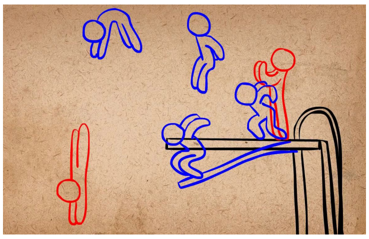


FIGURE 2.6: *Straight Ahead Action & Pose to Pose*: Examples of key poses layered together to define the action (Image courtesy: Becker, 2017).

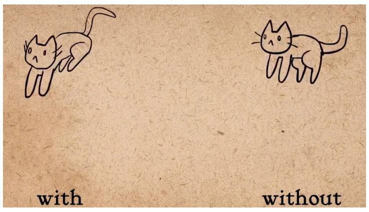


FIGURE 2.7: *Follow Through & Ovelapping Action*: A jumping cat has its tail moving and legs following through on the jump vs. no additional action (Image courtesy: Becker, 2017).

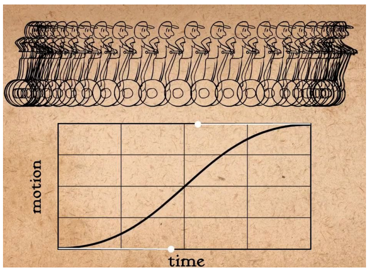


FIGURE 2.8: *Slow in & Slow Out*: The easing curve showing how motion is slower at the beginning and end (Image courtesy: Becker, 2017).

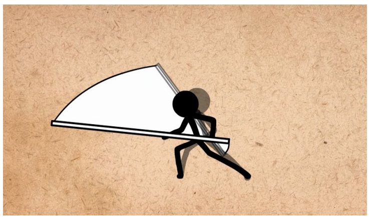


FIGURE 2.9: *Arcs*: a person swinging a staff moves in an arc (Image courtesy: Becker, 2017).

therefore choreographed before the animation is drawn. These different poses can also be called the *key frames* in modern animation. Using these ways of animating can lead to a different look of the final animation (Williams, 2009). Some animations can only be created using one of these methods (e.g., it is difficult to draw the frames between two key poses of fire).

Follow Through and Overlapping Action Actions are not performed in isolation. An animated character shows that it has a plan and moves from one action to the next without stopping. In addition, other parts of the characters body also move in response to the plan (Figure 2.7). This principle supplements anticipation and secondary action (presented below).

Slow In and Slow Out The speed of a motion is not the same throughout the motion. Action is slower at the beginning and end (Figure 2.8). This slow in and slow out movement makes a character's movement appear more natural.

Arcs Living creatures, including humans, do not move their limbs in a straight up or down or straight left or right movement. They move their limbs in arcs. Animated limbs should therefore also move in arcs (Figure 2.9).

Secondary Action Complementary actions that emphasize the main action. For example, a character licks his lips before taking a bite of a hamburger (Figure 2.10) or a character puts on a coat while walking out the door. Secondary actions aid in creating overlapping actions.

Timing Changes in the number of frames between a start and stop determines the speed of an action. Increasing the number of frames used for an action therefore decreases the speed of the action, and removing frames increases the speed (Figure 2.11). This principle is primarily relates to mechanics of film animation. Timing, however, also complements staging and how a scene is presented.

Exaggeration Exaggerated action makes it is easier for the viewer to understand the feelings of a character or the action that is happening (Figure 2.12). This principle is particularly effective when combined with the principle of anticipation.

Solid Drawing Drawings should look plausible and three-dimensional. Avoid creating *twins*, which are symmetrical limbs on a character, since it makes characters look stiff (Figure 2.13).

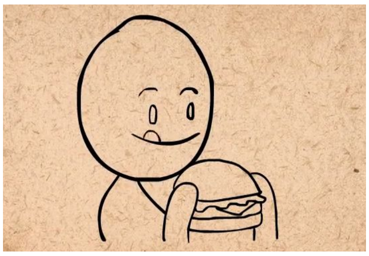


FIGURE 2.10: *Secondary Action*: A character licks his lips before taking a bite out of a burger (Image courtesy: Becker, 2017).

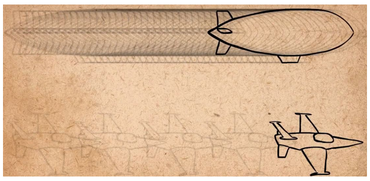


FIGURE 2.11: *Timing*: More frames of movement makes an item move slow and less frames makes an item move faster (Image courtesy: Becker, 2017).

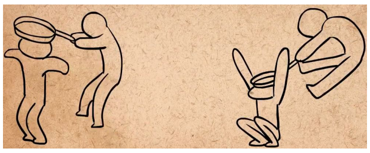


FIGURE 2.12: *Exaggeration*: Example of a person being hit with a pan being exaggerated (Image courtesy: Becker, 2017).

FIGURE 2.13: *Solid Drawing*: an example of symmetrical animation or *twinning* (Image courtesy: Becker, 2017).

Appeal All characters should be appealing irrespective of whether the viewer is expected to empathize or deprecate them. This principle relates more to the design of the character than to the animation. Creating appealing characters does, however, make it easier to watch and enjoy them (Figure 2.14).

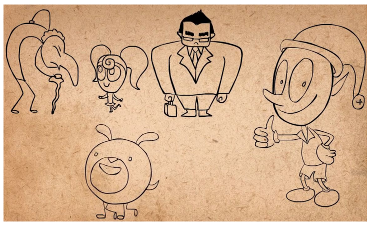


FIGURE 2.14: *Appeal*: Making a character design more dynamic or emphasizing certain body parts can make a character more appealing (Image courtesy: Becker, 2017).

2.5 Bridges & Ferries

We will now examine the connections between the areas of HCI, HRI, animation, and privacy research. We begin with the two computer science fields of HRI and HCI.

2.5.1 Connection between HRI & HCI

Goodrich and Schultz (2008) assert that HRI is a separate field. They, however, concede that there are convincing arguments that HRI is a part of another field such as artificial intelligence (AI), HCI, or robotics. I, having spent the last three years studying this area, tend to side with Goodrich and Schultz. HRI is, however, so multidisciplinary that the scope is wide enough for other disciplines to find a place within the field and contribute. HRI, for example, can be of interest to HCI researchers as the embodied nature of robots offers different challenges than ubiquitous computing environments where the computer is hidden. The physical presence of a robot has an effect that is different from displays (W. A. Bainbridge, Hart, Kim, & Scassellati, 2008). Others have argued that involving designers or using knowledge from fields like HCI may help in making robots in the home become a reality (Hoffman, 2019).

Creating robots requires the creation of software, hardware, and tools that make it easier for non-experts to create robots or program their behaviors. Suguitan and Hoffman (2019), for example, have presented Blossom, a social robotics platform that non-roboticists and designers can use in their research. Desai et al. (2019) have presented a method and software system that is targeted at novices and at the creation of more expressive robots. Blossom was presented in a HRI journal while Desai et al.'s software was presented at a HCI conference. The two could have been presented in the other venue, however. Serholt and Barendregt (2016) and Alves-Oliveira, Sequeira, Melo, Castellano, and Paiva (2019) both examine the use of empathic robots to teach children: one is presented at a HCI conference and the other in a HRI journal. The multidisciplinary nature of HRI therefore provides the opportunity for practitioners from other domains to be a part of the research and spread findings to other fields.

2.5.2 Connection between HRI & animation

We can see that animation has a presence in computer graphics (Lasseter, 1987). Animation is, however, also a HRI area of research. Paper 2 provides an extensive overview of the use of animation techniques in HRI user studies, and Paper 4 adds to this research via its experiment using animation techniques.

Animation has also been used as inspiration in the design of different robots. Examples include Kismet (Breazeal, 2002), Mask-bot (Kuratate, Matsusaka, Pierce, & Cheng, 2011; Pierce, Kuratate, Vogl, & Cheng, 2012), Quasi (Patel et al., 2007), EMSYS (Ribeiro & Paiva, 2012) and the Blossom robot (Suguitan & Hoffman, 2019). Some robots have also drawn inspiration directly from animators. For example, animators and puppeteers helped design the motion of the Vyo robot (Luria, Hoffman, Megidish, Zuckerman, & Park, 2016), and the Haru robot (Gomez, Szapiro, Galindo, & Nakamura, 2018) was designed with the assistance of artists and animators.

A number of tools have also been introduced to make it easier to animate robots. Some were initially targeted at a specific robot such as the iCat (van Breemen, 2004a; van Breemen & Xue, 2006) or Nao and Pepper (Pot, Monceaux, Gelin, & Maisonnier, 2009). Other tools have attempted to be more generic and more widely accessible (Balit, Vaufreydaz, & Reignier, 2016). The creation of formulas that model behavior is another way of helping to create animations (Gielniak, Liu, & Thomaz, 2010). These formulas are not tied to a specific robot, and can be used more widely. Providing a complete process by re-purposing other tools (Bartneck, Soucy, Fleuret, & Sandoval, 2015; Megidish, Zuckerman, & Hoffman, 2017; Ribeiro, Paiva, & Dooley, 2013) or by creating new ones (Desai et al., 2019) is another way of animating different robots.

New papers on animation techniques and HRI have been published since the review in Paper 2 was carried out. A number of new studies have also looked at animation principles. The study from Zhou, Hadfield-Menell, Nagabandi, and Dragan (2017) was mentioned in Paper 2, but we overlooked that this study used the principle of *timing* to adjust the speed of a robot arm to make it more expressive and provide people with a better understanding of its internal state. They found that slowing down the arm as it reached the point of manipulation had the most positive effect. Some participants perceived the slowing down as the robot helping to hand an hand over an object. Changing the speed did not, however, seem to effect perceptions of the weight of the object.

We did not provide a full review in Paper 2 of a study carried out by Szafir, Mutlu, and Fong (2014). They applied the animation principles of *arcs*, *anticipation*, and *slow in and slow out* to express the intent of an assistive free-flyer (AFF) as it scanned QR codes in a room. Szafir et al.'s results showed that participants preferred an AFF that used these principles. An AFF that moved using these principles also made the participants feel safer around the AFF, and feel the AFF 's movement was smoother and more natural. A later study has, however, shown that people's preferences for flying robot or drone movement do not necessarily match previous research in preferences for ground-based robot movement, at least in how they approach people (Wojciechowska, Frey, Sass, Shafir, & Cauchard, 2019).

A study run by Papenmeier, Uhrig, and Kirsch (2018) used a new technique. Participants viewed frames of a moving PR2 robot in which different movements and orientations were displayed. The objective was to examine how well participants could predict where the PR2 was going to move to next. Participants could view a frame as long as they wanted before proceeding to the next frame. The implication being that the longer the participant looked at the frame, the more time it took them to comprehend the robot's movement. It could therefore be concluded from the long viewing times that the robot movement was less natural and less predictable. The robot moved using four different velocity profiles: linear increasing, linear decreasing, constant, and sinusoidal (vaguely similar to slow in and slow out). The robot orientations used were forwards facing, backwards facing, facing to the left, or facing to the right in relation to the direction of motion. Participants spent most time viewing the frames of a robot that used the decreasing linear velocity profile and on the frames of where the robot decreased speed in the sinusoidal profile, but not when it increased speed in the sinusoidal profile. Decreasing robot speeds therefore affected the ability to predict the robot's movement. Viewing times were, however, unaffected by the orientation of the robot. But a robot facing in the direction of movement was judged to have more autonomy.

Anderson-Bashan et al. (2018) used the animation principle of *arcs* as one of the conditions in their evaluation of how effective their custom robot was at greeting people. Participants did not, however, mention the arcs when answering questions in the qualitative interview.

A study by Alves-Oliveira et al. (2019) was not focused on animation. But the study used animation techniques to move the robot and make the robot appear empathic or non-empathic in group learning exercises that were teaching children about sustainability. There were no differences between the learning outcomes of the empathic and non-empathic robot. The children, however, were less concerned about scores on the exercises and had meaningful conversations about sustainability when they had the empathic robot.

Finally, Li et al. (2019) drew inspiration from the work on robots, animation techniques, and performing arts, which includes the Laban method (Knight & Simmons, 2016; LaViers, Teague, & Egerstedt, 2014), when designing a motion path for a footstool robot that communicates the robot's dominance in a room with a participant. Participants found that motions that were based on human actors did affect whether they perceived the robot as "high status" or "low status". The participants also preferred "high status" robots when the robot's movement wasn't related to the participants, but liked "low status" robots when the robot moved away from the participant.

2.5.3 *Connection between HRI & privacy research*

Robots need sensors to obtain information about the environment around them. They also need to process the data obtained from the sensors. This can lead to concerns about what data is collected and what is recorded. Rueben et al. (2018) identified seven themes for future privacy research for robots: (*1*) data privacy, (*2*) manipulation and deception, (*3*) trust, (*4*) legal issues, (*5*) blame and transparency, (*6*) domains with special privacy concerns, and (*7*) privacy theory. We will examine the first five items more closely.

Data privacy is the most likely first issue when considering privacy issues and robots. What kind of data is collected and how is it protected (T. Schulz & Herstad, 2018; Syrdal, Walters, Otero, Koay, & Dautenhahn, 2007). This is also the starting point of the discussion in Paper 1. Calo (2011) argues that the presence of drones in our everyday lives may increase our awareness of privacy. We can also see data privacy concerns in attempts that have been made to find "clever" solutions when collecting data. One prototype used laser range finders (LIDAR) and mirrors mounted at floor level to mask identities (Pyo et al., 2013). Another prototype used pressure sensors to track positions without gathering too much information (Mitabe & Shinomiya, 2017). Data privacy also includes the issues associated with how the data is used. People may not want a robot to disclose information to other parties, particularly in some social situations (Hedaoo, Williams, Wadgaonkar, & Knight, 2019).

The theme of manipulation and deception discusses how a robot can deceive us about our privacy. It may, for example, be difficult to understand what a robot actually records and what it senses (Lee, Tang, Forlizzi, & Kiesler, 2011; Schafer & Edwards, 2017). A robot could also manipulate a person into revealing information that it was not meant to have access to or could provide false information (Geiskkovitch, Thiessen, Young, & Glenwright, 2019).

Privacy also goes hand-in-hand with trust. This is especially true for teleoperated robots, which are controlled by a person who is also sensing the environment. Knowing who is operating a robot has had an influence on where people allowed a robot to go (Rueben, Bernieri, Grimm, & Smart, 2017). Others have looked at how non-essential items in a teleoperator's camera can be masked from the operator (Butler, Huang, Roesner, & Cakmak, 2015; Rueben, Bernieri, Grimm, & Smart, 2016). It has also been shown that trusting a robot is necessary if a person is to work with it, and so is trusting that it will do what it claims it will do (Sebo, Krishnamurthi, & Scassellati, 2019).

Turning to legal issues, Kerr (2019) argued that robots do diminish people's privacy even if the robots themselves don't have legal concerns of privacy. Pagallo (2013) provides a good exploration of privacy issues from a legal perspective. In this work, Pagallo used terminology from privacy by design (Cavoukian, 2010) as a basis for exploring robots and privacy. Robots need sensors and connectivity to perform their tasks, this creates a privacy complication. Pagallo, in later work, examined how Japanese law has dealt with some of these privacy issues by creating areas for robots. Some European countries have started to follow Japan's example (Pagallo, 2018).

The theme of blame and transparency looks at the question of who is at fault when problems arise. Is a breach of privacy the fault of the manufacturer, the robot, or the person at home? Calo (2010) has examined how previous rulings on surveillance can apply to robots, and Elish (2019) posits the concept of *moral crumple zones* as a guide of how blame may be assigned in the future. A car's crumple zone crumples to absorb impact and protect the passengers. A moral crumple zone similarly protects automated technology from blame by instead wrongly attributing blame to an operator. Elish documents how these crumple zones have happened in the Three-Mile Island Nuclear Facility's partial nuclear meltdown and the Air France Flight 447 crash. This has not, however, been the case in the Boeing 737 Max crashes in 2019. The issue of who or what is at fault needs to be researched further in multiple disciplines.

Finally, Fosch Villaronga et al. (2018) provide a review and a taxonomy of privacy concerns for robots used in healthcare (healthcare robotics) from a European context. The concerns are: (*1*) Confidentiality, induced trust, and the nudging of disclosure (manipulation, deception, and trust from above). (*2*) The complexities of giving voluntary, informed consent when using robots in a healthcare context. (*3*) Managing privacy while engaged in a conversation with a robot. (*4*) Avoiding lock-in by data being portable between robots. (*5*) Privacy and robot data collection in the workplace. (*6*) A need to go beyond simple privacy by design that includes the understanding of legal obligations. These concerns all touch on aspects of the themes covered by Rueben et al. (2018) and show a strong bridge between privacy research and HRI.

3 *Method*

> There are more things in heaven and earth, Horatio,
> than are dreamt of in your philosophy.
>
> William Shakespeare, Hamlet (1.5.167-8)

The research questions of this dissertation are presented in Chapter 1. How does one go about finding answers to these questions? The choice of methods depends on one's *epistemology* or how one forms and obtains knowledge.

Epistemology reveals the philosophy that guides the research. For example, we can find the beginnings of the *philosophy of science* with philosophers such as Rene Descartes and Margaret Cavendish, who put forth an idea of an objective, material world that we can observe with our senses. A person can make observations about a phenomenon, create predictions about how the phenomenon works, and test that out. This can lead to a model of the phenomenon that others can use. The quantitative methods have their origins in this philosophy.

The philosophy of science works well for many types of phenomena, but it does not necessarily provide a full picture or understanding of some phenomena. Some things that we observe or experience refuse to be reduced to numbers. This can be the case when we look at many situations that involve people's opinions. Different methods and philosophies for approaching the world are needed for understanding in these cases. These are often where one finds qualitative methods.

Human-robot interaction is an interaction between robots that are, one can argue, objective in how they perform their tasks and humans who are subjective in how they interact with a robot. Investigations can therefore use a mix of methods to learn about the phenomenon, the combination of methods then used to triangulate the results, so resulting in a clearer picture of a phenomenon.

The methods used in this dissertation can be broadly divided into two schools of philosophy: the philosophy of science and *phenomenology* (Table 3.1). The method are: (*1*) applying a theory from one area to another, (*2*) using phenomenology to classify movement, (*3*) a systematic literature review process, (*4*) using the physical movement of the robot and mathematics to derive a new algorithm, and (*5*) experimental hypothesis testing. This resulted in a mix of qualitative and quantitative methods (Table 3.2). This mixing of methods is partially due to the

Table 3.1: Breakdown of methods by school of philosophy.

Method	Philosophy of Science	Phenomenology
Applying a theory		⋆
Classifying movement		⋆
Systematic review	⋆	
Deriving an algorithm	⋆	
Hypothesis testing	⋆	

multidisciplinary nature of the project and partially due to a desire to become familiar with a broad range of methods.

Table 3.2: Breakdown of methods by type and paper.

Method	Quantitative	Qualitative	Paper
Applying a theory		⋆	Paper 1
Classifying movement		⋆	Paper 3
Systematic review	⋆		Paper 2
Deriving an algorithm	⋆		Paper 3
Hypothesis testing	⋆		Paper 4

This chapter presents a brief summary of the schools of philosophy used, the methods used in each school, and how each method was used in the respective papers. I was, furthermore, involved in several activities and methods at Kampen Omsorg+ that led to results that are not part of this dissertation. Those activities did, however, help form the work presented here. They therefore should be listed and described.

3.1 Phenomenology

Phenomenology is a philosophical theory that focuses on examining the experiences of people, the people's experiences being seen as a valid part of the research. There is no grand unified theory of phenomenology. There are, instead, a number of interpretations that are founded on the views of the person that created the interpretation. For example, some philosophers say they base their phenomenology theory on Heidegger. Others say that they base their phenomenology theory on Merleau-Ponty's phenomenology. Merleau-Ponty's theory was inspired by Heidegger, but Merleau-Ponty made changes. Reviewing the differences between these two interpretations is beyond the scope of this dissertation. Svanæs (2013), however, provides a concise summary of the different interpretations of phenomenology. We restrict ourselves to a more general approach.

One way of explaining phenomenology, irrespective of the different theories, is through the statement that there is no such thing as an objective experience. There are only subjective experiences. But it is possible to apply an objective system to these subjective experiences. There are examples of using phenomenology in computer science, especially when looking at the design of systems for people. One example is *Understanding Computers and Cognition* by Winograd and Flores (1986). Winograd and Flores used Heidegger's phenomenology to argue we need to go beyond what they call a *rationalistic approach* to understanding cognition and computer science, as the rationalistic approach is too limiting. Using hermeneutics and phenomenology broadens our understanding of cognition and computers and gives us the ability to design computers and other technology (particularly artificial intelligence) that benefit peoples and is, to use Heidegger's term, "ready to hand."

Another example is *Where the Action Is* by Dourish (2004). Dourish used the concept of *perception* from Merleou-Ponty's phenomenology to explore *embodied interaction* in tangible user interfaces and social computing. He argued that embodiment is not part of a system, technology, or artifact, but is located in the *interaction between them and the people*. Based on this, Dourish built a framework for discovering how embodied interaction acts and suggested design principles for creating new interfaces.

These examples build on theories developed by others. Thus, it is fitting that Paper 1 applies a framework of one context into another.

3.1.1 Applying a framework in a new context

It can be difficult to examine privacy issues in a home environment in which a new technology is introduced. The technology itself may need to be created by the researchers (T. Schulz, Fuglerud, Arfwedson, & Busch, 2014). No specific sensors nor robots were decided on prior to the start of the MECS project. We therefore had to begin at a theoretical level in our examination of privacy issues.

One part of the examination of privacy issues was to ask people about their understandings of privacy (Section 3.3). A second part was the application of the boundary privacy framework of Palen and Dourish (2003) to reveal privacy issues in the scenarios. This framework looked at the networked workplace environment and showed where privacy boundaries need to be negotiated between workers, management, and technology.

We applied the framework to a home context in which people, robots, and sensors are present. We also applied the framework to the many network connections between the robots and sensors. The goal of the examination was to find potential dilemmas that designers

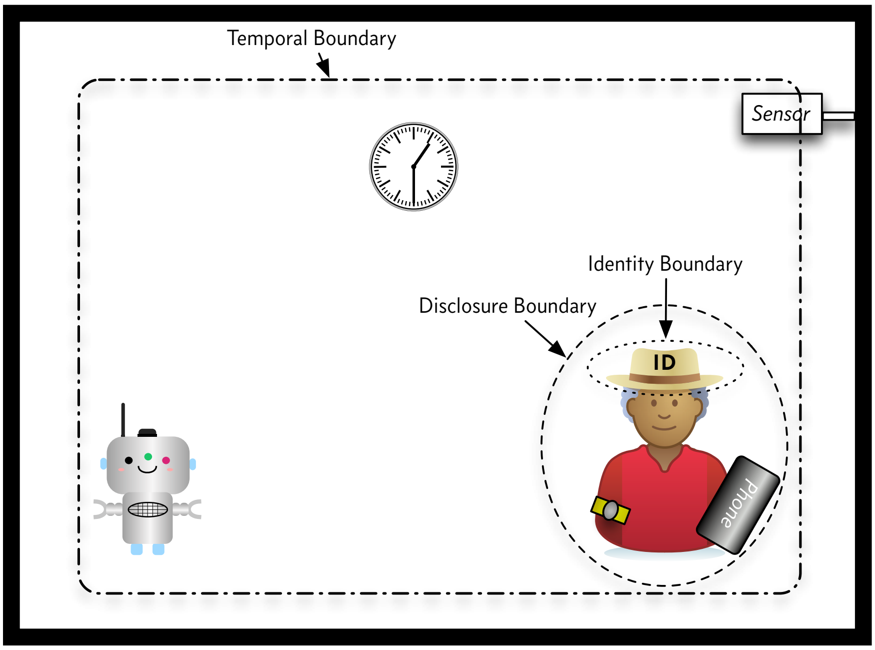


FIGURE 3.1: The disclosure, identity, and temporal boundaries from Palen and Dourish's boundary framework (2003) for privacy in a networked world as applied to a home in which there is a robot.

should be aware of when a robot is in the home. We used the framework to first identify where the privacy boundaries were between the person, the home environment, and the robot. Then we created a visualization of the boundaries, to allow them to be more easily related to (Figure 3.1). The next step was to examine the scenarios that could happen in the home and what boundaries would need to be negotiated in each of the scenarios. The scenarios in which there were no clear final outcomes in boundary negotiations became the dilemmas presented in Paper 1.

3.1.2 *Using phenomenology to classify movement*

We wanted, in Paper 3, to examine how people experienced movement in the home, and how this experience related to a robot moving in the home. Using phenomenology allowed us to look at the motion parts and the parties involved. This led to a classification of different types of movement (moving around an area versus just moving the parts of one's body) and mapping this for robots and humans. This allow us to map the different movements between them.

The creation of this classification, however, raised the question of how familiar would people be with a robot in their home? We examined other situations that matched our motion categories in the home, but with different actors carrying out the motion (perhaps an animal or train instead of a robot) or motion outside of the home. This also led us to examine how moving a robot using animation techniques can aid in making the robot more familiar, through the robot simulating the movement of other things which the observer has experienced before.

3.2 Philosophy of science

The philosophy of science has its roots in Descartes and Cavendish and is underpinned by the precepts of logic and the idea of a search for an objective *truth*. The principle of *induction* was, for a time, emphasized in the generation of knowledge and in the creation of theories of how the world functioned. The philosopher Russell (1912), however, argued that induction could only show the probabilities of something occurring and could not be used to prove or disprove a theory.

Popper (2002) proposed a different methodology. Popper argued that science was not a search for truth, as it is impossible to know what is true. It was, however, possible to know what is false. He therefore proposed that the degree to which something was science or scientific was based on how *falsifiable* it was. That is, the degree to which one could create an experiment or a test that could show it was false. For example, the verification of Einstein's theory of gravitation by Eddington's eclipse experiment in 1919 showed scientists attempting to falsify a theory to see determine whether it is wrong (Popper, 1997). Popper proposed that the ability to falsify statements demarcates the boundary between what is science and what is not.[1]

Some researchers document their methods in papers to allow others to use their methods to replicate (or falsify) the results. The literature review in Paper 2, the mathematics introduced in Paper 3, and the evaluation in Paper 4 are examples of method description. The following is an overview of the method and how it was applied.

1. Critics of Popper's arguments have pointed to items such as Darwin's theory of natural selection as not following falsification and still being considered scientific (Popper, 1997, Editor's note on p. 41). So, Popper's argument is not a unifying theory.

3.2.1 Performing a systematic literature review

A literature review provides an overview of an area. It also points to further explorations that can be carried out in a field. A literature review documents what has been researched previously; thus allowing researchers to build on this previous work and to avoid research duplication. For example, the social robotics chapter in the *Springer Handbook of Robotics* (Breazeal, Dautenhahn, & Kanda, 2016) can provide guidance on an area within robotics (HRI), the robots that have been used in work carried out in this area, and can point to where further information can be found. This chapter can provide more information on the subject than starting with a random year of conference proceedings or a random journal volume.

Researchers often carry out small literature reviews. These reviews form the building blocks of the background section of papers. They also indicate what work has been previously carried out in the area and where new work can fit into this research foundation. These reviews narrowly focus on the area being explored in the paper. They, though this, demonstrate that the paper's authors are aware of the research that has been previously carried out in that area.

Literature reviews can be classified into two categories: systematic and non-systematic. Non-systematic reviews are the most common, as they are the quickest to carry out. A non-systematic review can be carried out by a researcher entering the keywords for a topic into a search engine. The researcher then scans the titles and abstracts of the papers found by the search to see whether a paper is relevant to the topic and then makes a decision whether to include it in the review. The *snowball method* is a variation of this approach. The approach accumulates literature like a snowball gathering snow as it rolls down a hill. Beginning with one or a handful of sources, the researcher uses the references in those sources to find other relevant information.

These methods can quickly immerse a researcher in an area quickly, and provide a researcher with a reasonable overview of the area. These methods are, however, like hill-climbing. You may have reached the top of a hill (i.e., you have found all the literature on a subject), but the summit may just be a small top on the side of the hill and not the top of the hill itself. The literature found is therefore just a group within or one viewpoint in the literature. The methods used in non-systematic reviews are, furthermore, not documented, thus limiting the opportunities to reproduce or check the result of the search. A non-systematic review therefore provides some literature related to the topic. But it's difficult to know whether this is all the literature related to the topic.

A systematic literature review attempts to counter these issues. Using a system allows the literature review process to be documented and others to reproduce the results and determine whether your process was sufficient. A systematic literature review also requires the researcher to set goals for the result of the review and furthermore allows researchers to carry out a *meta-analysis* of the area. A meta-analysis is the process of gathering data presented in multiple studies and analyzing it. Analysis can be carried out using statistical methods (Rosenthal & DiMatteo, 2001) or by looking at patterns of what has happened (Weiss & Bartneck, 2015).

What does a systematic review involve? A straightforward classification comes from Budgen and Brereton (2006, p. 1052) who listed a number of characteristics:

- Create a review protocol that specifies the research question being addressed and the methods that will be employed in the review process.
- Define a search strategy for identifying as much of the relevant literature as possible and document it.
- Specify the inclusion and exclusion criteria to determine if each potential study should be included or not.
- Specify what information should be obtained from each study.

These characteristics help to ensure a robust review. A systematic review requires greater planning, but helps ensure that the review stays on target. It also provides documentation of how the review was carried out that makes it easier to answer questions about why (or why not) a piece of literature was included in the review and what can be drawn from it.

No process is perfect, and a systematic review process can also miss literature. A balance also needs to be struck between single-minded adherence to the process versus flexibility of adding known literature that is outside of the review. An example of this would be key literature that should be in the review, but for some reason does not match the search criteria. Following this process and documenting it, however, allows a researcher to achieve a sound review, and gives others the opportunity to verify the process and to arrive at similar results.

Our protocol for the systematic review in Paper 2 was to find out which animation techniques had been used in HRI user studies and which types of robots these animation techniques had been applied to. We then ran our searches on well-known indexes for literature in the area (the ACM Digital Library and IEEExplore). We decided to include papers that mentioned animation techniques and included some aspect of a human evaluation of a robot. We noted the animation techniques, the robot, what was evaluated, the number of participants, and other information for papers that matched these criteria.

3.2.2 Deriving the robot's movement for slow in and slow out

The phenomenology used in the first part of Paper 3 contrasts with the method used in the second part. The second part attempts to create an objective model of a robot's motion. It uses calculus and the physical associations that have been shown to exist by Newton (Figure 3.2). The mathematical route was chosen to allow a model to be built that can be turned into an implementation to move the robot. The mathematics used in the paper pairs well with kinematics and the software engineering approaches that are needed to implement the motion on the robot.

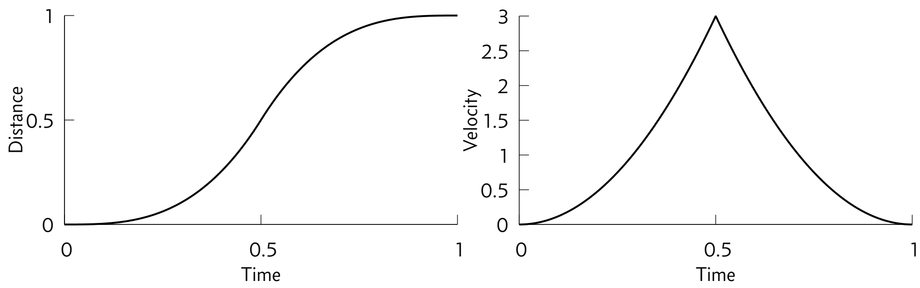


FIGURE 3.2: An easing curve for modeling the slow in and slow out distance over time (*left*) and the derivative of the curve using calculus, which represents change in velocity over time (*right*).

3.2.3 Experimental research & hypothesis testing

Time was spent examining the animation principles of slow in and slow out, and determining how this could be implemented it on a robot. The next step was therefore to test how this specific principle affects interaction between humans and robots. We expected that the change in the way the robot moved would effect how humans perceived the robot. But in which way? In how they liked the robot? How alive they thought the robot was? How safe they felt around the robot? But how can these changes be measured? An instrument for answering these types of questions and designed for comparative analysis already existed. This was the Godspeed Questionnaire (Bartneck et al., 2009). The questionnaire was designed to give HRI researchers success or good fortune in their journeys (i.e., Godspeed). It has been used in many studies (Weiss & Bartneck, 2015), and seemed to be a good fit for our purposes.

The focus of the MECS project is robots in the home. We therefore wanted to test this movement in a home environment. We believed that if we asked people to just watch a robot and give their opinion, then this would not result in true responses. People would quickly find a response based on us having just asked about the movement. We instead wanted people to perform a task with a robot, and then we ask them their opinions based on their interaction with the robot. We created a task in which it was important for the person to watch the robot as part of the interaction. We therefore developed a design that would be run in a home environment.

The experiment process and procedure is described in more detail in Paper 4. Additional data from the experiment is still being analyzed. But it's important to mention how the data for Paper 4 was analyzed. This requires an understanding of statistics. Analyzing experiment data may tempt researchers to look for "exciting" results that they can report, even though these results were not what was originally researched. This may result in, for example, *p-hacking* or changing hypotheses after the result is known (HARK-ing). These practices can lead to problems reproducing results (Bishop, 2019).

The term *p*-hacking comes from the practice of searching for something that is statistically significant in the collected data. This normally means testing the probability of a *null hypothesis* (*p*-value) being under a certain threshold (for example 5%). Others have discussed that the pursuit of a *p*-value may not lead to significant results (Johnson, 1999) and that other statistics, such as confidence intervals, may yield more reproducible results (Cumming, 2008).

If interesting data is obtained, then why not simply state this as a hypothesis? This is, however, reporting the hypothesis after the result is known. Exploring the data collected does not raise any issues. But creating a hypothesis post-hoc makes it difficult to test whether this is a true phenomenon. Furthermore, the probability that any single variable is within the threshold for statistical significance *by chance* increases as the number of measured variables in a group increases (Olejnik, Li, Supattathum, & Huberty, 1997). This is called the *family-wise error rate*.

Concerns for these issues among researchers in the HRI community has increased. In response suggestions have been provided for better reporting (Baxter, Kennedy, Senft, Lemaignan, & Belpaeme, 2016). This includes using more descriptive statistics, providing the procedure and data used, and registering hypotheses prior to execution. This call for better reporting has already become evident in newer research (e.g., Winkle et al. (2019) and Li et al. (2019)). We have followed these suggestions in Paper 4. We have used confidence intervals, documented the procedure, released the source code, documented the hypotheses in a earlier late-breaking report (T. Schulz, Holthaus, Amirabdollahian, & Koay, 2019), and used the Bonferroni-Holm method for reducing the chance of reporting a family-wise error rate.

3.3 Other qualitative activities at Kampen Omsorg+

The MECS project was concerned with creating a safety alarm robot for older people so they could live at home longer. HCI has stressed that it is important to involve people in the design process. One method that can be used is *participatory design* (PD). In this method, people who will be using a product or service play an active role in all parts of the design process. This design process can also address the power dynamics between different groups and lead to something that is fairer to all groups. An early example of this is the cooperation between the Norwegian Iron and Metal Workers Union and the Norwegian Computing Center to disseminate information to the union's workers on how to use technology and ultimately to influence the technology selected at their workplaces (Nygaard & Bergo, 1974). This resulted in technology that benefited both workers and companies. Bjerknes and Bratteteig (1995) examined a number of projects that used PD to show how it can bring democracy to projects by involving workers and their employers. Their work also has shown that PD sometimes fails to achieve democracy. Bratteteig and Wagner (2016b) have also discussed what a result or artifact from PD looks like and how participants perceive participation in participatory design (Bratteteig & Wagner, 2016a).

One reason for considering PD for MECS was to correct the prevailing narrative that we (as people, but particularly older people) lack agency in the endless march of technology. There was also a power struggle between the elderly wanting to live independently at home longer, the potential crisis in caring for the elderly, and an ICT industry looking for new areas in which to make money. It unfortunately became apparent that the research questions of this dissertation were not the correct venue for examining this. Some activities that can be considered to be PD were run in the MECS project. They are, however, not part of this dissertation.

User-centered design (UCD) is another method for designing a product or service. The broad idea behind this appproarch, which was first presented by Norman (2002), was that people (or users[2]) should be the focus. One way of practicing UCD is to us an iterative cycle of observing people, creating ideas for a design, turning the ideas into a prototype, and testing out prototypes (ideally with similar groups of people). Other ways of keeping people in focus include interviewing people who will (potentially) use a product or service about what it should do, or using information about a group of people to create a stereotypical user, sometimes called *personas* (Cooper, 1999), which can be used to argue for specific choices in a design. The practice of user-centered design should, ideally, include as many of the above as possible. This, unfortunately, is not always the case.

There are, regardless of the methods selected, ethical issues that need to be addressed when carrying out research in which people are the subjects of the research. These issues include data protection and treating people correctly.[3] A further issues in the MECS project is that the people involved are getting older and the technology is a long way from being fully developed and generally accessible. We often frame those who take the time to participate in a study as providing input that will assist people in the future (including themselves). A higher degree of altruism, however, is required by those who are older and will not necessarily live long enough to see the technology completed, deployed and brought into use. There therefore needs to be other benefits for those who participate in this research.

2. Norman presented user-centered design. But he later refers to it as *human-centered design* since "I decided 'user' was a bit degrading. Why not call people 'people'?" (Posner & Mars, 2016, timecode: 2:47).

Norman (2005a) has also pondered whether *activity-centered design* would have avoided confusion better. Raskin (2000) also felt that "user" may be a limiting word. That being said, user-centered design is more understood. I tend to use "user" only in this case and "person" or "human" in other contexts.

3. The research in the MECS project has been approved by Norwegian Center for Research Data (NSD), project number 50689. The study in Paper 4 was also approved by University of Hertfordshire's Health, Science, Engineering and Technology Ethics Committee (Protocol Number COM/SF/UH/03491).

The project discussed using both participatory design and user-centered design. We, however, ultimately chose a mostly user-centered design method for activities run at Kampen Omsorg+. A time line for these events is given in Figure 3.3.

The first activities were run in January 2017. The work began with a discussion between the University of Oslo, Kampen Omsorg+, and the part of Oslo Municipality that oversees Kampen Omsorg+ on how we should work with the residents. This was followed by a gathering with the residents of Kampen Omsorg+ in which we presented the MECS project and explained we wanted to investigate. The discussion between us and the audience was lively and helpful in planning future activities.

We held two focus group discussions with residents after this. One topic the focus group discussed was different kinds of robots (for example, service robots ranging from the Roomba vacuum cleaning robot to social robots such as Pepper), their suitability to the home, and their appearance. The other topic was a discussion on what people should do when they encountered a robot in the home coming towards them as they were walking towards it. Should the person or the robot yield? And how should the yielding take place?

This discussion led to the next activity at Kampen Omsorg+. The MECS project's master students held a technology fair to show technologies such as 3-D printers, robots, and virtual reality to the residents. Some residents just looked at the exhibits. Others took part in an experiment in which they experienced different strategies of a human and robot encountering each other as each travels to the other side of the room. The participants were interviewed about their experiences and their general opinions about robots after the encounters.

These activities were part of the students' masters' thesis (Søyland & Søyseth Dønnem, 2017). The activities also led to the creation of a framework for discussing how people facilitate different aspects of robot use: from preparing an area before a robot is installed, to radically altering an environment to make the robot perform better after it has been installed and been operating for a while. The facilitation framework was presented in the thesis and in a separate paper (Soma et al., 2018).

MECS also gave the residents the use of a robot vacuum cleaner in the home for a number of weeks. Participants kept a diary of their experiences, and we were available to help in case of problems.[4] We collected the vacuum cleaner at the end of the trial period and interviewed the resident about the experience. We used three different robot vacuum cleaners and eventually opened the study to people outside Kampen Omsorg+. Papers from these activities have focused on issues such

4. Happily, the biggest issue we encountered was the vacuum cleaner "running away" when one of the residents left the entrance door open.

as how feedback affects trust in the robot (Newaz & Saplacan, 2018) and how good feedback from the robot can reduce fear in the residents that are using it (Saplacan & Herstad, 2018).

We ran a workshop at the end of May 2017 in which we looked at the concept of safety with the residents. We wanted to examine and discuss what made residents feel safe in their homes, and how technology such as robots could play a role in this. This included examining how people and pets also give people a sense of safety in the home. We had scheduled the workshop too early in the morning and attendance of this activity was therefore low. We did, however, have useful discussions about these topics with the residents that eventually attended. Although we do not have any published findings from this activity, the residents' participation helped us to understand them better.

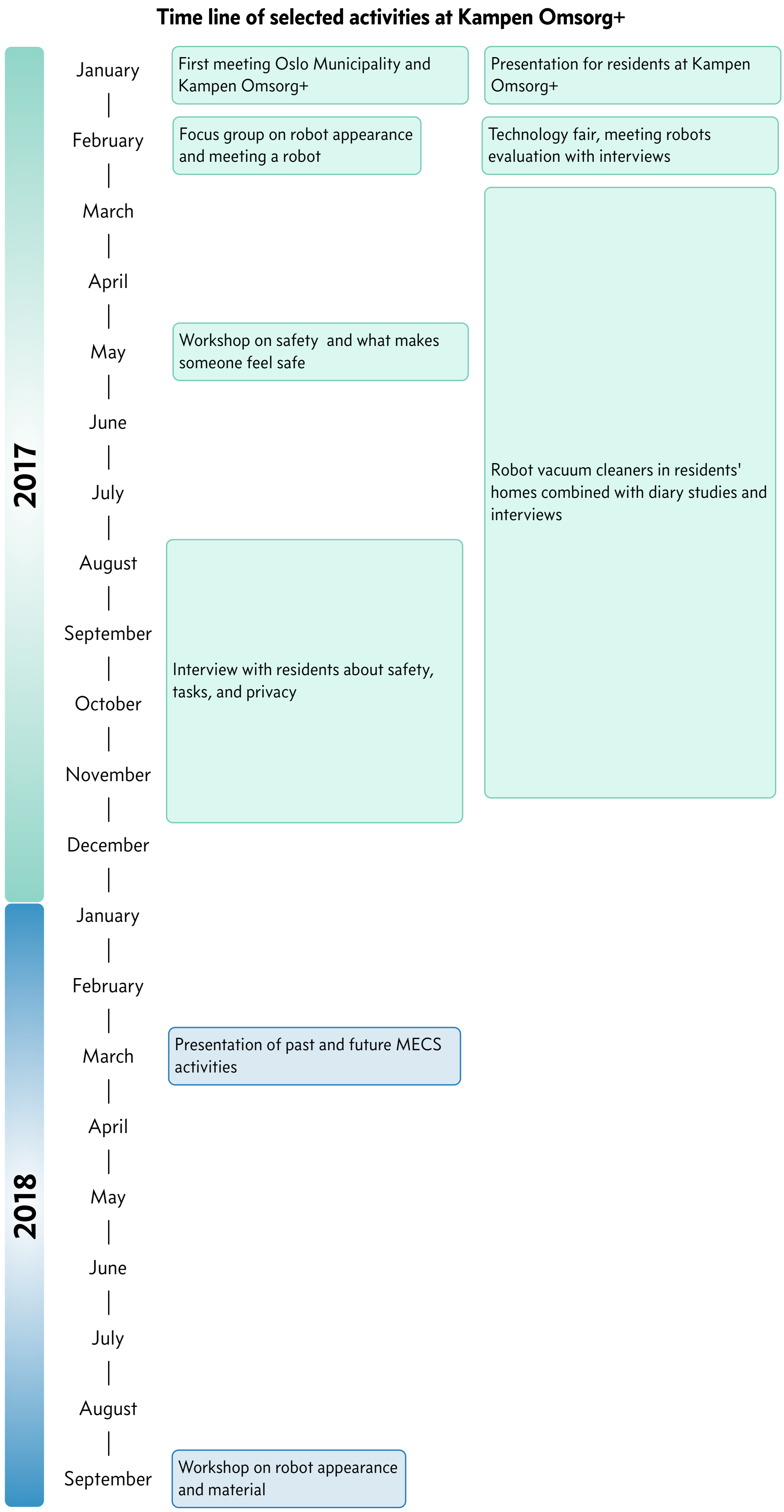
We followed up this activity with individual interviews, as we felt it would be easier to schedule time with a single resident. We also thought that this would allow the resident to expand more on the resident's opinion or experience that in a group. We had experienced this previously with other residents in the vacuum cleaner activity. Our interviews focused on privacy, observation, getting help from observers, items moving in the home, social aspects of a robot, and learning technology. We interviewed nine people between September and November 2017. The findings from the interviews are in the process of being published.

We wanted, after asking the residents to participate in numerous activities, to show the residents what we were doing in MECS, so they could see that their participation was aiding our research. We therefore created a small program in which different members of the project would present their work and show the residents some of the sensors and robots we were working with in the project. This program was run in the main room at Kampen Omsorg+ to give residents and visitors easy access. We also used the program to help generate interest in future project activities.

One of the final activities run at Kampen was a workshop held by master students on what the materials that could be used to create a robot's appearance. The workshop was run over two days in September 2018. Each participant started by picking a basic shape for the robot's body. Then they added different materials, such as cloth, aluminum foil, or plastic to build up the robot's appearance. This idea of was partially inspired by the Blossom robot (Suguitan & Hoffman, 2019) and partially by a wish for resident participation in the robot's construction. During robot construction, we asked questions about what the robot could do in the residents' homes. The participants were initially reluctant to take part in the process, but soon joined in enthusiastically. Details of the workshop are described in Bråthen et al. (2019).

This concludes the research activities of this dissertation that I participated directly in. Additional visits were made Kampen Omsorg+ in which we simply socialized with the residents or talked to the staff. Other master students have also traveled to Kampen Omsorg+ and carried out experiments involving robots with the residents. This section, however, only highlights the activities that were part of this dissertation. We now turn to the actual research of this dissertation and begin by introducing the papers that make up this paper-based dissertation.

FIGURE 3.3: Time line of activities at Kampen Omsorg+.



4 *Summary of Papers*

> Now here's something we hope you'll really like!
>
> Rocket J. Squirrel
> *The Rocky and Bullwinkle Show*

This chapter provides a summary of the papers included in the dissertation. An overview of the papers and how they answer each research question is given in Table 1.1 and the contributions of the papers were are discussed in Section 1.3.

4.1 Paper 1: *Privacy at Home: An Inquiry into Sensors and Robots for the Stay at Home Elderly*

Schulz, T., Herstad, J., & Holone, H. (2018, July 15). Privacy at Home: An Inquiry into Sensors and Robots for the Stay at Home Elderly. In *Human Aspects of IT for the Aged Population. Applications in Health, Assistance, and Entertainment* (pp. 377–394). International Conference on Human Aspects of IT for the Aged Population. doi:10.1007/978-3-319-92037-5_28.

4.1.1 Motivation for paper

One of the arguments behind the MECS project's investigation of placing a robot in the home is that the privacy issues in a home may be easier to understand with robots than with smart homes containing hidden sensors around the house. The promotion of this argument by the project requires, however, that the privacy issues of a robot in the home are investigated. This paper is an examination of these issues. All the paper's authors were interested in the approachable, straightforward boundary framework introduced by Palen and Dourish (2003). Palen and Dourish used this framework to examine the privacy issues that arise when networked technology is introduced into the workplace. Paper 1 is founded on an earlier paper presented at the 2017 British HCI conference (T. Schulz & Herstad, 2018). This earlier paper used Palen and Dourish's boundary framework to posit that the presence and sight of the robot provides an indication of what the robot may be recording. We, however, realized that as our understanding of the technology and sensors grew as we worked with them in MECS, that this idea may be too naive. We therefore used this paper to examine this and other dilemmas.

4.1.2 *Paper Summary*

Older people using information technology, such as smart house sensors and robots, to help them live independently longer at home is a possible vision of the future. It is, however, important that people's privacy is protected in the home environment. People will otherwise not trust these technologies and therefore not use them. Thus, they may reduce their ability to live independently.

But what does *privacy* mean? We used the idea in this paper that privacy is a *boundary* at which access is negotiated between people. This is the idea Palen and Dourish (2003) built their boundary framework on. They define three boundaries: (*a*) the disclosure boundary where we explicitly share information; (*b*) the identity boundary where the role that we play in a situation shares information; and (*c*) the temporal boundary where information is acquired over time.

Palen and Dourish used this framework for networking in the workplace. We, however, use this in the new context of a home and between a human, a robot, and its sensors. To aid discussions, we created a visualization of the boundary framework which consists of the robot, its sensors, the human, the environment, and the boundaries. To illustrate how this framework can be applied in the home, we presented three dilemmas in which these boundaries need to be negotiated. The three dilemmas were: turning sensors on and off, the robot sensing through walls, and machine learning. We identified the boundaries that must be negotiated in each of these dilemmas and discuss additional items for consideration. The dilemmas show that privacy issues needs to be examined if people's trust in having a robot in their home is to be increased.

4.2 Paper 2: *Animation Techniques in Human-Robot Interaction User Studies: a Systematic Literature Review*

Schulz, T., Torresen, J., & Herstad, J. (2019). Animation Techniques in Human-Robot Interaction User Studies: A Systematic Literature Review. *ACM Trans. Hum.-Robot Interact.*, *8*(2). doi:10.1145/3317325.

The paper was accepted for publication in February 2019 and was published in June 2019 in Volume 8, Issue 2 of *ACM Transactions on Human-Robot Interaction*.

4.2.1 Motivation for this paper

The second part of our investigation of robots in the home looked at how a robot should move in the home. We were interested in moving robots using animation techniques. This, however, was a new area to research. It was therefore necessary to obtain an overview of the research that has previously been carried out to establish the knowledge we could build on. We found papers that discussed animation techniques and robots, but there did not seem to be an overarching summary of the field. We therefore decided to create one. The process of writing this paper was instructive in how to carry out a systematic literature review and how to structure the review, analyze the literature, and write up the findings. This paper therefore provides a starting point for anyone interested in starting to work with animation techniques in HRI. I gained the impression, through the course of this Ph.D. study and from discussions with others in the HRI community, that others are interested in this summary.

4.2.2 Paper Summary

This paper is a systematic literature review of human-robot trials, pilots, and evaluations in which animation techniques have been applied to robot movement. We start by introducing animation techniques and principles. This includes the Twelve Principles of Animation and related topics such as motion capture and puppetry. We also briefly review other techniques robots can use to communicate through movement (such as the Laban Effort System). The concept of *animacy* (i.e., something appearing to be alive) relates to animation, and we discuss animacy in the paper. Animation techniques can be used to create animacy, but we do not explicitly look at animacy in our literature review.

Our literature review protocol used a method described by Budgen and Brereton (2006). It consists of deciding on the research questions, formulating and documenting a search plan, developing inclusion and exclusion criteria, and defining what information to extract from each piece of literature. Using a protocol assures our results can be reproduced by others. The initial search of the databases found 106 items. This was reduced, by applying our inclusion and exclusion criteria, to 27 papers that would be included in the review.

The 27 papers show that there is a variety of types of movement (locomotion or configuration), modalities (live or video), settings (in a lab or real-world setting), and data collected (such as looking at the emotion a robot shows, robot characteristics, and a robot's gaze). A number of the animation principles were also used in these papers. *Secondary Action* and *Straight Ahead Action and Pose to Pose* were, however, the most frequently used.

The review shows that applying animation techniques to robot movement helps people understand the robot's state or the emotion that it is displaying. It also helps people to understand robots that do not resemble a human or animal. This is a field that has areas that still remain unexplored. This includes applying animation principles to other types of robots and situations, combining animation techniques with other modalities, and long term testing of robots that move using animation techniques.

4.3 Paper 3: *Classifying Human and Robot Movement at Home and Implementing Robot Movement Using the Slow In, Slow Out Animation Principle*

Schulz, T., Herstad, J., & Torresen, J. (2018a). Classifying Human and Robot Movement at Home and Implementing Robot Movement Using the Slow In, Slow Out Animation Principle. *International Journal on Advances in Intelligent Systems*, *11*, 234–244. Retrieved January 16, 2019, from http://www.iariajournals.org/intelligent_systems/tocv11n34.html.

4.3.1 Motivation

This paper is an extended version of a paper presented to the Eleventh International Conference on Advances in Computer-Human Interaction (ACHI 2018) (T. Schulz, Herstad, & Torresen, 2018b). The conference paper was published early in our investigation of robot movement in the home. That paper argued using animation techniques could give a robot a style that could make it more familiar and easier for a person to relate to. We arrived at the movement classification presented in this paper from discussions during the paper's preparation.

Paper 3 provides a more in-depth presentation of the original presented material. The literature review (Section 4.2) had progressed since the conference paper, and now provided an opportunity to explore animation techniques and robots more deeply. This specifically includes how to apply the principle of slow in and slow out to robots and how to write up the results of this application. We found descriptions, during the investigation, of how a robot with wheels can move using a velocity profile. But we could find no discussion of how to apply slow in and slow out to create a different type of velocity profile. This gave us an the opportunity to conduct a technical discussion and to foreshadow the work carried out at University of Hertfordshire.

4.3.2 Paper Summary

This paper begins by looking at the issue of older, retired people living independently at home. We then review the robots used in research projects that studied or are studying this issue and then introduce MECS. Following this we looked at *global* and *local* movement, also called *locomotion* and *configuration* in robotics and HRI, and how this relates to using animation techniques to give a robot a style that can help the robot communicate with humans. This results in four classifying conditions: the human and robot are either both still, both moving, or one of them is moving. We then used these four conditions to examine whether these motions can also be found in other moving objects and phenomena such as navigating traffic on foot, by car, on a bicycle, and by public transport. Finding these motions in other moving objects and phenomena will therefore impart a familiarity to these four motions. Animation techniques could therefore be used to give a robot a style that makes the robot resemble one of the familiar situations and therefore make it easier for the person to interact with the robot.

The paper then turns to a specific case of how the principle of slow in and slow out can be implemented on a wheeled robot. This involves examining: (*a*) velocity profiles, (*b*) how velocity profiles are mathematically defined, (*c*) easing curves, and (*d*) how easing curves can provide the slow in and slow out effect. We, based on this, derive a new velocity curve that creates the slow in and slow out effect, and we document how we implemented it on two robots. The velocity curve does give slow in and slow out motion on the two robots. The motion does, however, need to be evaluated in the presence of people to understand how people perceive it. This paper presents a possible experiment to address this, the experiment being the basis for the next paper.

4.4 Paper 4: *Differences of Human Perceptions of a Robot Moving using Linear or Slow in and Slow out Velocity Profiles When Performing a Cleaning Task*

Schulz, T., Holthaus, P., Amirabdollahian, F., Koay, K. L., Torresen, J., & Herstad, J. (2019, October). Differences of Human Perceptions of a Robot Moving using Linear or Slow in, Slow out Velocity Profiles When Performing a Cleaning Task. In *2019 28th IEEE*

International Conference on Robot and Human Interactive Communication (RO-MAN). 2019 28th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN). doi:10.1109/RO-MAN46459.2019.8956355.

This paper was submitted and accepted to the RO-MAN 2019 conference. The conference was held 14–18 October 2019 in New Delhi, India.

4.4.1 *Motivation*

The slow in and slow out techniques was documented in the previous paper, and it was outlined how it could be tested. It was now time to try this approach out in a study to see how people react to the technique. This also gave us an opportunity to examine the extent to which one of the animation principles alone could affect an outcome. As part of this work, I traveled to the University of Hertfordshire in Hatfield, England to spend four months designing an experiment and running it with participants from the area. We documented the design of the experiment, the running of pilots, and our hypotheses in a late-breaking report (T. Schulz, Holthaus, Amirabdollahian, & Koay, 2019). Paper 4 follows up the report and presents a more detailed documentation of our method and the results from the outcome. Most HRI user studies use quantitative methods. I wanted to understand these methods better. This paper therefore also was an opportunity to use quantitative methods. Analysis, however, began to show that there was no difference between the two velocity profiles. It therefore seemed more important that the paper documented the result and provided a discussion that other scientists could use to improve their future work.

4.4.2 *Paper Summary*

The paper starts by introducing that robots should move in a predictable and legible way for people to feel safe when interacting with them. Changing how a robot moves (i.e., its velocity profile) can therefore aid predictability and legibility. One way to change a robot's velocity profile is to use animation techniques. *Slow in and slow out* is therefore an animation technique that may affect movement enough to change the perception of a person who is working on a task together with the robot.

We did *not* want participants to simply look at the robot moving and give us feedback. We wanted participants to engage in an activity with a robot that was similar to an everyday activity. We therefore created a scenario in which participants came to a home and helped in clean up. Four iterations were used: two in which the robot would moved using a linear velocity profile and two in which the robot moved using a slow in and slow out velocity profile. Participants would then complete the Godspeed questionnaire, which covers the robot's perceived anthropomorphism, animacy, likeability, intelligence, and safety.

We had five hypotheses, each looking at each of the Godspeed series. Data analysis, however, showed that differences in averages were not enough to reject our null hypotheses of no difference. We also examined the individual items and found that other events could have that overshadowed the velocity profiles. For example, the robot would get "stuck" more often using the slow in and slow out velocity profile than when using the linear profile. It is also possible that the difference between the two profiles should be greater. On the other hand, there did seem to be semantic items in the Godspeed Perceived Safety series that should be examined more closely.

The method introduced here is, overall, useful in the evaluation of how a robot moves when a person works with it, and it opens up possibilities for future research.

5 *Discussion*

> The ball is wild!
>
> Harry E. Williams

In this section, we begin by enumerating the contributions from the four papers of this dissertation. We then discuss the contributions in relation to the research questions presented in Chapter 1 and place the contributions in the context of the wider research of HRI and HCI. We then look at contributions in the context of the MECS project. Finally, we explore some ethical aspects of the research.

5.1 The results as a whole

We earlier in Section 1.3 enumerated contributions, papers, and the research questions. We now will look at how the results of those papers creates those contributions. The results provide, at the highest level, a snapshot of issues associated with suggestions for putting robots in the home, particularly robots that are to support people to allow them to live at home longer. This can be divided into three parts: (*1*) the privacy issues of the residents of a home with a robot, (*2*) a classification system for examining motion in the home between a person and a robot, and (*3*) using animation techniques to move robots.

We begin by looking at the privacy issues. Privacy issues are important when the objects concerned are in our homes. We often feel safe at home. However, a robot that shares our personal information, intentionally or unintentionally, leaves residents vulnerable. Examining possible dilemmas using the boundary framework provides a solid starting point and can help uncover issues that a group of designers may not have considered.

The motion classification provides ways for designers and roboticists to think about the movement of robots in a home context. These thought exercises can help create interactions that better fit everyday home life. This provides a starting point for examining robot movement in other contexts and, more generally, how robots movement can affect how lifelike (or animate) they seem when we encounter them (T. Schulz & Soma, 2018).

We can further divide the results on animation techniques into three parts that represent three contributions. These are: (*a*) mapping the current state-of-the-art for the use of animation techniques on robots and thus providing several avenues for future research, (*b*) an implementation of the slow in and slow out animation principle that can be used by other robots, and (*c*) an evaluation of this implementation that shows that using this principle alone is not enough to effect people's perceptions of a robot when working together on a task. The evaluation does, however, provide a starting point for further animation techniques and robots studies.

5.2 Linking results to the research questions

We will now examine the results in terms of the research questions defined earlier in Section 1.2. We will examine, one at a time, each research question and the resulting sub-questions.

5.2.1 RQ1. *What are the privacy implications of having a robot in the home?*

RQ1. is concerned with the practical aspects of a robot in a home. Specifically, how to preserve the privacy of residents of a home. This is divided into two parts. The first sub-question RQ1.1. is *How can we examine and discuss privacy issues associated with having a robot in the home?* The boundary framework from Paper 1 provides a straightforward way of discovering and examining privacy dilemmas associated with a robot being in the home. The dilemmas provide a focus for this discussion.

The boundary framework provides a partial solution to the second sub-question, RQ1.2. *What privacy issues and trade-offs must we be aware of when having a robot in the home environment?* The framework is an essential part of the design work, but it is not sufficient. Classic questions remain such as what data is being collected? Who is doing what with the data? For what purpose, and for how long?

Residents of Europe are gaining familiarity with these questions that also underpin the GDPR. The boundary framework highlights the points where privacy must be negotiated between the person, the robot, and others. These areas of negotiation will show what data is collected. The data can then be traced, this facilitating the answering of questions about what is being done with the data and how long it is kept. This can, in turn, form the basis of a privacy policy for GDPR compliance.

5.2.2 RQ2. *How does the use of animation techniques to move robots affect people's interaction with robots in a home environment?*

RQ2. is concerned with animation techniques, the focus being on interaction in a home environment. The three sub-questions divide this into three parts:

RQ2.1. *In what ways can a robot's movements be used to make it easier to relate to the robot and, by extension, make it easier to have in the home?*

RQ2.2. *How can an animation principle be applied to robot motion?*

RQ2.3. *How does the use of animation techniques affect people's perceptions of robot motion?*

Results from the papers can provide answers to the main question and the sub-questions. The Paper 2 literature review, which outlines how animation techniques and the principles of animation have been used in HRI studies, provides answers to all the sub-questions. It also shows that motion can make robots easier to interact with and lists the perceptions of robots recorded in a number of studies. Paper 3 provides answers to RQ2.1. and RQ2.2. by providing a classification system. This system can be used to examine how a robot's motion can be used to make a robot appear more familiar in a home. Paper 3 also provides an algorithm that can be used to move a wheeled robot in a slow in and slow out motion. There is an implementation of the algorithm as source code for a navigation plugin for the Robot Operating System (ROS) that is provided as extra material to Paper 4.

Finally, Paper 4 provides a real-world attempt at answering these three sub-questions. We ran an experiment in a home environment using the slow in and slow out algorithm and examined how it affected people's perception of the robot and whether it made the robot easier to relate to. The experiment did *not* provide a final, definitive answer. But it did show that the slow in and slow out animation principle did not seem to have an effect that a person working with a robot noticed. The experiment provides a starting point for examining further questions on moving robots.

5.3 Linking results to the fields of research

The island metaphor was used in Chapter 2 to discuss fields of research. We return to this metaphor here to see which islands the contributions travel to and which contributions can help build bridges or ferry routes between the islands.

The results from papers 3 and 4 create an additional bridge between HRI, animation, design, and HCI. As Hoffman (2019) has argued, higher levels of art and design collaboration may make robots a more compelling and viable technology that can, in turn, increase their use in the home. The results may well lead to satisfied residents in homes and successful robot production businesses.

Hoffman and Ju (2014) have suggested that designing a robot's motion is an important element in the design of interactions between humans and robots. This research has looked at animation techniques as a way of designing movement. Some researchers have focused on the use of animation techniques in studies. For example, Correia et al. (2016) built animations into EMYS robot for their card playing robot, and the Nao used in the Alves-Oliveira et al. (2019) study used animations in movement. Animators have also participated in and advised in the design of robots such as Haru (Gomez et al., 2018) and Vyo (Luria et al., 2016). The research contributions of the dissertation papers can also provide additional guidance to making robots move. Paper 2 can provide a starting point for new research into animation techniques and robots in HRI research.

Paper 4 may also provide some insight into conducting HRI research and reporting the results. It is important that experiments that do not yield an "exciting, statistically significant result" are reported for the benefit of the wider community. The HRI community is open and receptive to receiving these results, as it allows the community to build on what is successful and avoid the pitfalls.

The results from Paper 1 help form a bridge between privacy research, HRI, and HCI. Privacy mechanisms need to be easy to use for the general residents of a home. This also extends beyond typical HCI, HRI, and privacy areas to other disciplines such as law, policy, and sociology. Rueben et al. (2018) has shown how the boundary framework in Paper 1 is part of a new field of *privacy-sensitive robotics*.

5.4 Linking results to MECS & helping people live longer independently at home

We have discussed how the dissertation results relate to the research questions and the broader field of research. We should, however, also examine how these results relate to the MECS project and the problem area that we introduced in Chapter 1 of using robots to help people live independently at home longer.

Section 3.3 describes the other MECS project activities. These were not included in the dissertation papers. They did, however, lead to results that laid the foundation for the papers included in the dissertation. These activities can also lead to future activities and research for understanding the problem area and devising solutions. We document this below by describing some of the papers that resulted from these activities.

Section 4.1 notes that an iteration of the boundary framework was used in Paper 1. This was first presented in a short paper (T. Schulz & Herstad, 2018) presented at the 2017 British HCI conference; the motivation for this paper being to start examining the privacy issues of a robot in a home. The underlying idea behind this paper was that people could more easily understand privacy issues when this relates to a robot and its sensors than when this relates to many sensors installed in a home. This was presented as a strength in MECS. The paper helped introduce us to the boundary framework of Palen and Dourish (2003) and formed the starting point for further examination of privacy issues in MECS. This work resulted in a better presentation and understanding of the framework in Paper 1, the paper including dilemmas originating from discussions inside the MECS project and with others interested in privacy issues.

Another conference paper (Soma et al., 2018) presented at a conference was based on the work of two master's students in the project. The paper presented the *Robot Facilitation Framework*, which describes the work involved in introducing a robot in a workplace or home. Work does not necessarily disappear, but instead moves into different kinds of facilitation work: (*a*) *pre-facilitation*, the work carried out before a robot is added; (*b*) *peri-facilitation*, the work carried out while a robot is in operation or in maintenance; and (*c*) *post-facilitation*, the carried out to ease the future running of the robot. The paper presents three real-world examples where these types of facilitation were present.

We also presented research at this conference that looked at dividing human and robot movement into categories and posited that using animation techniques may give the robot a distinct style that can make it more familiar to a home's residents (T. Schulz, Herstad, & Torresen, 2018b). This work led to a work-in-progress paper that looked at the role of animacy (the ability of something to appear animate) in robots, and how animation could help create animacy (T. Schulz & Soma, 2018). Work from both of these papers was included in Paper 3.

One of the later activities at Kampen Omsorg+ was to ask residents to visualize what they imagined a robot in their home would look like, what it could do, and what materials it could be made out of. Residents were initially skeptical, but eventually embraced the activity, creating interesting robots and a variety of use cases (e.g., helping with dressing and being a dancing partner). The activities were led by three master students. The results were documented in a conference paper (Bråthen et al., 2019).

The final paper we will refer to here is the late-breaking HRI conference report (T. Schulz, Holthaus, Amirabdollahian, & Koay, 2019). This introduced the experiment and, coincidentally, served as a preregistration for the study presented in Paper 4.

5.5 Ethical considerations of results

The previous sections covered effects of the results on different parts of research and on the MECS project. It is, however, also important to focus on the societal and ethical issues. Ethical considerations of robots in the home have been examined by others in the MECS project (Torresen, 2018). This section focuses on other concerns, although there is some overlap.

Chapter 1 discussed how the physical presence of the robot makes it different from other types of information technology. Humans have a tendency to treat objects, especially technological objects, as though they were living things. This phenomenon is documented in *The Media Equation* by Reeves and Nass (1996), who explain why we can get angry at a piece of software or a device. If a robot can move and interact in a way that exacerbates the tendency to treat objects as though they were living, than this may lead to greater isolation of the person in the home.

This can work in multiple ways. If the robot is engaging, it might lead to the person not seeking out social connections with other people. Being able to talk to a robot to get information is a positive aspect. But to prefer to talk with a robot instead of with other people could have negative consequences.

This tendency could also lead to an effect that is the opposite of that intended. There is a danger that a robot in the home that can help someone live independently longer at home can result in the person losing contact with other people outside the home. The person may have had visitors who checked up and socialized with the person. Visitors, however, may decide as the robot is supposed to always be checking on the person, to stop visiting the person. Visitors may also not want to come to a home in which there is a robot. Caregivers, such as home care nurses, may also be offended at being replaced by a machine. A robot may, however, provide caregivers with the opportunity to spend more quality time with the person in the home. Adding a robot could also lead to more complexity and more work for the caregivers, an *irony of automation* as introduced by L. Bainbridge (1982).

There are a number of ways of addressing these issues. A robot can help support social contact in a number of ways. Fosch-Villaronga and Albo-Canals (2019), for example, suggested in relation to therapy for children with autism spectrum disorder (ASD) that the robot does not answer the question, but instead asks the child to ask a teacher or an adult. This could be adjusted to the home context. Asking the robot for the weather forecast would be fine, but longer conversations could be handed on to others. The robot could also suggest and encourage the person to participate in social activities. This, however, requires the person to trust the robot. There is also the question of how likely a person will obey the robot (Bedaf, Draper, Gelderblom, Sorell, & de Witte, 2016).

The other case requires people to understand that the robot is only helping the person and is *not* a replacement for human contact. The robot should also provide caregivers with an opportunity to spend more meaningful time with the person at home, and give them the opportunity to perform a variety of other activities in areas in which a robot cannot help. Both of these depend on a good understanding of the problem area and on the involvement of caregivers and home residents. Robots in the home should be designed with the goal that they will help the residents and caregivers, not save money for employers and visitors. This should help facilitate a solution that does not eliminate social connections with others.

Chapter 2 examined different definitions of privacy, before settling upon using the boundary framing of Altman (1975) and the resulting framework of Palen and Dourish (2003). This selection helped our research into this area. But "Individual and cultural definitions and expectations of privacy are ambiguous, contested, and changing," (Markham & Buchanan, 2012, p. 6). Let us return briefly to the framing of privacy as protection. Discussions of privacy in a protection frame often focus on the individual. There may, however, be a need for group privacy to protect the information of a family or group of people and the connections between them.

Ess (2015) presented this division by using two Norwegian words: *privatlivet* to denote an individual's privacy and *intimsfære* to denote a person and the connections to other people that should be kept private. Ess argued that classic ethical frameworks, such as *deontology* and *consequentialism*, make it possible to argue that protecting *privatlivet* is sufficient, thus making it unnecessary to protect the *intimsfære*. Ess argues that *feminist ethics* (also known as *ethics of care*) have an explicit focus on the protection of a group of people and their connections. The focus of this ethical framework therefore makes it essential to protect individual's and group's *privatlivet and intimsfære*.

Privatlivet and *intimsfære* are evident when a robot is in a home. The robot may be "assigned" to a person and many would agree that protecting this person's privacy is important (*privatlivet*). The robot is, however, in a home and is exposed to the *intimsfære* via all the connections and relationships that one person has with other people, such as others who live in the home and visitors. It is easy to imagine situations where people would prefer that the privacy of these connections were preserved. The boundary framework from Paper 1 is, however, robust enough to handle these issues. The framework's identity, temporal, and disclosure boundaries provide a different lens that can detect and protect *privatlivet* and *intimsfære*.

An interesting implication in Europe is that privacy is not just an ethical question, but a matter of law that must be complied with (Fosch-Villaronga & Albo-Canals, 2019). Frameworks for examining privacy, such as our framework in Paper 1, can help lead to compliance with regulations. Fosch-Villaronga and Albo-Canals (2019) also mention a future *robot impact assessment* in design of robots. This should, eventually, lead to a data protection and surveillance impact analysis. Our framework could act as a supplement to the creation of this robot impact assessment.

Examining legal obligations also inevitably leads to the question of how to guarantee the safety of the people in homes. What kind of testing and certification is needed for robots in homes? Who is at fault when something goes wrong? And what recourse do those in homes (or next of kin) have in these situations?

As people age, they also tend to develop other diseases and sicknesses that can affect each other and have a cumulative effect on a person's well-being. This can result in disabilities that may make ways of receiving information or interacting difficult. Researchers should therefore consider applying universal design principles and methods when creating robots or any other technology for the home. This will ensure that the greatest number of people can experience and benefit from robots (Fuglerud, 2014; T. Schulz et al., 2014).

6 *Conclusion & Future Work*

To be continued...

Anonymous

In this work, we have examined privacy issues associated with a robot being present in a home. We have examined how animation techniques can be used to make robots move smoothly and more naturally in a home environment. The goal of this is to make interactions with the people in the home easier. Contributions have been made in the form of: (*1*) a boundary framework based on the framework of Palen and Dourish (2003) for examining privacy dilemmas, (*2*) a literature review of user studies in HRI that have used animation techniques, (*3*) an examination and implementation of a slow in and slow out velocity profile for wheeled robots, (*4*) a categorization of movement in the home between a human and a robot, and (*5*) an evaluation of people's perceptions of a robot that uses a slow in and slow out velocity profile as compared with one that uses linear velocity profile while performing a task in a home environment. These contributions have been applied to the MECS project and can be applied to the fields of HRI, HCI, privacy research, and beyond.

The research presented in this dissertation spans the different fields of HRI, HCI, privacy research, and animation. Qualitative and quantitative methods from different epistemological roots have been used in this research. A multidisciplinary approach is a necessary condition for uncovering the richness of environments as varied as a home, the people that reside in them, technologies that can be used to address problems in their lives, and the interplay between all of these.

There are several areas in which this research could be a starting point for future work. We can begin with the area of robots and privacy in the home. The boundary framework introduced in Paper 1 helps find dilemmas at privacy boundaries where negotiation between the person and the technology are required. Paper 1 used a generic robot and a sample of possible sensors and possible scenarios. The next step would be to use the boundary framework on actual robots and systems used in the home to determine the dilemmas that can arise in these situations. Cataloging these different dilemmas may be of interest to determine whether these match other models or whether a taxonomy of dilemmas can be created.

Another venue could be the use of the boundary framework as part of the building blocks for the legal compliance of a robot, such as a privacy policy for GDPR compliance. Fosch-Villaronga and Albo-Canals (2019) refer to the forthcoming robot impact assessment framework for developing these policies for robots. It would be interesting to see how the boundary framework can play a role in with this forthcoming framework. Performing this work and documenting this combination can aid future robot designers and lawyers in the implementation of the steps required to get robots from the lab into the home.

Turning to animation techniques, we can see that animation techniques have been part of current HRI studies. There are still, however, areas within animation techniques that remain unexplored. There are also a number of animation principles that have yet to be applied to robots. For example, the principle of *solid drawing* at first glance appears to suggest that animators work to achieve consistency in drawing characters and scenery. But the principle also encourages animators to avoid twinning. That is, avoid drawing characters with limbs that mirror each other. This rule could easily be adapted to robot motions. A study of this symmetry or lack of symmetry could, furthermore, indicate whether this is worth implementing on robots.

It would also be interesting to look at slow in and slow out and the affect it can have on people's feeling of safety. There were some indications in Paper 4 that people may feel calmer around a robot that moves using slow in and slow out velocity profile. This could be a starting point for examining whether this has an effect on required distance for a robot to stop when it encounters an obstacle.

Studies could also look at how the principles can be combined and look at the additive effect they can have upon the perception of those watching the robot. This may be important, especially if parts of the robot are hidden from the person watching the robot.

There are other animation techniques that go beyond these principles that merit exploration. Williams created his *Animation Survival Kit* to help animators go beyond just "formulas, principles, clichés, and devices" (Williams, 2009, p. iv). Further research may provide an addendum for robot animation. One area of overlap is in the world of computer animation and games. Zhang, Zhou, and Liu (2019) presented their motion planning framework as suitable for robots *and* animation. Szafir et al. (2014) also borrowed from computer graphics to implement their easing on a flying robot.

This highlights how fertile human art and performance can be for robot motion. Some have noted that animation is just another form of acting (Williams, 2009). LaViers et al. (2014) and Knight and Simmons (2016) have applied dance techniques to move robots. There could well be other acting, theater, and film techniques that can provide additional inspiration.

Another topic that is related to animation is *animacy*. Animacy is the most common term for an object moving as if it is alive,or that it "has life". There are also other terms that are used to describe this, such as *liveliness* (Chow, 2013). Animation and animacy have the same etymological root. There is therefore a possibility that animation techniques could be used for creating this animacy in a robot. We have looked briefly at this at a theoretical level (T. Schulz & Soma, 2018). But it can be further explored as theory and in practical implementations. For example, Mohammadi et al. (2019) documented the creation of their "personality-driven" robot and investigated how participants measured the robot's animacy in two different personalities as the robot played a game with a participant. Using animation techniques with this robot could help in strengthening a robot's animacy.

This example shows that while investigating movement in isolation is an interesting area of research. It is, however, also necessary to investigate interaction and robot motion in scenarios. The experimental set up in Paper 4 resulted in most participants keeping their eyes on the movement of the robot. This set up could also be used in other explorations and questions on robot movement, irrespective of whether they include animation.

Returning to the problem area, Section 5.5 mentions that universal design should also be considered when creating a robot, particularly on that will be used in the homes of older people. Animated movement does not necessarily help those with a vision impairment, but may help those with a hearing impairment. An area of future research may be looking at how animation techniques can be combined to provide multimodal feedback to a robot.

The assistance from residents from Kampen Omsorg+ was important and useful to the MECS project. They provided valuable feedback on ideas and their opinions helped form the activities and the direction of the research. We may, however, have overlooked another group: the nurses and other caregivers that are involved in residents' everyday lives. A future research project should strongly consider including this group in the process. This may help identify additional areas in which robots can assist residents and caregivers. The caregivers' involvement may also ease fears that robot will take over their jobs. This can lead to the creation of a win-win scenario for all involved.

The goal of enabling older people to live independently at home with the help of technology is a noble one. If carried out correctly, people will have the dignity and the joy of participating in social and familial life. The caring duties of caregivers will also be made easier, thus allowing caregivers to focus on more satisfying caring tasks. Robots that move using animation techniques can make interaction easier for all parties. Robots should also protect the privacy of residents and caregivers. But we are still searching for a solution of how this can be achieved. Technology is just one part of the puzzle; other parts include governments and people. The research in this dissertation therefore represents just a small piece of the solution to this puzzle.

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Part II

The Papers

1 *Paper 1*

Schulz, T., Herstad, J., & Holone, H. (2018, July 15). Privacy at Home: An Inquiry into Sensors and Robots for the Stay at Home Elderly. In *Human Aspects of IT for the Aged Population. Applications in Health, Assistance, and Entertainment* (pp. 377–394). International Conference on Human Aspects of IT for the Aged Population. doi:10.1007/978-3-319-92037-5_28

2 *Paper 2*

Schulz, T., Torresen, J., & Herstad, J. (2019). Animation Techniques in Human-Robot Interaction User Studies: A Systematic Literature Review. *ACM Trans. Hum.-Robot Interact.*, *8*(2). doi:10.1145/3317325

Animation Techniques in Human-Robot Interaction User Studies: A Systematic Literature Review

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There are many different ways a robot can move in Human-Robot Interaction. One way is to use techniques from film animation to instruct the robot to move. This article is a systematic literature review of human-robot trials, pilots, and evaluations that have applied techniques from animation to move a robot. Through 27 articles, we find that animation techniques improves an individual's interaction with robots, improving the individual's perception of qualities of a robot, understanding what a robot intends to do, and showing the robot's state or possible emotion. Animation techniques also help people relate to robots that do not resemble a human or robot. The studies in the articles show further areas for research, such as applying animation principles in other types of robots and situations, combining animation techniques with other modalities, and testing robots moving with animation techniques over the long term.

CCS Concepts: • **Computer systems organization** → **Robotic autonomy**; *Robotics*; • **Human-centered computing** → *HCI design and evaluation methods*; *Interaction paradigms*;

Additional Key Words and Phrases: Robot, human-robot interaction, literature review, animation, motion

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1 INTRODUCTION

When the Kismet robot was introduced, individuals could interact with it via conversation or gestures as opposed to typing on a keyboard [18]. Human-robot interaction (HRI) requires the robot to also respond. A robot that gestures and moves can aid an individual in understanding what the robot is doing and aid in the interaction.

In movie production, we observed the phenomenon of *animation*—layering slightly different frames of an object to create the illusion of movement. Animators follow principles such that animations are believable and tell stories [85]. The principles are successfully used in computer graphics [49], and studies suggested that the principles should be considered for robots [68, 89]. However, what is the extent to which animation techniques are used with robots and how do animation techniques affect HRI?

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The present study maps the current knowledge by conducting a systematic literature review of evaluations using animation principles and techniques in HRI. First, we construct a foundation and context by examining movement, how movement affects an individual's interpretation of things, *animation* in the HRI context, and animation techniques (Section 2). Then, we present the method to perform a systematic review (Section 3). This is followed by the search results, where we provide a review of the articles that we examined (Section 4). We discuss the implications and potential areas for future research (Section 5) before providing a few concluding remarks (Section 6).

2 BACKGROUND: MOVEMENT, ANIMATION, AND ROBOTS

We first define types of movement. Then, we quickly review principles of animation as a way of looking at animation techniques for HRI and how they can be applied to robots. We briefly discuss other techniques for moving robots and conclude the section with an exploration of the concept of *animacy* and its relation to HRI and our study.

2.1 Movement and Animation

The phenomenon of *movement* is straightforward. In physical terms, movement is a *vector* with *speed* and *direction*. In robotics, movement that changes the position of the robot is called *locomotion* or *translation*. Robot movement that does not affect its position is called *configuration*. Locomotion and configuration can be combined. So, a robot can move toward a person (locomotion), wave at a person (configuration), and say "hi."

Animation in HRI uses techniques from animation in films or computer graphics (or inspiration from them) to specify how a robot moves. This movement should help a robot communicate with humans. This complements a suggestion by van Breemen [88] with using animation principles to help create "believable behavior" [88, p. 2873] in a robot. Ribeiro and Paiva [67] built on this definition and added that "…robot animation consists of all the processes that give a robot the ability of expressing identity, emotion and intention during autonomous interaction with human users" [67, p. 388].

Let us review some of these animation techniques, starting with the 12 principles of animation.

2.2 The 12 Principles of Animation and Other Animation Techniques

The idea behind traditional, hand-drawn animations for films corresponds to physics. That is, switch drawings sufficiently fast such that what is rendered appears to move. The idea also applies to computer animation or anything that is filmed. The actual drawing (or rendering) is considered as art. Thomas and Johnston [85] documented how animators at Walt Disney Studios practiced their methods of creating their animations until they obtained a few methods that "…seemed to produce a predictable result" [85, p. 47]. The artists termed these methods the *fundamental principles of animation*, and the principles were taught to new animators. Although the principles were not verified scientifically, they have been used in financially successful animated films and cartoons watched by millions. The 12 principles are as follows:

Squash and Stretch. Characters and objects should squash and stretch with their action, although they do not completely lose their shape.

Anticipation. Major action should be telegraphed such as reaching back before throwing an object.

Staging. An action should be clear to the audience. For example, the audience should understand the action by only viewing it in silhouette.

Straight Ahead Action and Pose to Pose. This principle describes how to draw an action. Drawing straight ahead involves starting to draw and simple continuing until the action is completed. Pose to pose implies that specific poses are desired in an action and are choreographed before the actual animation.

Follow Through and Overlapping Action. Actions are not performed in isolation. An animated character exhibits a plan and moves from one action to the next without stopping between.

Slow In and Slow Out. The speed of a motion is not the same during the time that it is performed. Action is slower at the beginning and end.

Arcs. Move limbs in arcs as opposed to of straight up-down and left-right motions.

Secondary Action. Create complementary actions that emphasize the main action. For example, a character puts on a coat while walking out the door.

Timing. Changes in number of frames that are between a start and stop determines the speed of the action, thereby increasing the number of frames and decreasing the speed of the action.

Exaggeration. Exaggerated action ensures that it is easier to understand the feelings of a character.

Solid Drawing. Drawings should look plausible and three-dimensional and *twins*—symmetrical limbs on a character—should be avoided, since it makes characters look stiff.

Appeal. All the characters should be appealing whether one is expected to sympathize with them or despise them.

A few of the principles are related to the craft of pen-and-paper animation and narrative of films, although they are shown as applicable to other areas, such as 3D computer-animated films [49].

The 12 principles are not the only methods to animate an object or produce cartoon-like movement; several other methods reflect aspects of the principles. For example, a common method involves the use of *key frames*, which are frames that define important (key) points in a movement. Then, the software or other animators interpolate the frames between the key frames. This is similar to the pose to pose part of the *Straight Ahead Action and Pose to Pose* principle.

A different way of animating movement involves an individual acting out the movement and transferring it to the animation media. One method is *rotoscoping* where animators trace individual frames of a filmed action to create a realistic and human-like animation. Another technique involves the use of *motion capture*, where sensors capture the movement and software translates the movement onto another model.

A field related to animation is *puppetry* and *animatronics* where a person controls how a puppet or other creation moves and reacts to a situation. This is a relevant method to consider for moving a robot, especially if the robot is teleoperated. Scherer [75] has argued that this is a fertile area to investigate for robot design.

Kinematics is a mathematical method to express movement and is used for robots that are composed of a chain of articulated nodes. *Inverse kinematics* is a method to solve for the different nodes (joints) to move to obtain a desired position by working backwards to its starting position. A common use of inverse kinematics is when a robot arm is picking or placing objects. In the real world, joints have limited degrees of movement, so not all solutions are valid. However, applying animation principles to the formulas (e.g., making movement follow arcs) can turn kinematics into an animation technique.

2.3 Other Techniques for Robot Communication Through Movement

Techniques for communicating through movement exist beyond those used in animation and film. These are not animation techniques, but were developed in other areas and have been applied to robots.

In the world of dance and acting, Laban created the *Laban Effort System* [48] that describes human motion in four effort factors: Space, Weight, Time, and Flow. Each factor has two elements (polarities) to adjust the factor's character. For example, Space has elements of direct versus indirect, and Time has elements of quick versus sustained. The system can be used by dancers and actors to better understand their own patterns and biases in movements and impart better quality on their movement. LaViers and Egerstedt [50] used Laban's work to make robots dance alongside other dancers using the robots' own style. The system was fully formalized for a humanoid robot [51]. Knight and her colleagues implemented a version of the Laban Effort System to express the internal state of robots with limited degrees of motion—such as only a head [45] or only a platform that can turn [44]. They investigated situations like sharing space in an office environment [47] and putting the Laban System on top of other tasks the robot was performing [46].

Other HRI studies have different solutions for robot motion and communication. Some studies have used colored lights flashing in different patterns to signify direction [81] for a flying drone and what a robot moving in the office is doing [3]. Citing an inspiration from animation, but not necessarily using animation techniques, Dragan and her colleagues have investigated the difference between what makes a robot's motion legible and what makes it predictable [26]. This tension between legible and predictable motion affects collaboration between a robot and a person [25]. They have also investigated how a person's familiarity with a robot affects how easily the person can predict the robot's motion [27].

2.4 Animacy

Animacy refers to an object moving as if it is alive (or that it "exhibits life"). The concept was traced back [6] to Piaget's study of children learning what is alive or not [63].

The motion that creates animacy is described as *animate motion*: "movement that is self-propelled but not necessarily created by other living creatures" [15, p. 837]. Even simple shapes can exhibit animacy. In a classic psychology study by Heider and Simmel [33], individuals watched a film of shapes moving around and then interpreted what happened. A majority of the individuals described the action in the film as a story and gave personality traits to the shapes. Subsequently, another study indicated that individuals perceive animacy in a particle if it moves on a path and speeds up [87].

Another set of studies examined how individuals perceived *contingency* [57]. Individuals watched films of objects moving and were asked to interpret them. In a few films, individuals said the movement of one object (X) was contingent on the movement of another object (Y). These aforementioned studies—and studies that built on the concepts—were reviewed by Scholl and Tremoulet [76]. Another study used simple films of objects depicting contingency and animacy to explore what parts of the brain were activated for each film [15].

Several HRI studies examined how individuals ascribe feelings and personalities to the way robots move, whether they look like a dog [8, 11], a vacuum cleaner [30, 73, 79], or simply an arm [100]. Other HRI animacy studies are based on Piaget and examine children's relationship to robots and other things that are alive [14, 56, 61]. Others have examined how individuals' interaction with a robot affects their willingness to end the robot's existence [4, 9, 10, 38].

Animacy references the original definition of animation (i.e., bringing an element to life) and the idea of an animate object—an object that moves on its own—versus an inanimate object—an object that does not move. Specifically, animation techniques in Section 2.2 and the other techniques mentioned in Section 2.3 can be used to create animacy. However, this study focuses on the use of animation techniques and not on animacy generally.

3 METHOD: LITERATURE REVIEW PROTOCOL

The systematic review followed a process outlined by Budgen and Brereton [19, p. 1052]. The process consists of five parts: (a) define a review protocol with research questions and methods employed for assessment, (b) define a search strategy, (c) document the search strategy, (d) specify explicit inclusion and exclusion criteria, and (e) specify the information that will be obtained from each item. We present each part as a subsection here.

3.1 Research Questions and Methods for Assessment

The goal of the review involved mapping the knowledge that exists for using animation techniques to move robots and see where further research can be directed. This resulted in several research questions: (a) What animation principles and techniques are used for moving robots? (b) What kind of studies are performed with animated robots and individuals? (c) How do animation techniques affect individual's interaction with a robot? (d) What data was collected in the aforementioned studies? (e) What robots are used in these studies? (f) What are the environments (lab or real world) in which the studies are conducted? (g) What was the modality for the study (e.g., a live evaluation or a video)?

Most of the answers are found in the study method, study results, and design of the robot. So, we can determine candidate articles by searching article metadata. Then, a reading the method and results section should determine if the study is relevant for the research questions.

3.2 Search Strategy Plan

We followed a similar search strategy employed by Riek [70]. We searched two databases, namley IEEExplore [40] and the ACM Digital Library [2], since they include many articles on HRI, HCI, and robotics. Neither databases index the HRI journal the *International Journal of Social Robotics* nor the HCI journal *Interaction Studies*, but it is necessary to balance the breadth of the search relative to the complexity of reproducing the method. The search was performed on 30 June 2018.

The search on IEEExplore only examined metadata, and the search string was as follows:

`((HRI OR "human-robot interaction") AND (experiment OR "user study" OR pilot OR evaluation) AND (animation OR animate OR cartoon)).`

The search of the ACM Digital library searched the *ACM Guide to Computing Literature* that includes additional items from other publishers. The search string for the ACM Digital Library was equivalent to the IEEExplore search string:

`+(+(HRI "human-robot interaction") +(experiment "user study" pilot evaluation) +(animation animate cartoon)).`

We included "cartoon" in the searches, since a few studies we were aware of did not mention animation techniques for movement, but they mentioned techniques for "cartoon-like movement."

3.3 Inclusion and Exclusion Criteria

Beyond the search string, the inclusion criteria corresponded to peer-reviewed conference and journal articles about robots that used one or more animation techniques to move and included a study with individuals. Therefore, a relevant paper included the following: (a) at least one robot, (b) at least one animation technique, and (c) at least one person that evaluated or interacted with the robot.

The goal involved mapping the use of animation techniques in HRI studies, and thus we were generous in what was considered a study and included pilot studies, informal studies, or critiques of a robot's movement.

Table 1. Number of Articles Found in Each Database

Database	Results
ACM Digital Library	68
IEEExplore	46
In both	(8)
Total	106

The review excluded posters, workshop announcements, and non-peer-reviewed books. We also excluded articles that: (a) only described a robot, (b) only described a tool or algorithm for a robot, (c) evaluated robot interaction with animals, (d) only studied animacy (as per Section 2.4), and (e) only evaluated interaction with virtual agents or virtual robots.

3.4 Information Obtained from Each Study

For each relevant article, we collected information about it for the review. The information was the following: (a) robot used, (b) embodiment of the robot, (c) animation technique that was used, (d) number of participants, (e) data that was collected, (f) whether the study was performed with a video or in real-life, (g) whether the robot was in a lab or not, and (h) what type of movement was involved (configuration, locomotion, or both).

4 RESULTS

The searches returned 68 items from the ACM Digital Library and 46 items from the IEEExplore database. The results from the searches were combined and controlled for entries that appeared in both the ACM Digital Library and IEEExplore. This resulted in a total of 106 items (Table 1). The searches produced a sufficient number of articles, although they were not overwhelming. We began reading the items to apply the inclusion and exclusion criteria.

For articles that matched our inclusion criteria, we wrote down information as outlined in Section 3.4. Articles that were missing this information or matched our exclusion criteria were excluded, and the reason for exclusion was documented.

The authors met to discuss the placement of the articles and agreed on a final list. We had initial disagreement on six articles [17, 28, 66, 86, 95, 99]. The final consensus was to exclude them as each lacked one of the inclusion criteria. This resulted in 79 articles that were excluded and 27 that matched the inclusion criteria.

There were three articles we expected to be in the search results, but they were not in the results due to missing information in the metadata. One article [68] was about applying animation principles to a robot for showing emotions. The article *does* include an evaluation, but it is *not* specified in the article metadata. The second article [80] used the animation principles of *Arcs*, *Anticipation*, and *Slow in and Slow out* for Assistive Free Flying robots, but there was no mention of animation in the metadata. The third article [54] documented the design process for an animated robot for the smart home but mentioned neither a user study nor animation in the metadata. On one hand, it is unfortunate that the databases missed these articles, and we chose to keep these specific articles out of the review to keep the method straightforward to replicate. On the other hand, several of these authors *are* included in our list of relevant articles. So, while a specific article may not be included, their research in this area is part of the relevant literature.

4.1 Paper Demographics

The majority of the 27 papers (20) were conference papers. Over three-quarters of the conference articles (15) were from HRI conferences (HRI, RO-MAN, and Humanoids). The other conferences

Table 2. Breakdown of Articles by Conference and Journal in Order of Number of Articles

Type	**Name**	**Articles**
Conference	ACM/IEEE Conference on Human-Robot Interaction (HRI)	8
Conference	IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)	4
Conference	IEEE-RAS International Conference on Humanoid Robots (Humanoids)	3
Journal	*ACM Transactions on Interactive and Intelligent Systems* (TiiS)	2
Journal	*Computers in Human Behavior*	2
Journal	*Autonomous Robots*	1
Conference	International Conference on Advances in Computer Entertainment Technology (ACE)	1
Conference	International Conference on Interaction Design and Children (IDC)	1
Conference	International Conference on Multimodal Interaction (ICMI)	1
Conference	IEEE Portuguese Meeting on Bioengineering (ENBENG)	1
Conference	Graphics Interface (GI)	1
Journal	*Journal of Intelligent Robotics Systems*	1
Journal	*Multimedia Tools and Applications*	1
	Total	27

articles were from conferences that focused on specialized HCI (ACE, IDC, ICMI), graphics (GI), and bioengineering (ENBENG). The remaining seven articles were from robotics, HRI, and HCI journals: two journal articles from *ACM Transactions on Interactive Intelligent Systems* (TiiS); two articles were from *Computers in Human Behavior*; and the last three articles were from *Autonomous Robots*, *Journal of Intelligent Robotic Systems*, and *Multimedia Tools and Applications*. The breakdown of articles from each venue is shown in Table 2.

4.2 Robots and Robot Types Used in the Studies

Although there are articles that examine the use of tools and frameworks that use techniques from animation for moving a robot [7, 69, 88, 90], the review examined the animation techniques with robots that are evaluated with participants, robots that are used in the evaluations. Table 3 sorts the studies by year and identifies the robot; type of robot (i.e., humanoid, animal, a head, or other); and animation technique used.

Twelve studies used a humanoid robot or a combination of a humanoid robot with an animal robot. Eight of the aforementioned studies used Nao [1, 12, 41, 52, 55, 58, 60, 84] one of the eight also used a Pepper robot [41]. These commercially available robots offer software to animate the robot using animation techniques and using key frames [65]. Robovie II is another commercially available robot that was used for two animation studies [5, 94]. Finally, SIMON and Alpha are custom humanoid robots that were used for one study each [13, 31].

Seven studies used robots that resembled an animal. Two of the studies used the iCat [5, 58], a cat robot that was designed using animation principles to have an expressive face [91]. The other robots are custom robots. One study [93] used Tofu, a fluffy, squash and stretch robot that resembles a bird. Another study [98] used a plush dog-like robot to dance. A study [97] used the Haptic Creature, which resembles a mouse. A study [96] used Probo, a robot that resembles a type of mammoth [74]. The final animal robot study [67] used Adelino, a custom robot that resembles a snake.

Four studies used a head to test animation principles. Each robot head was different. One study [24] used RAF, a robot that is a retro-projected face that is projected on a sphere. Another study

Table 3. Studies Sorted by Year Ascending, with Robot and Animation Technique

Year	Reference	Robot	Type of Robot	Animation Technique
2005	[13]	Alpha	P	Arcs
2005	[94]	Robovie II	P	Motion Capture
2007	[5]	iCat, Robovie II	A, P	Secondary Action
2010	[24]	RAF	H	Secondary Action
2010	[32]	Stem	O	Unspecified animation techniques
2011	[37]	Shinmon	O	Anticipation, Follow Through, Slow In, Slow Out
2011	[82]	PR2	O	Anticipation, Follow Through
2011	[93]	Tofu	A	Squash and Stretch
2011	[97]	Haptic Creature	A	Pose to Pose (Key Frame)
2012	[12]	Nao	P	Motion Capture, Pose to Pose (Key Frame)
2012	[31]	SIMON	P	Exaggeration
2012	[72]	Alphabot	O	Pose to Pose (Key Frame)
2013	[23]	DEVA	O	Squash and Stretch
2013	[77]	Parrot AR.Drone	O	Motion Capture
2014	[98]	Roomba, Reactor	O, A	Motion Capture, Puppetry
2015	[34]	Custom Head	H	Unspecified animation techniques
2015	[55]	Nao	P	Pose to Pose (Key Frame)
2015	[60]	Nao	P	Secondary Action
2015	[62]	Custom Head	H	Exaggeration, Secondary Action
2015	[96]	Probo	A	Secondary Action, Squash and Stretch
2016	[52]	Nao	P	Motion capture
2016	[58]	Nao, iCat	P, A	Secondary Action, Pose to Pose (Key Frame)
2017	[1]	Nao	P	Secondary Action
2017	[53]	ISR-RobotHead	H	Secondary Action
2017	[67]	Adelino	A	Inverse Kinematics using animation principles
2017	[41]	Pepper, Nao	P	Pose to Pose (Key Frame)
2017	[84]	Nao	P	Puppetry, "Animation Best Practices"

Type of Robot: A: Animal, H: Head, O: Other, P: Humanoid.

[53] used the ISR-RobotHead, a head with LCD screens for the eyes and mouth. Another study [34] used a computer monitor with animated eyes and neck that moved expressively so that it was possible to identify where the robot was looking. A robot head with expressive eyes and a creative use of tubing to make an expressive mouth was used for the remaining head animation study [62].

Seven studies used robots that did *not* resemble a animal, head, or humanoid. These studies represented a variety of robots. Robots had an appearance of a stick [32], a large alphabet block [72], or a smartphone [23]. Other forms included domestic robots like the Roomba [98], a quadcopter drone [77], a PR2 [82], or a custom, three-armed, marimba-playing robot [37].

4.3 Animation Principles and Techniques Used in the Articles

Eighteen studies used one or more animation principles. This includes counting key frames as a version of the *Pose-to-Pose* principle. Some studies explicitly name the principle. For others, we inferred the principle from the text, and have noted this below. Table 4 breaks down the number of studies for each principle.

The principle that is most frequently used (eight times) is the principle of *Secondary Action* where something else is animated in addition to the main action. The studies that use *Secondary*

Table 4. Breakdown of Animation Principle and the Number of Studies They Are Used in

Animation Principle	**Articles**
Secondary Action	8
Straight Ahead Action and Pose to Pose	6
Squash and Stretch	3
Anticipation	2
Exaggeration	2
Follow Through and Overlapping Action	2
Slow In and Slow Out	1
Arcs	1
Timing	0
Staging	0
Solid Drawing	0
Appeal	0

Ordered by number of articles; some articles use more than one principle.

Action make the robot react to a situation or show an "emotion" in the acting sense of showing an emotion as lifeless objects like robots do not have real emotions [1, 5, 24, 53, 58, 60, 62, 96]. In the aforementioned studies, one [62] names the principle explicitly and the others imply the principle's use as they either use a robot that uses this principle (iCat) [5, 58] or document that additional parts are animated during an action (e.g., eyes and eyebrows in addition to the mouth [24, 53, 96] or moving parts of the body while the robot is idle [1, 60]). These secondary actions aid in highlighting what is going on.

The next principle that was used six times corresponds to *Straight Ahead Action and Pose to Pose*. This principle is similar to the idea of key frames, since—in applying the pose-to-pose part of the principle—the animator is trying to create the key poses (i.e., frames) for the character in a situation. All the studies either explicitly name the method [55, 72, 97] or use software that uses key poses for driving the animation [12, 41, 58]. Studies that employ the principle examine synchronizing action to another event (e.g., entering or leaving the virtual world [72], dancing [55], or falling [58]), present the robot's emotional state [12, 97], or the impression a participant receives about the robot [41].

Although most individuals do not consider robots soft and squishy, the *Squash and Stretch* principle was used in three studies. In two studies [93, 96] the squash and stretch principle was used to make the robot more appealing to children. Another study used crawl, breathe, and curl gestures to create a smartphone that exhibits emotions and appears alive [23]. The study does not name the *Squash and Stretch* principle directly, but the resulting smartphone and the description of the gestures seem to evoke it.

The principle of *Exaggeration* was used in two studies such that it was easier for individuals to understand what the robot was doing. In one study [31], the SIMON robot related stories to participants and exaggerated certain gestures used in the story. The other study [62] combined *Exaggeration* with *Secondary Action* such that it was easier for participants to understand emotions.

The principles of *Anticipation* and *Follow Through and Overlapping Action* were used together in two separate studies to help a non-standard looking robots to express what it was doing. In one study [82], an animator was employed to design animations following these principles so it was easier to understand that the robot was delivering a drink, escorting a person, opening a door, or looking to recharge. One study [37] used the aforementioned principles along with the principle of *Slow in and Slow out* with the marimba-playing robot Shimon to improvise and signal to jazz musicians playing along with it.

One study had its museum guide robot, Alpha, use sine curves instead of straight lines to make the robot's arm movement seem more human-like [13]. Although it is not stated in the article, this is exactly the animation principle of *Arcs*. The robot's arms moving in arcs made it easier for individuals to understand what it was pointing toward.

Rounding out the review of animation principles, a few principles (*Timing*, *Staging*, *Solid Drawing*, and *Appeal*) are not mentioned in any studies. These principles have more to do with the craft of creating an animated film.

With respect to techniques beyond the principles, motion capture was the most popular other technique and was used in five studies. Two studies used motion capture of humans as an input to how the robot should react to it. One study [94] used motion capture to track the robot's and person's position. The robot itself used "nonlinear motion" [94, p. 408], which could be interpreted as the *Slow In and Slow Out* principle, but this is not explicitly specified. Another study [98] motion captured individual's movements and used pattern matching and frequency analysis to generate complimentary trajectories for a Roomba to follow along and act as the individual's partner.

The remaining studies used motion capture to capture humans moving and translate it to robot movement. In one of these studies [12], motion captured actors performing emotions and then used this to animate agents and a Nao. Another study [52] took videos of lecturers and converted them to as input for a Nao robot. The final study [77] motion captured actors using the Laban Effort System and used this motion to communicate affect to individuals using a Parrot AR.Drone.

Two studies used ideas from puppetry. Puppetry was used as an addition to motion capture as the second part of a study [98] to teach a robot dog how to dance by following the movements of a puppet cat. Puppeteers were consulted along with applying "animation best practices" [84, p. 61] to creating the Nao's body language.

One study [67] defined an inverse kinematics engine such that the Adelino snake robot moved in a word guessing game. The movements indicated to the human participant as to how close the participant's guess was to the correct word.

Finally, two studies used animation techniques, but the exact method was not documented. One of the studies [32] cited several animation techniques and animated movies as inspiration to creating a concept termed *emotive actuation* to move the STEM robot stick expressively. The other study [34] used animation sketches and tests to articulate a neck and head such that it appears to be watching participants.

4.4 Environments, Participants, Data Collected, Movement Types, and Modality

After examining the robots and animation techniques used, we examine other details of the studies. Table 5 shows the studies' environment (lab or real world), number of participants, whether the motion was configuration, locomotion, or both, the data collected, and the modality (video or live). Given the information, at least 1,180 participants were involved in HRI studies that used animation techniques.

4.5 Video or Live Modalities

Several HRI studies include individuals that interact with a robot in person, while other studies show a video of the robot performing. Since the animation techniques are derived from the movie world, it is potentially expected that most studies use video. However, the opposite was true, since 22 studies took place with the participant and the robot in the same setting, while only 6 studies

Table 5. Studies in Same Order as Table 3 with Environment, Number of Participants, Data Collected, Movement Type, and Modality

Reference	Setting	# Participants	Data Collected	Movement	Modality
[13]	Real	Not Listed	Questionnaire: Human-like	C	Live
[94]	Lab	23 & 23	Questionnaire on cognitive ability, intelligence, Lifelikeness	B	Live
[5]	Lab	62	Questionnaire: robot intelligence, animacy	C	Live
[24]	Lab	24	Where is the robot gazing	C	Live
[32]	Lab	Not Listed	Design critique, Interpret motion	C	Live
[37]	Real, Lab	6 & 21	Hypothesis test, embodiement and appreciation, audience appeal	C	Live
[82]	Lab	273	Qualitative and rating appeal, intelligence, competence, subordinate	B	Video
[93]	Lab	8	Observation of children	B	Live
[97]	Lab	32	Questionnaire: pick emotion, SAM, and confidence, plus open questions	C	Live
[12]	Lab	23	Questionnaire: identify emotion, valence, arousal	C	Live
[31]	Lab	54 & 68	Test memory of story, test where robot is gazing	C	Live, Video
[72]	Lab	34	Qualitative measure for continuity	L	Live
[23]	Lab	6 & 10	Arousal, valence, other things	C	Live
[77]	Lab	18	Questionnaire: SAM + interview	L	Live
[98]	Lab	20, 38, 11	Observation, Interview	L, C	Live
[34]	Lab	60	Authority, Monitoring, and Guilt	C	Live
[55]	Real	Not listed	Interest in the set up	C	Live
[60]	Lab	48	Questionnaire: TA-EG, Competence and enthusiasm, Hypothesis testing	C	Live
[62]	Lab	25 & 20	Compare emotions	C	Video
[96]	Lab	35	Identify emotion	C	Video
[52]	Lab	40	Questionnaire: Knowledge recall and attitude, Presentation and enthusiasm	C	Video
[58]	Real	22	Questionnaire: Godspeed likability, Big Five Inventory	B	Live
[1]	Lab	26	Questionnaire: Godspeed: Perceived Anthropomorphism and Proficiency, Task Performance, and attention	C	Live
[53]	Lab	9	Questionnaire: Identify emotion	C	Video
[67]	Lab	42	Hypothesis testing: Performance, Animation, and Intention	C	Live
[41]	Lab	3	Questionnaire: CH33 (Impression of Robot)	C	Live
[84]	Lab	96	Questionnaire: SAM, robot familiarity	C	Live/VR

Movement Type: C: Configuration, L: Locomotion, B: Configuration and Locomotion.

used video. Although only 6 studies used video, it is possible to recruit many more individuals to look at videos instead of synchronize a time to meet a robot. They did provide over one-third of the participants in the studies: 402 participants in video studies versus 778 participants that interacted with the robot in person. Most of these 402 participants come from one study [82] that used Amazon's Mechanical Turk to recruit 273 participants. However, with respect to the median number of participants for video and live (30 and 23, respectively), the number of participants for each study are much closer.

Table 6. Breakdown of Articles Versus What They are Studying

Study Examined	Articles
Robot emotions	9
Robot characteristics	9
Specific study hypothesis	8
Pilot study	3
Robot gaze	2

Some articles appear in multiple categories.

4.6 Study Environments

One reason for the literature review was to see how many studies were done in a lab setting versus studies that were done in a real-world setting. Most of the studies (24) took place in a lab environment (video modality was counted as a lab environment). There were four studies that used an environment outside of the lab (one article [37] had a study in a lab and real-world setting for the robot). Two of the studies in the real-world environment [13, 55] did not have a count on the participants or were only a pilot. This was the case for only one lab study.

4.7 Studies with Locomotion and Configuration

Given the different kinds of movement from Section 2.1, we wondered what the articles would say about the movement used in them. Surprisingly, most of the studies (25) focused on configuration. That is, the robot only moved parts of its body and did not change its location. Seven studies focused on locomotion. However, four of the locomotion studies also had the robot do some sort of configuration (whether it was to shake the person's hand [94], squash and stretch [93], communicate the robots intention [82], or as part of a humor skit [58]). Only one study [98] used two different robots for testing locomotion and configuration.

4.8 Data Collected and the Affect of Animation Techniques

The studies fall into groups about what researchers were studying: (a) studies where participant should identify the emotion shown by the robot, (b) studies interested in participants' opinion of a robot's characteristics, (c) studies asking participants where the robot is looking, (d) studies examining a specific hypothesis for a robot or situation, and (e) pilot studies. The breakdown for the articles is shown in Table 6. Let us examine these groups closer.

Nine articles looked at interpreting the "emotion" or disposition of the robot either through the robot's face or its body language. Of course, a robot does not have emotions, but it can display expressions that indicate an emotion. In the studies presented here, there are two main methods used for assessment. One method has participants rate the valence (the level of pleasure) and arousal (the level of enthusiasm) of a robot to create a two-dimensional field of emotion. The other method asks the participant to identify the robot's expression as one of the five universal, basic human emotions as defined by Ekman [29]. These basic emotions (happiness, sadness, fear, surprise, anger, and disgust) have corresponding levels of valence and arousal, but may be easier for individuals to relate to.

Two studies [12, 23] asked participant to rate the valence and arousal using Likert scales to show that the robots' movements indicate certain emotions as interpreted by the studies' participants. The self-assessment mannequin (SAM) [16] offers a alternative method using only pictures for identifying arousal and valence, and creates similar results. The SAM was used in three articles in the review [77, 84, 97]. One study used the SAM with the Haptic Creature [97] and found that the robot's motion communicated four of the nine conditions correctly to participants, and participants had correctly identified arousal correctly, but less well the valence. The second study [77] had statistically significant results for valence and arousal in the Laban Effort System factors of Space, Weight, and Time, but only for arousal for the factor of Flow. The third study using SAM [84] showed that the valence and arousal of the robot's movements were reduced when the person was under a stressful condition.

The method for using Ekman's basic emotions is to ask participants to look at the robot and pick the corresponding emotion. The final results are then compared against the chance of someone randomly picking emotions. Some articles that were excluded had participants match the facial expression using static pictures of robots (e.g., References [17, 21, 78]), but four articles in the review [53, 62, 96, 97] ran the evaluation with robots that were animated and used secondary action. Regardless of if the robot was animated or not, the selections of the participants matched the shown emotion well above chance, especially for happiness or sadness. But participants showed confusion between some other emotions (e.g., disgust was often misidentified as anger).

The nine articles evaluating characteristics of the robot were concerned with the participants' opinion about the robots motion or other qualities. The earliest study [13] asked individuals visiting their stand how human-like the robot's arcing arm motions were, with the arcs generally making the motion appear to be similar to humans. One of the questions in another study [31] was for individuals to classify how different amounts of exaggeration in the robot's motion yielded more cartoon-like or human-like movement. A different study [94] looked at lifelikeness but also asked about the robot's cognitive ability and intelligence. The robot scored higher when its motions were reactive of the person interacting with it, than if the motions were simply static. This measurement was further developed in a later study [5] to include animacy, where participants worked with either a Robovie II or an iCat to play a game. Though participants found Robovie II to be more intelligent than the iCat despite them both giving similar advice, participants spent more time looking at the iCat's animated face than they did the Robovie. A different study [82] had participants rate the robot's appeal, intelligence, competence, and how subordinate it was on a Likert scale along with describing what was happening in the scene. Here, the robot that was animated to show forethought before it did a task increased its appeal. Similarly, a robot that reacted to succeeding or failing a task made participants feel that the robot had intelligence and competence. As part of another study [52], participants were asked to rate a lecturer's likability and attitude for delivering a video presentation with most participants preferring the human form or an animation using the same voice over a robot or an animation of a robot.

The Godspeed Questionnaire [6] was created as a standard way to evaluate participants' perceptions of different aspects of a robot interaction. The questionnaire consists of scales for Anthropomorphism, Animacy, Likeability, Perceived Intelligence, and Perceived Safety. Each scale is independent, so HRI researchers can choose the relevant scales that work for them. The questionnaire shows up in two articles in this review [1, 58]. One article [58] looked at Likability between two robots and showed how a robot could improve its likability by laughing at itself after it fell over. The other study [1] used the Anthropomorphism and Proficiency scales to compare two robots, one moving only for static situations and one moving when it was idle, the idle action robot attracted more attention and scored higher on the anthropomorphism scale. A separate method for evaluating safety and performance qualities of robots, the CH33, was developed in Japan [43] and was used in one study in this review [41] to examine how well a model of motion perception matched to the perception of individuals watching different types of robot motion.

Eight articles had a specific hypothesis that was being tested. One article [37] investigated the musicians' appreciation for seeing the robot's motions when they improvised with it and how much having the robot and musician on stage appealed to the audience watching. A different study [34] examined the feelings of a person doing a task with an animated robot watching. Though participants could cheat for a better result in their task, they tended to be more honest with the robot watching with possible negative attitudes toward the robot. Another study [31] found that the exaggerated motions of the robot storyteller made those parts of the story more memorable. Another study [60] used animation techniques to simulate competence and enthusiasm in a robot playing the ultimatum game with a participant. Ribeiro and Paiva [67] had participants rate the performance of the robot, its animation, and its intention. A different study [52] looked at how much each student remembered from each lecture from a human, an animated human using the lecturer's voice, a robot, and an animation of the robot. The human lecturer followed by the animation of the robot resulted in the best scores for the participants' knowledge.

Two studies used only qualitative methods. One study [72] asked qualitative question about what children thought of the Alphabot and how the children understood the robot entering and leaving the virtual world. The other study [98] used observation and interviews to find out which methods worked best for teaching robots new ways to move.

There were two studies that used animation techniques and investigated where participants thought the robot was looking. One study [24] compared gaze direction with a spherical robot head versus a flat screen monitor. The spherical shape of the head and its use of secondary action in its eyes made it easier to see what was being looked at than the flat screen monitor. The other study [31] showed that the exaggerated motion of the robot made it easier for participants to predict the direction of the eye gaze than if the robot's motion wasn't exaggerated.

Finally, there were three studies that tested an animation technique with some participants to see if a concept could be further developed. Two studies [55, 93] involved testing if a specific set up would work with children, with general success. The other study in this group [32] was a design critique of a stick robot and how it moved.

5 DISCUSSION

This systematic review has looked at HRI studies done with robots that move using techniques from animation. What do these articles say about this area of research and what are future directions for research?

5.1 The Articles as a Whole

Table 3 shows that there have been some HRI studies using animation techniques back in the mid-2000s and at least one article about animation techniques in an HRI study every year since 2010. So, researchers are interested in researching animation techniques and robots and see how it affects individual's interaction with the robot.

Animation techniques help a robot communicating with a person, either directly or indirectly. Motion from animated techniques can make it easier to express some emotions. Animation techniques also help making a robot appear more appealing to the individuals who are either watching the robot or interacting with it. It can make the robot easier to relate to, approachable, or to have more intelligence.

The studies also show that animation techniques help beyond communicating an emotion. Motion from animation techniques can draw individual's attention to the robot. It can aid in understanding where a robot is looking, what it is planning on doing, or going to do next. This makes it easier to cooperate for human and robots to work together on a shared task.

The studies also indicate that animation techniques are useful for robots that do not have a standard animal or humanoid form. Hoffman and Ju [35] suggest that robot forms that are different from animals and humanoids may need to move in ways that are familiar to individuals to help individuals understand the robot. Animation techniques provide a method of movement that is familiar to individuals and easy to relate to based on the nearly a century of animation techniques in other media.

Looking at Table 5, we can see there are good measurement tools available for looking at aspects of using animation techniques with robots and comparing with other studies. This can help connect new research in animation techniques to the already existing research. If using an animation technique is to make the robot appear more likeable, safe, alive, or intelligent, then the Godspeed questionnaire is a readily available measure that has been used by studies using animation and other studies [92]. It can be a useful tool to compare new research with past results. If the goal of a study with animation techniques is to convey emotions, then using the basic emotions of Ekman [29], SAM, or rating valence and arousal provide a way of comparing results with past studies using other movement techniques. Of course, other qualitative and quantitative methods can be applied to look at new areas.

In general, the studies seem to indicate that using animation techniques is overall a positive experience for the individuals interacting with the robot. Returning to Ribeiro and Paiva's definition [67] from Section 2.1, animation techniques can certainly help make robots' behavior believable and allow robots to express identity, emotion, and intention. This suggests that spending time thinking about how a robot's motion will be perceived by others should aid in creating better robots to interact with, especially if robots may be part of what we see in our future everyday lives. Designers and engineers can enlist the support of animators, puppeteers, and others for determining how a robot should move (e.g., References [36, 54, 75]).

5.2 Future Research Directions

This literature review also points to different areas where further research in using animation techniques with HRI studies. These are some possibilities.

The 12 principles of animation are an area that can be further explored. Table 4 shows that four of the 12 had no study related to them. Some of these principles, like *Staging* and *Timing*, may seem to apply only for framing and directing a movie, but even bits of these principles may still be applicable to robots. For example, the principle of *Staging* states that action should be understandable only by watching the silhouette, and this could aid individuals checking the robots action from a distance. Even the principles that are about aesthetics (*Solid Drawing* and *Appeal*) are useful for creating motion for robots (avoiding symmetrical motion or stopping of limbs) or designing a robot (making the robot appealing to individuals who will be interacting with it).

Secondary Action is used in several articles to add a small animation to help convey another action. But it was mostly used for humanoid or head robots, and the one animal robot, Probo, has a more human-like face. It would be interesting if this could also be applied to the non-human, non-animal robots. For example, a part on the non-humanoid, non-animal robot on could be animated to have an analog of a blink.

Other principles can also be investigated on other types of robots. For example, the principle of *Slow in and Slow out* is only used in one study here, but it could likely be employed in many situations of different types of robot motion. The principle of *Arcs* could also be used for other types of robot motion. The *Squash and Stretch* principle can pose an interesting challenge to individual's assumptions of a robot made of hard materials.

Another principle that could be looked at is the principle of *Follow Through and Overlapping Action*. One obvious place is the transition from configuration to locomotion or when locomotion and configuration are combined. This would also be an opportunity to examine more of the animation principles using locomotion.

Since animation techniques have been adapted in computer animation [49], they have also shown up in graphical user interfaces on computers [20, 39]. So, some of these techniques have already been formalized. This is another area where tools used for creating computer animation and games can be adjusted to work with robots [7].

Using formalization from animation techniques to computer algorithms from above, animation techniques may also be a way of achieving motion that is defined in other ways. For example, LaViers, Teague, and Egerstedt [51] and Knight and Simmons [46] worked on formalizing the Laban Effort System for different robots. One study in the review [77] provides an example of using the animation techniques of motion capture to demonstrate how to move a drone as expressed via the Laban Effort System.

Animation techniques could also aid in the combating the *uncanny valley* (re-translated to English as Mori, MacDorman, and Kageki [59]). The uncanny valley is the idea that there exists a curve representing an individual's affinity toward a robot versus how human-like the robot looks. As the robot looks more human-like, the individual's affinity grows until it peaks and suddenly the looks are *not good enough* (i.e., uncanny) and the individual's affinity for the robot wanes. Continuing through the valley, at some point the robot's looks near that of a human and the individual's affinity for it rises again.

Although the uncanny valley is focused on the robot's looks, Mori et al. posited that more machine-like movement than organic movement makes the slopes in the valley even steeper. That is, if something *looks* more like a human, but does not *move* like a human, then it is difficult for us to have affinity for it. Takayuki, Kanda, and Ishiguro claimed that a robot that resembles a human, but does not move like one is "unnatural" [83, p. 101]. Since animation techniques affect how things move, they could also help in addressing this. Some articles in the review [53, 58] mention the uncanny valley explicitly as a motivation for their research.

Note that animation techniques do not solve all problems. Animation that is created to be shown on a screen is free of limitations of the physical world. Servos and other methods for movement have limitations in strength, friction, flexibility in movement, and other issues. These limitations need to be considered if an animation technique will move from the screen to a robot. But this is another area that could be explored: the quality of the animation created by the animation techniques and how this affects interaction. That is, what separates good animation from bad animation in robots? This may be useful if other considerations such as limited movement or energy conservation must be balanced against interaction with the robot.

Future research could look at the combination of animation techniques with the other modalities like sound or smell. This may result in a stronger or weaker effect than just the animation technique alone. Combining modalities also makes the robot more universally designed and accessible to more individuals. A robot moving its limbs to communicate its intention is useless if the individuals it is interacting with cannot see it.

Most of the studies in this review took place in a lab setting with one-on-one interaction. Even though a lab provides an environment to ensure a robot works well, others have advocated that it is important to try to get HRI studies out into real-world settings and test interaction over a longer term [22, 42]. Testing robots in the real world will help determine how well motion using animation techniques works when competing or cooperating with other elements in the environment and if the animation is effective or annoying over long term exposure. This may also mean not using video recordings of the robot and instead focus on individuals working with the robot live.

Having studies that take place outside of the lab also allows the introduction of non-lab contexts. One psychology study shows that context can affect how individuals perceive human faces [71]. Further research is needed to see if context has an effect on how individuals perceive robots' faces and actions.

Although there were some methods that showed up multiple times (e.g., the Godspeed Questionnaire, SAM, and choosing from Ekman's basic emotion), future researchers should not feel that these are the only methods that can work for evaluating animation techniques in HRI. Other methods also exist for evaluating the emotion a robot is displaying, such as the circumplex model of affect [64]. Quantitative methods testing a hypothesis were used in several studies and may fit for certain studies. Furthermore, in some situations, such as working with children or looking for a deeper understanding of a phenomenon, qualitative observations and interviews are necessary.

Finally, this review has focused on the use of animation techniques. As mentioned in Section 2.4, animacy is a closely related concept and animation techniques can certainly lead to the perception of animacy in a robot, though it is not the only way this can be done. There was some effort involved in separating articles out about animation technique and the concept of animacy. With this review of animation techniques in HRI studies completed, it makes the task of looking at animacy in HRI studies more straight forward.

6 CONCLUSION

We have run a systematic review of animation techniques from movies and computer animation in user studies and evaluations in HRI. This resulted in 27 out of a total of 106 articles that were returned from the ACM Digital Library and IEEExplore. There have been several animation techniques that have been adapted to work with HRI; this includes researchers using the 12 principles of animation (Section 2.2) and other techniques like motion capture. The studies in the articles show that motion created through animation techniques affect an individual's impression of the robot, help the robot express intention, or help individuals understand an expression a robot is showing. Having a better understanding of a robot can make it easier to interact with a robot, and it can also make it easier for the robot to interact with individuals.

The literature has shown that animation techniques can help in HRI and is an area that can be further researched. Given that animation techniques help in the motion of a robot, they are applicable in different types of HRI studies. If a researcher is interested in making a robot move distinctively to help interaction, then animation techniques are good places to investigate.

There is much to discover about animation techniques, robots, and HRI. Future researchers have a fertile frontier to explore in helping humans and robots interact better together.

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3 *Paper 3*

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Classifying Human and Robot Movement at Home and Implementing Robot Movement Using the Slow In, Slow Out Animation Principle

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Abstract—**We examine how robot movement can help human-robot interaction in the context of a robot helping people over 60-years old at home. Many people are not familiar with a robot moving in their home. We present four movement conditions to classify movement between a human and robot at home. Using phenomenology and familiarity, we recognize some of these conditions from other interactions people have with other moving things. Using techniques from animation in movies, we give to the robot a distinctive style that can make the robot's movement more familiar and easier to understand. Further on, we examine animation and present how to implement the animation principle of slow in, slow out with a research robot that can control its speed. We close the paper with future work on how to use the classification system, how to build on the slow in, slow out principle implementation for animated robots, and an outline for a future experiment.**

Keywords–human-robot interaction; animation; style; movement; slow in, slow out.

I. Introduction

In previous work [1], we saw that projections for people over 60-years old who will not be working (hereafter "the elderly") will be larger than the number of people working [2]. As people age, they tend to accumulate different aches, pains, diseases, and disabilities. The elderly will need assistance to continue to live independently with these acquired health issues. This aid could be a robot with sensors that could help monitor and assist the elderly person staying at home. If robots will be in homes, elderly and other people need to easily interact with the robots. We posit that making robots move distinctively using techniques from animation could make this interaction easier.

Previously, we used phenomenology to examine movement and classified robot movement in the home into classes [1]. We also discussed robot movements in the frame of proxemics [3], people's familiarity with robot movement, and animation techniques that could help make the movement more familiar. In this paper, we build on the previous work [1] by further exploring the topics of familiarity and proxemics, before introducing a formalized version of robot movement and a possible way to animate it using the animation principle of *slow in, slow out*. This contributes a combination of the phenomenological and the formalized exploration of moving a robot using an animation technique. This gives us a starting point for building future work on human-robot interaction (HRI), such as experiments or user evaluations.

We first present the context by examining robots for helping the elderly and robot's movement in the home (Section II). Then, we discuss robot movement and what animation and style means for robots and HRI (Section III). To make it easier to look at robots and human movement, we present a framework for classifying movement relations between a person and a robot (Section IV). We use this framework to aid in looking at the concept of familiarity and how robot motion compares to the motion of other objects people encounter in everyday life (Section V) and how animation can help with this familiarity. Then, we present a formalized version of robot movement and how to derive slow in, slow out movement from it (Section VI). Finally, we present ideas for future work (Section VII) before concluding the article (Section VIII).

II. Research Context: Robots at Home

Western countries are examining the issue of the "elderly wave" [2]: the number of people who will be retiring and needing care will be larger than the people entering the workforce for these jobs. There is a need for the elderly to live independently at home longer. Living at home as long as possible is also the wish of many people. One way of addressing this goal is to use *welfare technology* that can assist the elderly [4]; this includes technology like the Internet of Things and smart home sensors for reporting and helping elderly complete tasks [5][6]. Sensors can also provide a warning when things go wrong, such as an elderly person falling [7].

Instead of mounting the sensors all over in the house, we can mount the sensors on robots. Robots are mobile and can be customized for handling different tasks. This idea is the basis of our larger research project, Multimodal Elderly Care System (MECS), but let us first examine what other projects have done.

A. Other Projects Looking at Elderly and Robots

Several robots have been built to help the elderly. One example is Care-o-bot [8], [9] that can assist in multiple tasks for the elderly at home. The Paro seal robot has been used to look at how elderly and people with dementia react to a robot in a nursing home context [10]–[12]. Others have investigated how the elderly interact with robots. One study looked at a robot that interacted with the elderly in social situations and during card games [13].

The European Commission has financed several projects that investigate the elderly and robotics. The Acceptable robotiCs COMPanions for AgeiNg Years (ACCOMPANY) project modified the Care-o-bot to provide emotional and social support for the elderly [14]. ACCOMPANY also examined viewpoints of what the robot should do when the older people disobey the robot's recommendations [15]. The Managing Active and healthy aging with use of caRing servIce rObots (MARIO) project used a service robot to help address the issues of the elderly's feelings of loneliness, isolation, and dementia [16]. The Giraff robot was used in multiple projects. In the Enabling SoCial Interaction Through Embodiment (ExCITE) project, the Giraff robot was used for telepresence of other family members in the elderly's home [17], and in the GiraffPlus project, the Giraff robot was upgraded to include monitoring [18].

A recent review of healthcare robotics pointed out that robots can fill gaps and help overloaded care workers, but that there is no one-size-fits-all solution to most health issues [19]. If robots shall succeed, different groups need to work together. From asking the elderly, a survey found the elderly wanted help for specific things like recovering from a fall and fetching and reaching objects [20]. However, a report on the progress of robots for use in helping elderly live independently found that current robots must provide more help and services if they will truly aid people to live independently longer at home; these robots must be more than a tablet on wheels [21].

These are all points that we consider when we are working with robots in the home of the elderly in the MECS project. In addition, we have also sought the advice and cooperation of members from some of these previous projects.

B. The MECS Project

We are investigating collaboration between human and robots in the Multimodal Elderly Care Systems (MECS) project. This multidisciplinary project is funded by the Research Council of Norway and is examining helping the elderly at home by offering safety alarm functionality in a robot. The project investigates algorithms and sensor data to help predict abnormal behavior by checking the presence of the person at home, checking the person's breathing, or noticing if someone is unstable and may fall soon.

We are concerned that the elderly do not feel that they are under constant surveillance. We are investigating data protection issues and having the robot using privacy-preserving sensors like thermal sensors [7] or ultra wide-band sensors [22]. A robot at home may let the person feel in control and give the person some privacy. For example, an elderly person could tell the robot to leave the room so the person could be alone.

Robots cannot replace a human in every context, but they can provide support for issues when a person cannot be present or contact a person for assistance. The robot can also assist by taking over tasks of drudgery. This allows visitors more meaningful interaction with the residents in the home. Robots may help in ways that would otherwise require another human to always be present and have diverse knowledge. For example, robots can collect data and use algorithms to give early warnings about issues (e.g., falling down, low blood pressure, or suffering from poor nutrition).

In MECS, we work with Kampen *Omsorg+*, a program in the City of Oslo that aims at helping elderly people live longer at home. Kampen *Omsorg+* provides modern apartments with common areas for residents to socialize. Currently, most residents have a Scandinavian background. This setting provides a good context for understanding the residents' needs, designing robots and sensors that can be helpful for the residents, and evaluate these robots and sensors over a long-term period in the residents' apartments.

Having a robot at home means that the residents will have to interact with the robot. To aid in observation, the robot will move between the rooms and with people. One of the areas we are investigating is how we can have the robot move in the home and improve interactions between residents—the elderly—and the robots.

III. Movement, Animation, and Style

It is important to define terms related to this phenomenon. This section examines *movement*, *animation*, and *style*.

A. Global and Local Movement

Physical movement (or motion) is a change in position over time. We call this *global movement* (Figure 1a). If we were to imagine the robot in a house, global movement would mean the robot moves in a room or moves to another room. *Local movement* is when parts of a robot move, but its global position does not change—for example, a robot at rest and waving at a person (Figure 1b). For simplicity, we will also define when no parts of the robot move and no change in global position as a special case of local movement. Of course, local movement and global movement can be combined.

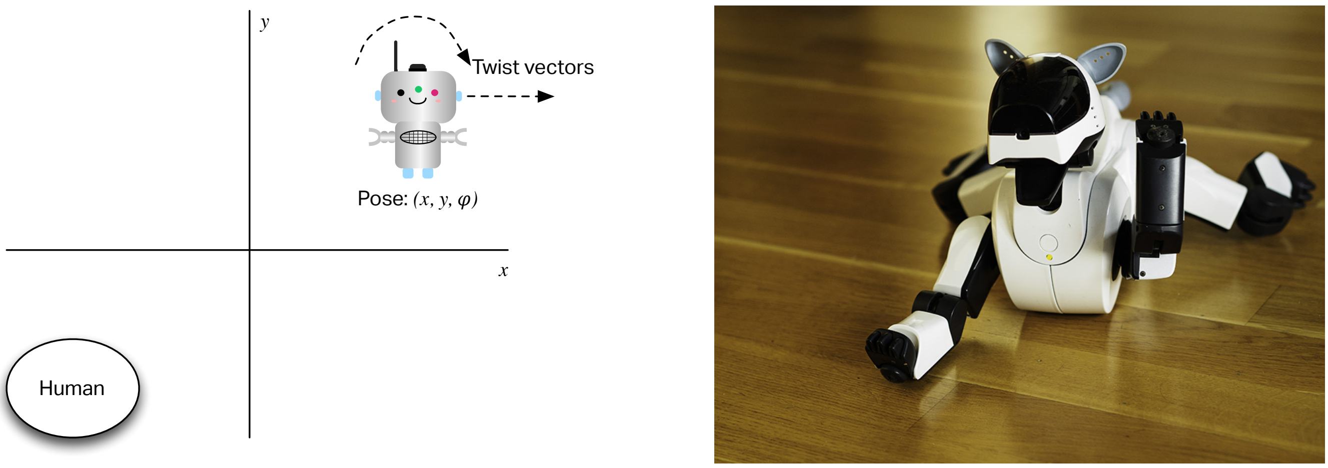
B. Animation and Style in HRI

There are many ways a robot can move. The robot can move at a constant speed, speed up quickly as it starts out, and slow gradually down when it reaches its destination. Or it can reverse to gather a running start or brake abruptly to signal its arrival. All of these different movements can be programmed.

In movie animation, animators use software, pencils, or pens to "program" the movement of their objects on a screen. So, one could argue a robot's movement could be animated. However, if animation was solely movement, then any movement would be animation. For *animation*, it is *not* the movement itself we are interested in, but *how the movement is done* and *how the movement is perceived* by the people interacting with the robot. Animation in movies shares these concerns. Some animation appears to audiences as smooth and believable, while other animation appears to the audience as jerky, quickly-assembled, and not believable. This implies some craft is necessary.

So, animation in HRI has two parts. The first part is using techniques from animation in movies or computer graphics (or inspiration from them) to specify how a robot moves. The second part of animation and HRI is the human side. How is this animation perceived by the humans that are interacting with the robot? If there is no HRI, then there is little reason to do the animation and instead optimize movement for other factors such as maximizing or conserving power.

We posit that animation can improve people's interaction with a robot. One way to improve the interaction is by using animation techniques to give the robot *style*. Style in this context means the way "a behavior is performed" [23, p. 133]. Style can also be thought of as *expressive movement*. Gallaher looked at people's style, and this concept has been successfully applied to robots [24], [25]. Animation gives the robot an interesting way of moving, a style. This animated motion can make the robot seem like it has a personality. The motion can also help the robot to better communicate what it is planning to do.



(a) (b)

Figure 1. Examples of global and local movement: in global movement (a), the robot moves in a two-dimensional plane; the Aibo laying down and waving (b) is an example of local robot movement.

C. *Principles of Animation in Previous HRI Studies*

Thomas and Johnston [26] documented twelve principles of animation that animators at Disney used to create their animations. These principles include: (*a*) *squash and stretch*—an animated object squashes and stretches its form, but never truly loses its recognizable shape; (*b*) *anticipated action*—an object needs to prepare itself before performing an action; (*c*) *follow through and overlapping action*—actions are not done in isolation, characters move seamlessly between them; (*d*) *arcs*—limbs move in arcs, not straight up-down, left-right motions; (*e*) *secondary action*—the object's main action causes other secondary actions to occur at the same time; (*f*) *exaggeration*—over-emphasizing an action helps people understand a characters feelings; and (*g*) *slow in, slow out*—the speed of motion is not the same the entire time, but slower at the beginning and the end.

Previous work in HRI has adopted some of these principles when creating robots. The principles were referenced when creating the movement and emotional reactions for the Kismet robot [27]. This made Kismet's reactions easily recognized by participants in the study. Van Breemen [28] advocated to use these principles for robots, and he applied some of them to make facial expressions of the iCat more natural and less machine-like [29].

Animation can make things "look alive" or give them *animacy*. This can cause people to treat the robots as if they were alive. For example, in several experiments, participants worked with an animated robot for a while. Then, the participants were asked to destroy the robot by turning off its power to erase its memory [30],[31]. The animated nature of the robot and its perceived intelligence made some participants hesitate to destroy the robot.

Applying animation principles has aided participants' interaction with a robot in several other studies. For example, animation principles can make it easier for a human to understand and predict what a robot is doing [32]. Using the principle of anticipated action made it easier for participants to predict what the robot was going to do [33]. Another example is using the principle of exaggeration on a robot telling stories. The robot's exaggerated motion resulted in participants remembering those specific parts of the story better [34].

So, using animation principles with robots has changed people's interaction with the robots. To examine this in the home environment, let us classify a human's and robot's movement in the home and see how this relates to other types of movements. Then, we can see how animation techniques can be applied to make robots' movements more familiar and provide a possible implementation of the animation principle of slow in, slow out.

IV. Classifying Human and Robot Movement

Traditionally, human-computer interaction (HCI) was the study of the use, design, and evaluation of people interacting with interfaces in different contexts such as stationary computers in workplace settings, public places, and home settings. Mobile computing raised the importance of the context of use and interaction to researchers' attention. This lead to the research area of *context aware computing* [35]. Ubiquitous and ambient computing raise the idea of computers in the home, but hidden from view and not moving.

The conditions for the interaction taking place between humans and computers in a stationary and mobile situation are similar; there is a stable spatial arrangement between the people and computers. In both situations, humans and computers are interacting in the same place, with a stationary relationship in-between the humans and the computers.

The spatial conditions change when robots enter the scene. We may be used to moving things outside our home like automobiles, buses, boats and trams. But in a home setting, we are not familiar with *things* moving around *on their own*.

In the home context, we can classify this movement: (*a*) Things that we move around: furniture, peripherals, clothes, machines like vacuum cleaners or furniture on wheels. (*b*) Things moving themselves: domestic robots (robot vacuum cleaners and robot lawn mowers) and other types of robots.

If we examine the spatial arrangement for movement between one human and one robot and classify the movement as *local* and *global* from Section III, we find the following four conditions (Table I):

1) Human moves locally and the robot moves locally,
2) Human moves locally and the robot moves globally,
3) Human moves globally and the robot moves locally, and
4) Human moving globally and the robot moving globally.

TABLE I. MOVEMENT CONDITIONS FOR HUMANS AND ROBOTS

Condition	Human	Robot
1	Local	Local
2	Local	Global
3	Global	Local
4	Global	Global

This framework for classification also gives a way to compare the human-robot movement with other objects. In Condition 1 and Condition 3, when the robot is moving locally (including being completely still), the human is either moving locally or globally. This is similar to conditions for interacting with stationary computers. We can see Condition 1 when a person watches TV, and we can see Condition 3 when a person approaches a switch or walks towards a remote control.

The other conditions are more unusual in the home before robots. For example, Condition 2 happens when toys are moving. But Condition 4 does not have good analogs other than perhaps chasing a moving toy. These other conditions also indicate something that is unfamiliar. Gibson and Ingold [36] find we are indeed familiar with movement, and they work out the importance of movement on perception. Let us investigate the phenomenon of familiarity and how moving robots in the home might become more familiar to the elderly at home.

V. Familiarity and Moving Robots at Home

We can examine the phenomenon of familiarity using phenomenology; that is we look at how people experience what is familiar and unfamiliar. Once we have an idea what familiarity is to humans, we can look at how we can make a robot's movement familiar. We can also see how animation and style can help in making these situations familiar.

A. Familiarity

Familiarity plays a role in how people interact and use things and objects. The familiar is often what we are comfortable and safe with, be it situations, technologies, relationships, activities or other people. We are often unfamiliar with things we do not engage with, things we do not understand, or things that are foreign to us.

These three concepts; *involvement*, *understanding*, and *unity of user-world* are, according to Turner and Walle [37], ideas that we can apply to understand familiarity. Turner and Walle stated that familiarity unfolds over time. Hence, familiarity points to activities of daily living where we are engaged and skillful people going about our everyday lives. When breakdowns or interruptions happen—for example, something is faulty, missing or in our way for us to proceed—the separation between people and their world is taking place, and equipment and activities become visible as objects for our analysis [38]. However, this is not the primordial way of being in the world.

Van de Walle, Turner, and Davenport claimed, "What is observable are the outcomes: easiness, confidence, success, performance, which are all manifestations or signs of familiarity," [39, p. 467]. This shows that familiarity is subjective; it can be described by observing activities or asked questions in interviews. One way of investigating possible ways of using robots in the home is to learn from what we already are familiar with of movement. Harrigan, Rosenthal, and Scherer [40] provided an introduction into non-verbal human behavior, including *proxemics*. Hall [3] observed that human-social spatial distances vary by the degree of familiarity between the people interacting and the number of people interacting. Hall later provided a framework that identifies the main social spatial zones by interaction and situations. He estimated these distances visually in terms of arms lengths, close contact and threat/flight distances—and researchers have since assigned precise numerical values.

B. Making a robot's movement more familiar

As Gibson and Ingold [36] claimed, we are all familiar with movement. Moving within a place, such as a home, is an example of movement that we all experience daily. We are familiar with seeing other people move. We are familiar with seeing things move. We move about in concert with things such as phones, watches, and footwear. There is nothing extraordinary with this familiarity of movement of things and other people. By focusing on the familiarity of movement, we build on people's preexisting involvement, understanding and relationship with the everyday world.

The concept of *human-to-human* proxemics has human-human movement at its base and has been used when designing interactions with robots [41]. This use of human-human proxemics has been developed further to take the context of the activity and the person's location into account in how the robot should approach the person [42]. All of this is dependent on people wanting to interact with a robot as though the robot was a human. Some people assume that robots are simply things and approach a robot much closer than they would another person [41]. So, depending on how people will interact with the robot, another possibility may be to use *human-thing* distances and proxemics as the starting point instead of human-human proxemics. This would be grounded in our familiarity with the movement of things.

If we think of familiar movement where an object moves with us, we can find some examples: (*a*) navigating traffic, with cars, bicycle and public transport material, (*b*) walking with a rolling suitcase, (*c*) operating a wheelchair, (*d*) operating a walking stick, and (*e*) operating a walker. We are all familiar with doing or observing such movements, but there is no distinct research field literature to find out more about these types of movement. However, the concept of familiarity helps us find these examples.

C. Making a robot more familiar by giving it style

In Section III, we posited that an animated robot moves with style. Several of the robots from Section III do not move from their location, but the way they move their parts makes them appear more friendly and easier to relate to. Animation also makes it possible to experiment with different kinds of interaction depending on the animation style.

In HCI and graphical user interfaces, programmers can move items across the screen in many ways, and animating user interface elements can help people understand what is going on when they are using a program [43]. There is a different mood or tone when a window minimizes by shrinking down to a small area on the screen versus simply scaling the window [44]. Just as animated graphical user interface elements help explain what is going on, the way a robot moves can be helpful in explaining what is going on in an interaction with a robot. Naturally, there are limitations—for example, robots must obey the laws of physics and some types of motion put extra strain on the robot [45]—but we can give a robot its own style by animating it.

Animation can be present in all conditions in Section IV. For example, in Condition 1, the robot does not move globally, but its local movement can still be animated by moving parts of its body. This animation can give the robot a style, add some personality, and give the effect of presence for the robot [46]. For example, if the person is asking a question or the robot is providing feedback, animation can provide feedback to the person about the robot's state and other relevant information. This does not have to be complex; a part of the robot rotating can suffice, or lights blinking to indicate the robot is listening. A simple rotation that follows the person can help keep the interaction going in Condition 3.

Condition 2 can build on the animation from Condition 1. Here, animating parts of the robot's body can be combined with its global movement. For example, if the person asks for some privacy, the robot can start moving away. This can give the person a sense of what the robot is going to do. Using animation techniques could also affect how fast the robot moves, combining several animations techniques could make a robot "appear" angry, sad, surprised, or happy.

Since these two conditions can build on each other, animation techniques can also help with the *transition* between them. This can offer the human a cue to the robot's intention. From the robot's side, it can also try to determine the human's cue to get information if it too should start or stop.

Condition 4 is still unfamiliar for most indoor settings. Animating the robot's movements can give it a style to make it seem like this condition is more familiar. The way the robot moves can imitate another person or an animal. These imitations can remind us of other situations where we and something else move, and this can make a robot and human moving at the same time more familiar.

There is familiarity in motion and there is familiarity in *forms*. Hoffman and Ju [47] posit that robots that resemble something we are familiar with may bring assumptions and expectations that are difficult to achieve given current technology. Instead, a robot that does *not* resemble a human or animal can move expressively to provide clues for interaction. These movements follow physical properties in the world that people are already familiar with and give them a starting point for their interaction.

Returning to proxemics, animation techniques can aid in building rapport between robot and human. One study has found that rapport is necessary for people to be willing to get physically near to a robot or answer personal questions [48]; until a rapport is established, certain actions that signal a good rapport (like maintaining eye contact) should be avoided. A different study found different distances for an approaching robot based on the posture of the human (sitting or standing) [49].

This framework for investigating movement gives insight in how to give this movement style through animation techniques. The way these movements are animated may influence how willing someone is to interact with it. A previous study found the speed and way a robot moved caused people to describe the personality or mood of the robot [50]. Building on this work, Another study found people associated negative and positive emotion to a simple robot simply by adjusting how it accelerated [51]. A proper balance needs to be found. For example, a robot moving too fast may prove frightening, and if a robot moves too slow, people may assume that the robot can never get anything done. If we desire interaction with a robot that moves, we need to make it an inviting experience. This is where using animation principles like slow in, slow out (Section III-C) may better mimic familiar movement of other objects. Let us explore how this can be done.

VI. Using the Principle of Slow In, Slow Out on a Robot

Having explored robots' movement and familiarity by using the theory of phenomenology, we discuss how to make a robot move following the animation principle of slow in, slow out. This focuses on global movement, but it can be applied to local movement as well. First, we start by describing robot motion formally and the robot's generic *velocity profile*. Then, we derive a new velocity profile based on the slow in, slow out principle. Finally, we discuss how this works for robots in the real world.

A. Poses, Twists, and the Velocity Profile

Robot motion is described in terms of *poses* and *twists* [52] (Figure 1a). A *pose* provides the position and orientation of the robot. If we are on a two-dimensional plane, a pose is normally recorded as a tuple (x, y, ψ) where (x, y) is the position of the robot in a room, and (ψ) is the robot's orientation, i.e., which direction the robot is facing. A *twist* provides information about the different velocities the robot is traveling. For a robot that moves on the ground, these velocities are the *angular* velocity—the velocity that the robot is turning and the *linear* velocity—the velocity in a line.

When a robot moves, it has a *velocity profile*. A velocity profile is a graph of the robot's velocity versus the distance that it travels. If we assume a robot moving in a straight line in ideal, non-friction conditions, the idealized velocity profile looks like a trapezoid (Figure 2a). The robot accelerating from a velocity of zero to its cruising velocity makes one of the diagonal lines (a_{RampUp}). The constant cruising velocity (v_{Cruise}) forms a parallel line with the distance axis. Finally, the robot's deceleration down to zero as it nears its final location forms the other diagonal ($a_{RampDown}$).

There is also a special case when the distance to travel is shorter than the distance needed to reach the robot's cruising speed. The robot accelerates up to a speed (v_{Peak}), but then slows down as it approaches its final spot. This case results in a triangle velocity profile where acceleration and deceleration form the legs of the triangle (Figure 2b).

We can formalize the different parts of these variables in terms of time (t), distance (d), and the different velocities (v).

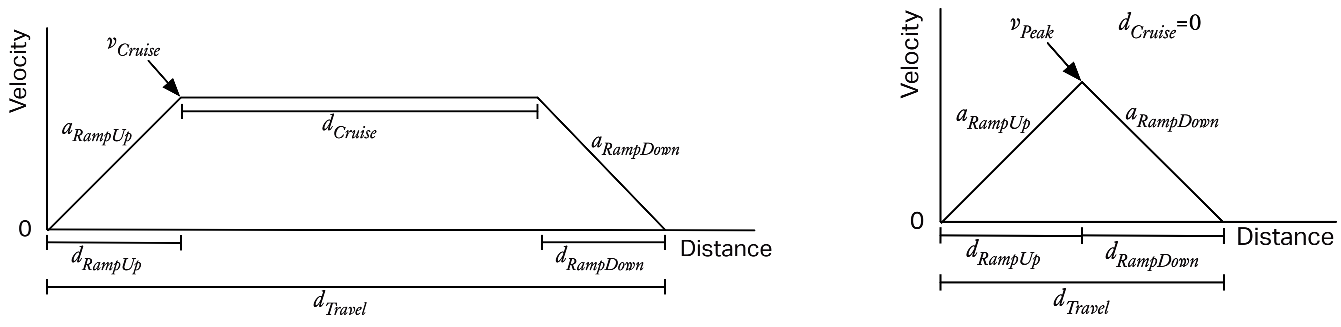


Figure 2. Examples of velocity profiles, a plot of velocity over distance. (a) The trapezoid profile is normally used for long distance movement. (b) The triangle profile is a special case of the trapezoid when the cruising distance is zero (adapted from Newman [52]).

$$d_{Cruise} = d_{Travel} - d_{RampUp} - d_{RampDown}$$

The cruising distance (d_{Cruise}) is the total distance traveled (d_{Travel}) minus the distance traveled during ramp up (d_{RampUp}) and ramp down ($d_{RampDown}$).

$$\Delta t_{Cruise} = \frac{d_{Cruise}}{v_{Cruise}}$$

The time spent at cruising speed (v_{Cruise}) is the cruising distance (d_{Cruise}) divided by v_{Cruise}.

$$\Delta t_{RampUp} = \frac{v_{Cruise}}{a_{RampUp}}$$

The time spent in the ramp up (Δt_{RampUp}) is the cruising speed (v_{Cruise}) divided by the acceleration at ramp up (a_{RampUp}).

$$\Delta t_{RampDown} = \frac{v_{Cruise}}{a_{RampDown}}$$

Similarly, the time spent in the ramp down ($\Delta t_{RampDown}$) is the cruising speed (v_{Cruise}) divided by the acceleration at ramp down ($a_{RampDown}$).

$$\Delta t_{Move} = \Delta t_{RampUp} + \Delta t_{Cruise} + \Delta t_{RampDown}$$

The time spent in movement (Δt_{Move}) is the sum of the time spent in ramp up (Δt_{RampUp}), the time cruising (Δt_{Cruise}), and the time spent in ramp down ($\Delta t_{RampDown}$). All of these equations allow us to define a distance function (Equation (1)).

$$d(t) = \begin{cases} \frac{1}{2}a_{RampUp}(t-t_0)^2, \text{for } 0 \le t-t_0 \le \Delta t_{RampUp} \\ d_{RampUp} + v_{Cruise}(t - \Delta t_{RampUp}), \text{for } \Delta t_{RampUp} \le t - t_0 < \Delta t_{RampUp} + \Delta t_{Cruise} \\ d_{Travel} - \frac{1}{2}|a_{RampDown}|(\Delta t_{Move} - (t-t_0))^2, \text{for } \Delta t_{RampUp} + \Delta t_{Cruise} \le t - t_0 \le \Delta t_{Move} \end{cases} \quad (1)$$

The velocity profile implies that the acceleration is *constant*; that is, the velocity changes at a constant rate until it reaches the maximum speed. This constant acceleration and speed gives us the mechanical movement that we associate with a robot. If we change the acceleration and the speed, we may be able to apply some principles from animation with the robot's motion.

B. Deriving Slow In, Slow Out for the Robot's Movement

When animating something in movies or in computer graphics, the movement of the object is controlled by drawing the object at a certain position for each frame that is shown on the screen. This gives the animator a great deal of control in the speed of the object. For example, if an animator changes the position only a small amount for each frame, the object will appear to move slow. The reverse is also true, a large change in position of an object between frames creates a fast moving object. If an animator wants to use the slow in, slow out principle, both of these techniques must be used.

A programmatic way to accomplish the movement is to use an *easing curve* (example curve in Figure 3). An easing curve specifies a time-distance curve that goes from zero to one for both the time and the distance. This way the animator needs to know only the starting point for the movement, the end point for the movement, and the total time to complete the movement to plot the animation.

Then, for each frame of animation, the animator calculates the frame's time as a percentage of the total time to complete the movement and finds out the percentage of the distance that should be complete. This technique is easy to automate, but requires someone to decide the initial inputs. An additional advantage is that different easing curves will create different effects. For example, an easing curve that goes over then under the distance of 1.0 before ending at 1.0 will appear to "bounce around" its end point before stopping.

The slow in, slow out animation principle states that an object should slow speed up to its top speed and then quickly slow down as it arrives at its final location. The slow in can be simulated by a curve like t^3 and the slow out can be simulated by the negative version $(t-1)^3+1$. To combine them together into one curve that goes from zero to one, the equation is:

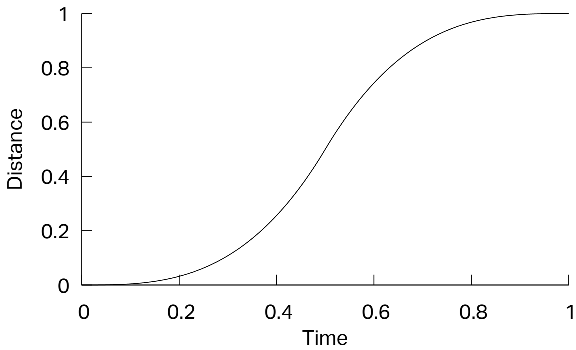


Figure 3. Easing curve for a cubic growth for the first half of the journey and cubic decline for the second half (Equation 2).

$$d(t) = \begin{cases} \frac{(2t)^3}{2} & \text{for } 0 \le t \le 0.5 \\ \frac{(2t-2)^3+2}{2} & \text{for } 0.5 < t \le 1.0 \end{cases} \tag{2}$$

The graph would look like Figure 3. (2) is noticeably different than (1), but (2) does not have to take into consideration acceleration.

This works fine when an animator sets the position of an object on a screen and worries only about how often a frame is shown. For robots, there are physical limitations such as how fast parts of the robot can move, friction, and inaccuracies of sensors and actuators. Rather than setting the position directly, the robot controls its acceleration or velocity, which are complementing ways of expressing motion.

From calculus, we know that the derivative of a distance function is a velocity function. This means that we can find the velocity at any point in time by taking the derivative of Equation (2). The derivative (graph in Figure 4) is:

$$v(t) = d'(t) = \begin{cases} 12t^2 & \text{for } 0 \le t \le 0.5 \\ 12t^2 - 24t + 12 & \text{for } 0.5 < t \le 1.0 \end{cases} \tag{3}$$

Equation (3) gives us slow in, slow out movement for short travel conditions. The curve does not go from zero to one (it goes from zero to three), but, as Equation (2) gives the position for a specific point in time, Equation (3) can be scaled to give us the velocity we need at a certain point in Δt_{RampUp} and $\Delta t_{RampDown}$. With no cruising velocity in Equation (3)—the curves up and down of Figure 4 resemble the straight lines of Figure 2b.

Since the triangle velocity profile is a special case of a trapezoid velocity profile, we can create a similar version for the trapezoid case. Conceptually, to make this profile similar to Figure 2a, the speeding up and slowing down should be split at $t = 0.5$, and the cruising speed should be put in between the split. Formally, it makes sense to divide things up into three parts. During Δt_{RampUp}, a quadratic curve is used to accelerate the robot. During Δt_{Cruise}, the robot maintains its cruising speed. Finally, during $\Delta t_{RampDown}$, a reverse quadratic curve is used.

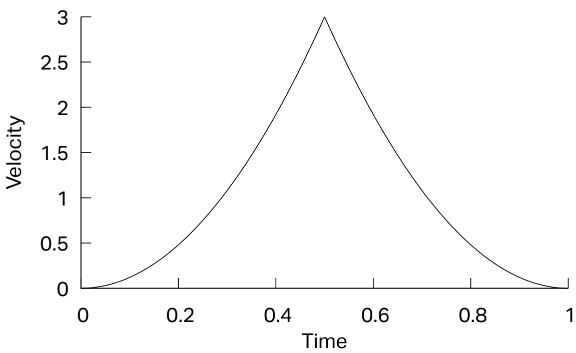


Figure 4. The derivative of the easing curve shown in Equation 3.

C. Implementing Slow In, Slow Out on a Robot

We implemented this algorithm for use with the "Burger" variant of TurtleBot3 (Figure 5). TurtleBot3 is a research robot from the Open Source Robotics Foundation [53]. The Burger variant has two wheels driven by servos and a ball bearing to keep its balance. Using the servos, the robot can go forward, backward, and turn itself around using skid-steer techniques.

The algorithm is a C++ node for the Robot Operating System (ROS) [54]. ROS functions as middleware where different nodes communicate by publishing and subscribing to different *topics*, such as twist commands. These nodes can be located on any machine or robot in the network. In this case, we are publishing twist commands about the angular and linear velocity the robot should be running on a topic called `cmd_vel`. The TurtleBot3 subscribes to the topic and adjusts the speed of the servos accordingly.

The node works by taking parameters for going forward and turning. For moving forward the distance to be traveled (d_{Travel}), the top speed of the robot (v_{Cruise}), and the time it takes to accelerate to achieve the top speed (Δt_{RampUp}) can be adjusted. Once the parameters are set, the node publishes twist commands periodically until the motion is complete. During the ramp up time, the node publishes twist commands that follow the curve $3t^2$. Once the robot reaches its cruising speed, the node publishes twist commands at the cruising speed until it is time to start slowing down. Then, it publishes twist commands that follow the curve $3(t-1)^2$ until the ramp down is completed. With the robot at its final destination, the node publishes a twist command with no angular or linear velocity to ensure the robot is stopped. For distances that are under the maximum velocity, the node finds a $VPeak$ by recursively reducing speed until it can create a curve that can accommodate the distance.

For turning, the parameters are: the number of degrees to turn (positive for left, negative for right) and the time to use on turning. The node then publishes commands for speeding up and slowing the robot according to Equation (3). Like the linear motion, it also publishes a twist command with no angular or linear velocity to stop the robot once the turn is complete.

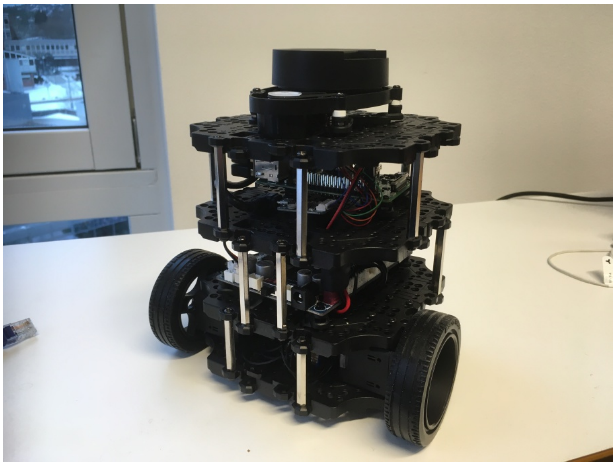


Figure 5. The TurtleBot3 “Burger” model that was used for testing slow in, slow out motion.

This node was tested against a simulation of a TurtleBot3 Burger robot. This was done with the “fake node” (a node that responds to the same messages as the real robot) and the Gazebo simulator (a simulator that includes gravity and friction). In both cases, the simulations of the robot show a difference between the regular constant movement and slow in, slow out movement.

Moving from a simulated TurtleBot3 robot in a simulated world to an actual TurtleBot3 in the real world revealed some limitations. First, the speed of the servos in the real-world are limited to 0.22 meters per second (m/s); that speed is much less than most people walking. However, this is only really an issue if you ask for a speed higher than 0.22 m/s. In those cases, an acceleration curve was generated for the requested velocity, but acceleration stopped once the TurtleBot3 reach its maximum speed and you would not see slow in, slow out movement. Regardless, even when using the correct speed the difference in the linear and slow in, slow out movement is visible, but less pronounced.

To see if this is an issue with physics in the real world or just the difference in speed, we have since tried the movement with a robot, a Fetch Robot (Figure 6), that can move at 1 m/s. This results in a visible difference in how the robot speeds up and slows down when using slow in, slow out and linear acceleration.

Another issue to explore is the number of times per second the node should publish new speeds. Originally, this was done 30 times per second. This works fine in a simulator, where the updates happen nearly instantaneously. In the real world, there is a small delay between broadcasting the signal, to receiving the command, and telling the servos to change speed. The result is that it is hard to know how many twist commands are actually processed by the TurtleBot3. Sending less commands, for example 20 times, 15 times, or even as low as five times per second still results in a noticeable change in the robot’s movement.

Figure 6. The Fetch Robot navigation stack was modified to provide slow in, slow out movement.

This node blindly sends out its twist commands. So, a mistakenly calculated distance may have the robot crash into a wall, fall off a table, or worse. A robot in the real world needs to be aware of its environment, and this node must be integrated into the navigation system. This means that the robot uses slow in, slow out to move while also being aware of obstacles and finding its own way to a destination. We have a preliminary plugin that can be used by the Fetch robot’s navigation code. This makes it possible to run evaluations of the different ways of movement with people interacting with the robot in a home environment.

VII. Future Work

There are limitations with movement classification from Section IV, since it only looks at a specific case of one human and one robot. There are opportunities to explore different directions of movement as well. However, even at its simple level, it gives us many questions we can investigate: how can the robot move to bring trust and assurance when the person is interacting with the robot? What activities can a robot do that are not available when a technology is stationary or handheld? What conditions are necessary so that people and robots can collaborate together? How are these interactions affected by the animation, proximity, automation, control, and delegation? We can also examine the transition between the different classifications.

Moving with style can be helpful. However, different people prefer different styles, and some styles may work better in some situations than others. Finding styles that are compatible with the robot, the people, and the situation will be a challenge.

Another issue is how the animation can be tested. Many of the animation studies that we cited in Section III were run in lab situations. This works well for testing items in a controlled environment, but robots at home need to work in dynamic environments. Testing the animations out in a home environment may be necessary to see if the animation is helpful for the elderly.

We did not examine who controls the robot in the home situation. From our discussions in gathering requirements from the elderly, people have different opinions about a robot moving at home when they have control of its movement versus it moving on its own. There is also a question about what control means in a home situation with the elderly. In Section II-B, we highlighted the idea of the elderly asking the robot to leave, but there are also situations when the robot should stay or come back quickly to join the elderly person autonomously.

As Chanseau, Lohan, and Aylett [55] found, people who wanted a feeling of control also wanted robots to be more autonomous. The size of the robot and a person's anxiety towards robots also influences proxemics. These issues are important when introducing a robot—especially moving robots—in the home of the elderly. Introducing a robot that can detect falls benefits no one if it moves around the home and becomes an obstacle to stumble over in everyday life. Then, it is a fall *creator* for the elderly instead of a fall *detector*.

The movement classification could be expanded and applied in other areas. Are there other situations outside of home where this classification applies as well? What happens when you add more "moving parts" like other people and robots? Does animating a robot work in all situations? What about animating robots that have limited movement? These are all questions to explore in future research.

As to the implementation of the slow in, slow out movement, since a robot using the implementation can now navigate in an area with humans, we are working on creating an experiment in the home context where people interact with a the robot and it moves using either a regular linear velocity curve or a slow in, slow out velocity curve. Our goal is to see how slow in, slow out velocity curves affect participants perceptions of the robot. Preparations for this experiment are underway and we hope to begin gathering data in the near future. If they are successful, we hope to repeat the experiment in other contexts or other robots to see if the slow in, slow out principle can be applied in multiple cases.

VIII. Conclusion

We investigated robot movement in the home and classified the movement in relation to humans and their movements. We have used the phenomenon of familiarity to link familiar movement outside the home with the unfamiliar movement of a robot inside the home. We also suggested that animating the robot will make it move with a distinctive style. This style can give to the robot a personality and make the robot more familiar to people living at home.

Further, we showed how we could apply one of the principles of animation (slow in, slow out) to a robot. We accomplished this by taking an easing curve from computer animation and deriving a formula that would be useful to a robot that can control its speed. This formula has been implemented as an algorithm in a node in ROS and tested both in simulation and in the real world with a TurtleBot3.

We are working with the elderly by running focus groups and discussing the issues of robots at home and how a robot's appearance and movement affects them. The information and the elderly's opinions have been helpful, and they seem interested in what things robots can do. We will be presenting this in future work and are integrating their feedback into our future activities. We will also be using the results from future experiments in our implementation to see how animation techniques can give the robot a distinctive way of moving.

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4 *Paper 4*

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