Autonomous Behaviour in Tangible User Interfaces as a Design Factor

Doctoral Thesis

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Abstract

This thesis critically explores the design space of autonomous and actuated artefacts, considering how autonomous behaviours in interactive technologies might shape and influence users' interactions and behaviours.

Since the invention of gearing and clockwork, mechanical devices were built that both fascinate and intrigue people through their mechanical actuation. There seems to be something magical about moving devices, which draws our attention and piques our interest. Progress in the development of computational hardware is allowing increasingly complex commercial products to be available to broad consumer-markets. New technologies emerge very fast, ranging from personal devices with strong computational power to diverse user interfaces, like multi-touch surfaces or gestural input devices. Electronic systems are becoming smaller and smarter, as they comprise sensing, controlling and actuation. From this, new opportunities arise in integrating more sensors and technology in physical objects.

These trends raise some specific questions around the impacts smarter systems might have on people and interaction: how do people perceive smart systems that are tangible and what implications does this perception have for user interface design? Which design opportunities are opened up through smart systems? There is a tendency in humans to attribute life-like qualities onto non-animate objects, which evokes social behaviour towards technology. Maybe it would be possible to build user interfaces that utilise such behaviours to motivate people towards frequent use, or even motivate them to build relationships in which the users care for their devices. Their aim is not to increase the efficiency of user interfaces, but to create interfaces that are more engaging to interact with and excite people to bond with these tangible objects.

This thesis sets out to explore autonomous behaviours in physical interfaces. More specifically, I am interested in the factors that make a user interpret an interface as autonomous. Through a review of literature concerned with animated objects, autonomous technology and robots, I have mapped out a design space exploring the factors that are important in developing autonomous interfaces. Building on this and utilising workshops conducted with other researchers, I have developed a framework that identifies key elements for the design of Tangible Autonomous Interfaces (TAIs). To validate the dimensions of this framework and to further unpack the impacts on users of interacting with autonomous interfaces I have adopted a 'research through design' approach. I have iteratively designed and realised a series of autonomous, interactive prototypes, which demonstrate the potential of such interfaces to establish themselves as social entities. Through two deeper case studies, consisting of an actuated helium balloon and desktop lamp, I provide insights into how autonomy could be implemented into Tangible User Interfaces. My studies revealed that through their autonomous behaviour (guided by the framework) these devices established themselves, in interaction, as social entities. They furthermore turned out to be acceptable, especially if people were able to find a purpose for them in their lives. This thesis closes with a discussion of findings and provides specific implications for design of autonomous behaviour in interfaces.

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Chapter 1

Introduction

Progress in the development of computational hardware is allowing increasingly complex commercial products to be available to broad consumer-markets (Satyanarayanan, 2001). New technologies emerge very fast, ranging from personal devices with strong computational power to diverse user interfaces, like multi-touch surfaces or gestural input devices. Electronic systems are becoming smaller and smarter, as they comprise sensing, controlling and actuation. From this, new opportunities arise in integrating more sensors and technology in physical objects (Adam, 2006). *Tangible User Interfaces* (TUIs) also represent a rising technology (Ishii and Ullmer, 1997), which in essence connects digital data to physical forms in order to leverage human abilities to handle physical objects.

These trends raise the interesting question of what impact smarter systems might have on people and interaction. How do people perceive smart systems that are tangible and what implications does this perception have for user interface design? Which design opportunities are opened up through smart systems?

Currently there is limited research concerning how intelligent machines could aid human-computer interaction and in manipulating digital content more broadly. One might ask, how this new form of autonomy in interfaces would affect human-computer interaction. Could the interpretations that people make of the systems' intelligent behaviour be used to create more engaging user interfaces? Might it be possible to build user interfaces that utilise such behaviours to motivate people towards frequent use, or even motivate them to build relationships in which the users 'care' for their devices? Of course, to this end, one might develop systems that demonstrate human or animal-like qualities to build on existing knowledge. However, research has also highlighted the interesting potential of developing interfaces that expose users to complex computational (intelligent) behaviour in more machine-like ways (Taylor, 2009). People's attitudes towards actuated objects have always been exceptional in comparison to inanimate objects; it has been demonstrated that we find autonomous machines fascinating and engaging (Poupyrev et al., 2007; Rasmussen et al., 2013). We also feel quite comfortable in describing mechanical processes in terms of social behaviour and reasoning that such technology has an intention and motivations (Braitenberg, 1986). Research has even shown that humans will display complex social behaviour such as politeness and empathy towards technology (Reeves and Nass, 1996). This effect is even further enhanced through embodiment. Robots receive stronger reactions and are more engaging than their software counterparts (Kidd and Breazeal, 2004, 2008; Mi et al., 2012).

I argue that between TUIs (Ishii and Ullmer, 1997) and fully-formed robots (Thrun, 2004) there is a class of interaction devices that exhibits increasingly autonomous and lifelike behaviour. In this thesis, I therefore coin and introduce the term *Tangible Autonomous Interfaces* (TAIs) (Nowacka and Kirk, 2014), which describes these tangible elements of an interface, expressing autonomous behaviours. Exploring and defining TAIs is a key contribution of this thesis. Autonomous behaviour can be defined as the capacity to perform a task in the world independently of any external input or aid. Figure 1.1 maps out the relationship between TUIs, TAIs and robots. In short, TUIs are physical interfaces which connect tangible objects to digital data and unlike

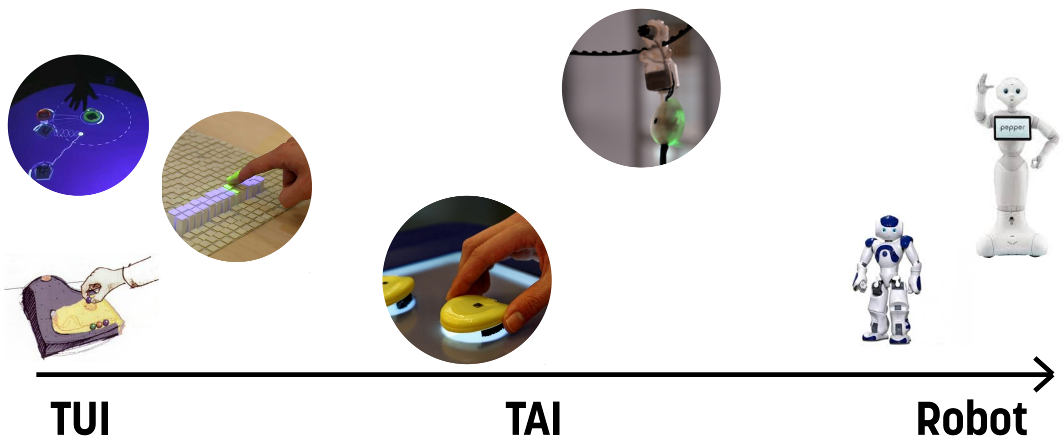

Fig. 1.1 An illustration mapping out the relationship between TUIs, TAIs and robots. Pictures taken from: (Bishop, 1992; Follmer et al., 2013; Helmes et al., 2011; Jordà et al., 2007; Nowacka et al., 2013)

ordinary interfaces (such as a mouse) embody mechanisms to control digital systems. Examples for TUIs are depicted on the left side of the scale. The use of physical tokens makes it possible to play back sounds like music (most top left picture (Jordà et al., 2007)) or voice mail messages (bottom left (Bishop, 1992)). Here, physical shape and interaction with it, is at the central mean of computational feedback (more on TUIs in Chapter 2). *Radical Atoms* (Ishii et al., 2012) (most right picture in the TUI area) take this one step further, by using dynamic physical materials and directly coupling these to digital states of a computational model. If the software changes, the material and shape of the object changes accordingly and vice-versa. The vision is to use materials to display, embody and respond to digital information. One example is presented by inForm (Follmer et al., 2013), an actuated shape display that provides physical affordances but also constraints to guide the user through interaction. Adding autonomous behaviour to these parts of the interface (e.g through actuation) results in TAIs. TAIs perform these elements of their own accord, without human guidance. They display autonomy, or intelligence, by giving people the impression of having an internal goal-state and show complex behaviour by reacting to external influences and the environment in an ambiguous way. The two examples in the illustration are actuated interfaces that are able to displace themselves and therefore appear as intentional entities in comparison to passive devices. Their aim is not to increase the efficiency of user interfaces, but to create interfaces that are more engaging to interact with and encourage people to bond with the objects in an emotional way. Newer actuated technologies, such as devices able to displace themselves through vibration or ultra-sound (Bader et al., 2015; Marshall et al., 2012; Nowacka et al., 2013; Seifert et al., 2014), which users are not yet familiar with, could benefit from this effect as well. Finally, humanoid robots integrate ideas from information technology with physical embodiment (Thrun, 2004). All physical technology shares the same physical space with the users. However, the field of robotics has striven to empower robots with the ability to act like humans, e.g. feature limbs to handle objects, be able to see and hear and be conscious (Harvey, 2002).

Within this enquiry, I am particularly interested in functional implementations, devices that are not designed to communicate socially with their users. Mimicking human communication poses a large challenge when designing technology and might not always be appropriate. Interestingly, research has shown that people perceive technology as something more than lifeless objects. As soon as technology acts in a seemingly autonomous manner, people perceive it as an intentional entity (Taylor, 2009). Therefore, I see great potential in the interaction space of humans and machines, with these machines acting like machines. The aim of this work is therefore to explore ‘interactive intelligence’ in new technologies in a speculative mode of design research (Dunne, 2006), and to explore how designed behaviours give rise to perceptions of autonomy. Research through design (Koskinen et al., 2012) in particular is an appropriate approach for investigating this complex relationship. Through the process of design and realisation of experimental prototypes, evaluation of people's perceptions of these, and through reflection on the process as a whole, I aim to uncover new understanding of interaction with autonomous systems.

One might question the benefits of such systems. I argue that autonomous interfaces have the potential to excite people, enabling a range of applications. If these interfaces create a social environment, people might start caring for their devices and feel obliged to look after these interfaces. To this end, it is crucial to gain knowledge of how to design for higher acceptance. Such technology could have a wide range of benefits such as helping to change behaviour, fostering education, motivating to live more sustainably, and reducing loneliness.

In this thesis, I set out to explore this class of technology. The introduction herein defines the term *autonomy* in technology in general, i.e. I explain what I mean when I write about autonomy in this thesis. Through a review of literature concerned with animated objects, autonomous technology, and robots, I will map the design space and explore factors that are important in developing autonomous interfaces. Building on this and two workshops coordinated with the assistance of other researchers, I introduce a framework that identifies key elements for the design of TAIs. To validate the dimensions of the framework I designed and realised two autonomous, interactive prototypes. These two case studies explore people's perception of this technology and provide insight into how autonomy could be implemented into TUIs. The goal of this thesis is to investigate the perception and preference of users towards TAIs. When designed in the right way I believe that such interfaces can bring benefits such as improving our interactions with technology and enhancing social wellbeing. With this thesis, I aim to gain a deeper understanding for tangible autonomous interface design.

I will begin, in the following sections, with discussion and clarification of the terms *intelligence* and *autonomy* and how they are going to be used in this thesis.

1.1 Intelligence

To show autonomous behaviour or give an impression of autonomy, an interface arguably needs some kind of 'intelligence'. But what does it mean to be intelligent? Experts from varying fields have competing understandings. Intelligence seems to be an everyday phenomenon, which is understood by everyone, yet is it hard to pin down (Wechsler, 1975). In everyday life, someone might be called intelligent when they can grasp concepts quickly and provide solutions to a variety of problems, which may rely on a good internal representation of the world. Short, precise definitions usually are framed as the following:

> "*Intelligence is the mental capacity of emitting contextually appropriate behaviour at those regions in the experimental continuum that involve response to novelty or automation of information processing as a function of metacomponents, performance components, and knowledge-acquisition components*" (MacKintosh, 1998).

Simply put, intelligence could be described as the ability to reason well and grasp the subtleties of the world around us. Intelligent people are quick thinkers who do well at universities and business. This might mean that intelligence is a property; it is one's capacity for learning, reasoning, understanding, to solve problems and predict future events. But how could this possibly be quantified and compared? How does this help us to understand when intelligence is present or not? Psychologists measure the *g factor* (general intelligence), determining cognitive abilities of people through written tests of e.g. verbal, spatial and numerical tasks (MacKintosh, 1998). Although these tests are well acknowledged, they have a number of drawbacks. It is possible to study for such a test and therefore improve its outcome, although *g* should be a general measure of intelligence and therefore not change much over time. Furthermore, a person's mental state on that day and the particular selection of the tasks might also change the result. Additionally, we should aim for a definition which is independent of the observer. Arguably, intelligence seems to be rather a constructive and relative property, highly dependent on the person who is assessing it (Cruse, 2001) or creating the tests. So, as these properties are hard to measure objectively on a scale, they don't allow assessment of intelligence in humans or machines or even distinguish if someone/something is intelligent or not.

Another way of making intelligence more comparable is to see it as the capability to reach a certain goal. The entity that is best at reaching that goal is deemed to be most intelligent. Consider online platforms such as 'Kaggle', which pose data science challenges and competitions that have to be solved, and award prize money to the participant with the best solution [1]. It is hard to set goals for a broad term such as general intelligence and also accurately measure success. Therefore, it might not be possible to see intelligence as an objective measure, a number on an increasing scale on which different entities can be placed. Intelligence in humans is incredibly complex and dependant on a vast number of factors. These include the current environment

[1] https://www.kaggle.com/

someone lives in or the environment they were raised in, occupational and social status, heritability, education (MacKintosh, 1998); all of these may even be interlinked. Furthermore, recent research into neuroscience has shown that the solving of various cognitive tasks occurs in distinct brain networks, substantiating that there is not a single measure for human intelligence (Hampshire et al., 2012).

Interestingly, researchers do seem quite comfortable in using the term intelligence when describing technology (Kynsilehto and Olsson, 2011). Intelligent technologies have been of interest to the HCI community for a substantial length of time, as evidenced by the existence of conferences such as IUI (ACM Conference on Intelligent User Interfaces) [2]. Simply phrased, computers or other devices are “smart”, a convenient homonym for “intelligent”, when they are able to connect to each other and exchange information (Goddard et al., 1997). Plenty of other factors can be added to this list, such as context-awareness (Dey, 2001) (the device is able to sense and derive information from its surroundings); the ability to be trainable and learn; adaptability and maybe even proactivity (Kynsilehto and Olsson, 2011). But again, smartness or intelligence in this context is defined through comparison with other technologies or devices, which do not have these abilities. In practice, the smartness of a technology partly lies in the eye of the beholder. A person who fully understands the functioning of a machine will follow and foresee its course of action. They will project less intelligence onto the workings than someone who has no knowledge about the machine (Dautenhahn, 1997). Attempting to make sense of a device’s actions analytically, without understanding the device, might lead to a strong overestimation of the device’s capabilities. The user over-interprets the behaviour (Braitenberg, 1986) and assumes that the machine is more intelligent than it actually is. In such situations a person might start to ascribe intention and emotion to the movement of objects, and feel quite comfortable describing these movements in social terms. Whilst it is clear to them that these objects are in no way alive (alive in the biological sense), nevertheless people are willing to interpret the behaviour and make sense of it the way they would with other humans (Breazeal, 2002). This is one of the ways humans handle uncertainty: they make assumptions about a system’s state to be able to predict future outcomes (Cruse, 2001).

To summarise, we’ve seen that there is no straightforward definition of intelligence. It is a nebulous term, ideally measurable on a flowing scale, influenced by innumerable factors, a very complex fusion of the past, the present, the environment and context and depending on the observer. Different observers might perceive a different level of intelligence. Consequently, when evaluating a user’s impression of a robot, intelligence in robotics is often referred to as

[2] http://www.iuiconf.org/

'perceived' intelligence (Bartneck et al., 2008). In this work, the interest lies in understanding situations that encourage people to believe an interface is autonomous. For this thesis the aim is to understand the design factors that lead people into believing that an interface acts autonomously and therefore holds intelligence. Autonomy is arguably a classic sign of intelligence; a system can only be truly intelligent if it provides functionality by itself and without human guidance. There are various ways in which a notion of autonomy can be exposed. The next section will examine various approaches of autonomy in technology.

1.2 Autonomy

As already stated, a system can be described as *autonomous*, when it is capable of solving a certain task by itself, without relying on external assistance. In Suchman's words, autonomy is demonstrated by the *capacity of action* (Suchman, 1986). Autonomy can be exhibited and perceived through various means, either by its behaviour (so by producing a certain output) or by its outer appearance. An object can already exhibit autonomy through appearance, by simply resembling another object, animal or person and therefore adopting its abilities and ascribing qualities - at least at the beginning of the interaction. One example of this is lifelike wax figures. Visitors to wax museums exhibit creative interactions ascribing the character of the model to the according wax figure (Taylor, 2009). Similar to this are encounters with animalistic robots. Machines that look like a cat or dog, for example, are imputed with the traits of the animal the machine is modelled on (Kidd et al., 2006). People who had a higher preference for a certain robot's appearance also rated this robot higher in other areas such as good personality traits (Syrdal et al., 2007), implying that the appearance of technology plays a large role for interaction. Studies have shown, however, that, during interaction, the importance of behaviour takes over and people perceive the robot's intelligence according to its behaviour and not its appearance (Bartneck et al., 2009). The behaviour of a technology, i.e. how reactive it is to a user or environment or how capable it is of solving certain problems, has a larger impact on interaction than visual appearance. Furthermore, appearance can create a false impression, which is quickly exposed during interaction (which will be discussed in Chapter 2 - *Pitfalls of Social Robotics*).

In the following, I will broadly map out the different forms in which technology can be autonomous. I examine these forms with regard to the technological aspects, namely *software* and *hardware* of the interface. Autonomy can manifest in the physical behaviour, through actuation of certain parts of the interface in hardware, or through virtually solving tasks and manipulating digital data in software (through *Software Agents*). The combination of these two approaches are *Robots*. Figure 1.2 illustrates the position of each technology, and how hardware and software add to the autonomy of a technology. When mapping out the degree of hardware and software challenges, a gap emerges. Autonomous software systems are *Software Agents*, autonomous software and hardware systems are *Robots*. This thesis aims to close the gap for technology that uses mainly hardware to convey a sense of autonomy. I introduce a new kind of technology, *Tangible Autonomous Interfaces*, that describes this 'hardware autonomy'. The following sections will explain the terms and the positioning.

1.2.1 Software Agents

This class of technology shows autonomy through the ability to reach goals and solve tasks on its own (Wooldridge, 1997) - in software. Software agents represent a form of *Artificial Intelligence* (AI) (Nwana, 1996; Wooldridge et al., 1995). As the name implies, a software agent mainly operates in digital space, functioning virtually without being embodied. Output can be visualised within an interface or on a display, but is usually not required as software agents operate in the background. Their main ability lies in processing digital data, for example information retrieval (Maes et al., 1994) such as browsing the web and finding the best offer for a product (Maes et al., 1999) or decision support systems for medical diagnosis (Larsson and Hayes-Roth, 1998). Software agents also play computer games, do sports betting and deal with financial trading. Although it might not seem apparent to us and may not be observable, these systems autonomously make their own decisions. For example, multiple agents can also collaborate and exchange information to improve a service (Metral and Maes, 1998). Usually, just the output of a software agent is displayed as only this is of interest to the user. Software agents are discussed further in Chapter 2.

1.2.2 Robots

Robots are automated, mechanical assistants and show their autonomy through both being physically embodied, and also comprising highly complex software (Thrun, 2004). Guided by a computer program, their purpose is to assist the human with various tasks, for example in industrial applications or for entertainment (Goodrich and Schultz, 2007). Along with mechanical flexibility, they are expected to employ aspects of AI. They are reactive to the outer world and

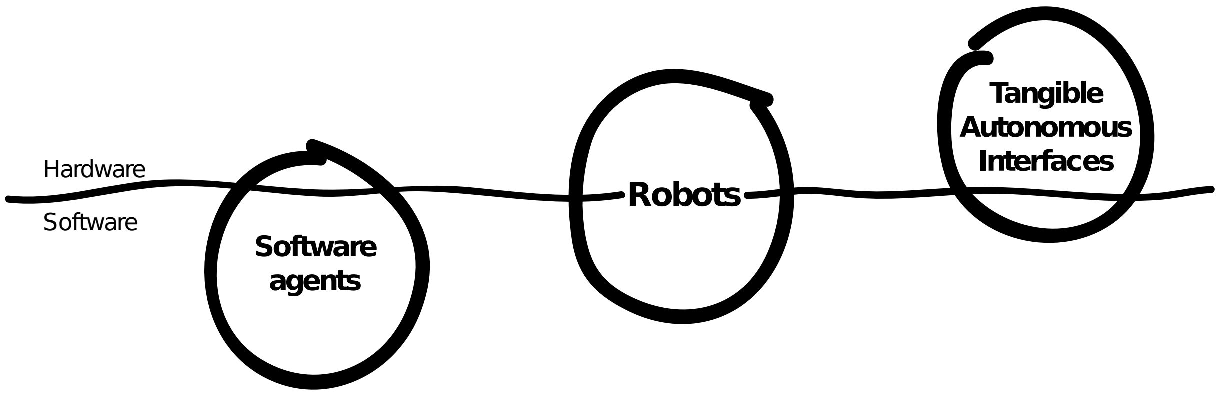

Fig. 1.2 An illustration mapping out how autonomy can be manifested in technology through hardware and/or software.

can solve complex tasks such as analysing their surroundings by capturing video and applying computer vision to recognise objects and humans. They can record readings of the world through various sensors such as light and temperature and learn from this data. They manipulate their mechanical parts using motors, enabling them to physically displace themselves - automatically or by remote control. Robots are the ultimate autonomous objects and embody the solving of tasks on their own accord. Numerous studies have shown that humans experience more empathy towards physical robots than virtual ones (Kwak et al., 2013), underlining the importance of embodiment. Robots will be discussed in Chapter 2.

1.2.3 Tangible Autonomous Interfaces

Tangible Autonomous Interfaces are interactive devices that expose autonomy through physical behaviour, mainly manifested in hardware. This is achieved by exhibiting reactivity to the environment and users through movement and through ambiguity in behaviour, e.g. movements whose purpose is not immediately apparent. They can be functional, e.g. interfaces, which solve or assist in a certain task in the household like the robotic vacuum cleaner Roomba or the family robot Jibo [3], or support behaviour change (Jafarinaimi et al., 2005). But also functionless - e.g. an art device or gadget without real function, other than entertainment, bringing engagement and joy, like Sphero [4]. Another example are the three rudiments (more in Chapter 2 Figure 2.8) of Helmes et al. (Helmes et al., 2011), which are speculative machines for the home, aiming to provoke curiosity and discussion around artistic and reactive interfaces. Devices can also be counter-functional, e.g. misbehaving (Bianchini et al., 2015) interfaces or interfaces that

[3] https://www.jibo.com/
[4] http://www.sphero.com/sphero

question their normal purpose (Pierce and Paulos, 2015) perturbing spaces and inviting critical reflection from users. This class of technology (TAI in the following) and how it can be designed for is the content of this thesis.

1.3 Problem Statement and Research Questions

This thesis seeks to explore the design space for the previous mentioned class of technology - Tangible Autonomous Interfaces. In this thesis, I aim to answer the following research questions:

a) *What makes a user interpret a tangible interface as autonomous?*

Through analysis of related work and two case studies I investigate what characterises autonomy in tangible interfaces and what role design plays in this characterisation. How can autonomy at a tangible interface be constructed and what does it take to appear autonomous? I identify key concepts for analysing and defining these interfaces. Are there different design features of appearance or behaviour that promote perceptions of autonomy amongst users? Which design decisions drive people to regard a physical, interactive system as a social agent and lead them to react in certain socialised ways? In this thesis, I set out to explore the design factors that make an interface appear autonomous and how we can design for autonomy in interfaces.

b) *What are the impacts on users when interacting with autonomous interfaces?*

The current situation is that we are rarely confronted with actuated elements in our environment that give us access to computational content and that we can interact with. I would like to imagine a future consisting of TAIs by presenting two case studies; tangible, prototypical explorations which I evaluated with a group of participants. I have created physical interfaces exhibiting varying degrees of autonomy, complexity and sophistication to investigate how people perceive these and what it would take for people to accept such interfaces in their environment. Ultimately, I wish to design autonomous interfaces, which are compelling and engaging for people. Furthermore, what would a minimally autonomous interface look like compared to a more sophisticated one? In this enquiry, I am especially interested in machine-like interfaces, which don't resemble humans or animals and explore human interaction with such interfaces.

1.4 Contributions and Structure of this Thesis

This section gives a short description of each chapter of this thesis and its contributions. As some of the research in this thesis is the result of collaborations it will further highlight where such work was published and the contributions I have made to each paper.

Chapter 2 (Literature review) discusses existing work on interactive objects and prototypes, which serve as examples for interfaces exposing autonomous behaviour. I discuss how people perceive animated objects as social actors, followed by an exploration of various prototypes in the form of abstract physical objects and everyday objects. I then examine a few examples of zoomorphic interfaces before discussing robots. The chapter provides a thorough discussion of lessons learned from these examples, and concludes with a summary description describing the challenges, articulating areas for further research.

Chapter 3 (Framework) explores the key factors that lead us to believe that an interface is autonomous. This chapter aims to give a deeper understanding of autonomous interface design. Through the review of related research and the exploration of autonomy in a number of workshops I have identified key concepts and characteristics which are important while designing and implementing Tangible Autonomous Interfaces. This chapter contributes a framework that aims to open up the design space for tangible autonomous interfaces and serves as a guide for design. It has been published in:

> Diana Nowacka and David Kirk. 2014. *Tangible Autonomous Interfaces (TAIs): Exploring Autonomous Behaviours in TUIs.* In Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI '14). ACM, New York, NY, USA, 1-8.

and nominated for the best paper award. To this paper I contributed the analysis of related work, the conduction and evaluation of the workshops and the writing.

Chapter 4 (Case Study 1 - Balloon) presents the first case study for investigating autonomy through creation of a physical prototype. This chapter uncovers perceptions of autonomous behaviour in interfaces by creating Diri - an autonomous helium balloon, used to document activity in spaces. This was achieved by implementing two different technological sophistications of Diri to compare the outcomes of various design decisions. This chapter presents the design and creation process, it illustrates a practical example of designing tangible autonomous interfaces using the framework. I describe the technical details, the evaluation workshops and conclude with opportunities and implications for designing autonomous behaviour into interfaces. This work also serves as an evaluation of the framework and closes with recommendations for adjustments of it. This work was published in

> Diana Nowacka, Nils Y. Hammerla, Chris Elsden, Thomas Plötz, and David Kirk. 2015. *Diri - the actuated helium balloon: a study of autonomous behaviour in interfaces*. In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15). ACM, New York, NY, USA, 349-360.

To this paper I contributed the prototyping, the design and conduction of the study to evaluate the prototypes, the analysis of the data and the writing.

Chapter 5 (Case Study 2 - Lamp) creates and evaluates the interaction space of an actuated notification device in the form of a desktop lamp. This chapter describes the exploration of the design space, which started with ideating movements with participants to communicate various messages and cues around the office environment. These gestures were analysed and used as a basis to design the behaviour of an actual prototype. In a semi-realistic setting the lamp was evaluated with a set of 14 people. This chapter is under review as:

> Diana Nowacka, Katrin Wolf and David Kirk. 2016. *Working with an Autonomous Interface: Exploring the Output Space of an Interactive Desktop Lamp.* (under review)

To this paper I contributed the design, deployment and evaluation of both studies and the writing.

Chapter 6 (Discussion and Conclusion) concludes this thesis by summarising the lessons learned from the literature review and the two case studies. I compare the results of the study and discuss the implications of these findings framing them in relation to the emerging dialogue around tangible user interfaces, and relating it to how humans expect tangible autonomous technology to function.

Elements of this thesis have been presented for discussion at:

- Diana Nowacka. 2014. Autonomous behaviour in tangible user interfaces as a design factor. In Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI '14). ACM, New York, NY, USA, 289-292. (doctoral consortium)

- University of Ulm, Human-Computer Interaction Group of Prof. Enrico Rukzio, 05/2014 (invited talk)
- University of Stuttgart, *Hcilab* of Prof. Albrecht Schmidt, 05/2014 (invited talk)
- Newcastle University, Lecture, *Intro to Human-Computer Interaction* 05/2014, 05/2015
- University of Southampton, *Agents, Interaction and Complexity Research Group*, 02/2016 (invited talk)
- Newcastle University, Lecture, *Qualitative Research Methods* 04/2016

Chapter 2

Literature Review

In this chapter, I discuss existing work on interactive objects and prototypes, which serve as examples for interfaces exposing autonomous behaviour. This chapter will unite a large variety of research areas to understand autonomy in interfaces. I visit studies of how people perceive seemingly intelligent abstract objects and cover an emerging use of technology through embodied interaction, *Tangible User Interfaces* (TUIs). With that I aim to underline the importance of embodiment and tangibility and why it is beneficial to consider autonomous behaviour as a design factor in TUIs. Lastly, I will talk about a range of interactive devices which can be classified as *Tangible Autonomous Interfaces* and more sophisticated and possibly more complex technology, *robots*. I summarise what I learned from this research, how it affected and framed my work and suggest areas for further research.

2.1 How people perceive autonomous objects

Research has shown that objects don't need to be very lifelike or intelligent to be anthropomorphised and perceived as smart and autonomous. Even social emotions such as empathy or social behaviour such as politeness can be evoked through interacting with plain objects. To improve their understanding about how something works in the real world, people build up a mental model (Norman, 1983). They create a representation explaining underlying processes, e.g. how a washing machine or a computer program works. Interestingly, this effect is adapted to even very simple things like inanimate objects or shapes. In the mid-1940s Fritz Heider and Mary-Ann Simmel (Heider and Simmel, 1944) conducted an experiment, where they showed

Fig. 2.1 (a) Heider and Simmel's Attribution of Causality: Movement of even very simple shapes can convey a rich and emotional story (Heider and Simmel, 1944). (b) The Dot and The Line, an animated short film about a line falling in love with a dot (Juster, 1963).

an animation film to people, in which shapes like circles and triangles move over a plain white surface (see Figure 2.1 (a)). The results of this experiment indicate that, in general, the viewers perceived the shapes as animated beings executing autonomous functions. The movements of the shapes were interpreted as actions and even emotions and intentions were ascribed to the objects. Primarily, people were able to impute the animation to a story, which contains casual centres, the shapes standing for people. As soon as people ascribe 'life' to an inanimate object because of its movement, they also ascribe intention, motives and needs and interpret their movements in relation to it. So the origin of the movement is attributed to the figural units and to motives, which leads to projection of human qualities onto inanimate objects (Heider and Simmel, 1944). The same results yielded a similar animation, *The Dot and the Line - A Romance in Lower Mathematics* (see Figure 2.1 (b)). This is telling a complex story of a simple two-dimensional line falling in love with a dot. Through solely displacing the forms and changing their shape, deep and credible characters were created, which were able to convey a large variety of emotions.

From these experiments we can learn that people's interpretation of simple movement-combinations is immediately connected with interpretation of personality-traits of the active actors (Heider and Simmel, 1944). This also shows that there might not be much needed to make something appear autonomous.

In 1986, through an elaborate thought experiment, Braitenberg (Braitenberg, 1986) demonstrated how willing people are to interpret the actions of machines as intentional and driven by an emotional motivation. Two simple vehicles are introduced, each containing two wheels and two light sensors placed at the front of the vehicle, which are connected to the wheels (see Figure 2.2). We imagine that the right light sensor of the first vehicle increases the motor strength of its right

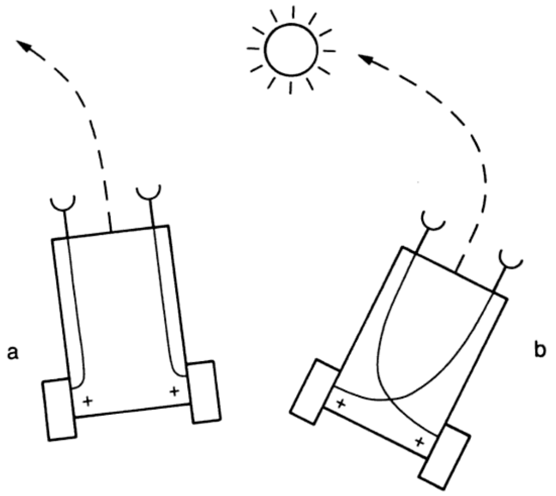

Fig. 2.2 Two Braitenberg vehicles (Braitenberg, 1986) consist of light sensors controlling motorised wheels and therefore enabling complex behaviour of the vehicles towards a light source.

wheel when stimulated by light and the left sensor increases the left motor. For the second vehicle the sensors and wheels are connected across, stimulation of the right light sensor increases the speed of the left wheel and equally the left light sensor controls the right wheel. How would such vehicles behave towards a light source? Both vehicles won't move until they sense light. When the sensor of the first vehicle finally perceives light it will trigger the motors and force the vehicle to move away from the light source. The more it turns away the slower it gets until the sensors are not stimulated by the light source anymore and it stops with its back pointing to the light source (see Figure 2.2, a). The second vehicle on the other hand will move towards the light. The closer it gets the quicker it will move until it crashes into the light source (see Figure 2.2, b). Somebody who doesn't have knowledge about the inner workings of the vehicles will assume that both vehicles have a certain interest in the light. The first one seems rather cautious and afraid of the light and therefore it turns away. The second vehicle seems to show aggressive behaviour towards the light since it appears to be willing to destroy the light source. The result of this experiment is that people use psychological language in describing behaviour and fall back to interpretations ascribing motivation and intention. Interestingly, anthropomorphic forms such as human or animalistic appearance are not needed to express social behaviour. As this exercise proved, people ascribe the ability to act socially even towards abstract objects such as simple forms and vehicles (Ju and Sirkin, 2010).

Braitenberg goes even further in his book, by applying more and more sophisticated mechanical means he produces links between his vehicles and humans. Step by step he increases the capabilities and intelligence of the hypothetical machines until he reaches very complex human characters like learnability, foresight and even free will. With this he is suggesting that our own social responses and behaviours, which are results from evolution, are merely procedural and can be replicated by a machine.

Steward (Stewart, 1982) explored which kind of movements lead people to distinguish an object as animate or inanimate. She invited participants to assess how alive certain computer animated dots appear. Changes in velocity or unusual deflections following impact did not contribute to the impression of animacy. Object avoidance where ascribed as animate, whereas direct movements towards a goal seemed intentional but inanimate. Gao et al. (2010) came to another conclusion while researching moving shapes which keep their fronts oriented toward a randomly moving target. These were perceived as animate because of their goal-directedness (Gao et al., 2009). However, a number of studies established that the main contributor to the perception of animation seems to be the fact that their motion cannot be explained by appeal to external forces (Gaur and Scassellati, 2006; Schultz and Bülthoff, 2013; Tremoulet and Feldman, 2000). Further studies confirmed that simple motions can communicate emotions (Mutlu et al., 2006; Park and Lee, 2010).

2.1.1 Anthropomorphism

Strongly related to what was described above is *anthropomorphism* (Waytz et al., 2010), which refers to the psychological phenomenon of people ascribing human mental states and qualities onto non-human entities. This effect appears to happen towards all kinds of entities such as animals, but also plants, the weather and as demonstrated above physical objects and animated forms. In their detailed review Epley (Epley et al., 2007) summarises three reasons for how and why anthropomorphism exists.

First, our self, our thoughts, and feelings are our basis for understanding the world, therefore we use this perspective to reason about the unfamiliar. Anthropomorphism is likely to be the result of us trying to comprehend actions and events that we can’t otherwise explain. This implies that anthropomorphism happens automatically, our thoughts and feelings serve as a default concept that ground the way we understand the behaviour of unfamiliar non-humans.

Secondly, we are strongly social creatures striving for connections and belonging. Research has shown that people who are socially disconnected create human-like agents in their environment to populate their world, meaning they anthropomorphise pets or plants more strongly (Epley et al., 2008). It is our natural - even subconscious - tendency in life to look for like-minded entities that we can socialise with. Even in cases where this entity is technology.

Thirdly, we have the urge to understand the world to make predictions about actions and events. *Effectance Motivation* describes the fact that humans have a basic motivation to control the environment and predict future interactions. Basically, again, anthropomorphising agents originates from people using their self-knowledge to explain situations to understand and gain control over their lives.

Now that we gained insights into why we anthropomorphise, it would be of high interest to explore how technology can be designed to leverage the fact that people could also ascribe human characteristics onto technology. This seems like an opportunity worth exploiting. Being aware of this phenomenon might be helpful as it possibly provides implications for interaction. Human-machine interactions are therefore possibly aligned with people's expectations in social situations with each other. Replicating human-human interaction into human-technology is a very challenging endeavour though that I will discuss later. The next section will first investigate earlier research on how people perceive computers as autonomous entities.

2.2 Digital Autonomy

People, at times mindlessly, treat computers as humans. They express certain social behaviours, like politeness or empathy, which they would normally reserve for other humans, towards computers. This might seem surprising as computers hardly resemble humans. Numerous studies across people of different ages, cultures, and educational levels have nonetheless suggested that computers excite social responses (Reeves and Nass, 1996).

In their book *Media Equation*, Reeves and Nass (Reeves and Nass, 1996) evaluated human reactions to desktop computers, all with the same outcome that humans treat computers as social actors (the phenomenon is called CASA - *Computers As Social Actors*). To give an example, people were invited to work on a desktop computer and afterwards were asked to fill out a questionnaire about the computer's performance - once directly into the computer and once on a piece of paper. The interaction between the users and the computer was solely text-based. Fascinatingly, the participants that filled out the questionnaire on the computer gave by far more positive feedback towards the computer and therefore behaved in a more polite manner when being confronted directly with it. This happened, despite the fact that all participants stated that they - consciously - would never personify an ordinary computer and did not perceive the computer as being alive in any way. These reactions appeared to happen subconsciously. Furthermore, the authors observed that participants treated the actual computer as a person and did not consider it as a representation of a programmer or a person controlling it remotely (Sundar and Nass, 2000). During the studies further social reactions and relational effects, which humans consciously only show towards each other, were demonstrated. For example, people are more willing to return a favour if they have been helped before. This also applies to computers (Fogg and Nass, 1997). Computers that praise others more than themselves are more likeable. When the computer and the user were both equipped with a ribbon of the same colour, people felt teamed up with the computer and interacted with it more.

The authors explain that one reason for this finding might be the basic desire of humans to understand the world from another person's perspective. As this is crucial for social interaction, we constantly aim to understand motivations of actions, equally with anthropomorphism. The human brain evolved to make simple assumptions of consciousness where doing so held some kind of evolutionary advantage (Dennett, 1993). Accordingly, we use social responses in situations where we perceive an object to be intelligent. Such examples show that there seems to be a general willingness amongst humans to attribute inanimate things with the ability to think (Taylor, 2009) - under the right circumstances.

Another study exploring social behaviour towards computers was presented by Shechtman and Horowitz (Shechtman and Horowitz, 2003). They asked participants to play a game on a text chat interface, to solve the Desert Survival Problem (a game where people have to rank the most useful items to survive on a deserted island). Half of the participants were told they interacted remotely with a human, the other half with a computer. Participants who thought they communicated with another human used significantly more social language and also led more in-depth discussions. What this study demonstrates is how users consciously expect to interact with textual-based interfaces. They did not expect the computer to react to their social behaviour. Therefore the participants did not make an effort to communicate with the computer in a different way than they are used to (which is highly procedural and not social at all). However, undoubtedly, people express rich social behaviour towards humans, which they might not show towards a computer. This does not imply that there won't be situations where humans might very well react socially towards computers as shown by Reeves and Nass (discussed above) (Reeves and Nass, 1996). These reactions might be more subtle but none-the-less existent. So this study does not exclude the potential that text-based interfaces may be perceived as social entities. Simply because their interaction with a computer was less social compared to that with a human does not imply that all text-based interactions happen in the same non-social domain.

To date, it is still very challenging to create a credible interactive software agent that is capable of having a dialogue with. This is shown by, for example, the failure of a smart word processor assistant in the form of an animated character. 'Clippy' is an interactive guide in the form of a small paper clip with googly eyes, which proactively offers help and suggests content and edits in a document editing program. This piece of software turned out to be a failure (Whitworth and Ryu, 2008). Promoted as the new generation of smart assisting, Clippy failed in understanding user needs and lead to frustration for many (Bahr et al., 2007). Through its apparently very limited awareness of user actions it would frustrate users by randomly popping up to make the same suggestion, even after being deactivated. For users, Clippy didn't seem smart enough, it was not learning from its mistakes or realising the user's irritation and therefore became annoying. Although Clippy is over ten years old and there has been a large body of work regarding virtual agents (Nwana, 1996), at the moment, only few virtual characters are included in our interfaces (Mimoun et al., 2012). It is presumed that the more *human-like* an interface is, e.g. computers resembling human characteristics such as an animated face, the higher the willingness to elicit social responses in humans (Nass and Moon, 2000). Studies, which compared interaction with text based interfaces to embodied interfaces (virtual characters with faces), however, found out that in general people prefer text-based interaction, because faces evoke higher expectations that couldn't be matched by the interface (Burgoon et al., 2000; Hindmarsh et al., 2001; Slater and Steed, 2002). This might be one reason why services to date decided against a virtual character.

2.3 Physical Autonomy

There is early work concerning human-computer interfaces, which indicates the importance of physical agents for social interaction in contrast to digital ones (Hummels et al., 2007; Kidd and Breazeal, 2004, 2008; Pereira et al., 2008; Wainer et al., 2006). One very interesting example for humans exhibiting emotions towards interfaces is the evaluation of a TUI on an interactive surface, Robotable (Mi et al., 2012). Robotable consist of a multi-touch table with wheeled objects operating on it, creating a mixed-reality environment. Direct manipulation of digital content is enabled either through touch of the surface or interacting with the actuated objects. Two different versions of the game *Pong* (a simple virtual version of table tennis) were developed for this. In the first version, a physical robot accompanied the players on the table; the second

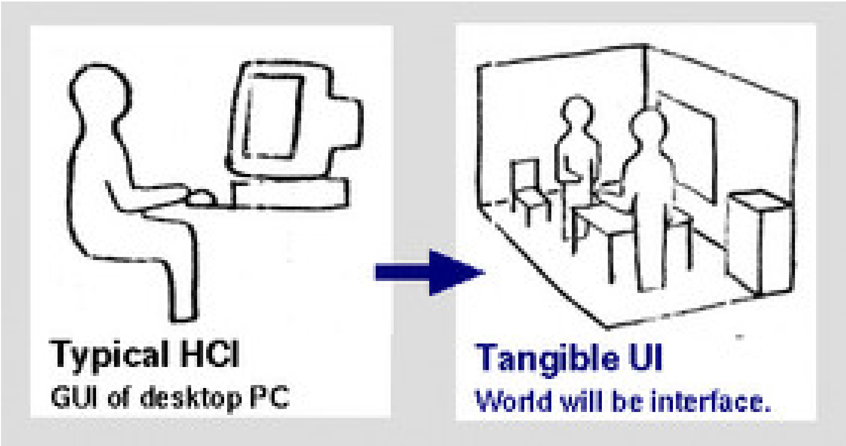

Fig. 2.3 Tangible User Interfaces are integrated into our environment; designated objects are used to access technology, instead of a traditional desktop (Ishii and Ullmer, 1997).

comprised a virtual copy of the robot. The evaluation of the game revealed that the players bonded much stronger with the physical agent than with the virtual one. They expressed feelings like happiness or anger towards the object while winning or losing the game. Also the interplay with the physical robot seemed to lead to a higher social engagement than with the virtual one.

Experiments such as the above indicate the importance of a physical entity and the presence of tangible objects as opposed to virtual objects. The evaluation also suggests that physical objects might be more acceptable than virtual ones. This opens up an interesting design space for technology, motivating physical computing as a possibly more engaging way of interacting with digital data. The following section will inspect a class of interfaces, which relies on embodying digital information through physicality and motivates the use of physical objects to access digital data.

2.4 Tangible User Interfaces (TUI)

There is a field in human-computer interaction which explores embodied interaction in technology. The idea of Tangible User Interfaces is to "connect the world of atoms and bits" and strongly couple digital content to physical objects (Ishii and Ullmer, 1997). This is achieved by making digital data more accessible through a physical environment. Traditionally, we only interact with computers through very restricted input, we see, we hear and we use simple, binary switches (see Figure 2.4). As opposed to a mouse, which maps its relative displacement on a flat surface

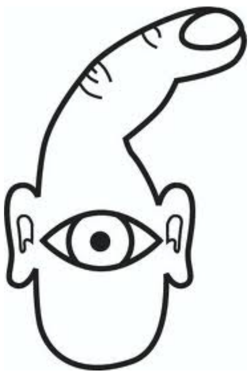

Fig. 2.4 How the computer sees us: the only input we can make to a computer is to click buttons or move the mouse; we furthermore see and hear (O'Sullivan and Igoe, 2004).

onto the movement of a cursor on the screen, a TUI aims to be input and output at once. Its physical state represents its digital state and the digital can be manipulated by manipulating the physical. A very simplified illustration is presented in Figure 2.3. In a TUI world interacting with a computer would mean to interact with the physical environment and not a specific workstation. The vision is to shift away from the *Graphical User Interface*, towards computers that are built into our surroundings and everyday objects. Accessing digital information happens through physically manipulating these environments and the objects. For an extensive exploration in form of frameworks for classification and also an aggregation of application areas see (Ishii, 2007; Shaer et al., 2004; Ullmer and Ishii, 2000). In the following I will describe the key aspects of TUIs.

Representing the digital through the physical The term *tangible* describes the coupling of digital data, e.g. sensor measurement (temperature, acceleration) or software status (active, waiting, inactive), with a physical artefact. The physical interface serves both as a representation of the data, but also functions as a controller, enabling manipulation of the digital data (Ullmer and Ishii, 2000). The advantage of this is that the data is more visible and therefore possibly easier to comprehend. Additionally, the physical and/or visual appearance shapes first impressions. It creates expectations in users how a device should be used and how it can be interacted with. The aim is to give various hints to the users on how the system works to provide a more useful, engaging and insightful interaction. This would lead to the user gaining a better understanding of the system and therefore perhaps a better handling of errors.

Continuous, analog states of the physical versus discrete states of the digital The physical world and the digital world differ in many respects, with one of the most prevalent being that we experience the world in a flowing state, whereas computers are discrete, software retains information in numbers and has certain states. Although there is a gradient, allowing somewhat flowing in- and output, it is by far not as fine as the real world. For this reason each computer requires an analog-to-digital converter to record or display information. TUIs try to overcome this by integrating digital data into physical objects and allowing continuous input, which is much more common for us than discontinuous input.

Intuitive interaction as people already know how to interact with tangible things in the real world Advantages of this approach are to abandon discrete states and embrace the richness of the physical environment to address all our senses. Instead of just switching a button, an interface like that can be squeezed or displaced to perform an input. The goal is to create a computationally augmented world, where interacting with computers is continuous and happens through familiar, physical objects. People don't need to learn how to use physical tools, these are skills which humans hold from interacting with the real world. Manipulation of these objects is grounded on our spatial and tactile skills. These affordances of a device (Norman, 1988) help to quickly understand how a device works and how to use it. Naturally, these devices also comprise mechanical constraints, which might hinder people from performing the wrong actions (Patten and Ishii, 2007). There is an assumption that, as this approach builds on our established skills, no learning is needed. This can be taken advantage of and extended for autonomous interfaces; the correlation between the appearance of an interface and its capabilities should be high (Duffy, 2003).

Furthermore, we have evolved to socially interact with embodied creatures. Many of our social skills and communication modalities rely on both parties having a body, we respond much stronger to physical presence (Mi et al., 2012). We use gestures to express our thoughts, we touch each other, we displace ourselves and objects in our environment. Interestingly, embodiment strongly adds to the perception of autonomy and creates a social presence, which we can't fight to react socially towards. This opens up opportunities to create physical technology, which is engaging and underlines the importance of physicality. As we already learned physical objects promote higher interest in users. This thesis aims to take advantage of the effect that tangibility builds on our experiences and understanding of the world. I wish to explore how tangible interfaces change people's perception thereof once they are actuated.

2.5 Tangible Autonomous Interfaces (TAI)

The concept of autonomy in TAIs has partly been evoked, within a large variety of interactive objects. The next sections illustrate this diversity by providing examples from research as well as industry. First, I will mention the most striking and influential prototypes from research on actuated interfaces. Following on that, I will discuss a variety of new products and prototypes, which are either commercially available or very recent DIY-projects. These examples have not been evaluated and researched yet, they, however, bring interesting insights on different possibilities of autonomous behaviour in interfaces. Within this enquiry the focus is on interfaces with an abstract, functional appearance rather than an anthropomorphic one. Researchers have warned about the negative effects of copying humanoid or zoomorphic appearance (Bartneck et al., 2009; Dautenhahn, 1997; Hoffman and Ju, 2014; Ju and Sirkin, 2010; Jung et al., 2013b; King and Ohya, 1996; Shneiderman, 1993; Złotowski and Bartneck, 2013). The criticism is motivated by the fact that we exactly know how humans and animals behave. Having to interact with an electronic copy, such as a technical device, gadget or even just a virtual representation oftentimes leads to disappointment and frustration, as these work and behave fundamentally different from the real thing (Gong, 2008). Relying on these cues might confuse the user and expectation of how the device works might not be met. Whereas it was shown that voice output in a smart object strongly provokes social behaviour, this one exploration was limited to a short interaction consisting of only one sentence ('bless you') (Jia et al., 2013). Recent research identified that interaction with conversational agents is challenging for users (Luger and Sellen, 2016). Still, carefully constructed, there are reasons such interfaces could be beneficial. Therefore, in this chapter I will cut into the fields of zoomorphic interfaces and robotics and conclude with the lessons learned.

2.5.1 Actuated Abstract Objects

Actuation in the form of movement has been explored as a means to create pleasurable devices, especially in product design. Numerous research projects aim to use movement as an additional output channel and to improve user experience, but also to change user's behaviour. This section will review actuated objects, which are designed in an abstract, object-like way and how these designs affected user perception.

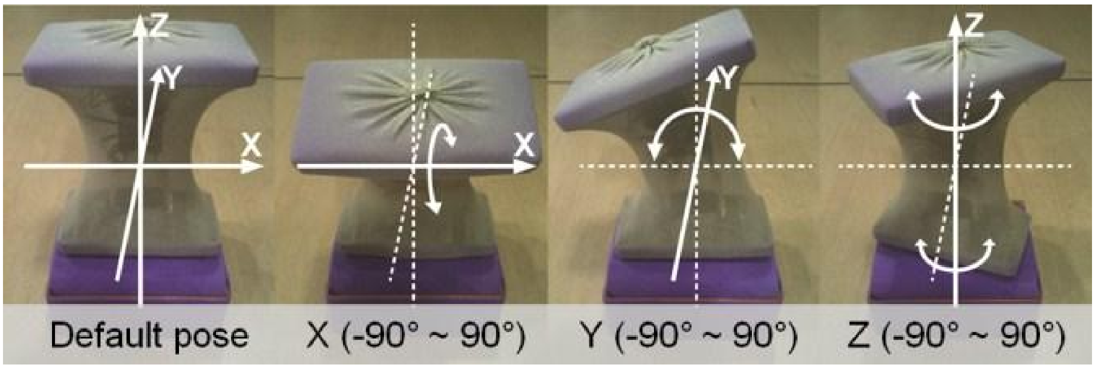

Fig. 2.5 An actuated torso that is capable of a wide range of movements around three axes to explore movements as a means of communication (Jung et al., 2013b).

To find a general 'movement grammar' for design which renders possible the communication of product messages, Jung et al. (Jung et al., 2013b) created a mechanical torso equipped with actuators and evaluated user's perceptions of its motions (see torso in Figure 2.5). The prototype is of plain quadratic shape, the four actuators are covered by a sheet of fabric. It is able to rotate sideways and tilt forwards and backwards. As it is inspired by a human torso, the top and the bottom can rotate sideways independently of each other - relating to shoulders and hips. Together with a group of body movement experts, 28 different forms of movements were designed. Properties such as speed and rhythm were also taken into account. These were then given a meaning each, such as bowing, thinking, 'Yes' and 'No' and it was tested how well people could recognise these.

The overall outcome was that there was a high agreement on some action-related movements, like *bowing*, *lying*, *dancing*; less on emotions such as *sad*, *angry* and *happy*. The participants also struggled to differentiate movements which only differ slightly, as for example between *sleepy* and *sad*. This teaches us, that although people do ascribe certain meanings to movement, the perceptions still differ and it is not possible to design certain actuations in a way that they are unambiguously understandable. While movement can be used exclusively, other modalities are also needed such as sound, light or context information.

A second trial of this kind aimed to map movements to possible product messages. The authors conducted this follow-up study to certify their new design method. The procedure for creating movements is as follows: identify the degrees of freedom that the device offers, select the messages which need to be expressed, finally find the optimal mapping between these two. A set of designers were instructed to use this method to create a household humidifier that communicates different messages. Another set of participants was instructed to just map movement to messages, without following any rigorous procedure. Interviews after the study revealed that designers which used the method felt more confident with their decisions, as they probably followed a more systematic approach. Interestingly, designers naturally picked movements which reminded them of humans or animals. However, the authors conclude that each designer or user might interpret movements differently, and designers have to embrace this fact and not rely on rigid mappings. This work underlines a potential for human-like movements.

Lessons learned Although some agreement was reached, each user may have different interpretations of a movement in the end. Actions such as bowing or looking around were easier to convey than emotions such as happiness or anger. Movements which are similar are almost impossible to distinguish and can be ascribed varying meanings. The authors expect movements to be more distinguishable when provided in a certain (real world) context. They furthermore propose product movement as a powerful tool when combined with other modalities, like visuals, sound or vibration.

Breakaway Breakaway (Jafarinaimi et al., 2005) is an example of a small desktop ‘companion’ to motivate people working in offices to engage in physical activity. Consisting of a tiny statue in the shape of a long strip, this device slouches when the user is sitting too long by their desk. This device is a calm display (Weiser and Brown, 1997), very unobtrusive, not showing any potential for distraction at work. An initial study with one participant over two weeks revealed that Breakaway indeed motivated movement and was not too intrusive underlining the potential for actuated devices in the workspace. It also nicely illustrates an application area for autonomous interfaces, spark behaviour change by providing subtle reminders through movement.

AniThings AniThings (van Allen et al., 2013) is a design concept consisting of a collection of small, abstract and plain devices (see Figure 2.6), which are placed on a desktop. They have access to the users’ personal data and depending on the context, they replay sounds or suggest content for the user through text or visuals. These devices are proactive and aim to serve as small companions to spark creativity. Compelling in this context is how autonomy is implemented in the interfaces. The authors use animation, proactive behaviour in form of notifications and collaboration with each other to make the devices come ‘alive’. Every device seems autonomous and appears to have its own intentions and a personality by expressing certain designed behaviours, from needy to nerdy to nostalgic. By this, the authors want to demonstrate how users could imagine devices to have an inner-life.

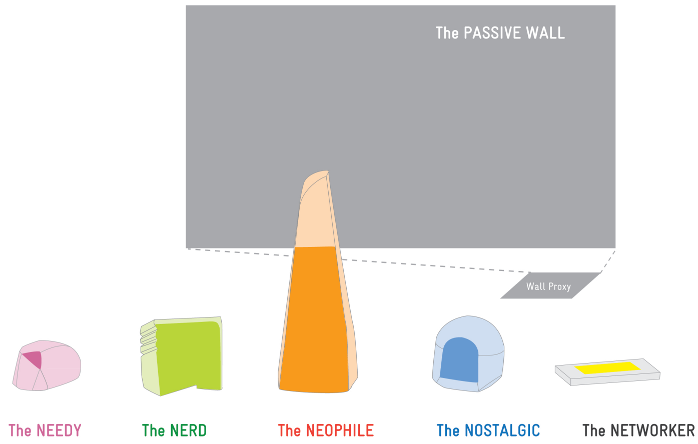

Fig. 2.6 AniThings: speculative design consisting of autonomous desktop devices that suggest digital content such as music or pictures (van Allen et al., 2013).

Lessons learned The authors conclude with this concept idea that *Artificial Intelligence* is not necessarily needed to create a "smart" social presence at home. Humans can project the lacking of intelligence onto devices during interaction. This means that the imagination of users makes the objects "smart", it is up to the users how they comprehend the suggested content. Other researchers argue that for creating intelligence only a copy of something intelligent is needed, e.g. human social behaviour (Duffy, 2003). When designing a system, the key is not to create an intelligent interface, but to display attributes of one. The authors also expect users to be more tolerant to low quality content or misbehaviour, as they can turn to another device in case they are not interested. Overall, this work provokes designers to shift their attention to devices which facilitate human intelligence and help explore and refine a problem rather than strictly aiming to solve it.

Pareidolic Robot The pareidolic robot is design exploration from the Royal College of Art (a prestigious public Art&Design university), consisting of a device, which contains two cameras (shown in Figure 2.7), and is placed outdoors to face the sky[1]. The camera stream is analysed to look for faces in the clouds and transmit these pictures to an online photo sharing platform. The concept of this work presents a thought exercise, to imagine having robots in our lives which aim to improve our free time. Robots are very efficient in computational tasks

[1] Pareidolic Robot - http://www.di12.rca.ac.uk/projects/pareidolic-robot

Fig. 2.7 The ‘Pareidolic robot’ is a machine, which identifies forms and faces in clouds (see footnote 1).

and could show us things that we would never be able to see. Although intended as a device to reflect on what people want machines to do for them, it resembles traits of ambiguity and autonomy, since the robot captures the moments it “finds interesting”. For a user the robot’s behaviour is non-transparent and therefore mysterious why the robot chose to take a certain picture. The act of doing it autonomously leads to think that this device has an intention and goals.

Lessons learned This example is particularly compelling as this device expresses autonomy through the sort of task that it is solving, which is not at all a usual for a robot. However, exactly this unusual intention of the robot, to ‘see’ and record something unusual and aesthetic, strongly conveys a sense of autonomy.

Rudiments 1, 2 & 3 The work of Helmes et al. (Helmes et al., 2011) has had a significant influence on this work. In their paper they investigate the possibilities of autonomy in interfaces by introducing three prototypes (referred to as rudiments one, two and three hereafter) of different sophistication. The approach of speculative design (Dunne, 2006; Dunne and Raby, 2001) is used to explore the effect of machine autonomy on people and to inspect how characteristics of artificial intelligence are interpreted by people through open prototypes. This research aims to provoke speculation; to think about autonomy and design and its implications in a new way. The first one of the three prototypes (see Figure 2.8) consists of a small wheeled module, attached to a magnetic surface like a fridge door. It is encapsulated in a wood and acrylic case and comprises an infrared sensor to detect nearby movement. Speed and direction are randomly changed, yet influenced by the sensor input, creating an ambiguous movement. The second rudiment is a plywood box with a movable arm and pen, attached to a servomotor. Microphones capture the sound surroundings in the room and control the arm’s movement, resulting in circular drawings on a white sheet of paper. The system's sensitivity increases for lasting sounds, creating a responsive yet seemingly autonomous output. The last prototype consists of a camera moving along an acrylic cog. The casement illuminates one of eight different colours, depending on the pattern which the camera captures. The video processing follows a complex machine learning algorithm which aims to detect the shape of a face in the camera stream. Each colour maps to a certain face shape and accordingly to the classified face the correspondent colour lights up. Once a face is detected the casement also tries to move towards the face along the string, every now and then making a random movement. As the interest of the authors lies in machine intelligence, the prototypes were intentionally designed with mechanical-like qualities, avoiding zoomorphic or anthropomorphic associations. The evaluation in two households over a four week period lets the authors conclude that the third prototype, the most sophisticated one, seemed to be the most engaging and received the most interest. One participant in the study was particularly appealed to its persistent behaviour and perceived the illumination of the same colour as a kind of recognition and greeting. It is remarkable how something as technical as an recognition algorithm and the flashing of an LED can be interpreted as social gesture like acknowledgement or appreciation. The repeating interaction, the device comprising some kind of "memory" led to some kind of relationship between one participant and the third rudiment. In contrast to that, another participant which wasn't recognised by the algorithm and therefore didn't receive a colour stated that the interface didn't "like" her. In the paper it becomes clear that the camera couldn't pick up the person because it was occluded by hair. This action or lack of action of the system was seen as a kind of rejection. As the rudiments had no specific function and didn't fulfil a certain task, participants did compare them with pets. This combination of lack of functionality and autonomy strongly reminded participants of domestic cats or dogs.

Lessons learned There are several conclusions that can be made from this work. People try

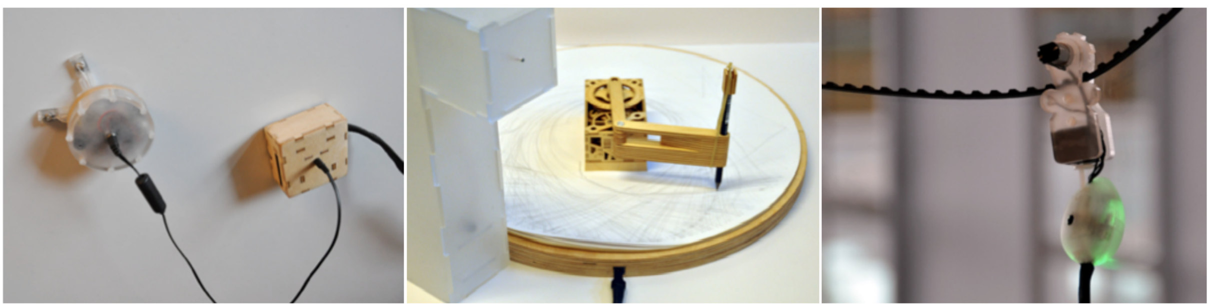

Fig. 2.8 The three rudiments: the nearby movement sensing, wandering machine; the motor arm drawing the home soundscape; and the face-detecting and moving camera (Helmes et al., 2011)

to make sense of machines that they don't know their functioning of, and try to interpret the machines' behaviour. They show interest in the general rules of patterns of actions. Higher sophistication in these cases seemed to lead to more interest and stronger emotional response. Ambiguity was always incorporated into the behaviour of the rudiments by adding random movement which seemed to strengthen the curiosity. Interestingly, despite their mechanistic appearance, the prototypes were perceived as pet-like.

2.5.2 Actuated Everyday Objects

Using actuation to communicate or just attract attention has also been explored in everyday objects, for example, in trash bins (Yamaji et al., 2011), toasters (Burneleit et al., 2009), faucets (Togler et al., 2009), or guitars (Vidyarthi et al., 2011). An actuated computer screen succeeded in persuading its users to improve their posture by changing its own posture (Breazeal et al., 2007). These examples show that even very mundane things such as garage doors could appear autonomous if designed in the right way.

Jung et al. (Jung et al., 2013a) evaluated three moving objects to convey messages and analysed the interaction over time. They present three prototypes: (i) an actuated water dock, consisting of a water bottle located on a bottle holder that was able to rotate and tilt left-right and forwards-backwards; (ii) a moving assignment-box, which can shake and tilt and (iii) a moving recycle-bin.

The first prototype (see Figure 2.9 (a)), the water bottle, was placed on a desktop and functioned as a reminder for people to drink more water during work. The authors measured the water

Fig. 2.9 The three actuated everyday objects serving as case studies: (a) water bottle; (b) assignment box and (c) trash bin (Jung et al., 2013a).

consumption of two users in an office setting and interviewed the users after four weeks. Interestingly, the participants changed their behaviour slightly and indeed drank more water. One of the two participants described the bottle as "cute", felt "watched" and showed empathy to some degree as the participant felt sorry when the device hit e.g. the wall. Even this simple experiment shows how easy lifelikeness and social presence can be created and that people naturally associate movements with human-like messages (like nodding, dancing). The second prototype (illustrated in Figure 2.9 (b)), the actuated assignment box, aims to assist students with their assignments by greeting them and communicating how much time they have left for their assignment and its urgency. In this setup, submission time was recorded as well as questionnaire responses about likeability, impression and general feelings about the box. Although the results show that people did not change their behaviour, e.g. submission time did not change, the assignment box caught their attention, people were looking at it more and talked about it more. The results also indicate, that students felt more secure with their submission as the box confirmed receiving in form of nodding ("yes"). Due to its ambiguity perhaps, students were quite confused about the box in general and its movements and felt partly frightened or even bothered by it. The last prototype was a moving recycle-bin (Figure 2.9 (c)), whose purpose was to suggest usage. It was able to rotate around itself, open its lid and furthermore detect people close-by through infrared sensors. This prototype was tested in a school with a class of four year olds. The authors hoped to provide an educational experience by having the bin reminding the children to pick up and throw away rubbish. Indeed, the bin raised awareness; after one week the control group with an inanimate bin were less motivated to use it. The children were even able to correctly identify the designed messages such as "feed me", "wrong use" and "searching for trash".

Lessons learned To summarise, first of all, the authors report that a lot of participants referred to animals in their interpretations. Carefully designed movements might even trigger certain emotional behaviours, people express empathy or change their behaviour, for example show more responsibility. The authors underline the importance of meticulous design of appropriate messages and effective movements. They further conclude that while product movement certainly succeeds to quickly attract attention, it must be handled with care though to not frighten or bother people. Clearly, these prototypes also show how important the context is; a shaking water bottle wouldn't make much sense in a mall, as well as an assignment box on someone's desk.

Actuated Doors and Televisions Even automatic doors (Ju and Takayama, 2009) and television sets (Mortensen et al., 2012) are attributed lifelike characteristics by using interactive motion.

Researchers explored user's reactions of different door gestures; they were interested if a door could be interpreted as being "inviting" through implicit interaction (Ju et al., 2008). In real social encounters, even subtle social engagement like eye contact and a small hand gesture create predictable responses, like for example when a doorman invites someone to enter by acknowledging that person and opening the door slightly. A significant finding was that people made attributions like cognition and intent to the physical, actuated object, even if these don't resemble anthropomorphic features. The attribution of character to animated objects was so strong, that participants felt offended by one of the behaviours of the automatic doors and even denied to fill out a questionnaire at the end of the study (Ju and Takayama, 2009). This underlines that emotions or messages like usage suggestions or product availability could possibly be conveyed by actuated objects.

Mortensen et al. (Mortensen et al., 2012) realised that perceived intelligence can be explained rather by the user interacting with the device than actual (artificial) intelligence. Perception of agency emerges as users and devices react to each others behaviours. Their study consisted of a Wizard of Oz setup, a rotating TV placed in a living room, which aims to communicate a positive attitude. Particularly intriguing in this study is the fact that the researchers compare one versus two users present and the social situation that emerges. In the interviews the participants stated that they didn't think consciously of the TV as a living or social entity. Most striking though is the fact that the TV indeed became a part of the users' social context. Another finding concluded that it was possible to communicate certain things non-verbally, such as likeability (positive and negative) and status using simple product movements (Rasmussen et al., 2013).

Lessons learned The authors hint to the fact that even conflicts could be inflicted by product agency. They conclude that interesting future studies should consider how the relations between multiple users, but also the personality of the users changes interaction and the perception of the device. Furthermore, the authors report that non-verbal clues like body language and eye contact might give hints to how communication works between moving products and people. They do underline though that there could be a pitfall as analysing such results might suffer from subjective bias and lead researchers to make personal interpretations.

Artificial Defence Mechanisms There is a selection of autonomous devices, which aim to protect themselves through the use of actuation [2]. These everyday objects are enhanced by additional technology to keep away from danger or avoid situations which might break them.

[2] http://jameschambers.co/objects/

Fig. 2.10 The Artificial Defence Mechanisms. Through simple actuation these devices convey a sense of self-awareness and desire to self-preservation (see footnote 2).

The first device is a hard drive which is elevated by a set of “legs” when water is spilled. The second device is a radio, which tries to avoid getting dusty and shakes itself to free itself from dust that has gathered on top of it over time. Finally, the *Antitouch* lamp avoids any physical contact if someone is coming too close, to not damage the halogen bulb.

Lessons learned These devices interestingly expose autonomy by showing the intention to find shelter or avoid a hazard. Through exhibiting simple actuations, which are strongly tied to context, they appear to express a strong sense of self-protection, self-preservation and self-care, which leads to the illusion of self-awareness. This in turn transforms them from ordinary technological artefacts to seemingly living beings.

Tableau Machine Although not tangible, another very interesting arts focused project explored the use of autonomy in practice. The Tableau Machine (see Figure 2.11) is a display installed in a living room, expressing the household’s activity by interpreting data from sensors distributed around the house. The display shows abstract shapes and curves which are mapped onto the sensor’s output in an ambiguous way. This research seeks for long-term interaction, by “opening unusual viewpoints onto everyday human activity, create pleasure, and provide opportunities for contemplation” (Romero et al., 2006).

A fact that seemed very important to the designers of this system is the non-human way in which the sensor data is interpreted by the system. The user is invited to assign his own meaning onto the autonomous interpretation of the system, or as called in the paper the alien interpretation of the system. Particularly intriguing is the evaluation of the system in three households. Initially planned to evoke reflection in the participants of the home activities, over time the Tableau Machine became a social presence in the houses. In the paper the researchers describe that the householders attributed personality and aliveness to the system and read meaning into the displayed colours and shapes. It seems that devices that display even the slightest capacity of interpretable behaviour also appear to provoke a level of curiosity about their inner workings. The households stayed engaged with the Tableau Machine throughout the full six-week deployment. Also noticeable is the following finding: because of a system error in one of the household's installations the Tableau Machine did not take use of the sensor data. The output of the system was completely random; so the participants, as opposed to the other households, were unable to develop rich stories about or form long-term attachments with the system.

Lessons learned From this work the following findings can be made: people seem to be curious about systems which appear to work autonomously. Interaction with these devices seems to be highly engaging. Also an appropriate amount of ambiguity helps to keep the system interesting and allows the participants to ascribe their own, unconstrained meanings to the system behaviours (Romero et al., 2006).

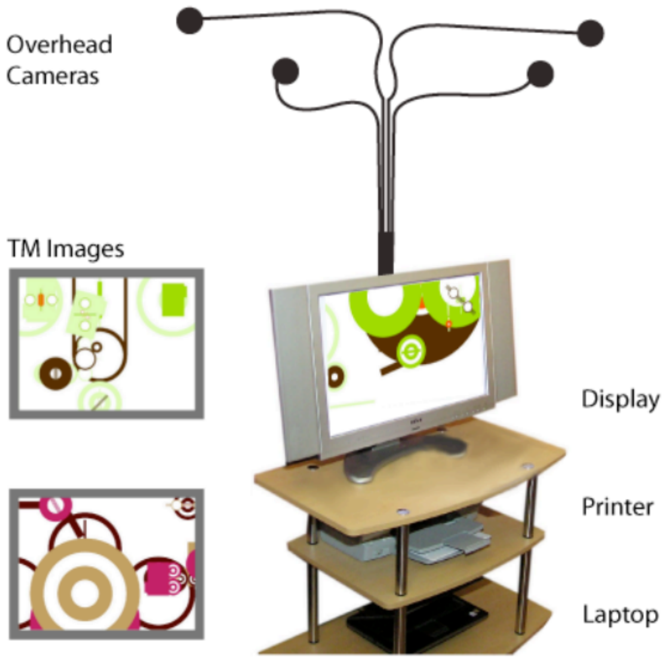

Fig. 2.11 The Tableau Machine parts consisting of a camera, an LCD Screen, a printer and a computer (Romero et al., 2006).

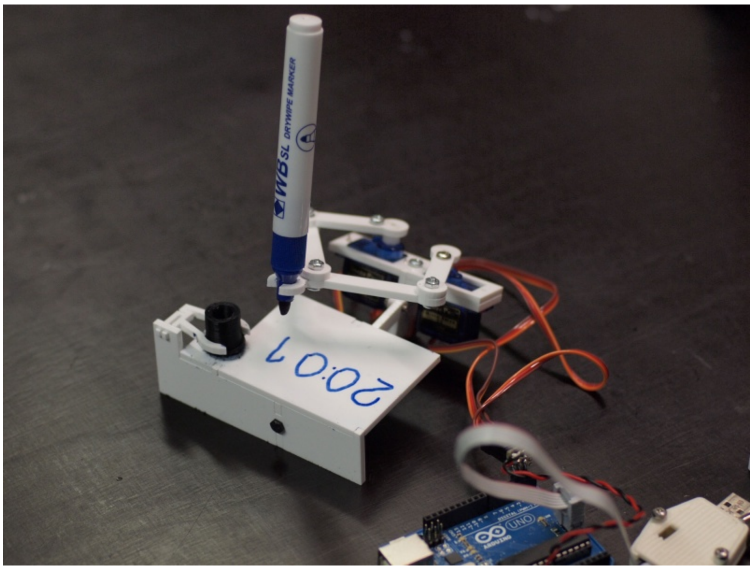

Fig. 2.12 Plotclock - A physical prototype that uses a whiteboard and a pen to plot the current time (see footnote 3).

2.5.3 Prototypes and Products

A lot of examples of autonomous interfaces come from the emerging maker culture, which consists of enthusiastic creatives, programmers and engineers. As access to tools and knowledge is widely available and affordable through *maker spaces* and websites presenting DIY-instructions, people create all sorts of new interfaces every day. This section aims to introduce the variety of tangible autonomous objects and how autonomy is achieved in different ways through actuation.

For example, Plotclock [3] is a small mechanical arm, which draws the current time on a white board every minute. Once the time is written, it grasps for a wiper and erases everything. Arguably, the strength of this somewhat whimsical device is its mechanical working; its embodiment is making it a physical agent and therefore more engaging to people than for example a digital animation (Mi et al., 2012).

Ollie is a blimp based autonomous and ambient robot [4], which flies around and reacts to sound by flapping its wings. A simple electronic circuit (micro controller, microphone, two motors and a battery) attached to a helium balloon enables a very friendly and engaging interaction. Although the time of interaction is very short, people sympathised strongly with Ollie and apart from drawing a lot of attention, the ambiguity and reactivity to people invited to a lot of interpretation. People reported that Ollie 'demonstrated humour and patterns of delicate emotions', 'observant,

[3] A Mechanical Clock That Plots Time - http://wiki.fablab-nuernberg.de/w/Ding:Plotclock
[4] Ollie - a DIY autonomous robotic blimp - http://meandollie.com/

Fig. 2.13 Ollie - a DIY autonomous robotic blimp, which flies around and reacts to sound by flapping its wings (see footnote 4).

often flying in a manner suggesting curiosity for the world around him'. Random behaviours make its actions difficult to interpret, and hence Ollie has been described as 'awkward' but friendly and exciting. This is a fascinating example of how social a rather purposeless and simple actuated object can appear and be.

Further examples of autonomous technology, which is commercially available, are the Mini Mobile Robotic Printer [5]; Clocky, the rolling alarm clock and Kooky[6], the large, mobile projector. The small omni-wheeled printer moves itself on a blank piece of paper and prints data which is transmitted via Bluetooth line-by-line. The aim of this device is fully functional, a device which is easy to transport and enables to print text from any device. As the mini mobile printer is just on sale, time will show if people react emotionally towards their devices. Clocky [7] is an alarm clock with wheels, which tries to roll away and hide whenever the snooze button is pressed. This should prevent people from snoozing too much and help them to get up on time. Nandahome, the company producing Clocky released a follow-up product, called *Tocky*. What is interesting is the way this product is introduced, the company presents Tocky as a new 'member of the family' and ascribes a gender to the alarm clock by stating that 'he' has many additional skills. This clearly underlines the aim of the company to present the product with a character and intentions, in this case being quirky and active to get you out of bed. This should lead people to anthropomorphise and sympathise with their product.

Kooky Keecker Robot is a large projector on wheels, additionally to projecting 1080p media on any surface, the robot is also able to move and drive to different rooms. These are compelling

[5]The First Mini Robotic Printer by ZUtA Labs Ltd.- http://www.zutalabs.com/
[6]Kooky Keecker- the large mobile projector - www.keecker.com
[7]The original alarm clock that runs away - www.nandahome.com

examples which illustrate that autonomy can also emerge from functionality. These devices need actuation to fulfil their purpose: print, escape or provide content. The focus of these devices is primarily on their outcome not on the fact that they may appear autonomous. Autonomous interface design might be the key for these devices to make them more attractive, comprehensible and engaging.

There are furthermore numerous projects (many of these crowdsourced) which aim to bring technology and development closer to kids by creating simple and tiny robots for the home. Little Robot Friends [8] became popular through kickstarter and comprise several trivial sensors to react to the environment by either sound or light output. They are also able to transmit and receive infrared signals which enable them to detect each other. In contrast to the other examples, which are rather functional and therefore have a plain appearance, these tiny robots consist of a head with a face. Arguably, these things aim to convey social information (like attention and emotions like moods) and serve only for entertainment, for this reason it is important, that they are easy to read/understand, therefore comprise a face, and also need to be attractive, as this is their sole purpose.

Lessons learned These examples present autonomous functioning machines, which serve as interfaces to digital content, but at the same time have the potential to establish their own social presence with a user. Commercially, they are highly popular and show that autonomous interfaces are becoming more prevalent. Interesting in this context is how many different facets autonomy is able to be shaped and appear. In essence, we see moving machines, either with actuated joints, wheeled, blinking LEDs, sound etc., sometimes connected which other technology to serve a purpose. But ultimately they become much more, designed in a mindful way they can emerge as social actors and make their users care for them. Research is still required to explore the design factors which are responsible for this effect and especially how it can be leveraged for HCI.

Roomba - the vacuum cleaning home robot Another example of the complex relationships people maintain with technology is "Roomba", a small vacuum cleaning home robot (Figure 2.15). This example is particularly interesting as it is a successful commercial product and aroused strong emotional responses by their owners, especially over time. Studies with Roomba unfolded interesting findings, Roomba was seen as a kind of "form of household companion with lifelike properties" (Sung et al., 2007). An evaluation of postings from an online Roomba forum found out that people imputed intentions and even feelings and unique characteristics into their

[8] Little robot friends are small and customisable robots - http://www.littlerobotfriends.com/

Fig. 2.14 (a) Clocky, the alarm clock on wheels (footnote 7); (b) The Mini Mobile Robotic Printer (footnote 5) and (c) Kooky, the mobile projector on wheels (footnote 6).

robots leading to building a kind of relationship in extreme cases. Participants would change their accommodation to make it a better place for Roomba and would show emotions like solicitude towards Roomba. People expressed worry about the Roomba when it got stuck somewhere or put things away that could harm their Roomba. One factor which seems to provoke these social responses is the unpredictability of Roomba's movement. People know that Roomba is moving around to clean the carpet, but they don't know why Roomba is doing a particular movement. This unpredictability seems to be an expression of personality, tricking people to believe that Roomba is an intentional actor and "somebody" to care for. Especially over a longer period of time, people build relationships and value Roomba. It is exactly the combination of these two, personification and bonding, which apparently also lead to more forgiveness towards flaws. People showed a higher tolerance towards unreliability, when seeing Roomba as a social entity at home.

The authors discuss that appearance also plays a strong role in people's responses. Although objects mimicking lifelike forms might increase the intimacy between the user and the device, a drawback might be inappropriateness and wrong expectations. Roomba has a certain function, to hover the floor, and is appropriately designed to fulfil this function and also does not suggest that is capable of more.

Lessons learned To summarise, there are a few design implications which can be derived from experiences with Roomba owners. Ambiguity doesn't necessary lead to confusion, but can open up the space for a user's own interpretations. It can lead to curiosity and interest in users as they are motivated to figure out the inner functioning, the "motivation" of a system. Especially complete reliability is not a strong requirement anymore, as people seem to show acceptance towards slightly flawed but personal interfaces. Another important finding is the fact that humanoid or animalistic appearance isn't essential to engender strong attachment and anthropomorphism.

Fig. 2.15 Roomba, the vacuum cleaning home robot (Sung et al., 2007).

2.6 Shape-changing interfaces

There is another class of actuated interfaces, which might be interesting due to the fact that it relies on independently altering its visual appearance by changing its outer form, *shape-changing* interfaces (Coelho and Zigelbaum, 2011). Shape-changing interfaces are physical, technological artefacts that self-reliantly transform their shape in two or three dimensions. They present great potential to display autonomy through their expressive actuation.

One early example, Lumen (Poupyrev et al., 2004) is an interactive (horizontal) display that consists of an array of small cylindrical shapes with optional backlight that can individually change their height (see Figure 2.16 (a)). The actuation allows the device to create images, shapes and physical motions. This device can be used to display information in a non-obtrusive way (Weiser and Brown, 1997) or allow physical communication between two people as the objects could copy the shape of a person's hand.

Shape-changing displays span a wide variety of applications, from information visualisation (Coelho and Maes, 2009), aesthetics such as clothing (Berzowska et al., 2008) or furniture (Sprowitz et al., 2010) and art installations [9]. For a review of the diversity of shape-change and interaction modalities, parameters and a topology of shape change see (Rasmussen et al., 2012). Different use-cases have been explored, from plain surfaces that expand to abstract shapes (Follmer et al., 2012; Leithinger and Ishii, 2010) to everyday objects that change their shape such as phones (Hemmert et al., 2008; Pedersen et al., 2014; Roudaut et al., 2013) (see Figure 2.16 (b)) and benches (Grönvall et al., 2014; Pangaro et al., 2002).

[9] http://www.smoothware.com/danny/pegmirror.html

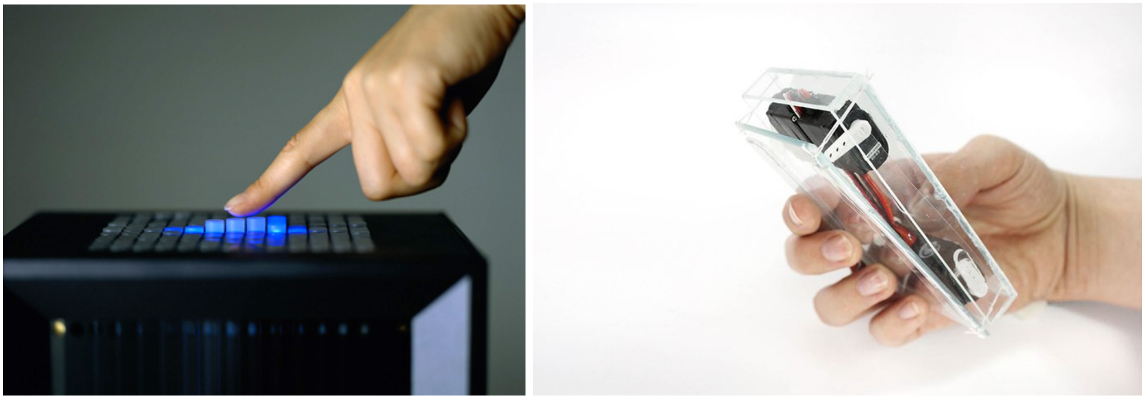

Fig. 2.16 (a) Lumen, the shape-changing surface (Poupyrev et al., 2004) and (b) a shape-changing phone, taken from (Pedersen et al., 2014).

In a study on expressive actuation of a mobile phone, lifelike gestures were implemented into a shape-changing device (Dawson et al., 2013). The authors evaluated ways of expressing emotions through bending, curling and inflating the surface of the device. Findings indicate that simple gestures are the most effective ones, it was easier for participants to map the movements to functions such as incoming call or notification.

Further explorations of shape-changing phones, where a prototype unfolded depending on the proximity of a user's hand, yielded that a lot of participants made references to animal behaviours and used animal metaphors to describe the device's movements (Hemmert et al., 2013). The designed movements were, however, interpreted in various ways. Actuations that should appear inviting, came across as an attack to some, whereas the aversion was seen as an invitation to pick the phone up. The interpretations were never swapped, however. People perceived the device as either friendly or dismissive. Again, we see that movements are connected to a person's attitude towards the device.

Pedersen et al. (Pedersen et al., 2014) created a range of videos, animating the shape of mobile phones for various notifications. The results show that the shape change had a large impact on perceived urgency, experience and emotions. The speed of the shape-change was perceived as less impactful and smaller shape changes were perceived as nicer experiences.

Explorations with a larger shape-changing interface, a bench, yielded that people did not personify the bench. The movement was rather perceived as a haptic sensation (Grönvall et al., 2014). Unsurprisingly, the authors furthermore identify context as being an important factor for people to make sense of the device.

Lessons learned Shape-changing interfaces are interesting in regard of autonomous behaviour in technology, as they present a somehow different way of actuation. By modifying the outer appearance, but without actually displacing itself, an interface can indeed convey autonomous traits. If these traits are interpreted as mere output depends on the link between the device's actions and the information that it is supposed to convey. Linear behaviour, e.g. programming a certain action to lead to a certain reaction and always producing the same behaviour for the same input, eliminates autonomy. Furthermore, certain changes might only be comprehensible in certain environmental settings and contexts. A shape-changing interface might be interpreted differently when it's on someone's bedside table as supposed to a seat in a mall.

2.7 Zoomorphic Interfaces

There is a lot to learn from another highly related field, interfaces which reflect a zoomorphic appearance and/or behaviour, e.g. resembling animal appearance. The next paragraphs will discuss examples and lessons learned from these 'lifelike' interfaces along with its dangers. I will explore interfaces which are inspired by animals, following on a section about humanoid interfaces, robots. These interfaces usually resemble animals that people are familiar with and evoke positive feelings such as dogs (Friedman et al., 2003), cats (Pereira et al., 2008; van Breemen et al., 2005), mice (Yohanan and MacLean, 2012), rabbits as ambient displays (Mirlacher et al., 2009) or abstract shaped or fantastic but furry creatures (Allen et al., 2015; Biever, 2007; Flagg and MacLean, 2013).

The main reason for borrowing animal appearance to create a robot is to build on existing knowledge and positive attitudes to ease interaction. There is a long history of relationships between humans and pets and researchers are trying to leverage this fact by relying on the factors that lead humans to start a friendship with such creatures, like proximity, similarity, attraction (de Graaf and Allouch, 2016). As already mentioned these interface harbour the danger of disappointment if they don't deliver what they promise. Robotic dogs, for example, are by far not as agile as their exemplars, they don't hold the same skills and therefore might be confusing to interact with (Jones et al., 2008). The anticipated capabilities are not met by the interface, expectations are broken and people lose trust in the technology. Furthermore, interfaces might be more effective if their design is focused on the task they should fulfil. For example, the functional shape of Roomba makes it easier to access space under tables etc. Carefully designed though,

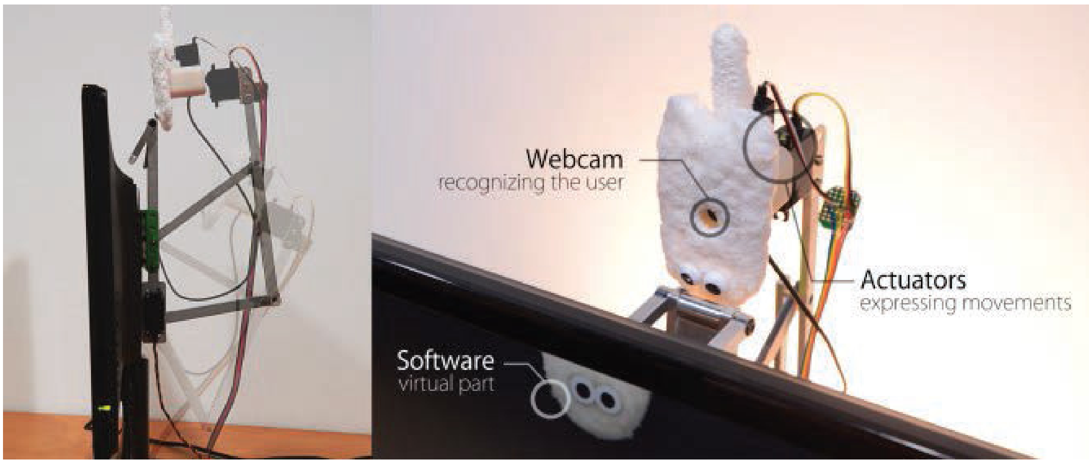

Fig. 2.17 Camy, the interactive prototype serves as a desktop companion (Row and Nam, 2014).

there could be potential for borrowing visual cues from animals to create lifelike interfaces. A recent study exploring the implementation of dog behaviours in robots concluded that although a too accurate copy of dog behaviour is inadequate, general biological primitives could set a good basis for communication (Gácsi et al., 2016). Research on the perception of insects identified new design opportunities for notification cues, leveraging knowledge from lifelong experience (Löffler et al., 2015). In the next subsection I wish to illustrate this potential through two examples of zoomorphic interfaces, which show how humans can benefit from such interfaces.

For further reading on the topic of robotic pets I recommend the work by Lazar et al (Lazar et al., 2016). It presents a review of the state of the art of robotic pets, debates robotic pet design in focus groups with elderly people with an interesting discussion on the ethics of robotic companions.

2.7.1 Camy - the little electronic dog assistant

With the aim to create a very special experience with technologies, Row et al. created a half-physical and half-digital desktop companion - Camy (Row and Nam, 2014). The authors aimed to explore how animal analogies (especially pets) could be used in everyday ubicomp product design. As humans form very deep and affectionate relationships with their dogs, the authors wondered how the key characteristics of these relationships can be applied to technical devices. Their prototype is a web camera covered in fluffy fabric shaped like a dog torso, which can move behind or over the screen, but also has a digital counterpart on the actual screen. Several usage scenarios are presented: a video-chat mode, where Camy moves rapidly to remind the user of an incoming online call; a security mode where Camy happily greets a known user and barks at an unknown user; delivering system information by catching the attention of the user. If the user follows Camy's recommendation, Camy is happy, otherwise it gets sad. So each action is accompanied by either a happy or sad expression depending on the user's reaction to Camy. The system was tested in a Wizard-of-Oz setup, where a participant was using a desktop PC, while a hidden operator triggered Camy's behaviour.

The outcomes of the study indicated that the users personified Camy and gave him a character. They also interpreted his action of absence thereof in social terms, like being 'lonely' or 'bored'. The authors furthermore experienced that Camy seemed more alive when its behaviour was unexpected and less alive when Camy was just repeating his actions or performing irrelevant actions. Finally, the authors conclude that due to its social presence, Camy might achieve a higher acceptability as a product, as users at times seemed more forgiving towards certain dysfunctional actions.

Fascinatingly, a study comparing the use of dogs vs. robotic dogs (AIBO, see Figure) in a care home found that both are equally suitable in reducing the feeling of loneliness (Banks et al., 2008). Furthermore, people felt only slightly (not significantly) less attached to the robotic dog in comparison to the real dog. Although some residents and staff initially hesitated to accept AIBO, the reluctance disappeared with time, which, similar to another study (Kanamori et al., 2002) with AIBO, suggests the willingness to accept such technologies in the future.

Lessons learned Although this work sounds very promising, a few questions arise. It is still up to research to explore how people come to terms with the pet analogies used in this study. Although the authors claim otherwise, most of the characteristics of human-dog relationships, in fact, do not map very well onto interactions with Camy. Camy partly represents a dog, but then fundamentally differs to a real one due to it being a technology. Unlike in real life its movements are strongly restricted, Camy can't really serve the same or similar utilitarian purposes (guide or security), let alone the strong physical contact that people maintain with their dogs. Researchers need to be very careful with these analogies, and be aware of their dangers. Furthermore, a pet analogy might arguably work in some situations, mainly entertainment applications. In other situations people might not take Camy seriously and find it annoying. The suitability for serious applications, e.g. problem solving, still needs to be researched. It is still interesting how positive the participants reacted towards Camy. The fact that Camy is fluffy and 'cute' seemed to earn a lot of sympathy.

2.7.2 Paro - the therapeutic seal robot

Paro serves as another interesting example of an autonomous interface. It is shaped like a fluffy seal, which aims to assist elderly in nursing homes. Especially for patients with illnesses, which make them non-reactive or unable to care for a pet. The idea behind Paro is grounded in animal-assisted therapy; enabling contact to pets like dogs as a form of therapy proved to be very effective for people's well-being (Kidd et al., 2006). With Paro, however, disadvantages, like the high effort that has to be put in to care for the animal, drop out and furthermore Paro never gets tired, so "works" all day. A lot of thought has been put into the look and appearance of this robot. The creators intentionally decided to shape Paro like a seal, instead of giving it a more familiar animal-like appearance like one of a dog or a cat. The aim of this was to not raise wrong expectations (Dautenhahn, 2002). Humans hardly have any experience with seals, they don't know how they behave, so they don't expect them to behave in a certain way. Therefore people don't get disappointed, because a robot would never be able to fulfil these expectations and act like a lifelike copy (Kidd et al., 2006). Although people are so unfamiliar with seals, one study with Paro revealed that some participants, based on their sparse knowledge of seals, were afraid that Paro would bite them. Some people even felt the desire to place Paro in water (Kidd et al., 2006), which they thought would be his preferred natural habitat. Interestingly, although people were aware that Paro is a technical device, patients as well as carers felt inhibited to 'hit' Paro or not treat it nicely, the way they would treat a living being. Most notable is the fact that Paro helps patients to remember old memories. They recall past interactions with their child or pet through interacting and embracing this creature. Paro is not a cure-all, not all patients are responsive to Paro and show these emotional reactions. Generally, people who were in a lot of contact with animals during their lifetime or owned pets before proved to be much more receptive and open to Paro. Studies revealed highly promising results, showing that e.g. activity levels of people with dementia increased (Sabanovic et al., 2013) and depression in elderly people was lowered (Wada et al., 2005) after short and long-term interaction with Paro. Although being often criticised as an attempt to replace humans and use robots to care for people, as we've seen, Paro opens up an interesting interaction space. It sits in a niche, not substituting but complementing emotional support. Paro seems to invite people to remember positive life experiences in its own unique way, making it a great example of how technology is able to enhance lives (Wada and Shibata, 2007).

Lessons learned What can be learned from this exercise are two things. Firstly, how careful designers should be when shaping devices, especially while borrowing animal appearance. For interaction design, as already mentioned, purely mechanical appearance doesn't face the

Fig. 2.18 Paro, the therapeutic robot (Kidd et al., 2006).

danger of deceiving the user of the system's abilities. Otherwise the system might give the user the impression that it comprises functionalities which it cannot accomplish. Furthermore, this device underlines how strongly perceptions of object's appearance are coupled to individual life experiences and expectations. In this case the envisioned purpose of the device fit its design and made it highly successful, to remind people of their past pets and therefore feel companionship.

2.8 Social Robots

The spectrum of complexity for embodied technological artefacts is varying in degrees. One could posit a very general scale mapping out TUIs which increases with complexity and autonomy. The more computationally complex a tangible computer system is and the more it is able to solve a task autonomously, the more it blends from TUIs to robots. Robots are interesting for TAI design as they represent the ultimate TAI: an interface that embodies autonomy. Therefore the next sections will explore interactive robotics and how this field is relevant to this thesis.

Robots can be described as mechanical agents that are guided by a computer program to achieve a certain goal, which usually aims to serve a human (Weiss et al., 2009). Due to their utility, robots are becoming more and more popular and cover a plethora of applications. Usually robots are grouped into one of three categories (Goodrich and Schultz, 2007). *Industrial robots* are deployed in manufacturing environments and operate on conveyor belts to for example assemble cars. *Professional service robots* assist people with their tasks, like work in contaminated areas, which are inaccessible to people, or manipulate substances in medicine with speeds and precisions that people just cannot match. Finally, *personal robots* assist and entertain people at home. Crucial for this category is that these robots should be designed in a way that people who don't possess special (technical) skills or training can interact with these robots easily. To make them accessible to everyone and integrate robots into people's everyday life, interaction shouldn't require prior knowledge on how to interact with them (Breazeal et al., 2004). An exhaustive review of the field of robotics is beyond the scope of this work. The interested reader is referred to (Dautenhahn, 2007; Fong et al., 2003; Goodrich and Schultz, 2007) for in-depth reviews.

To facilitate interaction, the aim of *Social Robotics* is to build robots, which can communicate with humans based on human social and behavioural norms (Bartneck and Forlizzi, 2004). Less realistic looking robots are described as *Androids*. Humanoid robots (robots which appearance is based on the human anatomy - a face with eyes, a body with arms and legs etc. (Dautenhahn, 1997)) are intriguing to us because they trigger our social senses even stronger. We are social beings, striving for interaction as soon as an entity resembles life. Their aim is to make interaction with technology identical to interaction with humans.

Research studies revealed that participants showed significantly higher interest and engagement towards a robot than a computer (Kidd and Breazeal, 2008). Looking at the previously presented findings in this literature review, it is not surprising that we also reply highly socially towards robots, treating them like humans in many different ways. We are *polite*, we feel *empathy* when robots display pain (Suzuki et al., 2015). Even non-verbal social behaviours such as gaze, shifts in posture or orientation (Breazeal et al., 2005) and backchanneling (Jung et al., 2013c) improve team functioning between humans and robots. We hesitate when we are supposed to turn off a lifelike robot in comparison to 'life-less' technology (Bartneck et al., 2007). In the same way that we mirror the posture of another human we feel close to, we mirror the posture of socially expressive robots when being engaged in a social interaction (Breazeal, 2002).

A reason for us reacting socially to robots might be the fact that we just can't help it. We don't know any other way of communication and as already mentioned, we have evolved to act social (Breazeal, 2002). To make the interaction with robots as familiar as possible, there is a research branch, focusing on creating a robot which behaves in a socially competent manner, *Social Robotics* (Breazeal, 2002). The following examples show the attempts of building *social* robots, which aim to communicate with humans like humans do with each other (Bartneck and Forlizzi, 2004). Although highly sophisticated and probably the world's best robots, these examples are still far from being human-like. They hold remarkable skills which nevertheless do not match a human. Robots to date struggle to operate in the real world, to move around freely and independently, especially in environments with obstacles. Nevertheless, it is an endeavour worth undertaking and there is a lot to learn from robotics. In the next sections I will introduce some examples as robots present the highest form of autonomous technology and there are a plethora of lessons to be learned from Human-Robot Interaction (HRI) for autonomous interface design.

2.8.1 Pitfalls of Social Robotics

Studies comparing the perception of robots that closely resemble humans with robots with a more mechanical appearance yielded varying results. At times the humanoid robots are perceived as more animate and likeable as the android ones (Ishiguro, 2008). Another study couldn't establish a difference in the perception of animation and likeability between humanoid and android robots (Nishio et al., 2012). Interestingly, in the same study, the authors showed that, when playing a game with the robots, participants seemed to trust the android more. Due to its human-likeness, the humanoid robot was perceived as possibly being 'selfish' and therefore more prone to cheating. Not surprisingly, it has been shown that people are more likely to attribute human-like qualities to robots with anthropomorphic features (Hegel et al., 2008). This was replicated in another study, where human-like robots were treated with more suspicion than a robotic car (Groom et al., 2009). The participants perceived the car as more friendly and having more integrity, possibly seeing the humanoid as a thread, whereas the car was perceived as harmless.

Unsurprisingly, humans empathise more with humanoid robots than mechanical-looking robots (Riek et al., 2009). The more human a machine looks like, the more we associate it with real humans rather than machines which causes a rise in empathy. However, as already mentioned with zoomorphic interfaces, numerous researchers exposed pitfalls of creating technology that looks more human and less machine-like (Bartneck et al., 2009; Breazeal, 2002; Dautenhahn, 1997; Hoffman and Ju, 2014; Ju and Sirkin, 2010; Jung et al., 2013b; King and Ohya, 1996; Shneiderman, 1993; Złotowski and Bartneck, 2013). I want to discuss the dangers and their origins in the following paragraphs.

Firstly, these robots may feel uncanny to us at times. Looking at something that appears and moves almost like a natural being (but not exactly - due to technical challenges) causes us to feel uncomfortable and can even trigger revulsion. Robots with a human form that move smoothly and lifelike in comparison to more mechanistic movements are unpleasant for us (Castro-González et al., 2016). This effect is called *uncanny valley* (Mori et al., 2005). Recent research in neuroscience has shown that a reason for our discomfort might be the way our brain responds to humanoid robots. In general, our parietal cortex connects our visual processing centre with our motor cortex, this basically means that we learn movements (of our own body) by watching others perform these movements (Rizzolatti and Craighero, 2004). This happens through so called mirror neurons or *empathy neurons*. In a study, 20 participants were shown different videos of humans and human-like robots while their brain activity was scanned with an MRI scanner (Saygin et al., 2012). In the case of the human-like robots the appearance and motion are not quite congruent. They look highly human, but their movement or behaviour in general (e.g. no breathing movements) is not quite smooth enough, but too mechanistic. This breaks our lifetime expectations, the robot movements don't fit to how we would move ourselves, which leads to a mismatch, where the brain has difficulties to process this information. In these situations discomfort emerges. Videos of humans or even machine-like robots didn't replicate this effect. Creating a credible, lifelike humanoid robot, which does not seem creepy to us remains a challenge.

Secondly, lifelike features such as eyes or having hands, lead people to believe that the robot holds certain skills like seeing, recognising people and objects or catching objects, although it might in fact not be able to do so. Interfaces that allow voice input and also provide voice output might convey the impression that they are able to conduct a conversation. People find out quite quickly that the robot does not perform and lose interest as it doesn't live up to the expectations. This leads to confusion and frustration and in the worst case to complete rejection. Technology and human skills differ tremendously. Making it seem more 'human' might constrain a robot in its functionalities. For example, equipped with the right sensors, robots are able to see the whole spectrum of light (infrared, UV etc.) or radiation. *"The human form and function is not the ultimate design reference for a machine, because it is a machine and not human."* (Duffy, 2003). Therefore, making a robot more humanoid, should not mean to constrain its functionality or conceal its capabilities, but only be used where it facilitates interaction.

2.8.2 Further ethical issues with robots

Fear of robots dominating the world was fuelled by action movies like Terminator, illustrating visions of robots reaching such sophistication that they were unbeatable by any human (Hancock et al., 2011). The outlook that such systems could be highly superior to us makes us uncomfortable. Robotics is also subject to more criticism, for example, that interaction with robots in the future might harm people (Friedman et al., 2003). Turkle (Turkle, 2005) is censorious of robots, suggesting that they might affect the way people, and especially children, think about their human identity. This class of technology blends what is alive and has real feelings and what doesn't. Therefore a hypothesis was constructed, expecting that human relationships will suffer as children, through the interaction with robots, will get a false sense of humans' emotions. Children learn about social relationships through interacting with other children. They learn about responsibility and justice. Robots might not be able to teach these moral responsibilities.

However, it is clear that it is an important task for HRI researchers to find a way to account and design for this moral responsibility. There are ethical issues and robots should not replace human relationships. Therefore, in the last years, a new field emerged, which sets out to tackle these issues. *Robot Ethics* revolves around exploring ethical and social issues, safety (Woodman et al., 2012), from perspectives regarding programming design, law, robot rights etc. (Lin et al., 2011). Plenty situations exist, in which robots will be beneficial and research has been already able to observe positive effects of robots, such as in assistive robots (Broekens et al., 2009; Roy et al., 2000). Robots already construct cars, clean swimming pools, mow the lawn, hover, play football, act as pets, and the list is growing very quickly. Why should a robotic companion be different than other appliances that serve us entertainment and comfort such as a TV or books? Of course, it needs to be evaluated if it might cause any harm to people, however, so far a range of studies confirmed a wide range of benefits (Lazar et al., 2016). In the following I will introduce a range of robots that have been used to date for various applications, which effect they had on humans and discuss the lessons learned.

2.8.3 Robots in arts

Numerous art projects explored the complex relationships humans can have with robots as well. Artists received strong social responses and interpretation even from rather simple installations. A pioneer in the field is Senster, a giant museum construct (illustrated in Figure 2.19), reactive to sound by moving its massive head towards the loudest location in the room. Its rather simple reactions to humans making noises created the appearance of a complex creature [10] and gave the impression of being alive. It was the first robotic sculpture that was controlled by a computer. Double-Taker (Snout) [11] is an interactive installation consisting of a large and long industrial robot arm inside of a plain, black, bendable pipe with a massive eye at the front (see Figure 2.19). This art piece is placed on the roof above an entrance and actuated so it turns its gaze towards people that pass by. This action emerges to a powerful behaviour, it seems that the eye is staring and observing people. It poses an interesting question on interspecies eye contact and surveillance. It strongly caught the attention and curiosity of the visitors. Inevitably, this behaviour suggests the robot being aware of the visitors' activities. Displaying surprise and interest in the visitors' activities lead visitors to wave to greet the robot. Tweenbots is another interesting art experiment consisting of small, wheeled cardboard robots, which are just able to move in a straight line. They aim to reach a certain place in a city (like a library) and solely rely on humans to reach their destination. Naturally, people get curious when they see a Tweenbot wheel around and its friendly face evokes empathy and motivated people to help find its way. Blabdroid/Boxie consists of a very similar idea, resembling Tweenbots simple design, a cardboard robot with a face. This robot is replaying audio in the form of spoken sound messages, which asks very personal questions. The appearances are made vulnerable on purpose, 'vulnerable interfaces' make people feel more in control and evoke empathy. This might be a reason that some people responded to the robot in a way they would not towards another person (Reben and Paradiso, 2011).

Lessons learned These examples show quite nicely how simple movements and reactivity

[10] http://www.senster.com/
[11] http://flong.com/projects/snout/

Fig. 2.19 (a) Senster - the first sculpture in the world to be controlled by a computer (b) Snout - the observing industrial robot arm; (c) Tweenbot - the friendly travelling robot. [see footnotes]

but also zoomorphic properties, such as a head or eyes, are incorporated into objects to fake 'life' and give the impression of the robots being aware of people interacting with them. It also shows again how quickly people are willing to ascribe intention onto object's actuations. The emotional responses are strong, ranging from interest and fascination to social behaviour like empathy or even trust.

2.8.4 Humanoid Robots

This section explores commercially available robots which resemble humans by comprising a head with a face and a body with arms and legs. Today, there are a number of examples for life-sized robots with human features. Pepper is the first commercially available life-sized robot [12], which registers and greets visitors and guides them to their destination in the building, e.g. a meeting room. It is designed to have many degrees of freedom to allow high mobility and also the skill to grasp for objects on various heights (illustrated in Figure 2.20). Pepper sold out after one minute of being on sale in 2015. "The robot that wants to make people smile" is able to communicate via speech, body gestures and has a tablet bond to his chest for easier interaction, installation of mobile applications. Interaction is aimed to be very natural (like human-human interaction), Pepper tries to detect humans' moods by analysing their pitch of voice and acting accordingly. Asimo [13] is highly sophisticated, it is packed with technology for

[12] https://www.aldebaran.com/en/cool-robots/pepper
[13] http://asimo.honda.com/

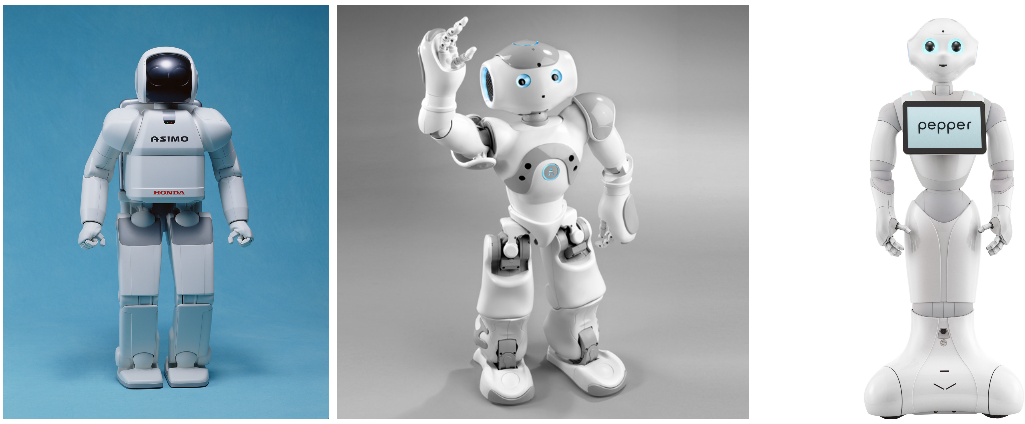

Fig. 2.20 (a) Asimo - the autonomous receptionist robot; (b) Nao - the small, programmable robot (Barakova and Lourens, 2010) and (c) Pepper - the commercially available, life-sized receptionist robot. (Pictures taken from websites - see footnotes)

image and voice recognition, motion and force sensors and wireless transmission to be able to communicate with an operator. It is able to walk and even climb stairs. Nao is a small-sized (57 cm in height) and affordable robot that is dedicated to academic explorations. It can be pre-programmed or remotely controlled and due to its availability and low price it has been used in a lot of different studies evaluating human behaviour. Researchers tested different speeds and variability of movements of Nao to explore if users could understand emotions that Nao is supposed to express (Barakova and Lourens, 2010). Interestingly, this yielded similar results to earlier studies on abstract objects; high recognition values were reported for sadness, nervousness and fear, lower ones for Anger and Happiness.

Kismet - the robotic head Kismet, a pioneer in social robotics, consisting of a robotic head that is capable of expressing emotions and reacting to people and the environment. The robot comprises two cameras, designed as eyes, which can detect people and objects and also express interest; two microphones, as ears, to react to voice and multiple motors to convey facial expressions. Kismet is not only reactive to the world around it, it also has a motivational system, it is programmed to switch between different "emotional" states. It can get bored and then wants to be entertained, but also get tired and in need of rest. A lot of thought was spent on creating the 'right' appearance and the impression that Kismet should make on people. Since strong and exaggerated voice and pitch is easier to analyse, Kismet was designed to be child-like, requiring ease and patience. By following an infant-caregiver metaphor Kismet establishes appropriate social expectations. Similar to interacting with a child, users exaggerated their prosody and facial expressions and gave Kismet time to understand and answer. Through this childlike appearance and behaviour Kismet succeeded to slow down the interaction and hide its perceptual, mechanical and behavioural limits (Breazeal, 2002). It is exactly this factor which makes Kismet 'believable', i.e. its appearance and behaviour are appropriate to its skills, the expectations of the users are met.

Lessons learned One interesting aspect for this work is the personality and intentions the people project onto Kismet's actions. Participants drew inferences about the robots' mental states, capacities and personality in a manner that went well beyond the robot's observable behaviour (because it conveyed emotional reactions; human traits, emotions, intentionality) (Eyssel et al., 2011). Even a mechanical process, like bending forward to be able to focus better or moving backwards because something it too close to focus on, were interpreted as emotions like interest and fear. This shows how powerful our social behaviour can be, even when interacting with robots.

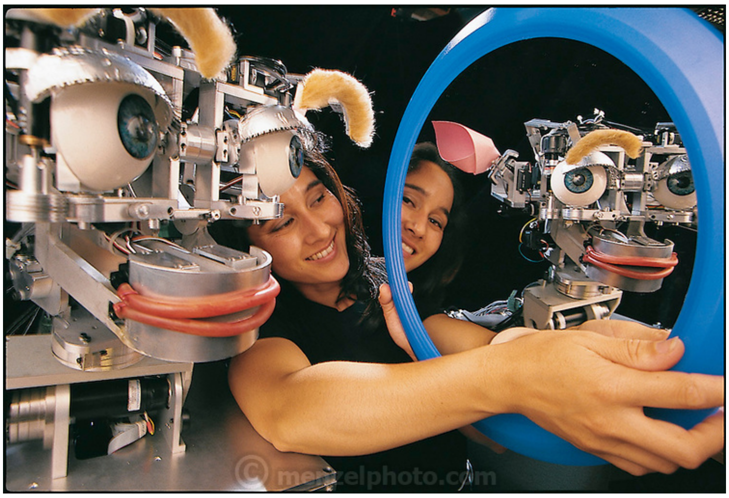

Fig. 2.21 Kismet, the robotic head (Breazeal, 2002).

Love and Sex with Robots As further evidence of the complex emotional relationship we might have with technology, there has been significant speculation concerning how people would relate to robots in the future; Levy suggests that people will even show emotions like love and sexual longing towards robots (Levy, 2007). The hypothesis indicates that as soon as it is possible to design and build robots that are almost indistinguishable from us, there are no good reasons not to fall in love with a robot. The author justifies his assumption by analysing the relationships people usually commit themselves to. People attach strongly to pets, but they also bond to electronic objects and as already mentioned even apply rules of social behaviour in their interactions with computers. Psychological research has shown that it can be assumed that people fall in love because of factors like repeated exposure, similarity, reciprocal linking and fulfilling of needs. If these factors are all programmable and robots can be tuned to appeal to a person individually, there is no reason to conclude that people will not have robots as partners (Levy, 2007). Although this work rests on the assumption that in their appearance and behaviour robots will not be distinguishable from humans, it indicates the notion that people might not dismiss technology as a social partner.

2.9 Summary

This chapter investigated how we could imagine autonomous behaviour in interactive machines and explored lessons learned from related work. Technology to date does not allow to use computers or robots, which are lifelike enough to be accepted as humans (Levy, 2007). Systems resembling human or animal appearance raise unrealistic expectations in users, which leads to frustration during interaction (Weiss et al., 2009). If a computer is providing a voice as an output, humans assume that it is intelligent enough to maintain a conversation. In fact, it is very challenging for computers to capture human speech and give a valid response (Roe and Jay G. Wilpon, 1994). Zoomorphic interfaces, i.e. user interfaces, which resemble animal behaviours, face the same problems as they impute behaviours that the robot is not capable of, leading to confusion. The interface loses its believability and credibility. But what still might be interesting is designing lifelike or autonomous agents which expose a new kind of intelligence: machine intelligence. Machines that are capable of solving tasks, in a way that is not completely transparent to the user and doesn't rely on looking or acting like a human or animal.

In summary, we learned that actuation is exciting for people and can lead people to show emotions and social behaviour towards devices, even when these devices don't resemble living being's appearance. Autonomous objects do not necessarily need to have strong computational intelligence, this can emerge through interaction between a device, the environment and the user. Ambiguous behaviour invited for own sense making; it is a strong resource for design that enables people to make their own interpretations.

From these examples we also learn that to design a tangible autonomous interface which receives social responses from people it is crucial to first of all be reactive to people and the environment. Any actuation, regardless of complexity, has no effect on interaction if it is leading to mindlessly repeating a task. By acting in the world and interacting with users, an interface suddenly becomes 'alive'. The combination of humans and machines makes new forms of agency possible (Wei, 2004). Furthermore, social response to technology is something that is inherent in people and was disclosed in a lot of research evaluations. The summary leaves us with a few questions though. Can we use these social responses to create compelling interaction with autonomous technology? What is the design space for tangible autonomous interfaces?

The aim of this work is therefore the exploration of interfaces, which show independent behaviour and invite people to interpret their outcomes. Two themes seem to dominate when we try to understand autonomy in interfaces. Firstly, it is important to understand how to design an interface to make it autonomous, and more importantly, to make it appear autonomous to people. Secondly, finding out how this curiosity could be taken advantage of and explore the consequences of autonomous behaviour in tangible user interfaces.

I want to end this chapter with further elaborations on how I am going to proceed methodologically. The next section motivates the methodological approach of this thesis and describes which methods were used in this thesis.

2.10 Notes on Methods

As discussed in the introduction, this thesis sets out to explore how autonomous behaviour in technology is perceived and can be designed for. In this section, I would like to discuss what the best way of doing this would be and how I proceeded in my PhD. Here, I build on various theoretical approaches and empirical frames, design-oriented perspectives within HCI, to plan and realise prototypes and interpret my results.

The first aim of this thesis is to embody various concepts around autonomy into technology, through material and behaviour. How can autonomous interfaces enter people's lives in new and unexpected ways? To answer this, in essence, experiments are needed, probing different arrangements of autonomy to understand how people respond to this class of technology. This seems most suitable through applying a creative and exploratory procedure, which sets up interesting and varying configurations of autonomy. Systematic empirical investigation seems inappropriate, as there are no numerical factors that can be measured. An open-ended approach seems more suitable for exploratory studies. Quantitative analysis was therefore excluded and I focused on qualitative analysis of the data.

What is needed to do that is knowledge about interaction design and more specifically understand the nature of the relationship between interaction design and HCI (Zimmerman et al., 2007). A method must be found to furthermore cycle design, building, and evaluating activities. This is at the heart of design thinking; investigate concepts, ideate creative ideas and iterate to refine the concepts (Dym et al., 2005).

For these reasons, a 'research through design' (RtD) (Zimmerman et al., 2007) approach was adapted, which supports this iterative process. RtD is the application of design knowledge to research (Koskinen et al., 2012) and is a contested term. In the following paragraphs I want to explain how I used RtD as a method to achieve my research goals. Rather than evaluating a single factor in isolation, design research explores a number of phenomena in combination (Zimmerman et al., 2007), imagining different states of possible future realities. Therefore, this thesis will use RtD to research technological prototypes that show autonomous behaviour and study how these interfaces can be designed to achieve different perceptions. RtD presents a highly suitable basis to interrogate key features of designing for autonomy and use it for inspiration to create novel interactions. These interactions can then be unpacked and explored in quasi-experimental settings with users followed by a reflection to refine the concept and increase fidelity (Odom et al., 2012).

Rather than finished products, the prototypes in this thesis present research tools to gain a deeper understanding (Bowen et al., 2016; Gaver, 2012). Knowledge is also gained through the process of making. During the act of making, reflection on the appearance and as well as the behaviour supports questioning the concept of autonomy and probe different possibilities of autonomy in interfaces. Furthermore this allowed me to understand what it actually means to hold autonomy and exhibit autonomous behaviour. As Gaver states: “the practice of making is a route to discovery” (Gaver, 2012). The design choices were influenced by constraints and challenges of technology, previous work and responses from participants. The outcomes will be more general to gain a deeper understanding and more specifically implications for design. I discuss these through justifying my rationale for design decisions and highlighting important issues during prototyping, but also reflection on the prototypes with participants.

To explore the different ways in which the device could be designed, it was crucial to be aware of the range of output possibilities. Creating the prototypes was an iterative and reflective cycle (Gaver et al., 2009). As the aim for this thesis is to explore the embodiment of autonomy, I focussed on various ways of actuation. I iterated through different actuators and how these make something move. I experimented with various styles and speeds of movements. Each step was documented by taking pictures. Different behaviours were probed with myself and colleagues and video recorded. These recordings served as a basis for further changes in design. A more detailed discussion can be found in the corresponding chapters of the case studies. Furthermore, I evaluated different ways and forms of encapsulating the electronics, with the goal to make it as abstract as possible. To allow easy replication, the casing should be easy to reproduce. Another design decision was made to convey the sense of an entity. To avoid biasing possible interpretation of the devices, the participants were not told about the intentions for the devices. When deploying the systems, as little description as possible was given.

As this is exploratory work, measuring various factors numerically might be inappropriate. Quantitative analysis in HCI is used to measure the achievement of predefined goals, for example, speed or accuracy indicate the success of a system solving a certain problem. This thesis requires an open-ended research method, because I want to analyse, reflect and understand people's experiences with systems that expose autonomous behaviour. Therefore, I had to exclude quantitative analysis and focus on qualitative analysis of the data. I want to uncover new opportunities, which would be difficult to uncover in studies of people's current behaviours and interactions with technology (Odom et al., 2012). My method was to probe people by presenting prototypes to them, observing and interviewing the participants, exploring their impressions. The interviews were audio-recorded, fully transcribed and analysed through thematic analysis (Braun and Clarke, 2006). Early themes emerged during the interview. The final themes, however, emerged from the transcripts, which were open coded. These open codes were then grouped in broader categories. This was done by going through the data, statement by statement, and by categorising single statements regarding repeating content and finding themes for these. The themes were then compared and compiled for all interviews. Finally, from these themes, design implications were generated.

The evaluation of prototypes, which are developed here, will not focus on optimising performance or precision, but how people perceive and value these prototypes. Partly, this could be realised through strange inventions, which challenge the reality. In this spirit, I want to encourage complex and meaningful reflection on what it means for interactive technology to be autonomous and exploring the role of design in this. What I finally hope to create with this thesis is generative designs and to inspire future technologies.

Critical design, as well as Speculative Design (Dunne, 2006; Dunne and Raby, 2001), also served as a strong inspiration in this thesis. Crafting questions around suitability of automation and partly provoking participants by confronting them with new and unseen interfaces is what this thesis set out to do. This is in line with the ideas of speculative design. To explore this kind of technology, one must look partly into the future, imagining new ways in which we could interact with technology. Therefore a speculative mode of design research was chosen, that contemplates different relationships we could have with technology in the future. To explore autonomous technology in our everyday lives requires to sample provocative ideas and ideate evocative concepts. These are vital factors in the success of Speculative Design (Dunne and Raby, 2001), therefore this approach was chosen.

Chapter 3

Designing for Autonomy

This chapter explores and maps out the design space for tangible autonomous interfaces. As introduced previously tangible autonomous interfaces are physical devices that are interactive and expose autonomous behaviours. To gain a deeper understanding of the space two workshops were conducted in which the properties of different devices that could be seen as tangible autonomous interfaces were discussed. Both sets of results are combined to develop a framework for TAIs that articulates a set of dimensions that can be constructively considered when developing them. I conclude with a discussion of the future role of TAIs and the emergent research questions which the framework raises.

As we've seen in Chapter 1 and Chapter 2, there is large potential to explore autonomous behaviours in technology. Herein, I want to explore how we can design interfaces that appear to have an 'inner life' and are therefore engaging for people. The focus lies on plain and functional technology, to avoid the drawbacks of anthropomorphism as discussed earlier. How do we react towards these plain, technological interfaces? And how can we successfully design interaction between humans and mechanical interfaces?

I introduced the term *Tangible Autonomous Interfaces* to define this class of interfaces. In the introduction a very simple dimension was introduced, which suggests the placement of TAIs between TUIs and robots. However, although these dimensions suggest that TAIs exist, they are not sufficient to map out the different stages of behaviour. A more sophisticated model is needed. Here I want to introduce a framework to create a design space for creating interactive autonomous devices.

Because of their variety it is hard to define a TAI clearly. There are various systems, which differ fundamentally in their purpose, physical appearance and functioning. Therefore, it is important to rather consider the autonomy of tangibles as flowing scales with no strict borders. The objects move on a nonlinear line on these dimensions, with these dimensions being merged and blurry. To explore how people understand and conceptualise TAIs, two workshops were conducted in which, together with other researchers, various autonomous interfaces were discussed. These workshops are presented in the next section.

3.1 Workshops

3.1.1 Procedure

The intention behind the workshops was to identify the relevant attributes of autonomous interfaces to build up key concepts for analysing and defining these prototypes. The two workshops took place in a meeting room and lasted between one and a half to two hours. They were conducted with four people in each workshop (three females, five males, aged 25-35) and was audio-recorded. Using illustrations on cards, five existing lifelike interfaces were presented and explained to the participants. To find similarities and differences between these interfaces, the *Repertory Grid technique* (Fransella et al., 2004) was applied. The *Repertory Grid technique* is an interviewing technique to measure personal constructs and experiences. People are asked to express their opinion about a certain topic, typically on a scale. This technique usually includes similarity-difference dimensions and consist of elements, which are representatives of a topic. The idea of the Repertory Grid technique is to get an insight into the understanding of people regarding a certain topic and to capture the dimensions and structure of personal meaning. This method was adjusted in this case to finding important characteristics of TAIs and to explore how people describe these. The examples included five prototypes: the three rudiments by Helmes (Helmes et al., 2011) (see Figure 2.8), Roomba (see in Figure 2.15) and the Paredolic Robot (see Chapter 2), all of which were already introduced in the literature review in chapter 2. These examples were chosen as they comprise different traits and facets of autonomy but also function, i.e. ranging from speculative machines to commercial products.

First, three of the five examples were shown to the participants and they were instructed to discuss their personal constructs of the examples in the group. The participants were then asked to spot similarities between two of them and then analyse how these two differ from the third one.

We repeated this for five random combinations. The discussion was transcribed and analysed using a thematic analysis. Themes, which emerged as strong points for discussion during the workshops, are presented below.

3.1.2 Findings

Over the course of the workshop a lot of discussion took place, which lead to the identification of some key aspects that I want to describe here.

When participants notice a direct mapping between the input and the output, the actions of the interface become transparent and it loses its ambiguity. A discussion about transparency of actions arose. "*When you see person steering a car, the car has less autonomy, comparing to just seeing the car move. The car moving on its own is suddenly autonomous*". Self-actuation means autonomy. When the user understands what the interface is doing and no interpretations can be made, the user does not perceive an intention of the interface. This insight emerged when the participants of the workshop discussed the second and third rudiment against Roomba. To the user it is not clear which kind of algorithms are running on the devices, e.g. what the movement of the arm exactly represents and what the light output is intended to mean. When comparing these to Roomba, the participants realised that its movement directly corresponds to its task to clean the floor, leaving less space for interpretation of its motivation. Interpreting a device as autonomous is enabled through the fact that the behaviour of the device is not completely transparent, but equally that the device is able to react to the environment and users. This is crucial as only mindlessly repeating a certain task doesn't make an interface autonomous. However, intentionally deceiving the user with wrong information leads to distrust and shouldn't be the goal. The designer should find a balance by blurring the connection between the input and output of a system to convey a sense of autonomy.

When the interface behaves in a surprising or unexpected way (for example, presents a sudden error), the user tries to make sense of it and starts to interpret the behaviour. This usually seems to lead to the ascribing of motivations. When for example the first prototype or Roomba executes a not foreseen movement, the user rather tries to explain this with a conscious act of the device. The participants discussed their experiences with dysfunctional devices and noted how quickly users perceive devices to seemingly 'intentionally' break down. This happens, for example, with printers, which don't want to print anymore or word processing software that crashes before the user is able to save the document. The impression arises that the device deliberately manipulated a task, because it holds an attitude or objection against the user. Although this might sound short-witted, not knowing about the internal processes of a technology invokes interpretations in people. Breaking expected behaviour leads to an appearance of autonomy. To expose this a bit further, when a user knows exactly about the movement patterns of the Roomba or the first rudiment, she or he will be less willing to perceive the objects as animate but rather as a functioning machine. By comparing Roomba with the first and second rudiment, they also noticed that it might make a difference to interaction if a device has a strict purpose. Roomba, for example, has the task to clean, whereas the rudiments have a rather artistic purpose.

When comparing the third rudiment and the Tableau Machine, the participants realised that due to their learning abilities, these prototypes change over time and adapt to the user. As opposed to, for example, the other two rudiments whose behaviour remains constant. These prototypes have more technical capabilities and a higher sophistication in behaviour. One participant mentions that "*clearly, when the device shows new behaviours over time it stays interesting, the potential to surprise keeps interest*". The inner state of such an interface is not completely clear to the user and when output of the interface varies over time it makes people curious as the future behaviour is not obvious. This might be a factor, which would enable people to bond to such interfaces.

One participant stated that "*People usually find out very quickly what a machine is capable of, due to their appearance*". The form of a machine functions as a metaphor for familiar objects. Physical appearance forms expectations and creates a basis for understanding the capabilities of the interface. Wheels imply that the interface can move. This understanding is also strengthened when the interface is anthropomorphised. For example, the arm of the second rudiment reminds of a human arm drawing on a sheet of paper. The participants noticed that "*Some prototypes are not so inviting to touch or interact directly, rather just observe*". This has implications on the interaction people are willing to have with an interface, based on their personal impression. Furthermore, another factor that might influence the interaction is the position of the device towards the user as one participant states: "*The positioning of the prototype might play a role, obviously something from above is more intimidating than something on the ground*". This implies that also inarguably the size of an interface can convey certain properties, functions or capabilities and make it seem intimidating or not.

3.2 TAI Framework

Building on the findings of the workshops and the related work I first identified the very general categories *Appearance* and *Behaviour* (see Figure 3.1), which are also common dimensions to classify robots (Dautenhahn, 1997). The appearance describes the physical form of the object, which comprises the shape and size of the object and the material it is made of. The two scales in this category are similarities to the real world (*Bio-Metaphor*) and the amount of physical modalities (*Capabilities*). The behaviour of a TAI can be described by its actions, composed of how the input is processed and accordingly which output is given to the user. This category has two main factors: Ambiguity and Complexity. In the sections below I will explain them in more detail and place two examples on each scale.

3.2.1 Appearance

Bio-Metaphor As illustrated in Figure 3.2 the physical appearance can be captured on a scale from biomorphic/zoo-morphic/anthropomorphic to mechanical. "*Mechanical*" indicates that the object doesn't comprise familiar visual cues from nature but rather from artificial systems. "Biomorphic" implies that the outer appearance of the object is based on animal or human appearance or other life forms from nature. For example, a plain camera lens like e.g. the one the third rudiment comprises (right image in Figure 3.2) indicates that the object is capable of capturing vision in a rather abstract way, whereas camera lenses in the shape of eyes would present a more natural recording of images and mimic a human or another living being. To

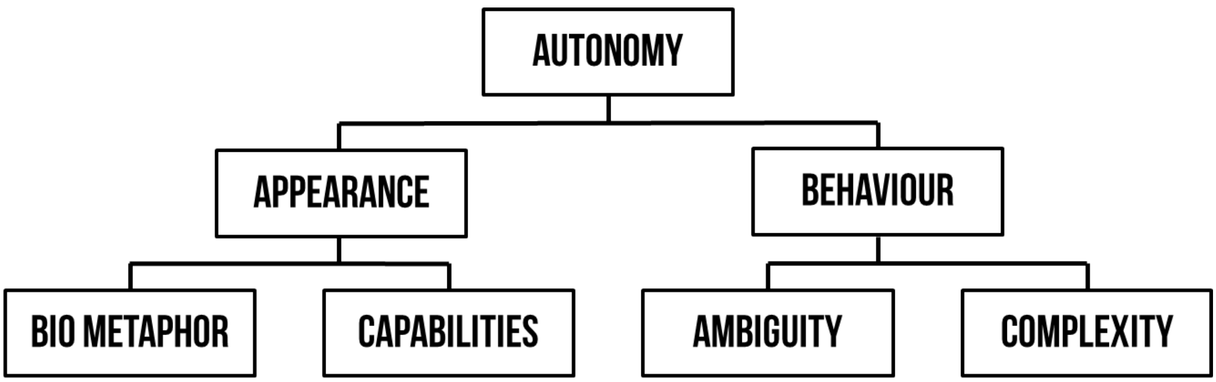

Fig. 3.1 This framework presents two dimensions, with two scales each, for the design of autonomy in TAI: the physical form, which comprises visually familiar cues and visible technology, and the complexity and ambiguity of the behaviour.

enhance the object with shapes like ears or an arm like e.g. the second rudiment (left image in Figure 3.2) or giving the object other body parts, which are lifelike usually implies that it is able to use these body parts in the same way a living being would use it. Eyes, for instance, might prompt the user to think that the device registers the environment, people and objects, which it in fact might not be able to. For designers it is crucial to keep the believability of the interface in mind. The visual hints given by the system's appearance can bias the user's perception of the capabilities even before the interaction occurred, which might not suit the system's role (Dautenhahn, 2002). To take use of affordances, which TUIs can provide, it would be useful to shape the appearance of the object in a way that indicates its capabilities (Schmitz, 2011). To rely on simple, mechanical designs might be better than applying designs, which directly imitate life, as in the first case the system appearance suits to its context and functionalities (Dautenhahn, 2002). Otherwise the system might give the user the impression that it comprises functionalities, which it cannot accomplish. To summarise this point; form and embodiment have a significant influence on the perception of an object, changing the user's expectations and his behaviour towards the object (Bartneck et al., 2009).

Capabilities Another factor related to the physical form of the object is the number of the sensing and output modalities. In this context, The focus lies on which and how many sensors the interface features. This scale ranges from just a small amount of different modalities, like one motion sensor, to many different modalities, like a combination of camera, microphone and

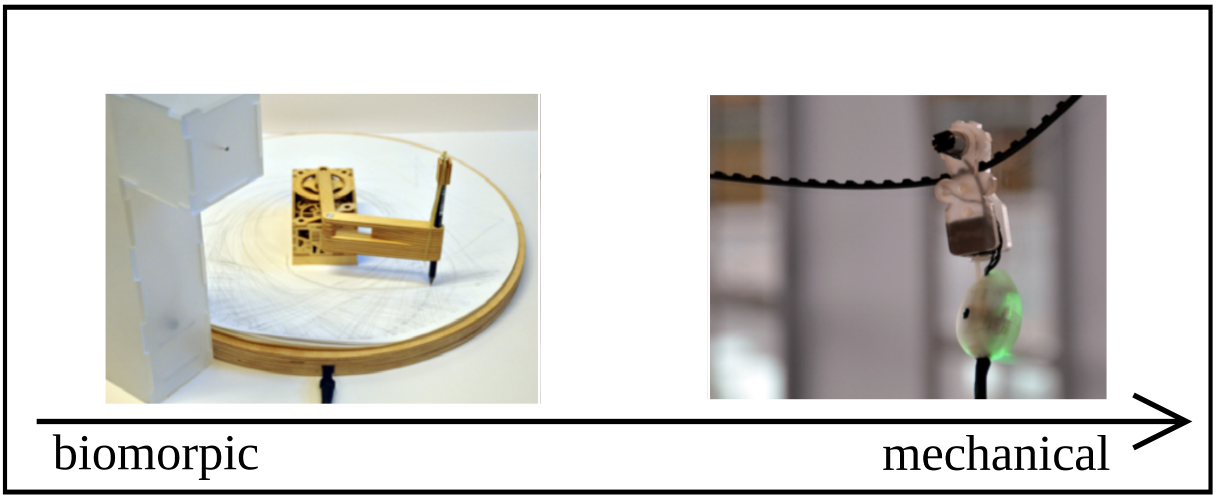

Fig. 3.2 This scale describes the bio metaphor of the appearance. The actuated arm of the second rudiment on the left appears more lifelike than the rather machine-like form of the third rudiment to the right (Helmes et al., 2011).

touch sensors. The sensory capabilities grow along with this scale, which allows more input and output possibilities, but also an advanced sensing of the environment. Towards the end of this scale, the interface can respond to the user and the environment in a more sophisticated way, allowing to express more advanced behaviour. This category is strongly related to the sophistication of the behaviour, as it also influences the possible behaviours of the system. As an example for this scale, we want to compare the first rudiment with Roomba (see Figure 3.3). The first rudiment comprises infrared sensors and therefore just reacts to nearby movement. Roomba comprises infrared sensors as well, to prevent him from hitting furniture and acoustic sensors to sense particularly dirty regions, but it is also able to communicate over radio. This allows the programming of areas which Roomba should avoid.

In their paper the authors stated that the first rudiment received only a small amount of attention in the study (Helmes et al., 2011). The participants were curious about the triggering of the movement, yet did not engage further with this prototype. Numerous studies with Roomba on the other hand indicate a strong engagement between humans and the service robot(Sung et al., 2007).

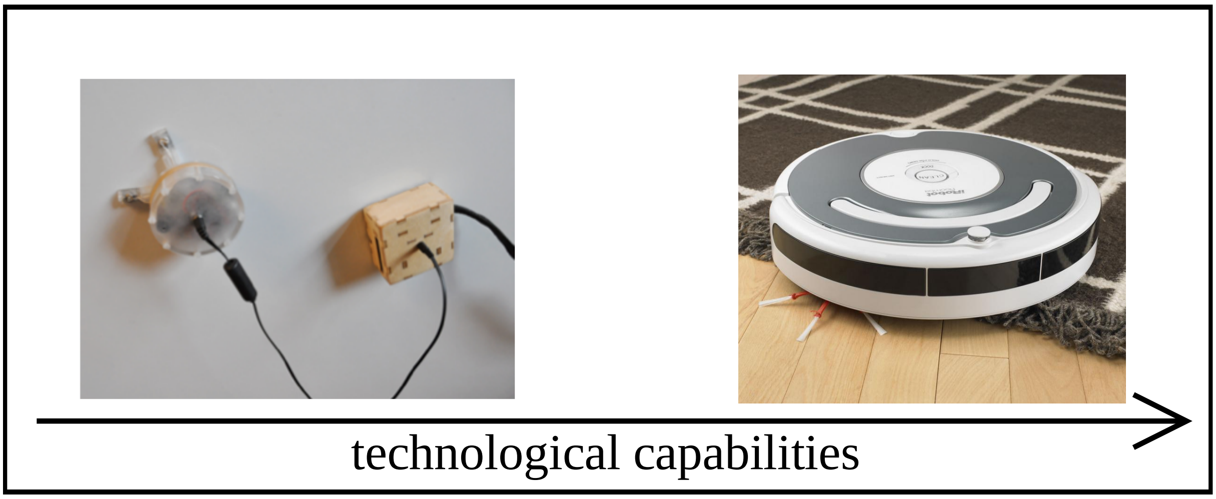

Fig. 3.3 This scale describes the sophistication of the hardware. Roomba (Sung et al., 2007) is placed on a higher place on the scale as it comprises more technical capabilities than the first rudiment (Helmes et al., 2011).

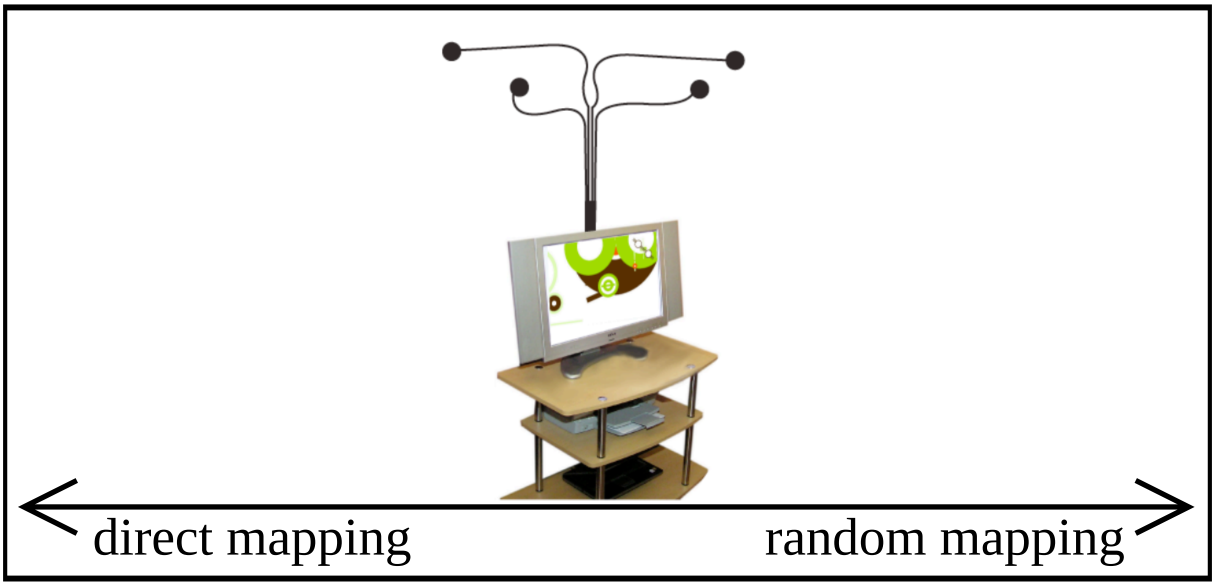

Fig. 3.4 This scale reflects the ambiguity. The Tableau Machine can be placed in the middle as it is neither unambiguous (does not comprise a direct mapping) nor is its output completely random (Romero et al., 2006).

3.2.2 Behaviour

Ambiguity This category defines the transparency between the user's input and the system's output. It can be described on a flowing scale, as illustrated in Figure 3.4, reaching from a direct mapping from input to output to a completely random mapping without any regularities. A direct mapping in this context means that one input always leads to the same output. The behaviour becomes completely predictable. A fully random mapping would give an arbitrary output, where no connection between input and output can be made. The desired point to aim for in this scale is the point in the middle. Making the object too transparent for the user eliminates all room for interpretation, the user has no space for giving his own meaning to the interaction or the output (Gaver et al., 2003). This is the case for input devices like mouse and keyboard, where the movement of the mouse is directly coupled with the movement of the cursor and every button has the same function on every hit. On the other hand, making the object's behaviour too ambiguous might lead to confusion as the output seems completely random and not very responsive to the user's interaction. The user can't make sense of the system's output and therefore he is not able to interpret or even interact with the device. As discussed in the workshop, ambiguity also breaks the expected behaviour as the aims of the system are not completely clear to the user. This might arouse curiosity and keep the user engaged over a longer period of time.

An example for applicable ambiguity are the shapes displayed by the Tableau Machine (see Figure 3.4). The shapes reflect an abstracted view of life in the participating households. Choosing the right amount of ambiguity between the actual data and the displayed shapes gave the users rise to attributing some personality to the system. This could not be achieved through the entirely random implementation.

Complexity The complexity of the input processing describes the computational abilities and the degree of computational working of the interface. The more complex and sophisticated the software is, the more autonomous the device seems to be, because it is capable of more action and reaction. Also the device is able to more advanced processing and can provide more interaction possibilities when having access to more sensors, which deliver the input from the user and the environment. When placing the rudiments in this dimension, it can be noted that the abilities grew from one prototype to the other, which relates to the degree of engagement of the users (see Figure 3.5). Regarding this work, a crucial factor to motivate long-term interaction seems to be the fact that people try to find patterns in the behaviour of the system and want to explore how the behaviour persists and changes over time (Bartneck et al., 2009). The third prototype appeared to be more interesting to the participants than the other two, as it seemed to learn and change its behaviour over time. Similar observations can be made for the Tableau Machine. The shapes and colours became more complex, resulting in an engaging experience over a long period of time. In these two examples the sophistication of the software was very high, both were utilising machine-learning algorithms, which ensure an adaptation to the users over time.

3.3 Discussion

Autonomy in interfaces can be used in a lot of different applications, reaching from general purpose devices, entertainment and educational applications. Virtual agents in games are already a well researched topic (Maes, 1995); findings in that area indicate that people enjoy the company of entertaining characters and receive an opportunity for emotional relationships. Learning environments also sound promising as children seem to embrace a notion of agency, helping them to view the world from different perspectives (Wyeth, 2007). One example of a TAI could be a small acrylic box with a screen, placed on a desk or a shelf. The device is wirelessly connected to the user's computer and would display a text field every few hours with

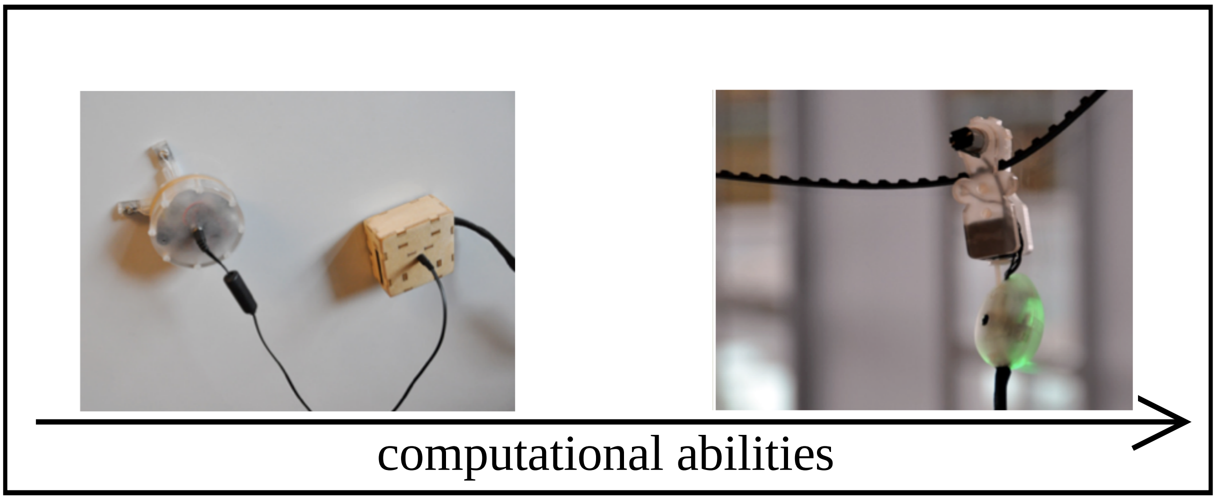

Fig. 3.5 This scale describes the sophistication of the software. As opposed to the first rudiment which just reacts to nearby movement, the third rudiment comprises more computational capabilities as it processes video data and adapts over time (Helmes et al., 2011).

news. The news items would be generated by topics from pages that the user frequently visits. In the herein presented framework, in the category ‘Appearance’ this device would be placed in the lower middle of the scale ‘Capabilities’ as it just consists of a screen and the infrastructure to communicate with an external computer. The small screen would rather remind of a technological device, similar to a computer screen or a TV. The ambiguity would be relatively low, although it is not transparent to the user why the device displays which information. The complexity is middle to high, as the device needs to determine the interests of the user and access new information. How would a person perceive this device over a long-term use? Would she or he perceive the device as an entity with a small personality? Further speculations would be about how the user trusts in the information displayed. Does he assume that they have a kind of bias, since they are provided ‘intentionally’ as opposed to generic, random news messages. Or would the user believe more in the information since it is displayed by its personal device, which he got used to?

3.4 Summary

In this chapter a framework to describe and compare *Tangible Autonomous Interfaces* was presented; interfaces, which show independent behaviour and invite people to interpret their outcomes. This framework was inspired by two workshops, which explored characteristics of

Tangible Autonomous Interfaces. I motivated the use of a notion of autonomy in interfaces to create compelling and engaging interfaces, which stay interesting over time. Rather than aiming to ‘improve’ user performance, such interfaces can offer a richer and more enjoyable autonomous interface interaction. The next two chapters will introduce the evaluation of two prototypes that investigate the presented framework. The aim of this is to explore if it is possible, using the suggested dimensions, to create autonomy in interfaces and furthermore if the framework needs to be extended. What follows is an exploration of how people construct their interpretations of new machines through prototypes, which arouse curiosity through autonomy and finding a way to take advantage of this effect.

Chapter 4

Diri - the Actuated Helium Balloon

This chapter describes the first case study for this research - the design, implementation and evaluation of an autonomous interface. To explore perceptions of autonomous behaviour in interfaces Diri was created, an autonomous helium balloon, used to document activity in spaces. Two different technological sophistications of Diri were implemented, to compare the outcomes of various design decisions. Specifically, this chapter presents the design process of the prototypes, technical details and evaluation workshops, and concludes with implications for designing for autonomous interfaces.

There is much to explore about the design decisions that drive people to regard an autonomous, interactive system as a social agent and lead them to react in certain socialised ways. In particular, considering how autonomous behaviours in interactive technologies might promote certain kinds of social reactions in users. Understanding this would allow to question whether autonomous behaviour in interfaces might be used as a resource for design to engage and promote specific user actions, perceptions and responses.

To capture and comprehend perceptions of autonomy and embrace human social responses, I designed, developed and deployed actuated helium balloons with attached electronics that fly autonomously, supporting high-res cameras to take pictures or collect video footage (see Figure 4.1). The purpose of these devices is simply to document the space (which might serve a variety of potential user functions). I was speculating around how perceptions of a camera interface change as soon as it is actuated. In an age made remarkable by the rise of unmanned aerial vehicles for military use, could flying objects also be designed to become our companions?

Fig. 4.1 Diri #1 and Diri #2 (from the term Dirigibles, i.e. airships) - the autonomous helium balloons.

As research through design (Koskinen et al., 2012), which builds on the premise of creating artefacts through a process of disciplined imagination, the aim was to create actuated, autonomous interfaces, which give users the impression that they have intentions and motivations and therefore become a social presence in the room. To be able to compare different design decisions two balloons were implemented, which differed in their designed behaviours. To evaluate people's perceptions of the balloons, five workshops were conducted, which consisted of a series of creativity tasks to be performed by participants, whilst two balloons flew around the room. After the tasks, participants were asked to complete some observations about the balloons' behaviour. Following the workshops, further one-on-one interviews with ten participants yielded more in-depth feedback and enabled further explorations of their responses to the observation questions. Specifically, high interest lies in how different design decisions influenced people's perceptions of the 'intelligence' of the balloons.

The existence of commercially available products demonstrates the interest in this class of flying technology and highlights the timely need to understand their user issues. This study represents the first attempt to qualitatively understand user responses to such devices, and specifically autonomous implementations for workplaces. This chapter delivers three contributions to this thesis. 1) The design and development of a low-tech, interactive flying interface for domestic or office use. 2) A first case study evaluating the design framework for Tangible Autonomous Interfaces presented in (Nowacka and Kirk, 2014). Finally, 3) through qualitative analysis of questionnaire responses and interviews a contribution is made to a deeper understanding of people's responses towards autonomous interfaces.

4.1 Related Work

The concept of autonomy has been evoked within a large variety of interactive objects. This diversity was illustrated in Chapter 2. This section will briefly discuss how helium balloons have previously been used as interfaces.

Helium balloons have been utilised for a wide variety of applications; in most instances for advertisement, but also in art and to support telepresence. Paulos et al. (Paulos and Canny, 1998) created 'space browsers', blimps that can be controlled remotely in a browser using a Java applet. The blimps comprise a video camera, a microphone, and a speaker to allow wireless internet-based communication between the remote pilot and people close to the blimp. Equally, Floating Avatars (Tobita et al., 2011) incorporated projection into a blimp-based telepresence system, and Yoshimoto et al. (Yoshimoto et al., 2009) used interactive blimps in performance art.

These projects, however, focus on the possibilities of remote control of the blimps in different applications, rather than their design and users' impressions of their behaviours. While research is aware of the attribution of intention in objects, there is still a lot to explore about how these interfaces could be designed to spark certain emotions, preferences or behaviours in users. Interesting in this area is understanding which factors lead to which perceptions in people and what is therefore important during design and development.

4.2 Design For Autonomy: Diri

In very simple terms, a tangible autonomous interface might be described as a device that demonstrates independence to some degree. If the interaction purely consists of a device reacting to a user's input (a device fully dependent on the user - which would present a typical interface), the interface lacks intention, its own behaviour and therefore autonomy (van Allen et al., 2013).

On the other hand, when the device is not reactive to the environment at all, fully independent of interaction, it is not ‘in the world’; the mindless repetition of the task extracts all interaction possibilities (Taylor, 2009). Proactiveness has also been suggested as one property that supports autonomous behaviour (Kynsilehto and Olsson, 2011); if devices, for example, suggest content or direct interaction, they shift from being purely reactive to devices, which seemingly have interests and a motivation (van Allen et al., 2013).

Another major factor of autonomous behaviour is predictability. Perceptions of autonomy arguably rise and fall with how well a user can predict a system’s potential functioning. When people understand the inner workings of a system (the behaviour) and it is therefore fully predictable, there is no room for the user to wonder and make their own interpretations. In this case the behaviour is functioning and transparent, it follows a set procedure without an ‘inner life’. Ambiguity in the system’s behaviour can bring surprise through unexpected actions and therefore engage the user to make sense of the system for themselves (Gaver et al., 2003). In this situation, the behaviour is not directly comprehensible or repetitive and therefore invites the user to assign their own meaning to the actions that the interface presents. In return, ambiguity in the appearance might frustrate the user, it is not immediately clear how to use the device. Therefore the prototypes presented here rely on functional design, which won’t mislead the user (Dautenhahn, 1997). The appearance of a system has a strong influence on predictability. If the device suggests its use by its shape and visible components, it facilitates its use (Norman, 1988).

The framework (presented in Chapter 2, see Figure 3.1) outlined some key concepts further elucidating these various issues underpinning perceptions of autonomous behaviour. These set out to guide the design and development of autonomous behaviours in interactive systems. Ultimately, the aim is to understand how to design autonomous interfaces, which invite social responses, but also may be beneficial in various application areas, for example, to lead to behaviour change, frequent use and motivate people to form a relationship with the autonomous interface. The framework consists of four dimensions, which help in the construction of perceptions of autonomy. I wish to revisit this framework in the following section and try to relate the design of flying actuated interfaces to the framework’s dimensions. Four concepts are presented: *Bio-Metaphor*: a dimension which maps the outer appearance on a scale from anthropomorphic / natural to mechanical / technical; *Capabilities*: which refers to the number of actuated and sensing components the prototype contains; *Ambiguity*: which describes the transparency of the behaviour presented; and *Complexity*: referring to the sophistication of the device’s behaviour.

4.2.1 Bio Metaphor

The appearance of an interface plays an important role for first impressions and also during interaction (Sung et al., 2007). Although the behaviour can be as important as or even more important than the visual nature of an interface (Bartneck et al., 2009), zoomorphic or humanoid appearance can lead to false expectations and frustration (Weiss et al., 2009). We've seen in the discussion on zoomorphic interfaces in Chapter 2 that lifelike interfaces can persuade people into thinking that they possess certain skills, like being able to speak or navigate autonomously, when in fact they are unable to do so. This leads to a decrease in believability and also to confusion and disappointment during interaction (Ju and Takayama, 2009). This danger is much less for objects of mechanical appearance. When something looks like a zeppelin, it is likely that it behaves like one. Therefore the aim for Diri was to create a plain and mechanical-like appearance - one which is as functional as possible. This also allows designing to support the function of the device. To enable better flight control and to be able to turn quicker, the balloons are round. To better distinguish the prototypes, they were given two colours: silver (Diri #1) and gold (Diri #2).

4.2.2 Capabilities

Equipping an interface with an increased number of input and output modalities extends the range of possible autonomous actions. Because Diri was aimed to be deployed in indoor environments such as an office, a size of 150cm in diameter should not be exceeded. Such constraints in size lead to a practical restriction in the weight that a helium balloon can carry. This further sets a limit on the number and kinds of components that can be attached to the balloon. The function of the flying balloons should be to document the space. This requires actuation of the balloon, some level of sensing and the capabilities to process those sensing signals to react to the environment. To remain stable in flight, sensors are needed that capture movement and rotation. The balloon should be able to displace itself to avoid obstacles; this requires proximity sensors around the balloon and multi-directional motors with propellers. Finally a controller is needed to enable autonomous behaviour.

4.2.3 Ambiguity

Gaver et al. (Gaver et al., 2003) see the use of ambiguity as a resource for interface design and an opportunity to be exploited; enabling more personal relationships, making interactive artefacts more thought-provoking and engaging. The right amount of ambiguity in the behaviour of an interface can change it from being predictable and functional to intentional and lifelike. Ambiguity can be added to a device through various means. For example, by performing a random movement at times (Helmes et al., 2011), through displaying visualisations and pictures (Pousman et al., 2008) or changing the shape of the interface (Grönvall et al., 2014). Random movements (to an extent) lead to surprise, the user wonders why this movement occurred and tries to figure out the intention. Furthermore, the balloons should be able to reach different areas in the room and would not just hover over the same location. Therefore the balloons execute random movements every 60-120 seconds. With the silver balloon (Diri #1) I aimed to populate the rather extreme points in the spaces of the framework, therefore I chose to make it fully ambiguous (which results in completely random behaviour). The golden balloon (Diri #2) periodically moves in a straight line. The aim was to let it actively 'explore' the room instead of getting stuck in corners or just randomly drifting around.

4.2.4 Complexity

As already mentioned, I aimed to compare devices of different sophistication and therefore the prototypes differed in complexity. Due to the additional capabilities Diri #2 was able to avoid obstacles, i.e. walls and maintain its height by tracking the distance to the ceiling. The sensors also supported stabilising the movement of the balloon once it was instructed to move forwards. I implemented a face-recognition algorithm for the low-res video stream from Diri #2, which initiates the taking of a high-res picture. Diri #1 is much less sophisticated as it randomly moves forwards, turns left or right or flies upwards. Turning results in spinning around its own centre. It also takes a picture every minute on a fixed schedule. Both streams can be stored, uploaded to a server or displayed immediately on e.g. screens.

4.3 Technical Details

The following section illustrates the construction and programming of the prototypes. Step-by-step instructions on how to create a Diri can be found on Instructables [1].

There are several reasons why flying interfaces might be useful. Due to their location and sphere of operation, they don't face the same problems as wheeled or walking actuated interfaces. They don't have to avoid furniture like tables and chairs and are less likely to obstruct people as they can fully embrace 3D space by operating at varying heights. Due to their potential vantage point, they also have a good overview of their location and are therefore quite suitable for documenting events and places. Quadcopters have become quite popular recently, and we have seen various examples of how they can be used in interactive ways (Bouabdallah et al., 2004; Kumar and Michael, 2012).

However, there are reasons why, in a domestic environment, they may not be the optimum solution for a flying interface. For example, most quadcopters consume significant energy and therefore have a short battery life, and when their battery life ends, they fall out of the sky, which has obvious safety implications. Helium balloons, alternatively, don't consume any energy to keep themselves in the air. As a consequence the battery needed to steer the balloon lasts up to 2 hours, rather than just 10-15 minutes. Helium balloons are also quite safe, non-flammable and pose no danger of dropping on people if they run out of battery. Pragmatically, the worst-case scenario is if they escape, whereupon it can become problematic recapturing them if they move to certain heights.

4.3.1 Hardware

Diri #1 has a diameter of 110cm x 50cm, whereas Diri #2 is larger with 142cm x 80cm, to carry more components. Diri #2 can carry about 300g. This is just about enough to carry an Arduino pro mini, a GoPro Hero3+ camera, three ultra-sonic sensors, a gyroscope, an accelerometer, three motors with props and a battery. Diri #1 is not able to lift more than approximately 160g, sufficient for the core components (camera, motors, microcontroller and battery), but required to remove the battery of the GoPro and power it from the external battery over the USB connector. The ultra-sonic sensors of Diri #2 are placed one on top of the balloon and two at the front

[1] http://www.instructables.com/id/Diri-the-actuated-helium-balloon

Fig. 4.2 The different designs that were tested for the electronics casing.

pointing left and right. The gyroscope tracks orientation to support the forward movement by counter steering with the motors, allowing a more stable path. Figure 4.4 depicts the circuit design and a picture of the inside of the golden balloon. Some components are sensitive to their orientation, the Gyroscope/Accelerometer board (Figure 4.4 - (2)) has to be fixed horizontally. For the rest, however, it actually helps if they are distributed evenly inside the enclosure to balance the balloon.

Since balloons at the required size and shape are hard to purchase, I created two customised balloon envelopes using two sheets of Mylar blanket for each balloon and a straightening iron. Mylar is an advisable material; it is a thin metallic plastic film, which is less porous than other materials such as latex and is therefore able to hold the helium for longer and also weighs much less. For Diri #2 I cut two circles out of a 142cm x 213cm Mylar sheet and aligned them on top of each other. By pressing the borders of the two sheets together with the iron for 30-60 seconds, the Mylar melts and bonds. This task has to be repeated for the whole circumference of the balloon, apart from leaving a small gap out to be able to fill the balloon with helium.

Due to the weight restrictions, the most suitable material for the electronics casing is balsa wood, a very lightweight material, commonly used for model building. Multiple designs were iterated, Figure 4.2 illustrates the round and rectangular designs. The final design for the casing is as plain and functional as possible as illustrated in Figure 4.3. To fit to and resemble the balloon envelope as much as possible a half-arc design was chosen. To create this covering, I bend a 20cm x 7,5cm balsa wood sheet to a half-cylindrical shape, similar to an arc. Two half-circle plates cover the sides of this case (see Figure 4.3). For actuation, high performance, electrical motors and propellers were used, which are commonly employed for mini quadcopters. The further apart the motors are, the stronger the turning force, allowing faster movement. Therefore the motors are attached to two dowels of 60cm length.

4.3.2 Software

The implementation of Diri #1 is simple. Every now and then, it randomly moves straight, turns left or right or moves upwards. Diri #2 interprets the readings from the ultrasonic sensor, and

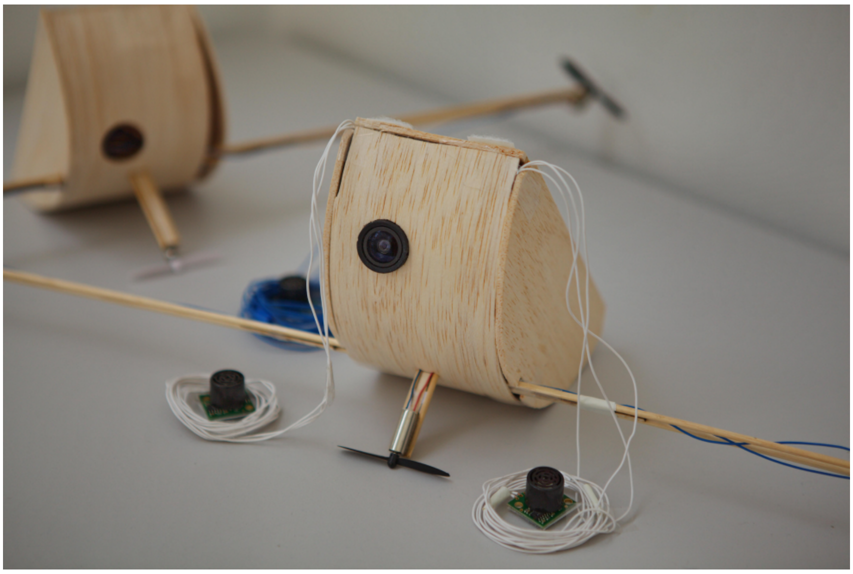

Fig. 4.3 Casing for the electronics of Diri #2 (Diri#1 in the back); two ultrasonic sensors are placed on the front right and front left (white wires) and one on the top of the balloon (blue wires).

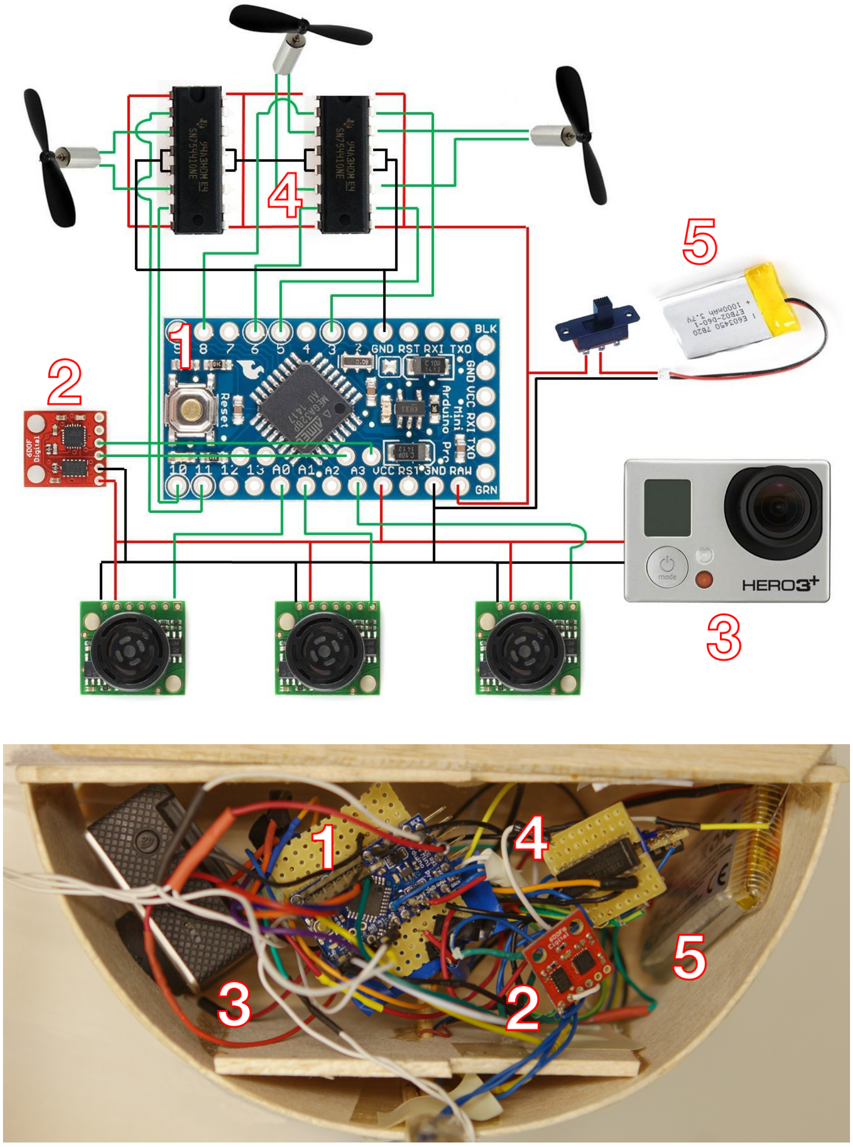

Fig. 4.4 The inner life of Diri #2: (1) Arduino microcontroller, (2) Gyroscope and Accelerometer, (3) GoPro camera, (4) H-Bridge for motor control, (5) Battery

accordingly either moves up or down to keep its height constant (depending on the height of the room, around 80cm from the ceiling), or turning away if an obstacle is detected. Once the obstacle is passed, the opposite motor counter steers to prohibit further spinning and keep the orientation stable. If both sensors detect an obstacle the balloon flies backwards. Finally, when there hasn't been any movement for a while, the balloon flies straight ahead for two seconds. Independent of these processes the camera of each balloon wirelessly streams snapshots to a computer. Diri #1 takes a picture each minute that is downloaded onto the computer. Diri #2 transmits a video stream, which is analysed on the computer using C++ and OpenCV, a Computer Vision Library [2]. If a face is detected, a picture in higher quality is taken and then uploaded.

4.3.3 Challenges when working with helium balloons

Helium balloons are far from being perfect and working with them has a number of challenges. The first challenge is to obtain a balloon which has the right size to lift all the components. The volume of a balloon determines with how much helium it can be filled, which is proportional to the upward force. If the load (the electronics and the casing) exceeds this force the balloon will not float. This significantly constrains the choice of components. The biggest constraint here is the battery; the less weight it is, the shorter it will last. To be able to carry at least the microcontroller, a battery and some motors, a helium balloon needs a diameter of at least 90cm.

Secondly, balloons filled with helium are very sensitive to any air flows and temperature changes in the room. As helium balloons always drift (i.e. there is no way to be completely still), they are strongly affected by air movements in the room. When warm air rises, it will also lift the balloon; the same counts for drafts which carry the balloon around in random directions. The balloons were tested in different environments and clearly, due to strong air currents, rooms with air-conditioning are not a suitable place for them.

Thirdly, because displacing a helium balloon consists of changing the inertia by actuating the propellers which creates a thrust, there is always a bit of a lag between the initialisation of a movement and the actual change in position. This delay takes a few seconds. As a result, the balloon can't react to outer influences that well and it is also very challenging to quickly avoid obstacles.

Finally, since helium is lighter than air it escapes slowly from any kind of casing. As a consequence the balloon has to be refilled daily or every other day depending on how air-proof the casing is. It can also be quite challenging to fill a balloon with the right amount of helium to make it fully floating, i.e. neither dropping nor rising in height. To reach the moment when the balloon is perfectly balanced it is advisable to fill it so that it is too light and equilibrate it with an additional weight (e.g. Blu-Tack) which can be taken off again easily.

[2]http://opencv.org/

4.4 Evaluation Method

The broad interest here lies in exploring how tangible autonomous interfaces might co-exist and operate autonomously in human living/working environments. Accordingly, two quasi-naturalistic studies were set up, in which users were asked to perform brainstorming and sketching activities. During these activities they encountered Diri #1 and #2 for extended periods both directly and indirectly. The first study probed user response during peripheral interaction (where the balloons operated autonomously to the users, as this might be a likely mode of future operation) and in the second trial, users directly interacted with the balloons to simulate more focused periods of interaction. I was curious if this direct interaction prompted a change in people's perceptions of the balloons. As I wished to develop an experiential understanding of users' perceptions and users' reactions to autonomous behaviour in interfaces, and was adopting a broad research through design approach (Koskinen et al., 2012), a qualitative data evaluation strategy was chosen. In the following I will explain the procedure and data collection methods.

4.4.1 Procedure

Both trials consisted of two parts, an ideation task and a questionnaire, during all of which the balloons flew around the room taking pictures. The task itself involved rounds of sketching and discussion, and represents relatively everyday design-focused activity in the lab, where the study was conducted. It was therefore an unremarkable activity for the participants. For this, 'Ideation Decks' (Golembewski and Selby, 2010) were used, a creative method for exploring design problems using pre-designed cards to inspire design sketches. The decks contained three categories with three items each: location (living room, kitchen, shopping mall), purpose (entertainment, education, problem solving) and input and/or output modality (audio, video, tactile). The project brief was to explore autonomy in tangible user interfaces, which means in practice to generate ideas and think about prototypes that work autonomously under the given circumstances. The participants had to come up with a technology, which fits these categories and is capable of exhibiting autonomous behaviour, by making notes and drawing. Following from this, the participants presented their sketches to each other and we discussed the outcome together. Lastly, the participants filled out the questionnaire.

Trial one consisted of three separate workshops, each with 4 people and lasting about an hour (n=12, 6F and 6M, aged 17-35). The presence of the balloons was explained to participants as being for the purposes of documenting the sessions. The differences between the balloons were not explained to the participants. Although the balloons were not an integral part of the workshop, participants were aware of, and had access to, the balloon-captured pictures via two large displays, which were positioned in the room (see Fig. 4.5).

Trial two consisted of two further workshops with 5 and 6 participants respectively (n=11, 3F and 8M, aged 21-37) with a focus on more direct interaction with the balloons. This trial used the same creative task, however, in each workshop the participants were further split into two sub-groups, each group was given a laptop, which received streamed pictures from one assigned balloon (Diri #1 or #2, time or face-triggered photo capture) and they were instructed to create ideas together in sub-groups. Each group was required to capture/document their creative output (design sketches) using their assigned balloon, either Diri #1 or #2. To achieve this, the participants could move around the room to pose for the balloons or displace them physically by grabbing a balloon by the case or the balloon itself and move it at will. To be able to fulfill the task I explained to the participants that - for the golden balloon - a picture is triggered when a face is detected, the silver one took pictures randomly. However, I did not mention further differences such as the ultrasonic sensing. Participants were asked to document their work by creating four pictures: i) a group picture, ii) a picture of their set of ideation cards iii) a picture of their sketches and iv) a picture of them working in the group. After 30 minutes the groups swapped balloons and did another round of the task.

Participants had different backgrounds (arts and sciences) but were mostly researchers and PhD students. The ideation task during the workshops allowed the participants to have enough time to observe the balloons and their behaviour. A subset (n=10) of the participants (over both trials) were invited to take part in a follow-up 15-20 minute open-ended interview. The one-on-one interviews gave me the opportunity to ask participants for more detail about their answers so as to deepen my understanding of their opinions. From the first trial, I picked (at random) one interviewee from each workshop, and then decided to add another, randomly chosen, to help balance the gender ratio - resulting in 4 follow-up interviews (2 females, 2 males). From the second trial I picked one person from each workshop sub-group and at random two additional people, 6 people in total.

4.5 Data Collection and Analysis

To collect the participants' perceptions of the prototypes and to create a starting point for discussion I asked them to fill out a questionnaire at the end of both trials. The questions posed to participants were are attached in the appendix.

The first question aimed to explore how people apprehend the behaviour of the balloons and how they perceive the differences in their behaviour. The second question focused on the appearance of the prototypes. I wished to find out if the participants perceived the prototype as functional in appearance (which was the intended goal) or if they saw anthropomorphic traits in it. The third question was exploring whether participants would use social language or suggest motivations and intentional states in the balloons. The fourth question attempted to find out about the preference of the participants and which design decisions they were basing this upon. Finally, with the last question, I intended to sample the general opinion people have about the prototype and whether they could imagine this prototype as a product in the home, again to look for signs of how aspects of autonomy might influence their broader perceptions of the technology.

To analyse the results from both the questionnaire (all participants) and the interviews (subset of participants) an inductive thematic analysis (Braun and Clarke, 2006) was used. Written answers

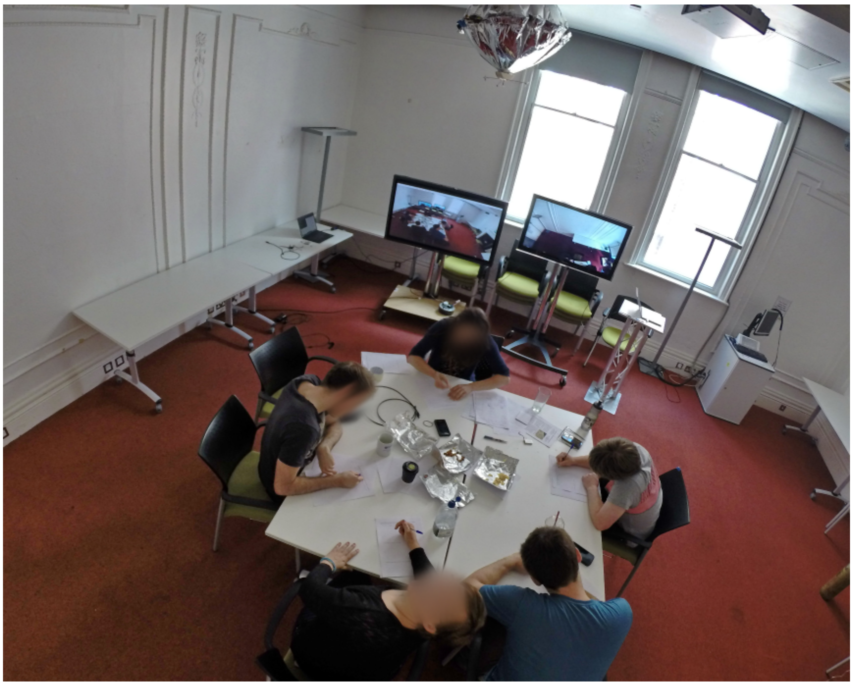

Fig. 4.5 A picture that was taken by Diri #2 during the first workshop trial.

were transcribed and overarching concepts/themes for each statement were distilled. Responses were then clustered into overarching themes, which are discussed below. All quotes are from the questionnaire; interview responses, which provide a more in-depth insight, are mentioned as such.

4.6 Results

The results from both trials, the peripheral observation (first) trial (P1-P12) and the direct interaction (second) trial (P13-P23), are presented separately below and coded into high-level themes. A comparison, deeper analysis and interpretation follows in the section 'Summary and Discussion'.

To shortly recap the difference between Diri #1, the silver balloon, and Diri #2, the golden balloon: Diri #1 movements are random, it moves up or down, turns left or right at various moments. Diri #2 keeps a constant height and avoids obstacles. Furthermore Diri #2 only transmits pictures that contain faces, Diri #1 takes a picture every minute.

In both trials participants were very engaged by the presence of the balloons. Most participants stated that the balloons left a strong impression, they were very present in the room and it was hard not to observe them. Directly interacting with the prototypes (as opposed to 'passive' observation) did not appear to change participants' perceptions of the prototypes as social entities. However, the nature of the two trial tasks meant, during direct interaction, participants might have been more aware of the balloons' differing sophistications.

4.6.1 Trial One - Peripheral Interaction

Overall, there were three broad themes: *Mechanistic and Animalistic Associations* (responses to the general look and design of the prototype); *Sense of being watched* by something (participants' surveillance concerns) and finally, *Assuming advanced behaviours* (perceptions of the actions and the functioning of the prototypes).

Mechanistic and Animalistic Associations Several of the participants made relatively straight-forward associations such as *"hot-air balloons"* or *"zeppelins"*. Both balloons were perceived as plain and as futuristic due to their metallic colour. A lot of associations, however, revolved around Sci-Fi, space-ships and extraterrestrial beings.

"They seem quite 'space-age' in terms of the metallic nature." (P2)

"Erm...UFO? Spaceship?" (P4)

Although the design of the balloons was aimed to be as functional as possible with no explicit attempt at zoomorphism, participants still saw a resemblance to living beings: *"Jellyfish."* (P5), *"A clumsy child."* (P6)

"Reminds me of a Bluebottle fly, because of the noise & directionlessness. I was expecting them to try and get out the window." (P11)

Being curious about the association with Jellyfish (P5), I asked the participant to further explain this at the interview. The participant remarked that for her it seemed like the balloons were *"just not flying and then sitting there, they are occupying a space, like in water you can occupy, but air, not many species can occupy that space"* (P5). I subsequently found out that she had previously created art installations revolving around jellyfish, hence her association.

Sense of being watched One questionnaire item asked if the participants could imagine such a device in their close environment. Most people were self-conscious about the camera and its implications for privacy. They answered that they wouldn't feel very comfortable being monitored.

"Might be annoying as it took photos without permission." (P3)

"I would feel like I had no privacy as the cameras would constantly be watching what I was doing." (P1)

Participants stated that a difference to other surveillance systems is the high visibility of the balloon. Due to its size and also due to the noise the motors produce, people are always fully aware of the balloon, its location and orientation and therefore the camera cannot be hidden. Some participants stated that they were aware of the balloon 'looking' at them:

"I feel constantly observed by the balloon - it is looking at me all the time!" (P3)

"The gold balloon took a long hard look at me whilst I answered this question." (P7)

After asking P7 again about his statement at the interview, he then explained: *"a camera is kind of like an eye ... So when the camera is kind of staring at you ... I was thinking about this question, I sort of referred to it in that way"*. Again the use of terms such as 'it' and 'watching' (rather than captured) and certainly the articulations around the devices 'looking' at the participants, arguably suggest a notion of the devices being entities with intentions rather than say passive devices. The natural association between cameras and eyes (exacerbated by the placing of the camera within the frame of the blimps) seems to have furthered this sensory impression that the devices were alive and had some kind of internal state in an animalistic way.

In an interview, together with the participant, we imagined the differences of having Diri at home in comparison to a normal surveillance camera. One participant stated, that this would constitute a very different feeling for her:

"I think you would have some sort of more of a relationship with the balloon in a way. Like you build up some kind of idea about the little pet kind of watching you. A normal camera? I'd turn it off." (P5)

This final comment underlines the extent to which a behavioural manipulation, involving mobility, when combined with some perceptual sensory quality (the device is 'looking at me') creates an artefact with which participants felt more inclined to form a 'relationship'.

Assuming advanced behaviours Some of the responses suggest that participants were imputing a mental life and mental capabilities to the balloons from observing their behaviour and ascribed characteristics:

"The gold one is oppressive." (P6)

"The silver one appears to be more agile." (P10)

"The silver one seemed 'clumsier'." (P9)

To evaluate which design decisions led to which preference between the balloons participants were asked to write down which balloon they preferred and why. Surprisingly, although most participants expressed that the balloons did not seem to differ very much, in the first trial they preferred Diri #1.

Reflecting on the design decisions around behavioural characteristics, it was surprising that the majority of the participants did not realise there was a difference in behaviour between the balloons. Both of the balloons were perceived as very similar. The participants had different reasons for that. People found Diri #1 ‘braver’ and ‘more active’, flying quickly across the room, and therefore more interesting. Because of its smaller size it was indeed able to move faster and due to the implementation it would quickly spin around its centre every now and then. Some people noticed that Diri #2 didn’t *“get stuck that much”* (P1). Four out of the twelve participants from the first trial did see a slight difference in behaviour though, and explained this correctly with the presence of more components. They also found the smaller balloon was worse at navigating compared to the other balloon as it did not avoid any obstacles:

“The yellow one appears to move more and explore more, but it may be just an impression...” (P12)

“Silver one spins a lot, maybe it can’t navigate so well.” (P6)

Since Diri #1 does not have any awareness of the other balloon or the environment, it would bump into Diri #2 from time to time. One participant stated that he perceived Diri #2 as *“bullying”* Diri #1. Participants would also remark that they saw the balloons *“fighting”* each other. During the sessions where colliding was rather rare, participants stated: *“sometimes they fight; don’t play with each other that much”* (P6). These things indicate that some participants perceived the balloons as somehow pet-like, randomly moving, sometimes being reactive to the environment and sometimes not.

“There is something nice about the idea of them floating around like little companions.” (P2)

Further to this, two participants, who coincidentally each come from a family with a lot of brothers and sisters, described the relationship between the two balloons being like siblings, for example, P5 suggests:

“They seem to have a sibling relationship - they even fight! They’re also quite child like.” (P5)

In the interview P5 further explained: *“They look the same, they are of the same species...it wasn’t aggressive between them, it was familiar in a way”*. Of particular interest here is the way the participants were using their experiences of social relationships to frame the relationships between the balloons. They were using a socialised understanding of the world to interpret otherwise mechanistic behaviours.

As Diri #2 constantly aimed to keep height despite the varying airflow in the room, the motors would turn on very frequently. This consistently created a fan-like sound, perceived as very noisy (P2, P6, P8, P10, P11) and at times annoying. For one participant this was curiously framed as some kind of attention-seeking characteristic, which, she stated in the interview, is very common for children:

"The movement is quite gentle, but the noise gives them much more presence, and it's like having a child in the room that needs a bit of attention every so often." (P5)

There were more quotes suggesting that - to the participants - the balloons have intentions and an internal representation of the world - even if it is a very weak one:

"They don't know where they are" (P11)

"They seemed to be more interested in features of the room (particularly the walls) than on people." (P12)

4.6.2 Trial Two - Direct Interaction

In the second trial comparable issues appeared. Two pictures taken by the balloons are shown in Figure 4.6. For example, participants expressed similar feelings about being watched. The direct interaction didn't seem to change surveillance concerns in the participants. Enabling direct interaction raised a few new points of discussion though. Here the focus lies on the recurring themes, which are of interest and new themes. The themes in this section are therefore *Mechanistic and Animalistic Associations*, *It was just a balloon* (perceptions of technology), *Responsibilities* (of the autonomous actions), *Playfulness* and finally *Embodied Intelligence* (how people imputed intelligence from observed behaviour).

Fig. 4.6 Pictures that were taken by the balloons during the second trial.

Mechanistic and Animalistic Associations Akin to the first trial, there were recurring associations like *"UFOs"* and *"Sci-Fi"* (P13, P20, P22), but also a lot of links to animals. People again perceived the balloons like a *"pet"* (P13, P15), *"like a machine 'social butterfly' "* (P16). One participant stated that:

"Gold definitely seemed like it was better at its job, but I felt silver was the one I liked better because I felt sorry for it, like the runt of the litter." (P15)

Although this participant was more content with the golden balloon, she sympathised with the silver balloon in the end - to her the fact that the silver balloon seemed more uncontrolled and "needed help" changed her preference.

Another participant (P13) answered in the questionnaire that the balloons are *"tortoise-like"*. When asked about it in the interview he further explained that he had hermit crabs when he was younger and felt a strong parallel:

"They sort of reminded me a little bit of the things that I liked about the hermit crabs. 'Cause they kind of, they have their own, it's like they have their own agenda, like they are doing something but they do it very slowly. So you can't really work out what it is what they are trying to do. So you know like tortoises, which sort of just decide that it's time to go somewhere else." (P13)

"I think just because they are moving, that is a part of it obviously, and I think they have one eye. Anything that moves and has got an eye, is kind of halfway to being alive really, isn't it." (P13)

Clearly, his positive memories of past pets lead to sympathy towards the prototypes and reminded him of his pets.

It was just a balloon Three of the participants avoided any social language and indicated that they saw these devices merely as technology, which fulfilled some limited functionality:

"They were just there and doing their kind of thing. I didn't think it had a personality or something, it was just a balloon." (P19)

One participant showed interest in the balloons, but explained in the interview that he did not feel any empathy towards it:

"I didn't feel the need to take care of it. I thought that if it bumps somewhere it is its problems and to deal with it. And it was more interesting to see how it deals with it and do not rescue it or something." (P23)

It seems to be an approach to technology in general, which seems to guide perception here. The participant explained further that, for him, it is similar to other things that exist around us and that we need to be careful for ourselves, like, for example, automatic elevator doors:

"They close themselves and if you decide to jump in when they are closing it is your decision and you want to risk to be stuck in or hit you, just don't do it. So I think it is the same with other objects and the balloons are similar." (P23)

Responsibility During the second trial one participant touched the propeller and slightly hurt her finger. I found that situation interesting and discussed it in the interviews. Participants were asked, if an autonomous device hurts someone, who is responsible for that?

"The person who deployed it, so I think it would be you in that situation in that particular context, it would be the person who was using that piece of equipment, if you want to reduce it to that." (P20)

"I don't know, I'm kind of always have the opinion that if things are really obvious hazard, that you don't have to be around, then it's kind of a little bit your fault." (P13)

Despite the perceived autonomy, and in many cases personality, of the balloons, participants abdicated the balloon of any responsibility for its actions. Though autonomous, it was still viewed as man-made and a *"piece of equipment"* (P20), with responsibility attributed to a user who was not careful enough, or whoever created and deployed the device without ensuring it was safe to use. I feel that this question is a potentially interesting litmus test for future explorations of autonomy.

Playfulness Although not an original design intention, participants commonly perceived Diri as playful:

"I mean flying objects are just fascinating generally, I think that the interaction with, especially the face tracking one, where there is this little flying thing and you want it to photograph you have to stand in front of it and you have to look it in the eye that's really unusual, like I've not tried to do that with anything other, I've never tried to interact with something flying like that." (P13)

"So it did move and it, we had to get out of the way but it was also the idea that it had facial recognition, which was just fun." (P19)

"Honestly, it seemed like they were being playful." (P15)

"Reminds me of fun/games I used to play when I was younger. It pertains a joyful and placid character. The tranquillity of the balloon (without the motor) and the way it flowed around reminds me of flying (which calms me :))" (P21)

One person who was in particular engaged and interacted with the balloons explained his excitement:

"I commented that felt almost playful, certainly the golden one that came down and came very close to you, it did feel a bit like a puppy or something playing with you or something like that, there was a playful element to it." (P20)

"I've got children of my own and they're obsessed with balloons and whenever they see a balloon they are very excited by it. So it brought back some of the childhood memories." (P20)

This indicates again how strongly personal experience and interests guide perception. Thinking about the good times P20 had with his kids and playing with balloons, that was almost the only thing he associated with the prototypes and this inspired his feelings of joy during the workshop.

Embodied Intelligence Similar to the first trial, participants were attributing mental capabilities (like knowledge) to the balloons from observing their behaviour:

"I enjoyed more the one that knew where it was going." (P21)

Actions were made sense of by ascribing a motivation and events were interpreted as intentional actions, e.g. when balloons would approach the participants:

"Sometimes they seemed to sneak up." (P13)

"They demanded attention." (P16)

Particularly intriguing was the way in which participants were projecting lifelike qualities onto the devices through their actions:

"I felt that the golden one was friendlier, it did more what it was meant to be doing. It was better behaved. Whereas the silver one was floating around and maybe not behaving as much." (P18)

"One of them was quite aloof and sitting back and watching and the other one was coming towards us more." (P20)

Due to the different ways by which pictures are initialized for each balloon in the second trial, the difference in behaviour was clearly more apparent for all participants. In general, Diri #2 was much more appreciated because it was easier to control in the participant's eyes, especially for the task to provide certain pictures. Interestingly though, half of the participants in the second trial also stated that apart from that, they thought both balloons were the same. Again, most of the participants found Diri #2 to be noisier (P13, P17, P20, P23).

4.7 Summary and Discussion

Below, the lessons learned for autonomous interface design are presented. Following on this, the framework from Chapter 3 is re-evaluated, reflecting on how the results supported it, but also suggesting how it might be productively modified.

4.7.1 Interfaces As Social Actors

People will be willing to accept autonomous interfaces, similar to a pet, in their environment This case study aimed at exploring how people perceive a camera interface as soon as it is actuated and if flying objects could also be designed as our companions. The evaluation confirmed earlier work regarding autonomous technology that people's tendency to perceive technology with an intentional character - especially when it shows indications of autonomy - is pervasive and frequently observable. Humans have a natural desire to reason about behaviour as it is of evolutionary advantage to make rapid categorical distinctions, for example, predator / prey / inanimate object (Reeves and Nass, 1996). Being able to make more accurate predictions served us well in the past. These things have made us experts in detecting movements and extrapolating meaning from them (Jung et al., 2013b). As noted in the workshops, this accounts for 'passive' observations, where users and the balloons are just present together in the room, as well as for direct interaction. There were a number of situations where the participants tried to make sense of a prototype's behaviour by explaining it in reference to social acts - change of orientation means shifting interest, colliding means fighting. Particularly in the first trial, where there was more opportunity for the balloons to interact with one another, participants were more likely to ascribe socialised understandings to the balloons' behaviours. Perceptions of autonomy are potentially further underpinned by seeing how the devices interact with one another rather than the user.

Interestingly, and further to the discussion of imputing lifelike qualities into the mechanical objects, are the strong associations to animals that the participants made, and especially to pets. This supports related work; seeing a similarity between certain technologies and animals is quite common (Helmes et al., 2011; Jung et al., 2013b; Sung et al., 2007). I assume that these associations arise because autonomous interfaces share characteristics with pets: they co-habit space with us; we try to make sense of their ambiguous behaviour; they are partly reactive; we can't communicate with them very well (we can't talk to them); they sometimes need our assistance.

I also noted that people are more understanding when social technology makes mistakes because this resonates with our human fallibility (Breazeal, 2002). For example, some participants were more forgiving of the silver balloon, the lack of navigational skills earned sympathy. We can deduce that people might be willing to accept autonomous interfaces in their environment, like pets, presumably making similar allowances for their otherwise non-deterministic behaviours (Sung et al., 2007).

4.7.2 Appropriating Autonomous Interfaces

It is futile to design for certain perceptions or social reactions This study set out to gain a better understanding of human perception. It became clear that perceptions are strongly coupled to individuals' life experiences (lebenswelt (von Uexklill, 1957)). I received a lot of differing opinions from the participants about the balloons. In the same way that a movie can give rise to differing emotional responses in different people or the same movement leads to different interpretations (Jung et al., 2013b), people respond differently to technology (McCarthy and Wright, 2004). For example, two participants, who each come from a family with a lot of brothers and sisters, described the relationship between the two balloons like that of a sibling relationship. One participant recognised their past pets in the balloons. This represents a strong indication that our own life experiences influence perception strongly and can lead to projection of our own experiences onto the interfaces (McCarthy and Wright, 2004).

How might autonomous behaviours in interactive technologies promote certain kinds of social reactions in users? The answer is that it does not seem to be possible to design to promote certain perceptions or social reactions, as this strongly relies on the user's life experience. Users naturally focus on the thing that they are interested in. There seems to be a *paradox of autonomy*. The more a designer aims to create autonomy, the more room is left for users' interpretations, leaving the designer with less control in the end. This underlines the importance of a system staying open to users' interpretations and the wide range of possible meanings to be derived from a system's appearance and behaviour (Sengers and Gaver, 2006). During the design process of TAIs, when incorporating autonomy into interfaces, it is therefore not advisable to rely on or design for rigid interpretations. In the trials I experienced that even with radically different interpretations, an autonomous interface can still be enjoyable and the interaction pleasant, as long as it is engaging or reaches the desired goal (to change behaviour, attract attention, support well-being etc.). Frequently, designers will struggle to foresee the associations that users will make. Therefore, they should embrace some ambiguity in their design, such that they can create something fitting for different lives, or even something that users can fit into their lives themselves. I therefore underline the importance of openness in designing TAIs.

4.7.3 Anthropomorphising Intelligence

Functionality is attributed to the object of interaction Striking was how the participants saw the balloons as self-contained entities and perceived that they - like any living being - solve their tasks independently. For example, apart from two participants who were familiar with face-recognition algorithms, the participants assumed that Diri #2 performed the face recognition, although the pictures were streamed and processed on a separate computer. This has strong implications for design, it underlines that at least some participants perceived the rather scattered technology as one; no matter how distributed the technology might be, for the participants the device is the one solving the tasks. It's a similar notion which exists with software agents like Siri. Users assume that Siri is comprised of a single entity, although this system consists of millions of shared processes, executed and transmitted between a plethora of servers and devices.

A similar notion is nicely depicted in the romantic science-fiction movie *Her* [3], where a man falls in love with an operating system (based on natural language), assuming it to be truly human-like.

Again, participants relate a system to what they know from real life - entities, which can't be invisibly controlled remotely or distributed. Dennett (Dennett, 1997) suggests that when we don't know the physical details of the device, we treat it as one of our fellow living beings. We can't help it and try to predict the actions of a device, driven by possibly shallow assumptions about its inner workings. The implication for design is, that people tend to take things as a whole, even if the processing is invisibly distributed between different technological artefacts. Data analysis can be outsourced, the user will still attribute the functionality to the autonomous interface with which they are interacting.

4.7.4 Exploring different Sophistications

Similarity in appearance can obscure difference in behaviour Perceived differences between the two implemented behaviours were less apparent for participants than initially anticipated. In evaluation, it is challenging to implement different characters and sophistications amongst devices with highly similar interfaces. One thing to keep in mind when designing with autonomy is that, under certain conditions, humans strongly impute intelligence and might ascribe qualities to objects that these in fact can't offer (Taylor, 2009). The participants demonstrated this notion of imputing intelligence into the devices. Although Diri #1 was arguably less intelligent (because it contained less complex sensing capabilities), people still seemed to project intelligence onto the device, despite actually lacking abilities, as it was highly similar in appearance to Diri #2. To my knowledge this is the first attempt to compare two autonomous interfaces that show such similarity in appearance, but possess different levels of internal sophistication and therefore behaviour. I suggest this as a challenge for designing with autonomy: differences in behaviour in devices, highly similar in appearance, can be too subtle and hard for users to spot, because people will look for socialised explanations of differences in the behaviours.

Helmes et al. (Helmes et al., 2011) attempted to compare different levels of sophistication, through three visually distinct autonomous devices. The observed participants showed higher engagement and interest in the most sophisticated rudiment. In contrast to rudiments 1 and 2, which followed very simple rules, rudiment 3 clearly changed its behaviour over the course of the deployment. It learned to 'identify' faces, but remained to an extent ambiguous. Not

[3] http://www.imdb.com/title/tt1798709/

only was it reactive to the presence of individuals, it also actively adapted to the users and the environment. Both of the devices followed pre-programmed rules, resulting in being reactive to the environment and at times acting randomly, but otherwise showing persistent behaviour over time. An adaptation over time, as an observable change in behaviour, makes users more likely to ascribe an additional level of sophistication to a device.

4.8 Summary

In this chapter I presented actuated helium balloons with an aim to explore autonomous user interfaces. The design process was described which potentially contributes to discussions of autonomous interfaces in interaction design. Through the evaluation of participants' responses to the balloons a diversity of opinions was recorded, which was used to develop further understanding of users' perceptions of autonomy. The results show that autonomous technology will be more acceptable to users, in a similar way that they are towards pets. Since every user brings his own life experience into the interaction, it is futile to design to prompt certain social reactions. The participants ascribed all functionality to the object of interaction, which opens interesting opportunities for design. And finally, through the study setup I realised that it is difficult for users to spot differences in behaviour of prototypes which look alike.

Chapter 5

Exploring the Perception and Output Space of an Interactive Desktop Lamp

In this chapter I present the second case study, an actuated desktop lamp for the office. We have seen that everyday objects can now be 'brought to life' through autonomous technology, and interfaces are disappearing within our environments (Weiser and Brown, 1997). The decreasing costs of embedded sensors, actuators and processors have meant that it is increasingly viable to design interactive actuated artefacts for everyday use. This phenomenon of ubiquitous computing has proved useful in many different application areas, such as domestic areas, health and office workspaces (Adam, 2006). In this case study, I aim to understand how users perceive and would interact with everyday objects that come to life through embedded actuators. We know that actuation makes technology come alive. But how do people actually feel about it in an everyday life setting? And what consequences does this have for designing technology? The first study in this thesis explored a new, ubiquitous technology exposing autonomous behaviour - actuated helium balloons. With the second study, I focus on a more personal device and design and evaluate an interface that only interacts with a single person. We learned in the previous chapter that people accept autonomous technology in their environment and that every person has their own interpretation of a device's purpose. Furthermore, differences in behaviour were hard to spot for users. In this chapter, in a *research through design* setting, I want to further explore these factors with a new prototype that exhibits autonomous behaviour. I was also interested in the implications of a user interacting with an autonomous interface on their own, in comparison to a group setting, which was investigated in the previous chapter. Another factor which was tweaked in this study was to provide a device with higher functionality. As the function of the balloons was more open - to document the space - the lamp should enable functions, which are more specific to the user. With this, I wanted to explore if giving an autonomous interface a more direct function would make it more acceptable.

To do this I decided to create an actuated desktop lamp, functioning as a small companion to transmit reminders and notifications. I set out to investigate how an interactive lamp could convey various messages and system states to an observer in a meaningful and human-readable manner, using only ambient movement. How could an interactive desktop lamp be designed to be acceptable and appropriate? How social or unsocial can an abstract, autonomous interface be? To investigate these issues two studies were set up. In the first study participants actively explored how an interactive lamp might display notifications related to a work scenario through enacting various motions with a passive lamp. I aimed to find out how people envision such a lamp to work and act on their desk, but also, functionally, which possible gesture sets of lamp movements might commonly be meaningful and interpretable by users. To this end, and as a part of a user-centred design process, instead of presenting suggested movements to the users, users should create movements and motion patterns themselves. This way I could involve users earlier in the design process. But how acceptable and usable would the generated designs be in real life? In the second study, a subset of the generated movements was tested with a new set of participants in a semi-realistic office setting. With this, I investigated the functionality and practicability of the lamp.

Conventional autonomous technologies in the office environment, like the interactive virtual guide Clippy, proved to be distracting and annoying and were not well received (Whitworth and Ryu, 2008). Consequently, to some extent I expected people to dismiss the idea of having autonomous technology in their work environment. Furthermore, literature on technology interruptions at work yielded various results, reporting on interruptions making people more productive but also increasing stress (Mark et al., 2008). Research also showed that reminder technology needs to show a degree of ‘politeness’ to be acceptable (Bickmore et al., 2007). Which behaviours of a desktop lamp would be seen as ‘polite’? I wanted to explore users’ perceptions of interruptions performed by autonomous technology. Hence, I asked how we could leverage the fact that people react socially towards technology to create autonomous devices that are acceptable? Ultimately, I was interested in aspects that make autonomous technology suitable at work or not.

5.1 Related Work

Research previously explored technological augmentation of desktop tables to support the user with daily tasks (Bailly et al., 2016; Ullmer and Ishii, 1997). Actuated desk lamps were mainly studied regarding emotional output expressions (Gerlinghaus et al., 2012; Hoffman and Breazeal, 2008) or user gestures to control the lamp's location and spotlight (DeVito and Ramani, 2014; Lin et al., 2014; Linder and Maes, 2010). In the following I highlight the most influential cases for this work.

Gertie (Gerlinghaus et al., 2012) is an open-source desk lamp, with five degrees of freedom (DOF). The authors analysed human body language to carefully design the expression of emotions into the lamp. In an online survey with 84 participants four different emotions (fear, joy, sadness, and surprise) were evaluated. The results show that users could reliably identify joy and sadness, but not fear and surprise, which oftentimes were confused with surprise and disgust. This chapter aims to investigate user-generated movements mapped to certain notifications, rather than predesigned ones which aim to communicate emotions.

DeVito et al. (DeVito and Ramani, 2014) created user gestures to control an actuated desk lamp. A depth camera was used to detect users' hands and therefore enables them to use their hands as an input. To design the different gestures, they used a user-centred gesture design with 23 participants providing gestures for different tasks such as turning the light on and off, dimming and shining at a certain location or object. A more playful example is a disco lamp (Lin et al., 2014), a lamp that tracks a hand to provide light in that area and can dance to music. The authors augmented an ordinary object with entertainment and tracking capabilities. Their prototype contains four DOF and an RGB LED and reacts to a user's hands and music. Whereas these two studies focus on gestures for the user to control the light, my aim was to understand the possible movements of a desk lamp for certain office scenarios.

The most sophisticated robotic lamp was presented by Hoffman (Hoffman and Breazeal, 2008), where a cognitive framework for fluent human-robot interaction is introduced with the case study of a collaborative desktop lamp. A work space is set up in which a user can direct the lamp's head and therefore guide the light with their hands, as well as change the light's colour. The presented cognitive architecture led to higher fluency as well as shorter task completion times in comparison to a normal control algorithm. Participants were impressed with the robot's performance and collaboration worked very well. Some participants even stated a feeling of inferiority during the task when mistakes were made, while the prototype solved the tasks.

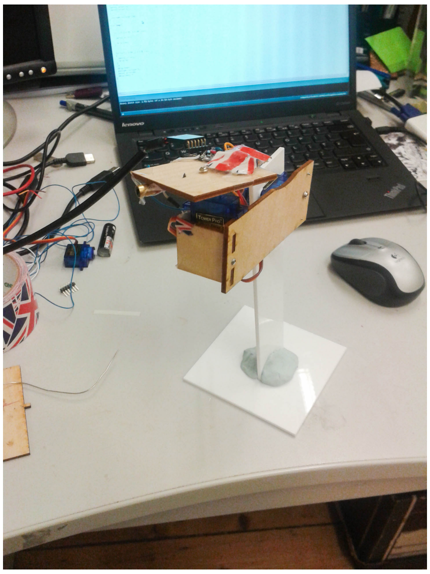

Fig. 5.1 This is an early prototype of the lamp, where I explored different ways of positioning the motors.

Inspired by these examples, I wanted to know how to design a desktop interface that is not intrusive, confusing or uncanny and is able to support users with their tasks in the office through notifications. Against this background of work (and earlier literature in general), I was also curious how the lamp would establish itself as a social desktop companion and therefore enable a more enjoyable interaction.

In summary, more research is needed in autonomous tangible desktop interfaces to understand what kind of interactive object behaviours users would accept and desire. The lamp presented in this chapter serves as an exemplary interactive object. Instead of focusing on user's gestures, I explore to what extent it is possible to communicate certain messages through lamp movements with a user-centred approach in the context of a working environment.

5.2 Interactive Desktop Lamp Prototype

Two versions of the desktop lamp were built, one for each study. The first interactive desktop lamp comprises two geared joints, attached to a box with a potentiometer. The second lamp comprises three joints, each consisting of an actuator. Various designs and different degrees of freedom were tried, see Figure 5.1 for an early prototype. In the end, three actuators turned out to be least constraining to the movement (illustrated in Figure 5.2).

The lamps are made out of laser-cut plywood and their design is plain and functional. For both, the top construct comprises an RGB LED, which has one degree of freedom, and can be turned/actuated each side by about 90 degrees (see Figure 5.2). The second joint is located between the two middle pieces, allowing the lamp to fold or bend forwards or backwards; it can turn by approximately 180 degrees. For the first study the bottom piece is glued to a box, which holds an Arduino board to control the lamp and a potentiometer (0 – 270 degrees). The second study included one additional motor at the bottom, which allows the lamp to rotate around its centre, approximately 200 degrees in total. The second lamp comprises an Arduino Yun board, and when connected to a WiFi network, its movements and light can be controlled remotely through a python program. For both devices, the potentiometer controls the light intensity, e.g. turns it completely on or off, or dims the light.

5.2.1 Relating the lamp to the framework

Like in the previous chapter, the framework introduced in Chapter 3 guided the design. The appearance of the lamp is not aimed to replicate human or animal joints, but look as much like a regular lamp as possible. The requirements for the material aesthetics were that the lamp should be plain and straight-forward. The form should primarily be guided by the function (conveying various messages to the user). Mapping out the lamp's position on the scale *zoomorphism* (see Chapter 3 – Bio Metaphor), would mean to place the lamp in the region as *machine-like* as possible. Again, the aim of this is to focus on the function and not convey skills through visual cues, that the lamp does not hold. Therefore the lamp only consists of two arms, so it can be adjusted upwards and downwards and a cone as the top holding the LED to provide light. To allow multiple DOF, the top construct can rotate as well as the bottom. Similar to all or at least most interactive desk lamps, the prototype is partly inspired by Pixar's "Luxo Jr." (a short animation with two lamps jumping around and showing human behaviour), as this is a very well-known and wide-spread example of an animated desktop lamp. To not bias the participants or encourage them to anthropomorphise the lamp, no name was given to the lamp.

The ambiguity of the behaviour lies in the fact that the participants were not told why the lamp executed certain movements. I was hoping that this would allow the participants to figure out the meaning by themselves and also invite them to make their own interpretations.

Finally, in the study, the lamp is remotely controlled (Wizard-of-Oz) and therefore the sense of autonomy is conveyed through remotely triggered actions. To the user, however, the capabilities of the lamp consist of having access to certain digital information such as messages, the user's calendar for notifications and also the ability to be actuated in a certain way to demonstrate notifications.

5.2.2 Quality of Movement

To make robots appear more lifelike, roboticists explored principles of animation to create more natural forms of movement (Ribeiro and Paiva, 2012; Van Breemen, 2004). Decades ago, animators established a set of practices which enhanced cartoon characters' motions to convey their emotions and attitudes (Price, 2009; Thomas and Johnson, 1981). To give a few examples, these principles include simple rules such as *Arcs*: lifelike movements are never linear, but vertical movement is always accompanied by slight horizontal movement. Similarly, *Slow In Slow Out* describes that movements never start and stop abruptly, a movement starts slowly becoming quicker and then slower again before halting. *Exaggeration* of a movement,

Fig. 5.2 The final lamp's DOF for the top and bottom actuator and the potentiometer to control the light.

so increasing the valence, helps to underline the intention of the character. Equally, there is a large body of work investigating ways in which robots are able to gesture towards humans (Bremner et al., 2009; Riek et al., 2010). To make communication between humans and robots as easy as possible, these robots need to contain humanoid forms to utilise human gestures. In this thesis, I wish to explore responses to machine-like interfaces, which don't aim to copy human movement but are expressive in their own technical way. In this chapter, therefore, I was curious to find non-human ways of communication between humans and machines and explore how this communication affects interaction. For this prototype, as I was aiming at a more functional design, the movement was designed in a simple, mechanistic way without applying the guidelines presented above. The lamp initiates its movement and it stays at the same speed till the movement stops.

5.3 Experiment Design

The aim for the studies was twofold. Firstly, to collect ideas for output that can be realised by a desktop lamp to 'display' information and through the analysis of the user-defined actions hopefully allow for the generation of guidelines for lamp-articulated communication. Secondly, to qualitatively understand how users would like such a lamp to function and how they would feel about interacting with such a device. To understand how to design such interactive technology, but also how it is perceived, I was interested in social reactions to technology and what social behaviours people would show towards the lamp. Which social norms are appropriate for an interactive lamp? What would be classed as unnecessary or an annoying activity?

Ultimately, I was hoping that the ideas collected in the first study would help design potential interactions for an interactive lamp that for instance reacts to input provided through a digital calendar or through information about the user sitting on the desk provided through cameras or physiological monitoring. A description of the first study follows, consisting of the gesture collection, and its evaluation and findings. Then I go on to describe the second study, a follow-up, exploring the designed movements in a semi-realistic setting.

Fig. 5.3 The office setup for the second study.

5.4 Study One - Gesture Collection

5.4.1 Setup

The setup for the first experiment consisted of an ordinary work desk in a small office room (see Figure 5.3). I tried to create a realistic setting and therefore cluttered the desk with various objects: a laptop, books, a mobile phone, some pens, and a water bottle were placed on the desk. Furthermore, a map and a picture of a clock were attached to the wall in front of the desk. Although this still represents a lab setup as the participants were not sitting at their own desks, such a configuration is surely not unusual, i.e. strongly resembling a modern hot-desking situation in various office environments (Höpfl and Hirst, 2011).

To discover and probe possible lamp movements, the approach relied on investigating user-defined lamp actions (which is quite common for other technologies such as surface computing (Wobbrock et al., 2009)). The study included 13 participants, ranging from 22-53 years (6 females and 7 males, mean age 30). The users were asked to use the lamp as a puppet and let the lamp display tasks that are messages to a person at the desk. Table 5.1 lists the 20 tasks that were shown to the participants (each task was printed on a card). These were grouped into four categories: (i) draw the attention of the user to something (the user / an object / place / event

1. Politely attract the attention of a person
2. Urgently attract the attention of a person
3. Shift the attention of a person to a thing on the desk
4. Shift the attention of a person to a thing on the wall
5. Shift the attention of a person to a place outside the room
6. Suggest that a person made an error (e.g. during typing something into your computer)
7. Notify a person to meet somebody in a meeting room now
8. Notify a person that their smartphone is ringing
9. Request a person to call Bob
10. Warn a person that the house is on fire and he/she must leave
11. Notify a person that a text message arrived
12. Notify a person that an email arrived
13. Suggest to a person that they go to lunch
14. Suggest to a person that they go home
15. Remind a person to go to Lisa's party
16. Remind a person to drink some water
17. Remind a person to move/stand up (engage in physical activity)
18. Suggest to a person to calm down, his/her heartbeat is too fast
19. Let the lamp say hello to you
20. Let the lamp say goodbye to you

Table 5.1 The 20 tasks that the participants need to communicate using the prototype.

etc.), tasks 1-6 in the table, (ii) notification of incoming messages or upcoming events (from a calendar, mobile phone or email client) – tasks 7-15, (iii) change the user's behaviour (drink water, motivate movement and calm down) – tasks 16, 17 and 18 and (iv) two social messages: say hello and goodbye – tasks 19 and 20. To explore a wide range of possible notification types, specific tasks (e.g. a new email arrived – Task 12), as well as more ambiguous and open ones (e.g. say hello – Task 19; catch a user's attention - Task 1) were chosen. This implies that the task meanings possibly overlapped. I was curious which solutions people would find for various types of communication. The cards were randomly mixed for each participant. Then the participants could create actions by changing the lamp's pose, position, and light intensity. Each person had to sit by the desk and manipulate the lamp so that it was displaying the information towards themselves. The participants were invited to talk along and explain their thoughts and ideas. Every session was captured with a video camera and lasted between 15 and 45 minutes.

5.4.2 Analysis

The analysis is separated into two parts; I looked at the 'lamp output' that users created, but also carefully observed any social behaviour and comments the users made towards the lamp. During analysis, while I created a catalogue to capture the gestures textually, I realised that the participants manipulated the lamp in one four different forms (and combinations thereof). The users changed the *posture* of the lamp (changed the position of the top or bottom joint or both joints), *displaced* the lamp by physically changing its location on the desk, *dimmed* or *turned the light on/off* or let the lamp *point* at something/someone or somewhere by directing the top to orient towards the desired target. Changing the posture of the lamp meant any manipulation of the lamp's form without pointing at something. Then all comments from the users that point at an envisioned usage or subtle utterances that describe the relationship the users form or imagine with such a device were transcribed. The next sections discuss the results of thematic analysis on this data.

5.4.3 User generated Lamp output

This section presents the results and findings from the first study. Two snapshots from the video recordings are illustrated in Figure 5.4. Here, I will firstly present how the participants let the lamp communicate the tasks and which gestures and outputs were used. Following that, I discuss the design opportunities that emerged through analysing the results.

Each participant stated that it is nearly impossible to communicate each task through a comprehensive and unique action, especially with a device that holds such limited actuation. However, they also realised that not every reminder message necessarily has to be unique. The context in which the device is embedded is of high importance. One real-life example for this might be a standard alarm clock. People just need the cue and naturally understand the purpose. Therefore, the participants did not worry that outputs for different tasks were very similar. They stated that they would know what the lamp wants to communicate in that special situation. For all participants, it was harder to 'visualise' abstract things like 'call Bob' or 'go to Lisa's party' than point out specific things such as 'your phone is ringing' or 'drink some water'.

Overall, all outputs can be put into one of two categories. The participants either used the lamp for (i) pointing at the user, an object or a location or (ii) making a gesture with the lamp / set the lamp in a certain posture, which is independent of the environment (e.g. to lower the user's

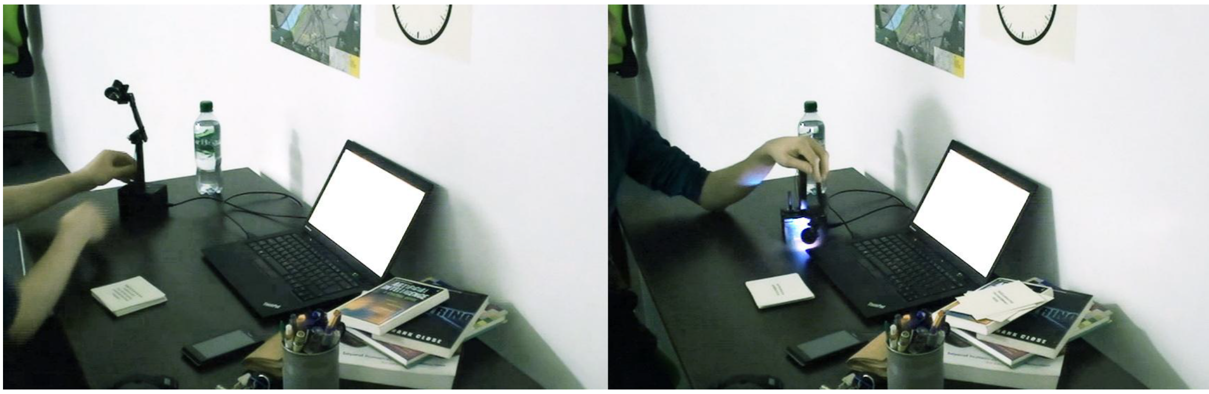

Fig. 5.4 Pictures with participants manipulating the lamp, extracted from the video documenting the study.

heartbeat or remind the user of a party). Additionally, light was used to either attract the attention of the user, to change the atmosphere (dim the light, turn it off) or communicate a message very subtly.

For catching the attention of the users or drawing attention to something (tasks 1-6), most participants used the lamp to point (70%).

To remind the user of something (tasks 7-15), the participants again mostly pointed to the object of interest (66%) and flashed the light (45%). For the lamp output these tasks were very similar to tasks 1-6 (attract attention) as for the participants they followed a similar agenda: find the object of interest and direct the user's attention towards it.

For the behaviour change tasks (tasks 16-18, drink water, engage in physical activity and calm down) the participants saw the lamp as a physical role model, mimicking actions a human would do, for example getting up or breathing slowly. For standing up (engage in physical activity, task 17), eleven participants would change the posture of the lamp. For calming down the user (because their heartbeat was too fast, task 18), six participants chose to change the posture of the lamp. Ten people would flash the light either to the heart beat of the user or the desired (slower) one.

Typical responses for the 'social' tasks (19, 20) were to point or 'look' at the user's face (participant's choice of words) and then change the posture (58%) for example by waving 'hello' or 'goodbye'.

5.4.4 Social behaviour towards the lamp

In this section, I would like to discuss ‘issues’ identified by the participants or interesting aspects and behaviours that were observed during this study. Overall, three themes emerged: *Appropriateness and Politeness* informed the participants’ statements about how the lamp should behave. *Familiarity and Context* discusses how the behaviour of the lamp could change once people got more familiar with it. Finally, *Perception and Appearance* depicts the associations to other living beings people had while interacting with the lamp. Each section is described by providing quotes from the sessions and closing with design implications.

Appropriateness and Politeness A lot of comments revolved around appropriateness of such a device in the workspace and ‘polite’ behaviour of the lamp:

“It could point at me but not my face to be polite” (P2)
“Flash in my eyes only when it is really urgent” (P3)
“Right in your eyes is very annoying, it is intrusive and not very pleasant” (P5)
“To be polite I would dim it down a lot” (P9)

Not surprisingly a polite movement needs to be subtle and slow and also easy to ignore. Some participants tried to solve politeness for the lamp by relating to human behaviour:

“wave slightly is polite” (P1)
“polite means like knocking the door, but not opening it” (P11)
“A very polite gesture...almost like waving to a waiter” (P12)
“politely, like a whisper.” (P8)

Other actions resembling human behaviour appeared: knocking with the top of the lamp against the wall to indicate a place outside (task 5), ‘dancing’ (task 15), repeatedly leaning backwards and then forwards to imitate ‘breathing’ (task 18) or doing ‘press-ups’ to motivate physical activity (task 17). Users let the lamp ‘faint’ by quickly bending it backwards or ‘relax’ and lay back by slowly bending it backwards (task 17 and 18). Folding the lamp was used for ‘sleeping’ (task 20).

Furthermore, it is crucial for an appropriate lamp not to interrupt the user during their work. The participants underlined the importance of the lamp being responsive, it should be able to detect when the user notices the lamp’s prompts and stop producing output or at least decrease the strength. If a message is very important and the user is not reacting though, increased measures could be followed:

"If I have not responded, flash on my face" (P6)

Other interesting situations emerged. A few participants placed the lamp between themselves and the laptop if something really urgent came up or the user did not react to previous output. Some participants could even imagine that the lamp 'knocks' its top part against the user's wrist or even their head. However, such salient lamp actions were only desired by few participants. The social behaviour expected from the lamp seems to differ a lot between the users and might depend on their personality.

Familiarity and Context It was interesting how participants realised that not every reminder message has to be unique and explicit to be understandable, but that it is something that needs to be agreed upon beforehand.

"I am aware that I have to do something, so when it lights on the clock, I would probably check my calendar, just to make sure" (P9)
"There are too many things, you almost have to develop a relationship with her so you know exactly what she does." (P11)
"I would have to know that, it is not very intuitive" (P9)

Therefore although participants tried to create distinct gestures, they did not worry about gestures being similar. They stated that they would still be able to understand the output in the context.

"I guess you get to know the lamp and know this is actually worth getting up for or it's not" (P9)

The lamp's output could possibly become weaker with time, as users might pick up on the messages and be able to identify what the lamp aims to communicate.

"It could start doing it less as I learn what it means. As it is noticing that I'm doing a lot of mistakes, it will not go up all the time, it starts just a little bit." (P2)

Customisation was also seen as a great benefit, e.g. to let users easily change things they could not accept:

"It is something I chose to have, if it bothers me I would put it away" (P5)
"Minimal movement would be polite, otherwise when it shines into my eyes, that is the quickest

way to make someone hate the product." (P6)
"Would be great if I could set this myself" (P13)
"[Shining in my eyes] would be really annoying, to accept that I would have to set it up" (P6)

One participant suggested that it might be helpful to implement gratification into the behaviour of the lamp and therefore enable the lamp to 'learn':

"Some way of giving immediate feedback to the lamp could be useful, to help it to learn; like patting it on the head if it did something I appreciate." (P2)

The design implication for this case is that it is important to allow customisation. Users should be able to set the output in a way that makes sense to them. This would make it a lot easier to build a relationship with their lamp. A certain degree of reactiveness, so letting the lamp be sensitive to user's input, is another important factor. One example for this is automatically adjusting the strength of the lamp's output when the user notices the output (or not).

Perception and Appearance Although the visual design of the lamp was not inspired by or based on human appearance, participants strongly related the lamp's joints to human joints. The top of the lamp functioned as a head for the participants, with the LED resembling an 'eye' and the rest of the lamp the torso, which can lean back or bend forwards like a human.

"like a little animal telling me: look at the computer" (P10)
"Maybe look at me, it sort of is like an eye giving you attention, it would feel like it notices that I'm here, it's not very nice to get light in your eyes, but I do get noticed." (P9)
"I imagine the lamp putting its own actions as a proxy and demand the person to imitate what the lamp is doing" (P5)

Some participants further stated that they enjoyed when the lamp faced them, because it creates a connection which is similar to the one we have with other living beings:

"Maybe it faces my desktop and then looks at me and would say: are you serious? And then face again the desktop, so it would be a little fun." (P13)
"That's great to have a lamp like that in your environment, it can be your best friend" (P7)
"You feel a more personal relationship with it" (P9)

In particular, the idea of eye contact seemed important:

"but that's nice if the lamp faces me" (P13)

"Could be a very nice way of interaction, watching at me giving me a good morning as well as goodbye." (P7)

"I like the idea of eye contact" (P8)

"I still like the idea of the lamp looking at me [...] This lamp is a lot like an eye I feel like someone is looking at me so it would get my attention" (P9)

"My gaze would follow to see what it is looking at" (P12)

This again underlines how people treat technology as a social actor (Reeves and Nass, 1996). It also shows the perception of the participants that eye contact would make the experience nicer, the interaction more acceptable, and might help people to bond with the interface.

5.4.5 Summary

It was remarkable how diversely each participant approached the lamp. Each person had their own interpretation to start with, their own way of approaching the device. Some saw it as a companion, others as a mirror of oneself, a teacher/parent (a device that dictates its use) others just as a light. The results indicate that people's approach towards actuated interfaces strongly relies on their approach to technology in general, underlining a need for customisation once again.

All participants apart from three were very positive about having such a device in their environment. They stated that they were quite sceptical about the noise, but when carefully designed it could bring great benefits as a notification device. Therefore, a second study was set up to evaluate the suitability of the actuated desktop lamp. The three participants who were not very keen on an autonomous lamp explained that it might interfere too much with their work and be too distracting. One participant was concerned about the personal data such a lamp would need to collect to function ably (e.g. personal messages and calendar).

Before moving on to the second study I would like to summarise people's recommendations for the lamp's behaviour. In the following are a few design recommendations and implications, which are compiled from the participants' statements.

The lamp needs to be *polite* – unsurprisingly the lamp should act in a way that is appropriate in an office. It should not flash into people's eyes and only make subtle movements. The movements shouldn't be too erratic or too frequent. Although its movements are highly mechanical, the device should still ‘behave’ like a polite human. Some form of eye-contact could be a means of respectfully checking with the user and initiating contact.

The lamp needs to be *aware* – the lamp should be able to recognise when a cue has been detected and in that case stop giving hints. It should also be aware of a task being urgent and demand the user to act in that case as this would make the lamp helpful in getting certain things done or not missing out on important tasks. It also should know about its own environment, the things that are laying around, the room it is located in, and where the user is. This knowledge could be leveraged to provide clearer cues.

The lamp needs to *change over time* – the longer the interaction, the more a user gets used to the lamp’s cues. Therefore, with time, shortcuts can be made. After having interacted with the lamp for longer, the lamp can decrease the magnitude of its movements. It may only need to make small movements which the user would be able to understand because they were familiar with the lamp’s movements.

The lamp needs to be *customisable* – different people need different functions and cues. It should be possible to adjust the messages that are communicated or even be able to add new functions. It could also be useful to be able to control the frequency of the cues. The user could decide depending on how busy their day is, how often cues should occur.

5.5 Study Two – Gesture Exploration

5.5.1 Setup

To explore the movements, recommendations and social aspects which evolved in the first study, a follow-up study in a semi-realistic office setting was conducted. As illustrated in Figure 5.5, the study setup was very similar to the first study. Again, a desk in a small meeting room was set up with a laptop, books, a glass of water, pens, and the desktop lamp. I was curious about the appropriateness of the cues and how people would react to a little desktop notification device. I picked a subset of 6 notifications that the lamp would execute during the study (at least one prompt from each category): (1) Say Hi, (2) a text message arrived, (3) an email arrived, (4) drink some water, (5) look outside the room, (6) say bye. I picked at least one prompt from each category - seeking attention (5), change behaviour (4), a notification (2, 3) and communicate

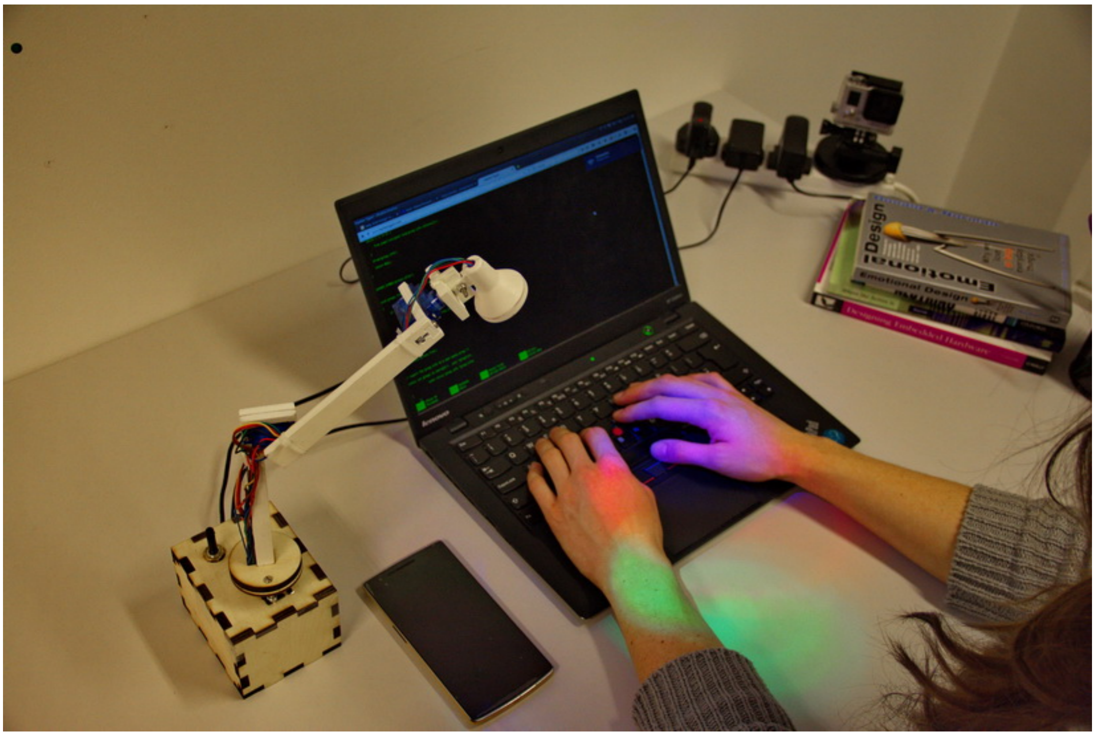

Fig. 5.5 The setup for the second study, a normal desk with a laptop, a mobile phone, some books, a glass of water (not in the picture, to the left of the lamp) and the lamp. The GoPro camera at the top right records audio and wide-field video.

socially (1, 5). To create these cues, I looked at the corresponding, proposed movements from the first study. Based on the majority, when at least half of the participants performed the same gesture, this choreography was adapted for the according cue. Furthermore, based on the results of the first study and key issues identified by the participants, the following design decisions were made:

(1) Make the lamp *polite* and *friendly* - to make the lamp more acceptable, it registers a message as 'received' or noticed when the user establishes eye contact. No more action is needed to reply to the lamp. The lamp can 'check-in' with the user by facing it before giving a prompt. The lamp should give the impression of being friendly and comfortable to be around. This is supposed to be achieved by the social prompts (say hi and bye) and direct addressing (gaze) but also by not being too active.

(2) Make the lamp *useful* - to make the lamp more functional it should react to people by registering attention and reacting to the user's reactions e.g. repeat notifications if the user is not showing any reaction. The focus was laid on only a few tasks and to not give too many notifications; as identified in study 1 this could get annoying quite quickly. Therefore, the lamp

also doesn't repeat a cue more than three times. The lamp is supposed to be subtle and in the background. It should still be useful and remind users when they have forgotten something. Therefore, the lamp repeats a notification if the user forgets something and doesn't react at all. Awareness also seemed to be of high importance, and the lamp should – to some extent – know its context, e.g. where the phone, laptop and the water bottle are.

5.5.2 Designed Movements

For the second study, the movements were based on the input generated by the users from the first study. I made sketches from the proposed movements and implemented these into the device. To make a mechanical and functional device, which isn't anthropomorphic, remained the aim. During the first study, additionally to turning the top part and folding the middle part, the users frequently turned the lamp around. Therefore the lamp was slightly altered for the second study and one additional motor was added to the bottom, which allows the lamp to rotate around its centre (approximately 200 degrees in total). In the following, the designed movements are illustrated and explained through a series of photos.

Standard Position and Gaze Figure 5.6 (a) illustrates the standard position, whereas Figure 5.6 (b) shows the position in which the lamp faces the user, it 'looks' at them.

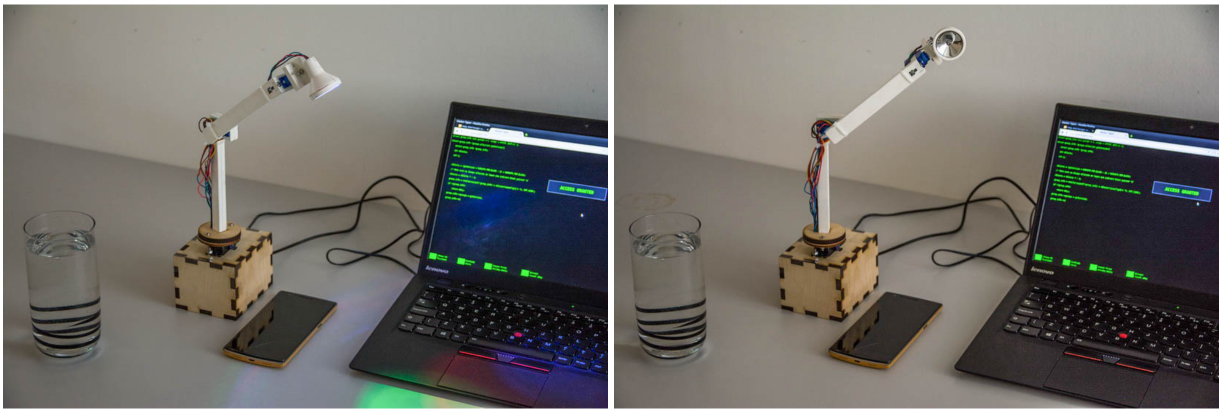

Fig. 5.6 (a) The basic position of the lamp on the desk. (b) The lamp is focused on the user. The top is turned, and the middle and bottom actuators stay in the basic position.

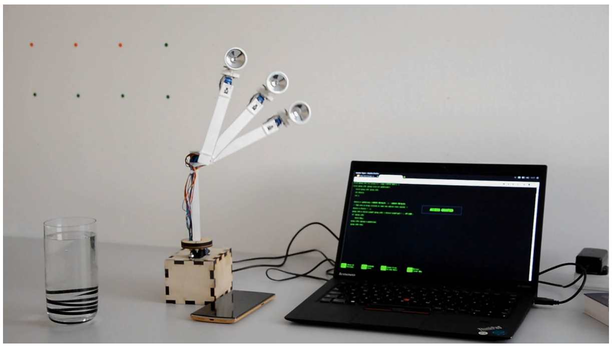

Fig. 5.7 Multiple pictures superimposed illustrate the movement of ‘Saying hello’.

Saying hello

This movement is supposed to greet the user when they arrive at their workplace and sit down in front of their desk. The lamp’s arm swings up and down three times and then moves back to the basic position. For the eye-contact condition the top is pointed towards the user, for the other condition the top is just in the basic position.

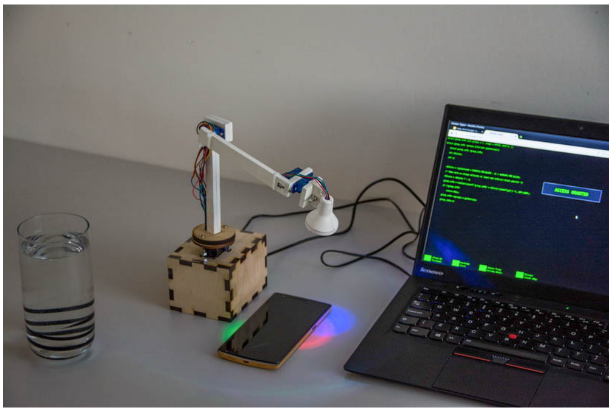

Fig. 5.8 The lamp indicates that the user received a text message to their phone.

A text message arrived

When a text message arrives at the user’s phone - in this study a message was sent me - the lamp leaves the standard position by bending over and therefore pointing at the phone. It then blinks three times. The top and bottom actuators don’t change position. Then it rises back to the standard position.

Fig. 5.9 The lamp notifies the user that a new email arrived.

An email arrived

During the study, I sent a trivial email to the user. In that case, a few seconds later, the lamp turns its top towards the screen and blinks three times to indicate the new message. The middle and bottom actuators retain their position. After this the lamp moves back to the standard position.

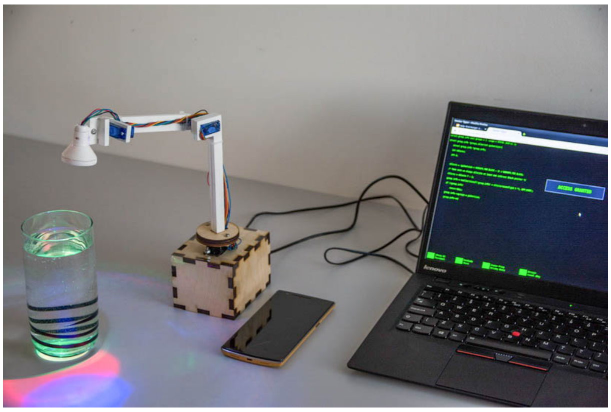

Fig. 5.10 The lamp points at the water glass to remind the user to drink.

Drink some water

To indicate that the user needs to drink some water, the lamp turns its bottom actuator and points towards the glass of water. The motor in the middle bends the device slightly downwards. It blinks three times before moving back to the default position.

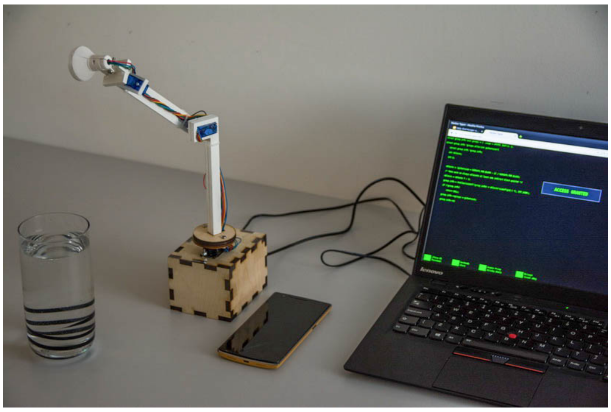

Fig. 5.11 The lamp points outside the room.

Look outside the room

To notify the user that there is something interesting outside the room (I was standing behind the door), the lamp turns around and faces the door. First, while the top is still in the default position it turns its bottom actuator around and then simultaneously the middle motor rises and the top turns to the right. The lamp stays in this position for about 10 seconds before returning to the standard position.

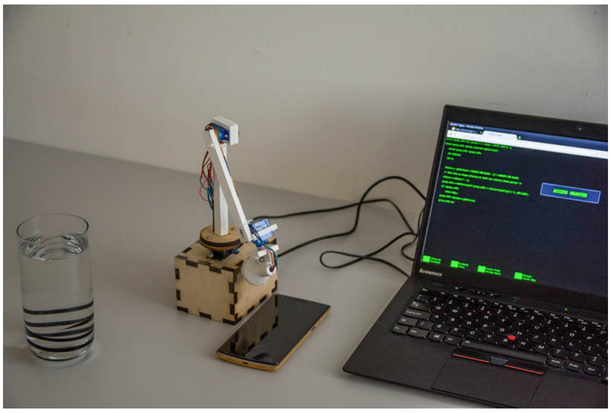

Fig. 5.12 The lamp folds to display inactivity.

Say bye

At the end of the study the lamp 'says bye' by folding and going into a 'sleeping' position indicating inactivation.

5.5.3 Procedure

Based on the findings of the first study a protocol for the second study was created. Between each prompt there was a time gap of 3-4 minutes. The study was Wizard-of-Oz, I hid in the back of the next room in a way that I could look through the glass door and see the participant and remotely trigger the movements. A random email or text message was sent before the lamp would point towards one of these devices. When a person did not react at all, e.g. didn't look at the lamp, turn their head towards it or show any reaction otherwise, I waited 10 seconds and repeated the prompt. After the third prompt the notification was dropped. It is possible that people might notice the lamp's actions without showing any reaction. However, the aim here was to simulate a system which is actually able to register affirmative behaviour, therefore the lamp repeated its behaviour if no obvious reaction could be detected.

To, again, resemble a typical hot-desking situation, each participant was asked to bring their laptop, their phone and something to read. While the participant filled out the demographic questionnaire and signed the consent form, I placed their laptop and phone next to the lamp on the desk in the room. To explore the intuitiveness of the movements and how easy these would be to understand, I didn't tell the participants which meaning the movements held. I merely mentioned that this study evaluates autonomous technologies and that they should go into the room, sit down and imagine they are at their desk working or reading. Basically, the participants were left uncertain about the study procedure. As soon as the participant sat down, the first cue ("Say hello") was given.

The study was split into two sub-sessions. Each participant experienced two versions of the lamp (in alternating order). One version of the lamp contained 'gaze', as most participants in the first study identified this as more 'friendly' and engaging. The lamp established 'eye-contact' by turning its top part (containing the LED) and therefore facing the participant for a few seconds before displaying a notification (with the LED turned off). In the other mode the lamp went straight to the notification. I was curious how the 'gaze' would impact on interaction and if people prefer it to rather functional behaviour. Each of the two sessions lasted about 15 minutes, and the order of the condition was swapped after each participant.

5.5.4 Data Collection

The room in which the study took place was audio and video recorded. After the second trial, a semi-structured interview was conducted, which lasted 20-30 minutes on average. The semi-structured interview explored the understanding of the lamp's functioning and preference and acceptability of the lamp's behaviour. As the participants could only guess the aim of the study, I first asked them how they felt to explore their perception of such a device. Then I asked if the participant noticed a difference between the two conditions and which they would prefer. If a participant didn't notice a difference it was explained to them. Next I wanted to know if the participants understood the cues by asking if they could make sense of the lamp's actions.

During the interview, each movement was replayed and the participants were asked about their interpretation. At the end of this, in the cases where the participants could not explain the meaning, the intended function of the movements was explained. The participants were then asked how it would make them feel to have such a device in their environment and what would make it more or less acceptable. I was curious how the participants felt about the movements and asked how they would customise them if they were able to. I asked if the lamp made the impression that it was alive and if it seemed like the lamp had its own intentions to explore whether it was perceived as a social actor. Finally, the participants were asked questions about interesting situations that occurred and which were observed during the study.

5.5.5 Analysis and Findings

Similar to the first study, audio was transcribed and video annotated. In the video, the participants' facial expressions and reactions to the lamp's movements were observed and interesting situations were noted down. The data was analysed in two ways. First, a thematic analysis was conducted on the interview data and six overarching themes were identified. Then, unusual, surprising or accidental situations, which occurred during the study, were picked up. I analysed people's reactions and behaviours in these situations through analysing the interaction. In order to develop a broader understanding of the potential of autonomous office technology, I unpacked these specific behaviours that occurred during the study. That is, to understand how people perceive and react to certain actions of the prototype and how a social situation with technology is constructed.

In the following I want to start with a broader description of what people answered in the interviews and how they behaved towards the lamp. The answers are themed in six categories. *Attitudes towards the lamp* explores the participants' feelings of living and working next to an autonomous desktop lamp. *A lamp that cares* discusses that people actually felt looked after by the lamp; and *The lamp as a team partner* how some participants teamed up with the lamp. *The lamp with an inner life* reflects the answers towards the question about whether the participants felt that the lamp was alive. As some participants struggled to understand the cues, *The annoyance of miscommunication* recaps their feedback. Finally, how people reacted to the lamp establishing eye contact is reflected on in *The challenges of mechanical eye contact*. Following this I want to present a second analysis, this time of the video data, containing snapshots of interesting situations where coincidences uncovered attitudes and dispositions of participants towards the lamp.

Attitudes towards the lamp I want to start with probably the most important topic and examine how the participants felt during the study and what they felt towards the lamp. They were asked to describe the lamp and also if the lamp felt alive or they perceived the lamp to have any intentions or motivations. People drew interesting implications from the lamp's actions.

In general, the responses towards the lamp were very positive. When analysing the video, I noticed that the first reaction of most participants, when they sat down and saw the lamp greet them for the first time, was to smile or even laugh. People perceived the lamp as a "little desk companion" (P3, P4, P8, P13), that supports them in everyday tasks.

"A little desk companion that hints at you [...] when it was looking at me it felt like 'hey, I am your friend' kind of thing." (P3)
"I felt that this is 'Hello, I am your assistant, I'm here'." (P5)
"I find it funny rather than creepy. To face me is probably good as a kind of like 'and now we are working together' sort of thing." (P12)
"I felt like the chemistry was right between us." (P14)

Every single participant had something positive to say about the lamp. Most probably due to its small size, repeat comments were made about the lamp being 'cute'.

"This lamp is so cute!" (P3)

"It strikes me as quite cute like a little pet that you have on the desk, I quite like it." (P7)

"Yeah, I'd like having it, it was cute." (P8)

"I thought it was like a cute little thing that would have its own thing. It's just so dinky, this little thing. It's quite sweet." (P13)

A lamp that cares Interestingly, people felt sympathy towards the lamp and interpreted its movement in a good willing way, as if the lamp would actually care for them. The perceptions went far beyond the intended functions:

"I think it was reminding me to get back to...not necessarily get back to work but sort of refocus on the screen. I think it kind of wants me to be sort of balanced, to make sure that I am not sitting down, staring at one thing for a good matter of time it wants me to sort of divide my attention." (P7)

"It is quite fun to be with, it is like having a child and it was, like a child might ask you if it could do something and you kind of maybe ignore it or say no and just like the lamp you kind of like 'Erm no not going to do that'. Yeah, it was interesting to have it doing different things. Like this little distraction thing. Not really distracting, this little playful thing in the corner that's kind of trying to tell you what to do but you are not necessarily going to do it because it tells you to. I kind of made it feel like I had a little companion and also it kind of felt, make me feel like I should be sat here working rather than just sat here, checking Facebook and things, so I went on like Twitter, but I went on that very quickly, because I kind of there was this little thing that was kind of trying to make me more productive." (P8)

As demonstrated in the two quotes above, some people felt the lamp would motivate them to work and keep up a schedule. Others thought it wants them to live healthier:

"Seemed benevolent, good willing, it was letting me know if I had a notification and suggesting that I stayed healthy, it didn't seem to force any agendas on me - it's like a little companion, I think I made a new friend." (P4)

"It's guiding you to take breaks and have a drink and move, look at other things away from your screen I think." (P5)

"[Interviewer: Do you think the lamp had a motivation to do things?] Yeah, in terms of, a plan to make sure I was OK, sort of drinking and notify me that I've got some messages and stuff like that. So a helper, an aid." (P9)

One participant even felt as though the lamp was keeping track of his actions, tolerating or dismissing them at its own discretion.

"Well, I saw the water and then I thought 'oh' I didn't know if you left that there or if it was part of the study and I thought I'm actually quite thirsty but then it wasn't till the lamp sort of gave me permission to drink it and I was like 'oh OK, that's cool I'll have some water'." (P14)

The participant was not sure about the lamp's intention and the thought came up that it only wanted to distract him:

"When it looks at, when it turns its head towards you, you think, 'oh, it wants something, what does it want?' So when it did that I thought it was just trying to distract me. So it was weird, sometimes I just thought 'oh, it sort of cares about me, it tries to help me by pointing at my phone and stuff', but then other times it was just felt like it was just trying to distract, cause I was trying to concentrate on something I'm reading, a new thing that I need to use [Interviewer: get on with it?] yeah like afterwards at times I ended up to me like 'what was I doing again? Can't remember' So he's troubled that one!" (P14)

These quotes reveal how quickly people imbue this autonomous interface with strongly positive intentions. The actions of the lamp, e.g. pointing at water or the phone were interpreted as some kind of support but at times as a distraction as well. Pointing to things in this scenario meant caring for the user and their health or inviting them to act or respond, being around meant monitoring. The lamp was perceived as being observant of its 'owner' and even looking after them. The lamp's focus on the user and its purpose to keep the user up to date was interpreted as a friendly aid. Ambiguity in the lamp's behaviour helped the people to make their own interpretation of the lamp's purpose and behaviour. This shows that purposeful autonomous technology is perceived as positive, friendly assistance.

The lamp as a team partner Participants also realised themselves that they were acting socially towards the lamp.

"I think we kind of teamed up after a while, I also noticed that I was kind of moving a little bit more towards the lamp to be a little bit closer." (P11)

The participant continued to explain how her perception changed during the course of the study:

"I perceived it after a while as, you know, it's my team partner in this room and we are working together on something somehow. So even when it pointed out 'ok take a drink', I was like 'oh thank you'. And I like the waving of course also notifying me, OK experiment is over. Thought it was a very friendly lamp. Like in the first round when I was not so used to what it can do and like the range of functionalities or the things that it points out, I thought it was more about, OK interrupting me, but this kind of felt OK, getting more into the setting and getting used to like OK these are the things and this is what I can do, so actually now it's partner in crime." (P11)

This quote indicated that the user, in the short period of the study, engaged in some kind of relationship with the lamp, almost feeling closeness and togetherness.

Earlier comments indicated how more participants saw the lamp as some kind of friendly and well-intentioned assistant.

"It is a nice company to working I think when you're alone, when you're kind of in an isolated mode of working, it's quite cheerful. [...] The gestures they are quite unusual for me, I don't have anything like this in my home or anything so I think it's really cool, a little robot. It's a really nice addition to your desk." (P13)

The lamp with an inner life Another participant explained that the lamp felt like an intentional, almost thinking entity to him:

"It is weird how you get the sense that it is looking at something when it's not looking at anything. But the tendency is to follow its gaze. Or when it looks at you and you're like 'What?What is it?' I can see it being like something that reminds you to maybe look around you and have a glass of water or take a break but at the same time it is more sort of you know, like, was looking at me, and it wasn't just, and it wasn't clear what it was looking at over there, on the screen. It looked at the phone like it knew something was going to happen and then it beeped. And then the second time I happened to have automatically picked up my phone and I sort of thought 'oh, should not have done that' I thought it would be like: 'what are you doing? Why are you taking it away?' So I guess you do start to think of it as like a thing." (P14)

Remarkably, in the study this participant tried to figure out what drives the lamp, and he does it by trying to understand the lamp's 'thought process'. Why is it looking at me? What does it 'think'? Almost as if the lamp is a living being with thoughts and desires. Consequently, he is worried about his actions on the desk and how this might be perceived by the lamp, e.g. picking up his phone. He continued:

[Interviewer: So you did think it was alive?] yes it does seem like that, it does its funny little dance at the beginning as well and even if it dies at the end it sort of seems like 'uhhhh' or like it's gone to sleep or something, it's like the pixar lamp actually. So there is a sort of analog for living lamps, culturally. It seemed like it was, it seemed like it was saying, you know, take a break, or look around you. And that seemed very deliberate that it was doing that. You do get the sense it's looking at stuff, you know, I know that doesn't really make a lot of sense, well I guess it does but you're just making that up, it's not looking, it's doing the opposite, it's projecting." (P14)

Interestingly, this all happened despite the fact that the participant was aware that the lamp was probably remotely controlled and only a piece of technology, a desktop lamp, and he was realising that he was making analogies that are a bit skewed, such as shining at something means looking at it. Still, the lamp became a companion. Other participants felt similar and when talking about the lamp it sounded like they were talking about a person:

"Yes it seemed that it was observing what I was doing. It really seemed that it has a life on its own. Like an assistant remind you of things that you forget when you are drawn too much into what you're doing." (P5)

"We do understand each other, but I'll have to teach it, if it would live with me. The movements, it has its own style. But the actions. I don't know if I would be creative enough [to customise it], it would need to be crowdsourced like 'oh other people teached their lamp to do this trick' or suddenly my lamp started doing things it has seen other people do." (P4)

The participant explained that it would be important to him to have access to a 'library of actions' to choose from so he can make more use of the lamp and try different prompts. In his descriptions it seems like he is referring to a living being, a pet or something similar, that can 'see' and 'learn'.

In some cases, interpreting too much into the use of such words, i.e. describing object actions using terms, which would only be used for humans or animals, is problematic as it might just be a lingual artefact. We refer to tables having legs without actually personifying them and actually thinking of a table as being alive. In such dissections we have to be careful and aware of this fact. The participants are, however, making explicit comments about the lamp 'thinking' and 'caring', which strongly indicates that this artefact can be dismissed in this case. They directly refer to the lamp as a conscious entity, for example P14 explained at the end of the interview:

"It is not just a notification device, I mean it looks, I thought it was looking off into the distance, and I was like 'what is it looking at'? It looked past the screen so my impression was that it was just looking by itself, at stuff that it was interested in." (P14)

During the interview, one participant pointed at the lamp and was wondering what it might be doing while being in the standard position:

"It's a little guy, a bit silly like look at it now, what is he looking at?" (P1)

The annoyance of miscommunication Three participants had trouble understanding the lamp's purpose at all and its behaviour was not apparent to them. They struggled to understand the movement and the functionality as something meaningful.

"I feel weird. I didn't understand, I assumed it just did its thing unrelated to me. I didn't notice it was responding to my actions. But the thing I'm sure of that when it went there, it told me: 'look here'. So that is so obvious, but when it kept spotting here [laptop], I got so annoyed. So why the hell are you spotting here? Just leave me working. So when I held my mobile I didn't sense that it was coming after me or something. So I stopped interpreting what it was doing." (P6)

"I could tell it was doing something, I just didn't know what that something meant. [Interviewer: Did it seem like it had an intention?] No it didn't, not to me, but that may well be because I didn't connect, I didn't make the connection between the different things." (P12)

After describing the purpose of the device to the participants, they could see benefits in using it though.

"It will be very helpful and very cute on the desk, it's like you are not sitting alone, you are sitting with a cute assistant. I see it like that." (P6)

"Well, given that I deliberately go out of my way to disable all notifications, I probably don't want something to tell me when I got an email or a text, however, I would use it, potentially, use it in another ways, drinking water." (P12)

"If I understand the purpose, to drink or stand up, I would consider it less annoying." (P2)

This shows that not informing the participants thoroughly about the lamp's behaviour doesn't work for everyone and some people couldn't make sense of the lamp without an explanation. The statements of these participants however also shows that allowing customisation of such a device makes it more acceptable, even to people who didn't know what to make of it and its actions at first.

The challenges of mechanical eye contact An interesting finding during the interviews was that the difference in behaviour – so the difference between session one and session two, which was the additional gaze – was not so apparent to the participants. When being asked if they noticed a difference between the two sessions, only four participants noted that the gaze of the lamp was different in each session. Four more recollected the difference after they have been told about it. The remaining participants couldn't recall that the lamp pointed at them separately to the gestures. This implies that relative small changes in autonomous behaviour are hard to notice for users (Nowacka et al., 2015).

People still do have a preference once they notice and the different behaviours might still make a difference to them – even subconsciously. Again, surprisingly, 10 out of the 14 participants reported that they would prefer the version in which the lamp is not facing them before providing a notification or prompts.

"I prefer the second one, that it simply notifies instead of pointing to the direction because I could skip it if I wanted, but if it points directly on my face I would actually have to look up and stop what I was doing. So I prefer simply 'ok he is changing the location of the light from here to here to here' but it doesn't disrupt my work or me looking at something or doing something." (P5)

"I think without the looking at me, so I guess like in the first round. Well, I think if it turns off and looks at me, it disrupts me a little bit more, and otherwise it is just like pointing out, so I think like even though I might feel a little bit more addressed by the lamp, you know turning towards me, but I think it would be a little bit nerve-wracking over a while because you know you want to get on with work and not like 'ok, stop now!' and then do something." (P11)

"For notification it's better when it just blinks at something. Rather than looking at me and then go to something. If realistically I were working on my desk I wouldn't, I just wouldn't pay attention to that detail, I don't think I would be looking at it. It'll be too distracting actually." (P13)

Eye contact demands immediate response, which seems unnecessary for notification technology. Although participants in the first study identified eye contact between the lamp and the user as useful and something that helps to bond, in practice it is rather irritating and disruptive. Additionally, there is a general understanding between people about eye contact, which doesn't seem to exist between humans and technology or at least seems to be unnecessary.

"I was scared that it was going to point at me and then turn the light on and then blinding me. Yeah, it felt a bit weird." (P8)

"I probably wouldn't make it stare at me, unless also sort of looks to say hello or something like that. It is so weird." (P14)

However, the four participants that did choose the gaze explained that it felt very personal and nice to them:

"I like the second one cause it is more personal and cute but the first one was less distracting in a way." (P3)

"I kind of liked it when it was looking at me, because it kind of felt more like a pet, like a dog would sit and look at your like waiting for a command or waiting for something to happen. I'm really desperate for a little pet generally, and having a little pet like this would be really cool. When it points into the face I thought it was more cute, like I feel like I can just look at it, smile, and look back, it didn't feel like it was asking me to do anything. It felt like it was just checking I was there, like a pet." (P7)

"I don't really kind of think that the facing you is necessary but I think it would add a bit of personality or something. I'd probably prefer it for that reason." (P10)

These participants also acknowledged though that the lamp facing the user would make the lamp's behaviour less functional or less purpose-directed for that reason.

Summary

Overall, the participants behaved socially towards the lamp. They felt they interacted with an intentional character that cared for them and that they could team up with. Although being highly mechanical, the participants perceived the lamp as a cute, little assistant that helped them with their tasks. Although having a 'gaze' helped the participant to understand where the lamp was pointing towards, making eye-contact through the gaze was not wanted and felt weird to the participants. In the next section I will have a deeper look at more specific behaviour that was exhibited towards the lamp by some participants.

5.5.6 Social Reactions towards the Lamp

For the second part of the analysis I picked incidents of interesting behaviour from the participants that occurred during the study. I did this because I was interested in idiosyncratic situations where people reacted in a social way towards the prototype. The interest lies in how people make sense of the lamp's actions and how this understanding can be seen in their actions. I want to investigate these situations without trying to assign them to existing taxonomies. These moments stand for themselves, they are independent of each other. This analysis aims to understand how the design of the lamp leads people to react in certain social ways. This is achieved by gathering situations where social interaction occured between a participant and the user.

Here, illustrations in the form of snapshots are provided, where participants reacted socially towards the lamp in a way that they would react towards a human being (rather than technology). I present 6 different critical events that occurred during the study; 6 special situations of people who demonstrate interesting embodied behaviour. These are explicit moments of interaction, interaction 'problems' or opportunities that serve as a point of reflection when designing interfaces. Below, these distinct moments are presented and the participants' responses to these situations are described.

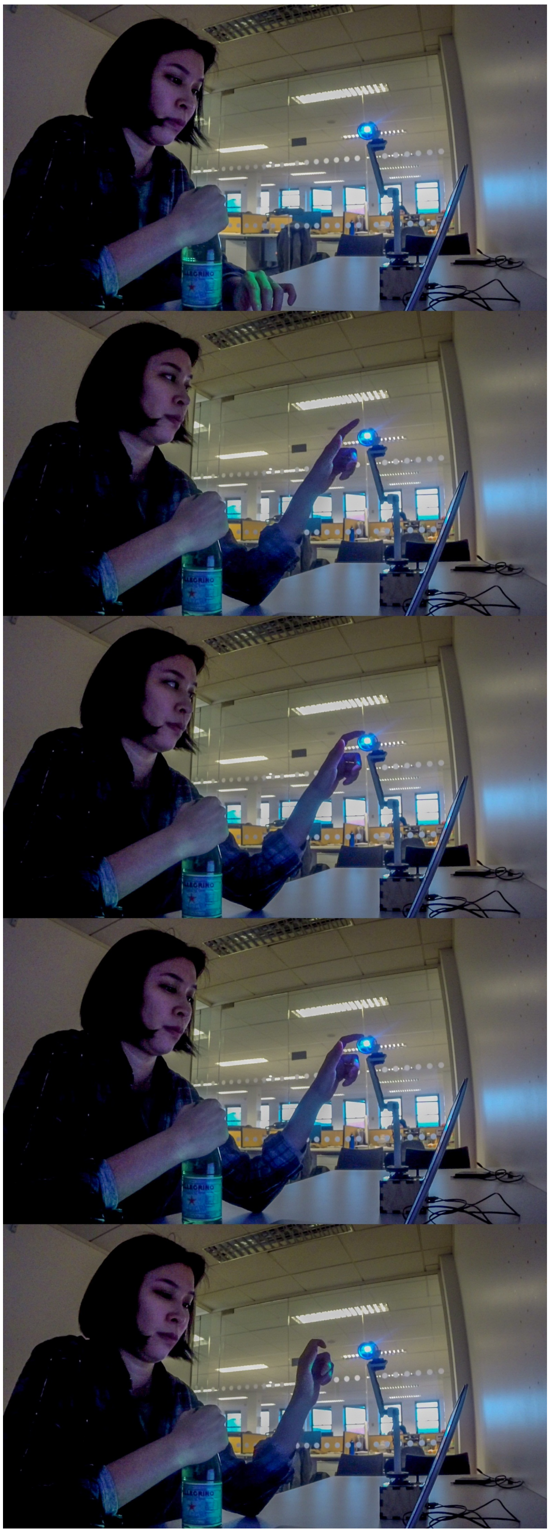

Fig. 5.13 P13 strokes the lamp as if it were a pet.

The pet lamp - This situation occurred halfway through the second part of the study, where the condition was that the lamp didn't face the user before giving a prompt. The lamp prompted the user that a new email had arrived by turning the top and blinking at the screen. At first, Participant 13 didn't react to the cue at all, but chose to stroke the top of the lamp (2-4) after the lamp returned to the default position. In the interview she explained her action:

"It looked at me and it felt like it was a pet, it was acting like it was a pet. It was just moving, I think only the head moved, and I thought it needed some reassurance that I was aware of it, that it knows I am aware of it doing something. I have a pet, that might be why, my cat does that, it comes in when I use my computer and walks around on my desk around the screen. It comes very close with its face here [points next to the screen], I am used to having something that moves around, he sometimes even goes on my keyboard. Because the lamp was here it reminded me of that, because the cat would poke its head out at the same spot. I liked it!"

Although the prototype shows no visual resemblance to a cat, the participant felt strongly reminded of her experiences with her pet at home and therefore reacted the same way she does at home to show approval and compliance.

This situation illustrates how the lamp's mechanical behaviour is triggering some association with routine domestic behaviour.

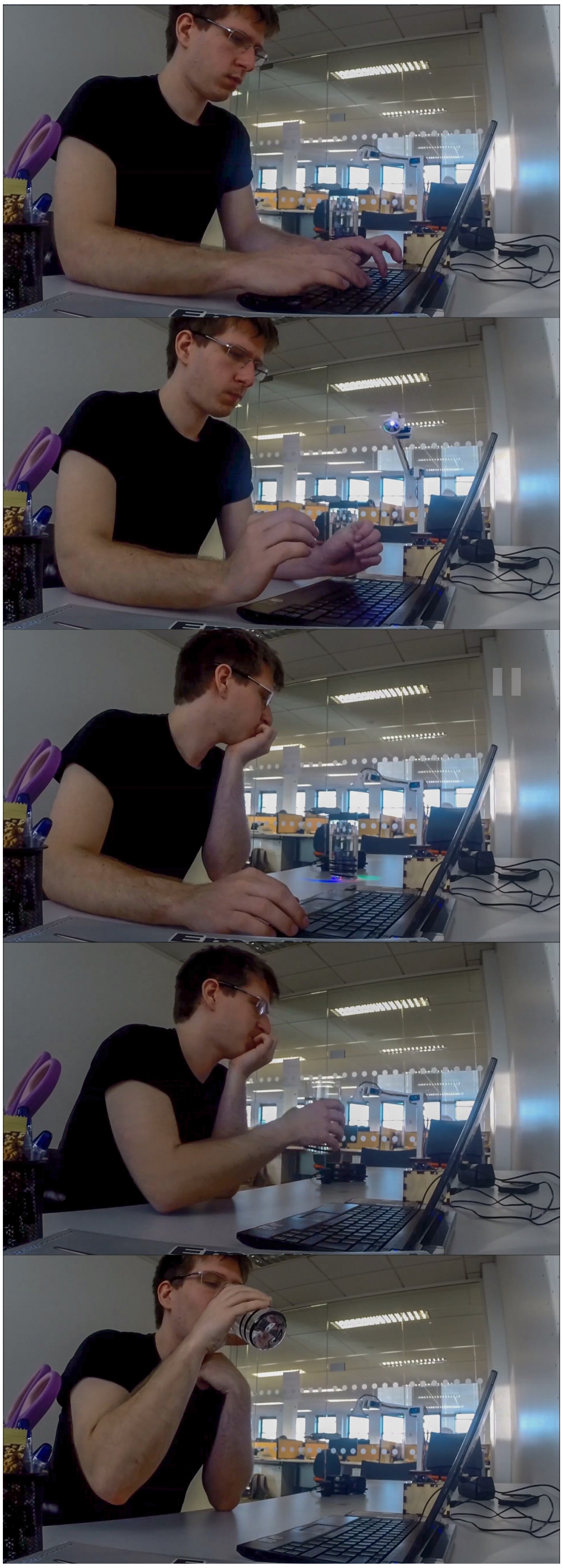

Fig. 5.14 The lamp convinced P9 to drink some water.

The persuasive lamp - In the middle of the second session, the lamp pointed at the water (1). The condition was without using gaze. The participant didn't show any reaction and kept typing on his computer (2). No reaction was observable so ten seconds later the cue was repeated. The second time the participant seemed to notice the prompt and took a sip of water (3-5).

Participant 9 stated in the interview that there was a situation where the lamp pointed at the water glass. The participant explained that he indeed registered the cue the first time but was coding at that time and didn't want to be interrupted, so he ignored the cue. The second time the participant reacted and drank the water. Later in the interview he explained:

"*[Interviewer: did the lamp seem alive to you?] It's a bit alive, I didn't interact with it, it interacted with me. Although, there was a time where I was just finishing off some code and it flashed at the water and I was like 'yeah, good idea, but I'm gonna ignore you, because I am doing code, maybe next time'. But then it did it again immediately, so I said, 'fine, OK, I'll have a drink'. Then it didn't prompt me a third time so I guess that was me responding to it and it responding to me by stopping. There is a bit of rapport between us. Understand each other.*"

This situation nicely illustrates a feeling of mutual respect between the lamp and the user. Furthermore, it shows the lamp succeeding at persuading the user to do something.

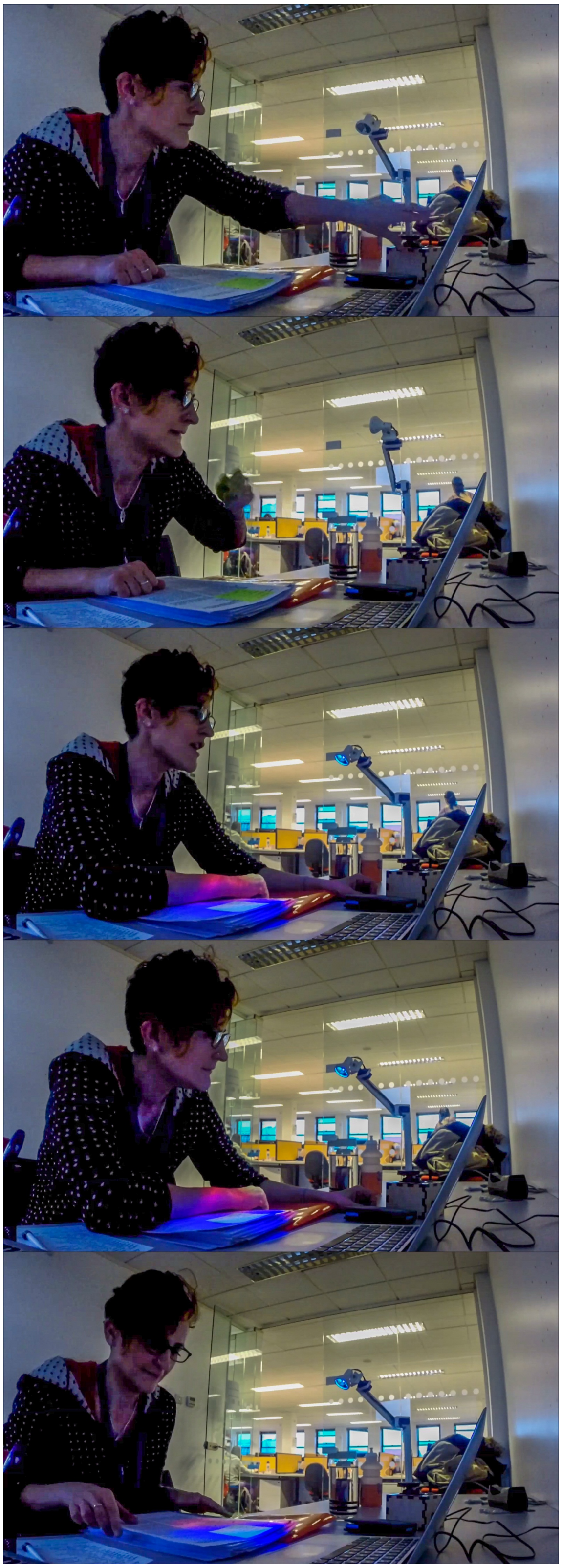

Fig. 5.15 P12 is interrupted by the lamp while she wants to change the light. She apologises.

The reprimanding lamp - For participant 12, due to a transmission error, a delay of about 10 seconds occurred during the very first cue. The participant sat down and examined the lamp (1). She wanted to turn the light up and touched the rotor, when the lamp started its movement to ‘Say hello’ (2). She immediately went backwards and said ‘sorry’ out loud (3). Then she looked at the lamp, possibly waiting for a reaction to her apology (4, 5). In the interview she recollected the event:

[Interviewer: Did the lamp seem alive to you?] it seemed, well that’s funny cause I did say sorry to it so that kind of implies that I was treating it as a sentient being, I did, I worry about alive but it seemed animated, it seemed quite, the way that it moves is quite funny. [Interviewer: Why?] just like because it is still for ages I think and then it suddenly jiggles about. I think that contrast is inherently amusing on some level. That it goes from nothing to doing something. And doing things that, you know, not just turning on and off like a lamp would normally, moving about on its own accord. So yeah, kind of. I would hesitate to say it seemed alive but it definitely had life, it had movement and it had, you know I could tell it was doing something, I just didn’t know what that something meant.”

The ‘reaction’ of the lamp to her trying to change the light was interpreted as reprimanding and the lamp not allowing her to change the light. This situation illustrates how the participant showed an immediate social reaction even to new and unknown technology which shows autonomy.

The monitoring lamp - This situation occurred as the lamp cued the user to drink some water. This happened in session two, where the lamp faced the user before cueing. Participant 14 waited a few seconds before picking up the glass of water. Throughout the whole process of picking up the water, drinking it, and putting it down, the participant held eye contact with the lamp (1-4). He explained:

"I looked at it because I felt like it was looking at me and I was feeling observed and I was doing its bidding. And It gave me permission. I was thirsty and it wasn't clear if I could drink. When it pointed out the drink I was looking to make sure I was doing the right thing. I didn't know how it would behave, and I wanted to make it right. Because I thought when I would do it right I would get a response. So that it would tell me that I was doing the right. [...] I wasn't sure if it was going to monitor whether I did something or not and all get annoyed at me if I didn't do it. When I moved my phone as well like, I wonder if it's happy with that. I'd better put it back! I was wondering what does it want? What is it thinking?"

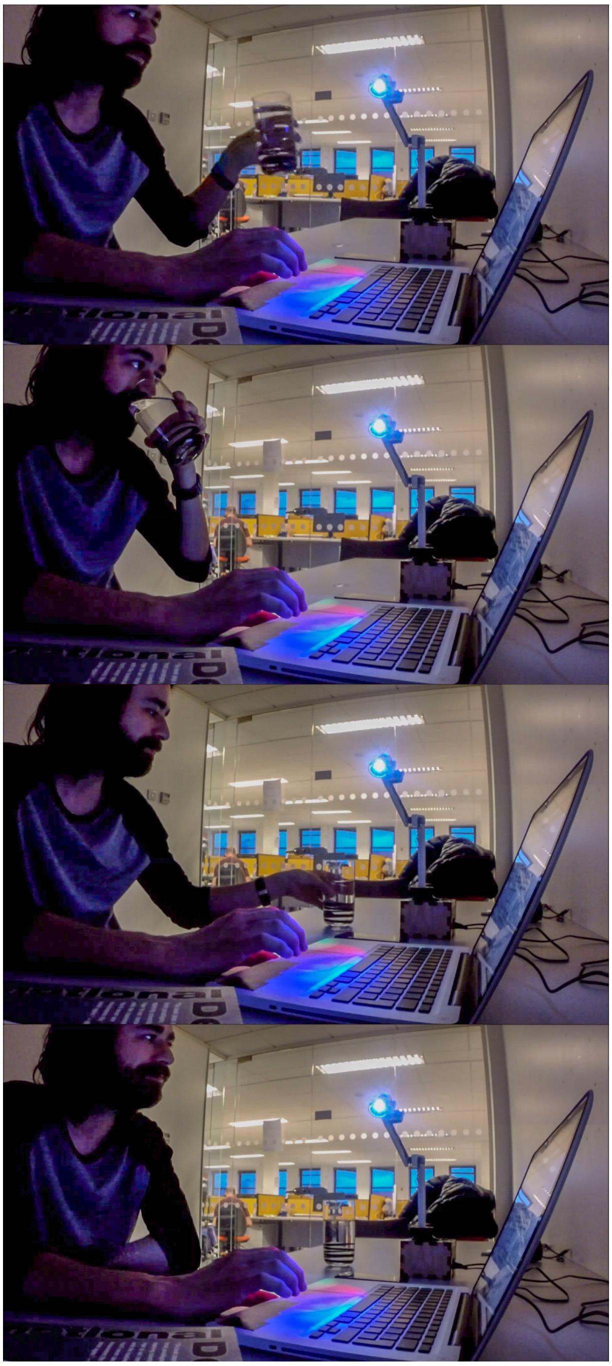

Fig. 5.16 The participant does not break eye-contact while he is drinking.

During the study the participant explored the functionality of the lamp. How does the lamp react to my actions? What happens if I do this or that? This situation shows how the participant somehow treats the lamp similar to a 'conscious' being, something that is aware of the surroundings and reacts depending on its 'character.'

The friendly lamp - The situation depicted in Figure 5.17 occurred right at the start of the first session with P9. The participant entered the room and sat down (1). It was the first time he encountered the lamp. As soon as he sat down the lamp started moving, it faced the participant (gaze mode) and then performed the movement ‘Say hello’. He seemed struck by the unexpected movement. The participant then felt compelled to greet the lamp and waved to it (2-4). Afterwards, he remembered this moment in the interview.

Fig. 5.17 P9’s first encounter with the lamp animated him to wave to the lamp to greet it.

“[Did the lamp seem alive to you?] it seemed like it had a vivid character to it [Interview: Which character?] A little bit playful I think, how it started, I don’t know if I did it or not but I was tempted to wave to say hello. It’s not like it’s a cold device, it felt like it had some warmth and it’s colourful as well. I did, it make me jump a couple of times, the first time, the motors suddenly kicked in made me jump. And also it’s quite a nice design, that’s wood isn’t it? Is that burnt? It’s a nice contrast. I like that. [Interviewer: You wrote me the message that you have a new friend?] Yes, I guess it kind of has this testament to it, like a character.”

Clearly, the participant’s first reaction to the greeting is to greet the lamp back. He explained that the lamp made a friendly impression and therefore he reacted in that way. This shows how autonomous technology can make a friendly first impression and quickly initiate social reactions.

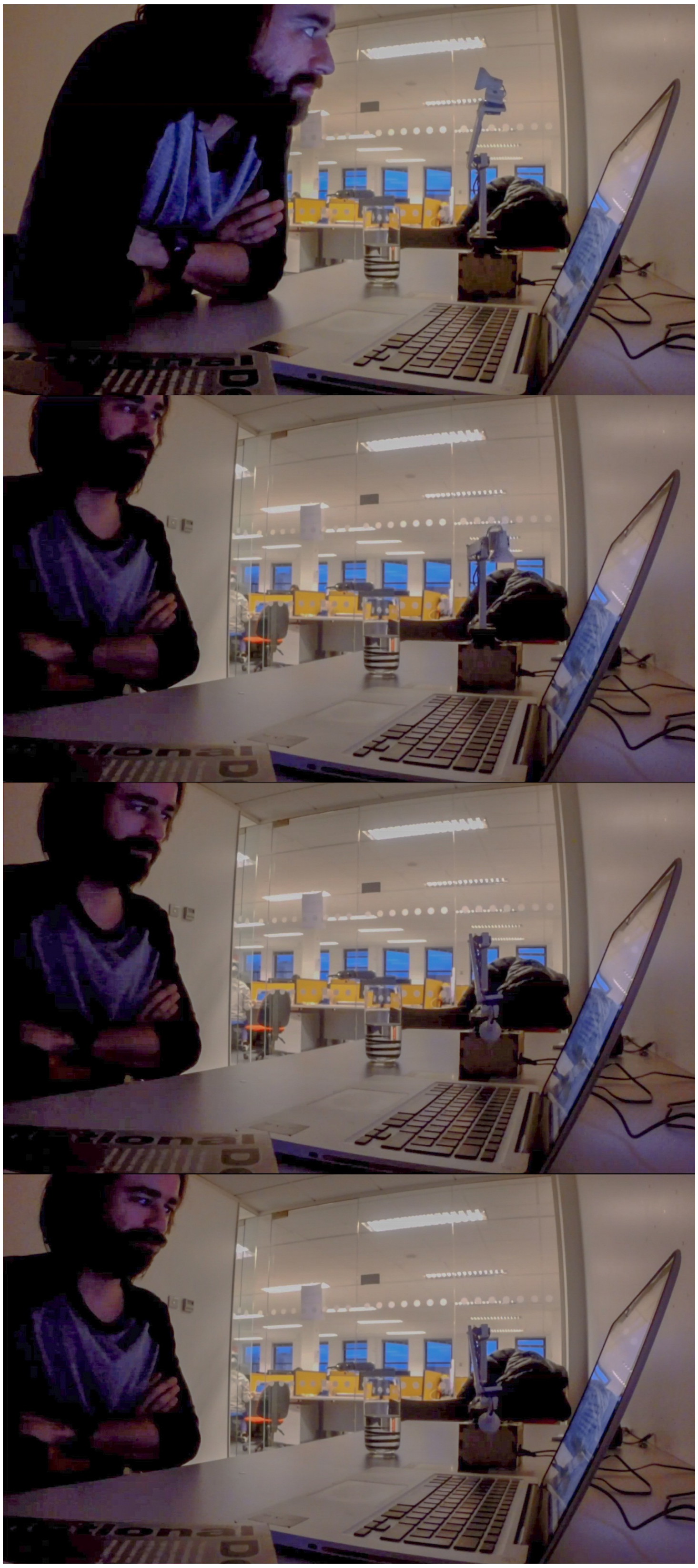

Fig. 5.18 P14 makes a sad face when the lamp goes into inactive mode.

The dying lamp - Participant 14 grew quite fond of co-existing with the lamp, throughout the whole study he was rather responsive, e.g. reacted to every movement and was observant of each cue. At the end of the study, when the lamp bowed to bid farewell, the participant made a sad face. In the interview he elaborates on his reaction:

"Cause it died. It looked like it bowed but then also kind of died. Because it is under tension all the time, so that makes it kind of alive, and then when it goes, once that tension goes and it drops down the life is gone from it. It was looking at you and interacting with you, so you kind of had a relationship with it and then it suddenly died. And it's cute, you don't want it's head to go down!"

The participant associated the lamp buzzing and being active or inactive with being alive or dead. The fact that the lamp became 'inactive' at the end of the study made him sad, which shows how the participant saw the lamp as a companion.

Situation	Social characteristics
The pet lamp	approval, companionship, care
The persuasive lamp	persuasion, suggestion
The reprimanding lamp	politeness, etiquette
The controlling lamp	curiosity, contemplation, checking
The greeting lamp	friendliness, warmth
The dying lamp	companionship, bid farewell

Table 5.2 The interesting situations that were picked to illustrate how people reacted socially towards the lamp are listed, faced with social characteristics.

5.5.7 Summary

The situations elaborate on a set of social behaviours that the participants exhibited towards the desktop lamp. In this analysis, I did not aim to classify these behaviours in existing taxonomies, but rather to make visible how people react socially to autonomous technology. Table 5.2 shows the variety of social or companionable gestures from the participants towards the lamp. These can be seen as opportunities for design. I tried to map these to characteristics from human relationships. At times, the corresponding social characteristics were exaggerated to understand the underlying meaning of the behaviour. The lamp appeared as a pet at times, leading to people petting it (1), feeling its warmth (5) or feeling sad for it (6). People treated it similarly to a person, apologising when making a mistake (3) and seeing interaction as a dialogue (2) or showing curiosity towards its behaviour and perception (4).

These situations make visible why and how participants might treat technology as a social actor. Each behaviour describes people's perception of the lamp but also how they expected to treat the lamp and react to it. This analysis presents a snapshot of situations around autonomous objects giving us insights into human-machine interaction. They illustrate how participants resolve uncertain situations and otherwise unknown interaction with machines. In throwing the participants into these unknown situations and leaving them to themselves to figure out the situation and the meaning of the setup, I was able to capture a number of fascinating occurrences and illustrate the richness of social interactions with an otherwise rather simple device. The long-term challenge for designing robots still persists in terms of creating technology that is easy to use for humans, i.e. that acts like we do. However, it was shown that as long as the actions stay fairly ambiguous, they are open to interpretation, and humans can make sense of the situations themselves and perceive autonomous technology as a companion.

5.6 Discussion

Generally, the users could imagine such a lamp on their desktop, which however requires careful design of the lamp's appearance and behaviour. The first study revealed that there are mainly two different ways users imagine desktop devices to convey messages, either by having the device pointing at something or mimicking a basic human movement. Interestingly, users attached great importance to customisation, as the same movement evoked different feelings in users and therefore movement needs personal adjustment. The expected social norms for an interactive lamp, e.g. how polite a lamp should be, are individually different, and the degree to which something is distracting for someone also fluctuates. Unlike most traditional computers and devices that have the same output convention for each user; interactive objects with pro-active behaviour should act with respect to the personality of the user. Such differentiation of interaction behaviour would require empathy to allow for personalised lamp output or the possibility to configure the lamp's personality. Furthermore, people would get familiar with their lamp, able to understand little cues after a while and therefore needing less output. I discussed short vignettes of interaction which illustrate how different people react to our lamp. Although the movements were purely mechanical, the lamp's behaviour was perceived socially and the participants interpreted the actions in meaningful ways. I showed that it is possible to create a functional and plain looking interface that lets people get emotionally attached and even makes them feel cared for. This can be explained by the fact that they saw a purpose in the lamp's actions, which was to assist and support them in their daily tasks. Leaving the purpose of the device open and letting the participants discover the purpose for themselves, while still giving the lamp a function (Gaver et al., 2003), proved successful in this case. Not everyone was able to understand what the lamp communicated, our participants could make space for the lamp though and saw various purposes that they would like to use the lamp for. Interestingly, the recommendations of participants of the first study to enable 'eye-contact' through gaze as a 'friendly' interaction was not well received, most people in the second study stated that it was too distracting and unnecessary. In the following, I want to close this chapter with some design recommendations for autonomous interface design.

Is anthropomorphism unavoidable? In the second study it turned out that such a device might be much more acceptable than expected. When put on a desk next to a working person, all participants felt quite positive about it. As already discussed, previous literature proved that bio-metaphoric resemblances carry a lot of pitfalls. Resort to human or animal like appearance and behaviour can help in understanding cues though. For autonomous interfaces this happens quite naturally and is hard to avoid Nowacka et al. (2015), therefore it needs to be carefully balanced. For example, the lamp was interpreted as having an 'eye' to point at things, being able to 'wave an arm' like a human or 'bow' to rest. Even though it had a very plain appearance, participants mapped lamp movements to human movements. To communicate different messages, they treated the lamp as a proxy to imitate human behaviour, like 'dancing' or 'sleeping' or used the light to point (i.e. the lamp to 'look') at things and locations. Most probably due to its small size, the very mechanical appearance of the lamp was perceived as 'cute'. Using these 'anthropomorphic affordances' Schmitz (2011) proved successful for communication between the autonomous interface and the user. There is a fine line between borrowing social metaphors which are pleasant, e.g. using gaze to point, and intense ones such as using gaze to make eye contact.

Social behaviour and norms of technology In the end, it turned out that the lamp, although being strongly mechanical and its movements functional, was perceived as a social actor and people also behaved that way by expressing very rich, social behaviour. As we've seen, an interface doesn't need to resemble animals or other living entities to seem alive and evoke social reactions. These reactions imply that the participants treated the lamp as a living being. The effect that people can't help but treat actuated interfaces, even highly mechanical ones, as social actors has an important implication. Even functional technology needs to contain some knowledge about social norms and retain an awareness of social behaviour. This could be, for example, to respect personal space but also acknowledge requests with some form of response. This knowledge would make the interaction with the lamp easy and make sense to the user. As soon as we design autonomous behaviour into an interface, we also need to provide a socialised understanding, as there will always be a social response from people. People have a socialised understanding of the world, which also extends to autonomous technology. Being aware of this fact and knowing that autonomy is always embodied is of great importance in autonomous interface design.

Transmitting Social Signals A great amount of work is put into lamps following a user's face[1]. Interestingly, the study revealed that users might not accept 'mechanical eye-contact' and prefer a more salient and subtle style, which nevertheless seems friendly and inviting. Participants

[1] Aur - the robotic desk assistance (http://video.mit.edu/watch/aur-robotic-desk-lamp-autonomous-desktop-assistance-2941/), Pinokio (http://www.ben-dror.com/pinokio/), Anados (http://anodos.co.jp/ral/), Junior (http://www.trieuvyluu.nl/living-lamps/)

stated that in a practical setting not relying on eye contact made it easier to use or ignore the lamp if they want to. Eye contact is a strong social means of communication that doesn't seem to work with mechanical interfaces. It makes the interaction weird as people are not able to understand why the device is 'looking' at them. This is grounded in the fact that human eyes are much more expressive, allowing for more explicit signals, which is not the case with the lamp's top. Because the lamp is so constrained in that manner, the only sensible output for the lamp is to use its gaze to point, which did work well in the study. Users could confirm to the lamp that they received a cue by simply looking at the device though, and this seemed to work well as participants reported this as a convenient way to interact. There were a few more downsides when people interpreted the lamp's actions in a social way. The 'gaze' of the lamp was felt as a form of monitoring, the repeated cues were seen as insisting and not letting the user alone. When the lamp stopped moving, it was seen as 'dead'. Careful design could circumvent these, by e.g. adding slow 'breathing' gestures to keep the lamp alive Zuckerman and Hoffman (2015).

5.7 Conclusion

This chapter presented the findings from two studies that let users imagine the usage of an interactive desktop lamp through user-generated actuation. Previously, related work explored user gestures to control and guide the light of a lamp. The approach presented here relies on the movements/gestures of the lamp rather than user gestures. I discussed the participants' outputs, which were explored in a semi-realistic setting, and close with insights and design implications for interactive desktop lamps. This work aimed to open up design spaces, and inspire and generate new designs or ideas for actuated interfaces. Users' expectations of smart objects around them that are pro-actively behaving were gathered, and it was shown that a quasi-social behaviour, politeness, and a learning curve in understanding each other are desirable. Interestingly, the finding from the first study, that gaze would make the lamp more interesting, turned out not to be suitable when tested. I further found that people always have socialised understandings of even mechanical movement and therefore interactive technology needs to include knowledge about social norms.

Chapter 6

Discussion

In this chapter, I would like to reflect on the case studies from Chapter 4 and Chapter 5 and recap their findings, discussing them in a broader context, elaborate on how they extend previous work (presented in Chapter 2) and further address the research questions posed in this thesis. Then I will reformulate the findings into more specific design implications. I start with *Perceived Autonomy*, which summarises how the participants experienced the encounters with the autonomous machines in the studies and how these two compare with respect to interaction. In *TAIs as Social Actors*, I look back on what makes people perceive technology as a social actor and what implications this has for design. *Difference in character* examines the finding that interfaces with the same appearance but different behaviour are hard to distinguish for users. Furthermore, there is a dilemma in autonomous interface design. If an interface is supposed to act autonomously, how much control should it have over the interaction? And how much does the user want to control the interaction? To discuss these issues, *Human/Object Control* reflects on the design opportunities for the behaviour and how this dilemma of giving either the object or the user control over the interaction could be solved. Finally, I reflect on the framework, considering the prototyping of the two TAIs in this thesis and their evaluation.

6.1 Perceived Autonomy

The perception of autonomy in objects is created through the interaction between humans, objects and the environment.

Previous work has evidenced that the perception of an object being intelligent evolves through interaction (Greenberg et al., 2011; Taylor, 2009; van Allen et al., 2013). Applying ambiguity in the behaviour of an interface, can change it from appearing predictable and functional to intentional and lifelike (Nowacka and Kirk, 2014). The question here is: How can human interaction with an object give the impression of autonomy? How should an object behave to make it seem intelligent / autonomous? Can we create interesting and engaging interfaces with 'life' without using AI?

Striking in both studies in this thesis was how the participants saw the balloons as well as the lamp as self-contained entities and perceived that they - like any living being - solve their tasks independently and on their own. During interaction, they perceived the device to actually hold all skills, whereas, technically, this was not the case. Even though some participants reported on having thoughts about how the lamp's behaviour was created (being remotely controlled or pre-programmed), this didn't seem to change the fact that it was perceived as an intentional, capable being. The actions were interpreted as self-contained acts and not relying on an external infrastructure of sensors and processing power. The same counts for the balloons, which were accounted as being able to detect faces. The capacity to be able to fulfil a certain task on its own is ascribed to the object of interaction. It does not matter if the device is remotely controlled, the technology distributed, pre-programmed or autonomous, people perceive the ability to be embodied in the artefact.

The case studies presented in this thesis showed that being appropriately reactive to the user along with the user's attitude are more important than the sophistication of the behaviour. People's responses were quite positive towards the interfaces. During the first study, the participants showed diverse reactions towards the balloons. In the workshops, the balloons became part of the social environment. In the group, people were able to decide to move towards the balloons and use them to take pictures, or stay with their colleagues and avoid interaction. The balloons were part of the social circle, which was demonstrated by the fact that more outgoing people were more open to get up and approach the balloons whereas more introvert people avoided such behaviour.

Similarly, the desktop lamp received a large variety of social reactions. Some people became attached to it and became 'friends' with the lamp while few others barely accepted its presence. In comparison to the balloons though, the lamp received higher approval amongst the participants and people were more attached to it than to the balloons. Furthermore, more direct social reactions were received in the study with the lamp. In general, the lamp was more interactive than the balloons due to being situated closer to the user and trying to communicate with / responding to them directly. The lamp's higher utility but also the fact that the lamp was a designated device, directly interacting with only one user and therefore being a more personal device, surely contributed to this.

6.2 TAIs as Social Actors

Mechanical technology leads to social reactions and requires a socialised understanding of the interface.

Earlier literature states that people have a tendency to personify technological artefacts (Helmes et al., 2011; Reeves and Nass, 1996). It is a phenomenon rooted in how our brains evolved - we are hard-wired to detect movements and make predictions about behaviour. We understand others through the way we understand ourselves and therefore we impute lifelike behaviour to everything we try to understand - objects as well. As soon as technology shows signs of autonomy, a new interaction space emerges that is comparable to how humans interact with pets. Both try to make sense of each other, creating a new kind of communication. Although related work already reported on social reactions to technology, I wanted to understand this space and how it can be designed for. In this thesis I focused on the functional aspect of the devices. Both devices were designed to let form follow the function, e.g I made the balloons round to enable them to turn quicker and only equipped the lamp with two straight arms. Despite the functional design, people still perceived both prototypes as life-like.

Emotional responses might be stronger towards interfaces that resemble animals in comparison to more abstract ones, or interfaces that are designed to communicate socially. Through everyday experiences we are familiar with these biological cues and therefore they tickle our social senses. Interaction with e.g. a furry interface with eyes might feel 'warmer' than interacting with an abstract interface that is made out of acrylic. However, this comes at the cost of user frustration and possibly disappointment as e.g. a dog-like interfaces currently are by far not as agile as their biological exemplars. I am proposing that functional-looking, interactive machines yield similar relational behaviour in comparison to lifelike interfaces while also eluding the dangers of the uncanny valley. Participants interacting with the prototypes presented in this thesis also expressed emotions, attachment and showed social behaviour. They perceived the prototypes as social entities with feelings and desires, as lifelike qualities were imputed to these mechanical objects. This opens up a space for technical and mechanical, but nevertheless relational interfaces, which create a social environment with the user. Both devices, the balloons as well as the lamp, could have been enhanced by lifelike characteristics such as dog ears, fur or human features such as eyes. However, as a consequence, this would not allow users to make their own interpretations, e.g. see the balloons as hermit crabs or the lamp as a cat. Furthermore, by not relying on anthropomorphic visual cues, these devices do not deceive the user about their abilities or through their appearance suggest skills that they do not hold. Their appearance reflects their actual skills and therefore they do not disappoint the user.

A similar effect can be observed for the perception of an object's movement. Users fall back to metaphors resembling human behaviours equally when describing mechanistic movements, even though the interfaces were designed to comprise purely functional actuation. The motion qualities of the prototypes were designed not to be flowing movements, but erratic, mechanical and unnatural. Intentionally, I did not follow any laws or guidelines, such as Two-Thirds Power Law (Lacquaniti et al., 1983) or Laban Movement (Hodgson, 2001; Lourens et al., 2010), that would make them appear more lifelike. These state that, for example, biological movement is not executed linearly, like a servo motor does. Still, movements were interpreted as if a human or animal would be the one performing. I observed this in various situations in studies with my prototypes. A balloon's change of orientation meant shifting interest, colliding meant fighting (see Chapter 4). Similarly, the lamp 'bowed' in front of the user when folding down, it 'looked' at things it was 'interested' in. People didn't like the lamp to establish 'eye-contact' through its top, functioning as the lamp's 'head'. Using the top to 'look' and point at things in the direct context turned out to be a very successful form to communicate messages though (see Chapter 5). Identifying these social references in interfaces seems to be a phenomenon, which, even for mechanical interfaces, comes naturally and is hard to avoid.

It is in humans' nature to personify lifelike objects as we are self-centred and see behaviour and appearance in our image. And because we are social in nature, we try to understand these in social terms. Therefore, I conclude that it is of high importance, even for mechanical devices, that people are supposed to interact with, to equip the interface with knowledge (or rules of use) about social norms. Amongst others this would be to respect personal space or acknowledge requests with some form of response. It has been shown in the two case studies that people will respond emotionally and socially to (mechanistic) technology. Interactive technology does become part of a user's social environment and therefore it also needs to react accordingly. Being aware of this fact and knowing that autonomy is always social is of great importance in autonomous interface design.

6.3 Difference in character

Similarity in appearance can obscure differences in behaviour.

Reflecting on the two case studies, another similarity between the both prototypes became apparent. In the first case study, most participants did not realise that there was a difference in behaviour between the two balloons. Equally, most participants in the second case study were not able to recall a difference in behaviour between the two versions of the lamp. They did not realise that one version of the lamp was pointing at them before each cue whereas the other went straight for the cue. This leads to the conclusion that, for short interactions, it is challenging to implement different characters and sophistications amongst devices with highly similar interfaces. Small changes in autonomous behaviour, which hold the same physical appearance, are hard to notice for users when experienced for short episodes of time.

Relating this back to *anthropomorphic affordances*, humans strongly impute intelligence only based on the similarity in appearance and might ascribe qualities to objects that these in fact do not offer. And as already discussed we do this because it helps us to understand the world and predict occurrences. The notion of imputing capabilities into devices was demonstrated with the balloons and also with the lamp. Although Diri #1 was arguably less complex (because it contained less complex sensing capabilities), people still seemed to project a certain competence onto the device, despite the lack thereof, as it was highly similar in appearance to Diri #2. Arguably, people found the lamp 'cute' and friendly because they saw a resemblance to the pixar lamp (Price, 2009), imputing liveness into it. This presents another challenge for designing with autonomy: people will look for socialised explanations of differences in the behaviours. So in order to create a noticeable difference in behaviour, two interfaces, visually, need to be sufficiently dissimilar.

6.4 Human/Object Control

An interface open enough, leaves room for interpretation.

There seems to be a paradox in autonomy design. A system can only be truly autonomous if it fulfils the functions by itself, possibly restricting the user. So who should lead the interaction? The object or the user? Research showed that although autonomous technology requires skills like proactivity, these might be raising concerns about loss of control (Kynsilehto and Olsson, 2011). Furthermore, there might be situations where the user wants the device to do something different than what it is doing or let it do nothing at all (Fraser et al., 2008). So which behaviours are desirable? How would a successful interaction and 'collaboration' look like? And in that context, how does a user understand different qualities of actuation at all?

First of all, the studies with Diri showed that it is not straight forward to map certain design decisions onto certain behaviours. Similar findings were observed when users interacted with the desktop lamp. Although most participants exhibited social reactions, each of their social behaviours was unique and can't be exclusively attributed to specific outputs of the lamp. This suggests that, as these interfaces open a social space, this space is defined by the user's personality, preferences and life experiences. Giving the users the possibility to adjust an interface might provide a good solution to that problem. People seem to prefer interfaces that are similar in character to them, therefore customisation is key. Then the users can decide how much interaction and activity they desire.

Furthermore, leaving the purpose of a device open enough for people to let them make their own interpretation to why their device behaves in a certain way makes an interface more interesting. For example, in the study with the lamp the participants were not aware of the meanings of the lamp movements, leading to a wide variety of emotional responses. Similarly, people ascribed socialised understandings to the balloons' ambiguous behaviours. This also seems to have strong implications on acceptability. The function is described by the action that a device is doing, e.g. the lamp pointing to the glass of water. The purpose however is determined by the user. And if the user can find their own purpose in the device, e.g. through pointing out the water, the lamp keeps the participant healthy, they will be more willing to accept a device. The balloon's function was more subtle, to document the space. Whereas some participants found that compelling and useful, others couldn't see the purpose in this.

Further to this, the studies presented here support related work that showed that people prefer fallible (Row and Nam, 2014), bored (Biswas and Murray, 2015) and at times stupid robots. Imperfections add personality to a robot, which makes it more acceptable. This was also shown to be true for TAIs. Participants were more forgiving of the silver balloon, the lack of navigational skills earned sympathy. Due to its constraints, the low range of movements and its small size, people perceived the lamp as friendly and likeable. When reflecting on and comparing the prototypes' behaviours, it seems that communicating an intention strongly conveys an appearance of being alive. Short et al. (Short et al., 2010) discovered that if a robot cheats, it seems more alive because it wants to win and therefore exhibits intention. The desktop lamp also seemed to have communicated its intention to the participants via its movements and actions. Pointing out different notifications conveyed the intention of wanting to support the user with their tasks. If technology communicates an intention, even in a mechanical way (solely pointing at water), their actions will be perceived as social (caring for someone). If the balloons would have exposed more intentional behaviour, search for a spot with least drift to be 'comfortable' for example, they would likely be perceived as more social and therefore as more autonomous as well.

Finally, the findings were used to review the TAI framework and a modified version was presented. Consequently, we begin to bridge the gap to understanding how to design to support perceptions of autonomy at the interface.

6.5 Revisiting the TAI-Framework

Throughout the process of designing TAIs, the framework was very helpful. It aided in identifying design 'ingredients' to achieve autonomy. As suggested by the framework I have received various social responses from the participants that relate to the appearance of Diri and the ambiguity in their behaviour. Even stronger so for the lamp. However, based on the experience gathered in these projects I propose to adjust some aspects of the framework.

Firstly, even though it has been suggested that the dimensions in the framework are interlinked (Nowacka and Kirk, 2014), I found it difficult to tease apart individual effects that each aspect has on perceived autonomy. For example, I found that many users do not notice a difference in behaviour if two interfaces have very similar appearances. Therefore, putting interfaces on different points of a scale in the framework does not necessarily lead to a stronger perception of autonomy. Instead, the results suggest that personal experience has the most significant effect on the perception of Diri, and hence also the largest effect on the social response. Similar observations have been made for the lamp, where the majority of participants could not directly identify a change in behaviour. Although this is an important argument to be made, it, however, does not weaken the framework as a design reference for autonomous interfaces. The scales in the framework should therefore not be seen as distinct, independent attributes, but should instead be viewed as interlinked measures that create a merged constellation of autonomy. As only changing the behaviour of the interface does not change the perception of the autonomy, there is a strong link between the appearance, ambiguity in behaviour and capabilities altogether with autonomy.

Secondly, no indication that users make a distinction between the *Capabilities* of an interface and its internal *Complexity* as suggested by the framework were found. Although I acknowledged before that these two scales are heavily related, from experience, i.e. during the development, but also during evaluation, they could be taken together and seen as one. It may be more helpful to view increased *Complexity* to be a consequence of increased *Capabilities*, instead of two related scales. I would unite these two, and use only the term *Capabilities* to describe the system's sophistication of software and hardware. I therefore propose to restructure the framework as illustrated in Figure 6.1. *Bio-Metaphor* still significantly impacts on appearance, and *Ambiguity*, as before, is needed in the behaviour of an autonomous interface. *Capabilities* now spans appearance and behaviour, and all aspects reside on the same depth.

Thirdly, I also realised that the dimension *Capabilities* must include the potential for inter-device communication, e.g. TAIs capable of interacting with each other, as I felt that this changed the users' perception. If a device can visibly interact with other devices, it has to be placed higher on the scale than a device that does not comprise these capabilities.

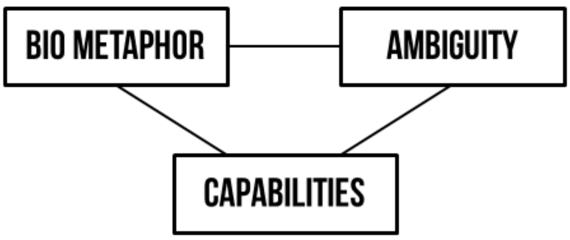

Fig. 6.1 The modified framework for Autonomy in Interfaces.

6.6 Design Strategies for Compelling TAIs

Throughout the process of designing TAIs, the framework was very helpful to create autonomy in interfaces. Through the studies I was able to justify why the dimensions of the framework served as a successful design reference. In this section, I want to transform the findings of this thesis into more concrete design suggestions. Here, I want to answer to the question about what should people build if they want to make a compelling TAI. Therefore I present four specific implications for designing interfaces with autonomy. The implications speak to the three dimensions of the framework:

1. **Ambiguous Behaviour** I mentioned earlier that evoking an appearance of autonomy in an interface happens quite quickly. Any form of actuation (audio, light, movement) suffices to give the impression that the technology has an intention. The key point of keeping an interface autonomous is to provide varying output over time and keeping the output's purpose vague. This means ambiguity has to be added into the behaviour. Participants expressed curiosity and wonder in situations where the behaviour of the balloons was not clear. Equally, leaving the purpose of the lamp's cues open, invited the participants to make their own interpretations. Designers should consider adding unexpected actions into the interface's behaviour. The interface should also not always provide the same output for the same input, as this makes the interface procedural and the autonomy is lost. Unexpected behaviour on the other hand supports the perception of the interface having a 'character'.

2. **Abstract appearance** To create a credible and acceptable TAI, form should function instead of relying on anthropomorphic cues. Designers should focus on abstract design that fits the purpose of the interface. Otherwise the appearance of the interface suggests skills that it in fact might not hold. Functional design avoids the danger of deceiving the user about the device's capabilities and also evades the uncanny valley. This in turn might have positive implications on acceptance and also leads to a relational interaction. Both my studies showed that nevertheless people show social behaviour, i.e. recognize the technology as an intentional and social character. They expected the highly mechanical interfaces to be capable of understanding social norms and containing a socialised understanding of the world.

3. **Custom Behaviour** A degree of customisation of a device's behaviour allows people to adjust the interface to their preference. This includes preferences regarding frequency of output but could also include other factors such as invasion into personal space. One possible implementation could be to allow users to choose certain personality traits (Spadafora et al.,

2016) that vary, for example, in politeness. Equally, this would make differences in behaviour more apparent. The responses of participants in both studies showed that each person has a different expectations of how an interface should behave and therefore customisation could serve as an opportunity.

4. **Distributing Technology** Another finding of this thesis was that people don't necessarily think about where the computational power is contained, but ascribe all capabilities to the object of interaction. This allows the designer to outsource the technology as much as possible into the environment, people will nevertheless ascribe the capability to solve the tasks into the device. This can be useful, especially when constraints regarding computational power, size and battery life are present.

Chapter 7

Conclusion

This thesis critically explored the design space of autonomous and actuated artefacts, considering how autonomous behaviours in interactive technologies might shape and influence users' interactions and behaviours. Since the invention of gearing and clockwork, mechanical devices were built that both fascinate and intrigue people through their mechanical actuation (Schaffer, 1999). There seems to be something magical about moving devices, which draws our attention and piques our interest. As the sophistication of ubiquitous computing technologies develops, with advances in processing power and diminishing size, there is increasing opportunity for users to interact with embedded interfaces, which actuate elements of our environment. This raises interesting challenges around how people perceive and respond to technologies that move for themselves, physically responding to our interactions and which appear, to a large extent, autonomous. There is a tendency in humans to attribute lifelike qualities onto non-animate objects (Reeves and Nass, 1996; Suchman, 1986; Turkle, 2005), which evokes social behaviour towards e.g. technology.

In this thesis I set out to show that between Tangible User Interfaces and fully-formed robots there is a class of interaction devices that exhibits increasingly autonomous and lifelike behaviour. Whilst the world of robotics has for many years sold visions of anthropomorphic and zoomorphic aids, these are often not perceived as credible or disappoint due to unfulfilled expectations of their abilities. Therefore in this work, two prototypes were designed with machine-like appearance in mind. I hope to underline the potential of tangible autonomous interfaces for various application areas. The two prototypes were evaluated in studies, which revealed that autonomous technology strongly attracts people's attention. This effect could be used to change human behaviour. For example, one could imagine using TAIs to motivate people to engage in charitable purposes, to live more sustainable, but also possibly for other causes such as fostering education or reducing loneliness. I furthermore set out to explore the design space of tangible autonomous objects. How can we create autonomous interfaces that are not patronising or manipulative (Gaver, 2009), but exciting and engaging? To work towards this we need to know: what can be designed? What are the factors that can be tweaked to make something seem autonomous? Without a doubt, it is the visual appearance; the material, shape and size of an object, along with the qualities and associations this creates. Furthermore, we can manipulate the behaviour of an object, add interactivity by making it aware of the environment and its users. Entangled with the factor before, we can create a function for the object and enable the object to solve this task and determine how well the device performs. And finally, the behaviour of an autonomous interface can also be designed to change over time. Below, I will elaborate on these regarding the prototypes presented in this thesis.

In response to research question 1, to understand what makes a user interpret an interface as *autonomous*, I explored earlier work regarding autonomous technology and experimented with different sophistications of autonomous prototypes. Through the review of literature and related technologies, a framework was constructed that identifies the key aspects for designing autonomous behaviours into tangible interfaces. The term *Tangible Autonomous Interfaces* (TAIs) was established to describe this class of interfaces, which exposes autonomy by giving people the impression of having an internal goal-state and show complex behaviour by reacting to external influences and the environment in an ambiguous way. To evaluate the dimensions of this framework and also to explore what the impacts on users are when interacting with autonomous interfaces (research question 2), as research through design (Koskinen et al., 2012), two case studies of the design process and realisation of prototypes of TAIs were conducted. The first one being Diri, which consists of actuated helium balloons that autonomously document activity in spaces. The second case study used an actuated desktop lamp as a notification device in the office.

I will close this thesis with a listing of the contributions made by this work and a further discussion on limitations and future work.

7.1 Contributions

This thesis makes the following contributions:

- After identifying a gap in physical computing regarding tangible interfaces, which exhibit autonomous behaviour, I coined the term *Tangible Autonomous Interface* (TAI) and defined the design space.
- Through a thorough analysis of previous literature along with realization and analysis of ideation workshops, I created a framework underpinning explorations of design for TAIs.
- The technologies themselves, the helium balloons and the desktop lamp, as artefacts and their application serve as a contribution because they present themselves as examples for autonomous technologies.
- Finally, after probing these artefacts with users, the empirical insights are a contribution.

7.2 Limitations and Future Work

Many of the findings indicated herein suggest new research questions and avenues for future work. In this section I want to discuss two factors that can be regarded as limitations of this work. Furthermore, this section will discuss what is left to do and what should follow.

The first limitation concerns the choice of application area. The application area in this thesis was constrained to the office and office activities. This facilitated conducting studies in the office rooms and being able to fully record the interactions (which might not have been appropriate in other settings). In both cases, with the helium balloons as well as the lamp, I kept to a professional setting. The limitation for this is that the findings don't necessarily translate to other scenarios; for example, the home or public space. However, TAIs developed in these settings should still adhere to the implications that were established in the framework, see 3.

The second limitation surrounds the population under investigation. The recruitment took place through the university's email mailing lists, containing Computer Science Students and Staff. Although I aimed to not focus on a specific population, choosing people from a university and especially computer science students, might have an influence on the outcome of the evaluations.

Such participants, because of their nature to work in a technical field, might be more open and positive towards technology. It is a general limitation of qualitative data collection, subjective interview evaluations have the limitation that participants may wish to please the experimenter, and will not be completely honest about their experience.

Several improvements have to be made to the framework. Although it provides a guide to design autonomous behaviour in interfaces, at the moment it is not considering interactions which are longer term. Habituation, i.e. the effect of decreased reaction to a repeating stimulus, has been studied with robots with interesting results. After weeks of interaction people reported feeling less threatened or intimidated by robots. It was also observed that preferences towards the robot's appearance and behaviour changed over time (Koay et al., 2007). The studies presented in this thesis focused on relative short encounters, 30 minutes to an hour, to explore first impressions, perceptions and how people start to get familiar with autonomous devices. It remains unclear how user perception towards TAIs changes over longer periods of time such as hours, days and weeks of interaction. Although some applications of autonomous technology only involve short encounters (e.g. receptionist robots), TAIs aim at establishing themselves as a social entity and ultimately should adapt their behaviour. Will people at some point see through the ambiguity of the interface's behaviour and not see the interface as autonomous anymore but as a mere machine? How do we have to design the device's behaviour to counteract the loss of ambiguity? Consequently, it has to be explored how much the behaviour has to change over time to remain interesting. All these questions could be explored by deploying prototypes of different sophistication in various environments over a longer period of time. As a consequence of this, it would be interesting to explore if, as stated in Chapter 5 with the desktop lamp, people actually learn the behaviour of their devices and get to know their 'habits'. The question for design is, if people will need less output with time as they get to know their devices? What happens if the novelty wears off? What happens when people actually get familiar and bond with their autonomous devices?

Related to this, another fascinating aspect emerges. We live in times where systems are expected to learn as quickly as possible and magically acquire new capabilities in an instance. For example, current technologies, such as mobile applications and learning algorithms, strive to maximise their usefulness to the user as quickly as possible. TAIs, however, could benefit from a slow learning process over longer timescales. A trackable trajectory of change might be required for the user to notice that the system is actively adapting to them. We learned that, to stay interesting, a TAI needs to change its behaviour accordingly. Future work should explore how behaviour in

TAIs can adapt over time in a process that is trackable for the user, and it what way that effects the user's interpretation.

As in this thesis the studies were executed in semi-realistic setups, field trials would furthermore represent worthwhile investigations for the future. Of interest would be how people make place for their devices in their lives. Technically, this is a large challenge which nevertheless would provide valuable insights into everyday interactions with autonomous interfaces. Further interesting in this context is how people then reflect on their experiences with their devices. Research showed that the way people report on experiences while they happen in comparison to reflecting on them long after they happened, differs when autonomy is involved (Takayama, 2009). In the moment, people might react more socially towards technology, perhaps unconsciously, whereas this occurs less often when people reflect on their reaction towards autonomous interfaces later. A field trial would provide more understanding of that space.

Furthermore, I would like to evaluate the situations where multiple people and multiple autonomous interfaces come together. How could a group of interfaces interact with each other and how would people perceive these interactions? To some extent it can be expected that interfaces, which are able to communicate with each other, are perceived as more autonomous and more intelligent. How would people react to the desktop lamp pointing at the balloon or exchanging information such as telling it where to go? This opens up a new interaction space, a new social circle consisting of an interplay between a number of humans and a number of machines. This topic has been touched by previous work, e.g. an autonomously rotating TV was used with two participants (Mortensen et al., 2012) or robotic pets have been proposed as 'tickets to talk' (Lazar et al., 2016) meaning that they engaged various people to more social activities. These are, however, only propositions further opening up this space.

Another interesting aspect to think about is also the role of TAIs as cherished artefacts and explore the role that autonomous object play in people's lives from that perspective. A large body of work examined how and why people ascribe high worth to their possessions (Grenier and Miller, 1991). People do get sentimental about their things, especially at home (Kirk and Sellen, 2010). There is a strong link between one's identity and one's possessions (James, 1890). The value of these objects is generally personal and created through past experiences and by reflecting life stories (Hoskins, 1998) rather than their actual economic value. Objects which are unique, or one of a kind can be especially appreciated or valued (Grenier and Miller, 1991). Interesting in this context is the question how this would relate to valuing autonomous objects. An area for further research would be to explore how a relationship between a user and their interface is established depending on the interface's origin. A recent study demonstrated how people show more attachment to robots that they assembled by themselves (Groom et al., 2009). This compelling finding indicates the impact on perception when it comes to how the robot was acquired. Does it change if the device is a present from a close friend or if even the friend has built it by themselves?

Finally, the studies here uncovered that if people can find a purpose for a device, they are more likely to accept it in their environment. People who enjoyed taking pictures of themselves with the balloons showed higher acceptance towards them in general. So how does this happen? This is something that seems to strongly depend on the context the device is used in. This thesis has shown that tangible autonomous interfaces can be useful in various applications within an office environment. Domestic environments or public spaces are equally relevant areas where autonomous devices could prove themselves useful. This is illustrated in the multitude of domestic entertainment robots or arising personal assistants (e.g. Siri or Amazon Echo).

Therefore, for future work, it would be reasonable to extend the framework, so that it includes the factors mentioned above. This could be realised by learning from deployments and identifying the factors that lead to success. Especially how best to design intercommunication between several TAIs and how people form relationships with their TAIs depending on how these were acquired. This becomes even more interesting when observed over a longer period of time.

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Appendix A

Chapter 4: Questionnaire and semi-structured Interview Questions

A.1 Questionnaire

1. How complex do you think the balloons are in comparison to each other? Do you think the balloons differ in complexity? In what way?

2. Does the balloon remind you of something?

3. What were the balloons doing? How would you describe what they did?

4. Which one did you like better and why?

5. What would you feel about having an object like that in your environment (at home, in the office)?

A.2 Semi-Structured Interview Questions

- Did you ever had pets in your life?

- When you saw them first what was your first association? Did that change over the course of the workshop? Did you also have other associations?

- do you not have any privacy concerns: how compared to CCTV, blimp is better? more acceptable?

- how much did you interact with the balloons during the workshop and why?

- who do you think is responsible if the ballon hurts someone?

Chapter 5: Interview Questions

- How did the study make you feel?

- How would you describe the lamp to someone else?

- Did you understand the lamp? Did the lamp's actions make sense to you?

- Did you notice a difference between the two versions of the lamp?

- Which version did you prefer?

- How would you feel having such a device in your environment? What would make it more or less acceptable?

- How did you feel about the movements? If you could customize the movements, what would you do?

- Did the lamp seem alive? If so, why? In what way?

- Did it seem like the lamp had its own intentions? In what way?

Ethical approval

Chapter - Diri the actuated helium balloon

Application

University Ethics Form Version 2.1

Date submitted
25/11/2016 13:33:37

Applicant Details

Is this approval for a:
Student Project [A2]

What type of degree programme is being studied?
Postgraduate Research (e.g. PhD) [A3]

Name of Principal Researcher:
Diana Nowacka

Please enter your email address
d.nowacka@ncl.ac.uk

Please select your school / academic unit
School of Computing Science [A6]

Please enter the module code

Please enter your supervisors email:
david.kirk@ncl.ac.uk

Please select your supervisor's school/unit:
School of Computing Science [A6]

Project Details

Project Title
Diri-the actuated helium balloon: a study of autonomous behaviour in interfaces

Project Synopsis
In this project I present a study in the form of evaluation workshops of a new interactive technology. To explore perceptions of autonomous behaviour in interfaces I implemented two autonomous helium balloons, used to document activity in spaces, which I evaluate with users in an open group setting.

Project start date
25/01/2016

Project end date
25/02/2016

Is the project externally funded?
No [A3]

Does your project involve collaborators outside of the University?
No [N]

Existing Ethics, Sponsorship & Responsibility

Has ethical approval to cover this proposal already been obtained?
No [N]

Approval

Ethics Form Completed for Project: Diri-the actuated helium balloon: a study of autonomous behaviour in interfaces

Policy & Information Team, Newcastle University <noreply@limeservice.com>

Fri 25/11/2016 12:51

To:Diana Nowacka (PGR) <d.nowacka@newcastle.ac.uk>;

Ref: 10197/2016

Thank you for submitting the ethical approval form for the project 'Diri-the actuated helium balloon: a study of autonomous behaviour in interfaces' (Lead Investigator:Diana Nowacka). Expected to run from 01/08/2014 to 01/03/2015.

Based on your answers the University Ethics Committee grants its approval for your project to progress. Please be aware that if you make any significant changes to your project then you should complete this form again as further review may be required. If you have any queries please contact res.policy@ncl.ac.uk

Best wishes

Policy & Information Team, Newcastle University Research Office

res.policy@ncl.ac.uk

Chapter - Exploring the Perception and Output Space of an Interactive Desktop Lamp

Application

University Ethics Form Version 2.1

Date submitted
25/11/2016 13:44:58

Applicant Details

Is this approval for a:
Student Project [A2]
What type of degree programme is being studied?
Postgraduate Research (e.g. PhD) [A3]
Name of Principal Researcher:
Diana Nowacka
Please enter your email address
d.nowacka@ncl.ac.uk
Please select your school / academic unit
School of Computing Science [A6]
Please enter the module code
Please enter your supervisors email:
david.kirk@ncl.ac.uk
Please select your supervisor's school/unit:
School of Computing Science [A6]

Project Details

Project Title
Working with an Autonomous Interface: Exploring the Output Space of an Interactive Desktop Lamp
Project Synopsis
This project explores how people might envision interaction with autonomous technology in the office. The pres-study involves 13 participants to design and enact movements with a passive desktop lamp to communicate 20 simple messages. The main study will explore a subset of these generated gestures, using the lamp as a personal cueing device in an office setting with 14 new participants in an office space.
Project start date
01/03/2015
Project end date
01/01/2016
Is the project externally funded?
No [A3]
Does your project involve collaborators outside of the University?
Yes [Y]
Please provide a list of the collaborating organisations?
Katrin Wolf - Research Associate at University of Stuttgart - helped designing the lamp

Existing Ethics, Sponsorship & Responsibility

Approval

Ethics Form Completed for Project: Working with an Autonomous Interface: Exploring the Output Space of an Interactive Desktop Lamp

Policy & Information Team, Newcastle University <noreply@limeservice.com>

Fri 25/11/2016 12:45

To:Diana Nowacka (PGR) <d.nowacka@newcastle.ac.uk>;

Ref: 10196/2016

Thank you for submitting the ethical approval form for the project 'Working with an Autonomous Interface: Exploring the Output Space of an Interactive Desktop Lamp' (Lead Investigator:Diana Nowacka). Expected to run from 01/03/2015 to 01/01/2016.

Based on your answers the University Ethics Committee grants its approval for your project to progress. Please be aware that if you make any significant changes to your project then you should complete this form again as further review may be required. If you have any queries please contact res.policy@ncl.ac.uk

Best wishes

Policy & Information Team, Newcastle University Research Office

res.policy@ncl.ac.uk