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Toward Acceptable Domestic Robots: Lessons Learned from Social Psychology

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Abstract Social psychology offers a perspective on the acceptance and adoption of technology that is not often considered in technical circles. In this paper, we discuss several adoption-of-technology models in respect to the acceptance of domestic robots. We raise several key points that we feel will be pivotal to how domestic users respond to robots, and provide a set of heuristics that roboticists and designers of robotic interfaces can use to consider and analyze their designs. Ultimately, understanding both how users respond to robots and the reasons behind their responses will enable designers to creating domestic robots that are accepted into homes.

CR Subject Classification H.1.2 [Models and principles]: user/machine systems–*software psychology*

1 Introduction

Over the last 25 years, robots have permeated a huge array of industrial processes and have made steady inroads into many application areas that involve subtle human elements; one need think only of successful robotics-based innovations in medical, military and public safety contexts. On the other hand, robots are only now starting to be introduced into the 'domestic' environment, as consumer products that enter into the everyday experience of individuals and families in their homes and communities. From robotic vacuum cleaners in millions of homes to robo-receptionists in Japan to autonomous robots carrying medicine around hospitals, robots are poised to become a part of life for much of the general public. Similar to how we encounter computing in our daily lives it is likely that people will soon have little choice in the matter of interacting with robots, a movement that presents intractable problems and persistent challenges for robotics designers and producers.

A question for roboticists, then, is 'As robots start to enter homes, what are the key dynamics and factors that influence how people perceive, understand, and ultimately accept, robots?'. Certainly there is no question about the utility of robotics in the domestic context, especially in an era when more consumers seek relief from the day-to-day chores that eat into ever-scarcer leisure time. There is no question either of the immense consumer appetite for electronics goods in a huge variety of leisure markets. One issue is that most robots exist in forms more appropriate for industrial applications. Also, there is an issue of cost as few household robots are available at mass-market consumer prices. However, these factors were common to virtually all advanced technologies that have been previously innovated in a domestic context. Robots, on the other hand, are a unique entity that present dynamics different from existing technologies, a concept we explore in this paper. This means that robotics designers and producers

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must consider these differences and cannot simply rely on existing ideas of technology acceptance.

The issue of domestic robots illustrates a gap in exploration of innovation phenomena, the question of whether innovations are driven by demand or supply [14,47], a problem especially acute for the heterogeneous consumer markets. Moreover, consumer markets are not based solely on utility and price, but also by subjective calculations concerning social gains and function [29,53]. The 'classical' Schumpeterian position is that demand plays no role and that innovation is directed entirely by entrepreneurs who force the development of new markets [45]. However, evidence suggests otherwise in industrial markets [44], and the role of consumer demand in innovation is much more oblique, often involving subtle transfers of social trends and preferences from consumers to producers [34,57]. Innovation in consumer environments is highly dependent upon factors of socialization that merge utility with symbolic and cultural factors.

We argue that one of the most important and unique barriers to the widespread domestic adoption of robotics is an especially complex socialization. The robotic case is far more complex than for most already-established consumer technology environments, and far more significant in a domestic environment than in an industrial one. Domestic robots, by design, aim to enter into our personal spaces, where their mere physical presence will have an effect on the environments they occupy [9,60]. We contend that this socialization in the domestic context is far more than a conventional 'human factors' design problem, in which barriers with technology are solved through the design of interfaces, infrastructures and routines. Neither is it merely a conventional 'diffusion' problem whereby efficiency and mass-production markets are created through positive feedback as more consumers experience and adopt a technology [43,52]. Instead, we argue that the domestic socialization of robots is largely dependent upon subjective consumer perceptions of what robots are, how they work and what exactly they are and are not capable of doing in a domestic environment. We argue also that understanding these perceptual elements requires that we understand them in the context of the social interactions, institutions and hierarchies into which domestic robots intervene.

In order to explore these arguments, we introduce several perspectives from social psychology, a branch of the social sciences that seeks to explain the relationships between individual perceptions and social behaviours. The perspective is not entirely new to the innovation context, but neither is it particularly common. The economist Tibor Scitovski [46] was an early advocate, suggesting that consumer satisfaction was related more to the psychological expectation of acquiring a product or service than to its actual acquisition. Subsequently, the perspective has been explored in more formal analytical frameworks - for example, Montalvo [37] uses social psychological models to show analytically how decisions to innovate are conditioned by subjectively-defined 'willingness' factors. Our paper does not attempt to offer a methodological contribution to social psychology. Rather, we borrow several concepts and analytical methods from social psychology and bring them to bear upon the questions and problems regarding the adoption of domestic robot technology. Essentially, we explore the adoption and acceptance of domestic robots through the subjectivity in consumer perceptions. Moreover, by using these ideas to interpret recent domestic robot research and applications, we suggest how the insights gained from these comparisons might help re-conceptualize the design problem for domestic robots. We end this paper by distilling the social-psychology analysis into a set of heuristics for analyzing and considering the design of domestic robotic interfaces.

2 Background

A key tool in understanding how people perceive technology is an examination of the reasons for or for not adopting it. Such examination results in an understanding of how much and in what fashion a person or home is willing to adopt a technology, or its *receptive capacity* [12]. Domestic robots, however, require special attention, and existing ideas on the adoption of technology cannot be applied directly to robots. We outline this below.

Socially embedded meaning – how an individual shapes their understanding of a technology is directly linked to the evolution and changes of the more general social attitudes. These do not deterministically move toward an optimal goal but rather are constructed from various social relationships, interactions, conditions and environments. Technology and understanding of technology are areas of social activity [5,41,59], and our understanding of technology derives from these complex networks of interacting factors [9,11,59]. That is, the meaning of a technology is not limited to the mechanisms or physical properties, but extends to how people think they have to (are supposed to) interact with it and how it will (or should) integrate into and affect their lives. The technology itself is defined in part by how people (and society) view, respond, and react to it.

Limiting our scope – the number factors contributing to how people see entities is astronomical (consider the entire moral economy, for example [48,49]), including such points as cultural, gender (e. g., see [16,62]), social, generational, class, and political, as well as the relationship between intention to adopt, adoption, and post-adoption use [43]. In this paper we look only at a piece of this problem, taking a more focused stance. We assume the social context of modern-day North American culture and look at few key factors outlined by the social psychology models we present.

Domestic robots are fundamentally different – some people refer to robots as merely advanced computers, often drawing comparisons to the ubiquitous PC. However, robots have an invasive physical presence and a different interface paradigm: they are entities that actively and physically share spaces with people and have a level of autonomy and intelligence. Unlike the PC, which stays where it is placed and must be actively engaged and enabled, a robot will physically interact with and alter its surroundings and may not remain in a simply-defined allocated space. Furthermore, unlike the physically safe PC virtual environment filled with desktops and browsers, interacting with a robot is more like interacting with a living entity. The robot may move unexpectedly, users must follow its motion cues and physical state, and may not have direct access to orthodox interfaces such as a keyboard or display panel. Users of robotic technology often have to learn new interaction styles such as manipulation through remote control devices or voice commands [27].

Domestic technology models – although not robot-specific, there are domestic-specific models (such as [2, 15,33,55,54], discussed later) that consider user satisfaction, social image, and other concerns that people have. However, these models do not address the fundamental differences presented by robots with their mobile, autonomous physical nature.

Non-domestic research – existing research into the adoption of robotic technology generally focuses on financial, business, and economic concerns. This approach explores specific tasks and goal-oriented problems in terms of *robotisability* [18] (ability to automate by robot), or industrial and automation research issues (e. g., [17,18,59]), macro and international-level industrial issues (e. g., [32]), and even more commercial and office-related work, and does not generally consider domestic social concerns (e. g. [51,57]).

In this paper we attempt, as far as we know for the first time, to consider the receptive capacity of robots in domestic environments, explicitly relating our analysis to the design of robots and the field of human-robot interaction.

3 Human-Robot Interaction

When a person interacts with a robot, there is a lack of common understanding which hinders communication; robots think in bits and bytes, a language that humans cannot inherently understand. When a robot enters a home, this general problem scales, and the robot may clash with existing social structures.

A recent movement in the field of Human-Robot Interaction is the design of *sociable robots*, those which understand and communicate using social human language to allow them to participate and be understood as social actors [6,39]. For example, sociable robots could use human-like facial expressions to represent their general state, gestures such as shrugging to indicate that they did not understand a user, or monitor peoples' facial expressions to determine if they are happy or distressed. This approach, in addition to the pure utility of communication, also considers the user comfort, perception, naturalness and ease [6] of communication.

A danger with designing robots that will directly mimic human social mechanisms is Mori's *uncanny valley* [38], a theory that tries to explain how certain robots can elicit a negative, uncanny, or eerie feeling in people. Generally, this theory proposes that likeness to a human can be directly related to familiarity, where the more human-like a robot is the more believable and comfortable people find it. However, as likeness increases there is a breaking point beyond which familiarity drops and robots become eerie. This dropped level of comfort is called the Uncanny Valley. Examples of this is are CB2 Baby robot [36] or the Repliee R1 [31]. Mori claims that this eeriness will not be overcome until robots become so near to humans that we have difficulty telling that it is a robot.

Interfaces and designs which elicit such negative feelings have a very high chance of failure and so the Uncanny Valley is of high interest to roboticists. Follow-up work attempts to build a more comprehensive model [7, 24,31,35,58], and some projects attempt to avoid the Uncanny Valley by using mechanical designs [25,26] or interfaces that use social principles without appearning human-like [61].

Research in sociable robotics recently discusses higher-level behavior patterns. Hamill and Harper [23, 22] propose that we can learn from Victorian-age servant-employer-relationships in designing robots: robots should stay out of sight whenever possible, understand complex social contexts, predict the employers' needs and wants without being presumptuous, and so forth. Through this approach, robots can enter a home and form a social relationship which people can relate to, and is less intrusive than forcing the domestic environment to change in order to fit the robot's particulars.

The design methodology of a robot, in terms of appearance, actions, and even behavior, will have a large affect on how people perceive domestic robots and the condition of owning one. In particular, the communication paradigm and strategy the robot design employs to understand and fit into social contexts will be a crucial component in the robot's chances of acceptance into an environment.

4 Domestic Robots

The general population, arguably, has a practical understanding of what a robot is, but most people would have difficulty coming up with a clear definition. Roboticists generally resort to domain-specific definitions or simply rely on *common sense* understanding, where robots are often described as machines that have intelligent behavior, resemble (physically and behaviorally) a human or animal, are mobile, are able to physically interact with their environment, and so on.

The concept of a robot is currently subject to a large degree of *interpretative flexibility* [41] where meaning is very wide and depends on the context of the situation, the people involved, and the task at hand, more than on some universal meaning; the social understanding of a robot has not yet reached a social consensus. While at conception *robot* meant an artificial worker [10], since then development in industrial applications and general automation, science fiction media, as well as science-fiction-inspired advanced research has muddled and diversified the meaning of *robot*. For example, while a toy company may sell an electric, walking toy as a robot, others may argue that it is not a robot due to the lack of intelligence.

Fleck [18] predicted a movement away from the aspired-for *universal robot* toward application-specific robots, and argued that social understanding of *robot* will similarly move toward specific domains and usages. This process is expected to lead toward closure, providing clear distinction between robots based on categories such as their task, operation setting, and level of autonomy, for example, industrial, military, commercial and domestic robots.

It is yet not clear, then, how domestic users on a large scale will respond to robots that enter their personal spaces, and how this interpretation will relate to peoples' perception of other kinds of robots such as military robots. Will domestic robots be seen as just another electronic appliance along with the microwave and home theater system? Will people relate more strongly to science-fiction-inspired concepts of domestic robots? Or will domestic robots trigger a new and unique response? We believe that domestic robots will be perceived by users as a new kind of entity.

We define (for the purposes of this paper) a domestic robot to be a machine which is designed to work with the general public in their personal and public spaces, and which can intelligently interpret its environment and physically interact with it. Our definition does not require robots to resemble humans, to be mobile, or to communicate using natural language. Note that *intelligent* is adding a very subjective criteria, which complicates the issue and inhibits a simple, hard-line categorization for domestic robots.

The fundamental question then remains: *how* will people view domestic robots? What factors will influence this perception? What previous experiences or understanding will people look to when building this understanding?

4.1 Instances of Domestic Robots

While we discuss many robots in this paper, we generally use two domestic instances that represent a practical robot and a futuristic robot, and thus provide a base for discussion.

The iRobot Roomba [25] (see Figure 1(a)) is an autonomous and mobile vacuum cleaner robot that is unique in that it is affordable, has effective utility, and is a commercially successful product. The Roomba has fit into existing home environments, with the overall product (design, implementation, etc.) being sensitive to the existing in-home cultures and routines where it must co-exist with families. This has been backed by various studies (e. g., [19]). The Roomba, however, is a utility robot which is meant to independently do its task while staying out of peoples' way. Its design is such that a user can simply push a start button and walk away, adhering to many characteristics of the traditional servant (as in [22, 23]).

The second robot is the RIKEN RI-MAN [42] (see Figure 1(b)), a personal assistant robot that is currently under development. RI-MAN is designed to lift people who need assistance and to carry them around their homes. The RI-MAN can dramatically improve the quality of life for the people it helps, and lower their dependence on other individuals. Unlike the Roomba, which works by itself (to clean floors) and stays out of the way, the RI-MAN is designed to directly work with humans, its users being the most crucial component of its design space. This introduces unique questions such as how robots like the RI-MAN will relate to personal space and privacy, as well as a larger trust concern. The RI-MAN can physically hurt people, or can cause problems by failing to perform as required, for example, by not carrying them properly to their medicine cabinet.

(a) iRobot Roomba [25]. (b) RIKEN RI-MAN [42].

Fig. 1 The two domestic robots used in our analysis.

5 How People Perceive Robots

We present four social-psychology behavior and decision-making models that have been generally used to try and understand how people adopt technology, although they have not before been explicitly applied to robots. We present these theories and consider them from a human-robot interaction perspective, intersecting them with domestic robots. Our intent is to gain insight into factors that affect how people see domestic robots.

One such model, the Theory of Reasoned Action (TRA) [2], assumes that rather than being controlled by capricious unconscious forces, people are generally rational and leverage information available to them. This rationale, TRA claims, is based on personal (attitudinal) and social (normative) beliefs about the outcomes of adopting a technology. TRA's attitudinal concerns include personal opinions of aspects such as utility, efficiency gains, and how a technology fits into a particular lifestyle, where normative beliefs are the perceptions of social views, pressures, expectations, and reactions regarding adopting a technology. In TRA, perceptions are more important than actual outcomes, and perceptions of outcomes can be more important than the views of the robots themselves: a person may have an aversion toward robotic technology but may purchase a utility robot anyway because they *believe* it will result in more free time, even if it actually does not. As key to shaping these beliefs, TRA points to lifetime experiences, and to past actions and events. Sometimes beliefs are inferred from other understanding, and many beliefs are dynamic, where some change often and some persist [2].

The Theory of Planned Behavior (TPB), an extension to TRA, adds an explicit focus on perceived behavioral control and points more to external factors (media, social acceptance, etc.) than to previous experience [33]. A third model, the Technology Acceptance Model (TAM) [15], is specifically designed to explain and predict computer use, behavior, and adoption. TAM lacks explicit consideration of social and normative variables and focuses on the perceived ease of use and usefulness of computers, based on external variables, as core to how users form attitudes. This emphasis represents a more narrow (but focused) version of TPB's perceived behavioral control.

These models take particular perspectives in hopes of unveiling important relationships [33]. The focused nature of TAM may restrict the scope of its considerations, for example, if social pressure is part of a person's evaluation of a technology's ease of use. TPB would explicitly consider this in the framework from various viewpoints while TAM would simplify by integrating it with other ease of use concerns. However, the more thorough (and wide) nature of TPB may make it difficult to apply meaningfully across various contexts.

The above models primarily take a personal perspective, and are less attentive to the domestic household as an entity in and of itself. The Model of Acceptance of Technology in Households (MATH) [54,55] is a domestication of technology framework that focuses on the home, developed around an extensive longitudinal study of the adoption of PCs into over seven hundred households all across America. MATH (and the study) is concerned primarily with the factors that people cited for the adoption (or non-adoption) of domestic PCs. Interestingly, the factors cited for adoption (status and utility gains) did not line up with the factors cited for non-adoption (fear of obsolescence and media influence), and only 45% of those who claimed they intended to adopt the PC did so six months later, suggesting that fears may strongly overpower perceived gains.

MATH identifies that, in comparison to other contexts, household decisions have a more normative structure and are highly affected by social pressures, views of relevant others, and media [8,55]. This includes the perception of hedonic gains (entertainment, fun), family, friend and social network influence, and perceived barriers or rules surrounding adoption, such as lack of knowledge (inability to properly use a product), prohibitive cost, or regulations requiring/restricting adoption of a technology [13,55]. Media influence from secondary sources such as TV and newspapers is particularly strong for early adopters [43] where there are fewer informed friends and families to exert pressure, and the media often provides the first impressions.

The hedonic value (pleasure) and social gains derived from a product, both possession and use, have played a strong role in technology adoption in the past [43]. Pleasure is the primary reason for adoption of such things as video games, and adopting a technology has social gains including public recognition or being a reference power [56]. Finally, from a practical attitudinal perspective the home has a strong focus on factors such as price, depreciation, maintenance, and space requirements: Venkatesh et. al [55] found that non-adopters primarily cited fears of technology obsolescence.

Through the process of building the MATH model, the study raised a few interesting points. Status gains from having a new technology were primarily cited as the reason for adoption, with social pressure from family members, hedonic gains, and personal utility following up. People intending to adopt cited utilitarian gains twice as often than actual adopters cited it in retrospect (suggesting rationalization of decisions), while rapid changes in technology was often cited as a concern from all groups. In relation to this, it appears that in general, early adopters tend to be better educated than later ones [43, 55], related to the fact that perceived ease-of-use is more important for inexperienced users. For non-adopters (both intenders and non-intenders), the social influences and barriers were most significant, with negative influence from secondary sources being the largest factor, such as parents fearing for the safety of their child through access to the internet due to media representation.

As a key note throughout all models, influences are subjectively perceived and interpreted and are not necessarily related to actual outcomes. For example, media pressure may represent a robot to be a required part of a modern home, and portray it to be quite a bit more capable and reliable than it actually is. Regardless of actual outcomes of adoption of a technology, negative perceptions of constraints can inhibit adoption [1].

6 Social Psychology and Robotic Design Challenges

In this section we explicitly address how people consider domestic robots as outlined by the social psychology models and robot design approaches presented above. We directly apply core concepts from these models to actual robotic instances, and present the analysis in a form relevant to creators of domestic robot technology.

6.1 Initial Exposure to Domestic Robots

The core of the TRA model is that beliefs about a given technology are based on lifetime experience [2]. This is supported by initial studies that suggest the way that robots are introduced to a home (or person) is crucial to the lasting opinions [19]. Since robots have not yet entered the home on a large scale, this suggests that existing experiences with other technologies will have a strong influence on beliefs. Which previous experiences people will draw on, however, is a function of how the robots and the condition of owning a robot are perceived. Perhaps some robots will be seen as just another home appliance much like PCs, TVs, and personal music players, in which case people would draw on their experiences with these to understand domestic robots. However, if robots are perceived as being fundamentally different from other domestic entities then it is not entirely clear which experiences people will look to.

Perhaps for sociable robots people will draw from their experiences with children or animals. We argue, however, that robots will fall in between these categories, with people building on past experiences and external sources, inferring new beliefs specific to robots. The image of owning a robot is based on beliefs (not necessarily facts), and so (as MATH points out) media has a strong influence on shaping these beliefs. This is particularly true for earlier adopters who have less to go on, and may be amplified by the unique nature of robots. Perhaps the strong role of media and exposure to science-fiction has prepared people and has conditioned Pavlov responses [40] to domestic robots, such as fear of large robots or the attraction of cute, small robots.

TRA also points to the utility, effectiveness, and price of robots. While we can expect the trend of utility gains from technology to be continued by robots, people must *perceive* them as having a useful purpose. However, recent findings [19] suggests that people (without experience) are not always ready to believe that robots are effective, hinting that other attitudinal factors may have to initially play a larger role in the way robots are perceived. However, utility may not be as key as it seems. For example, A. Venkatesh [54] found in their study that people who intended to adopt a PC cited utility as the motivation twice as often as adopters did in retrospect, suggesting that utility may be an initial-adaption excuse used as a rationalization when other factors were the real motivation. People who actually want robots for social gains (to be a modern person or reference power) may use the utility excuse in a similar way.

For price, consumers consider the expense-versus-gains for adopting the technology: a large part of the Roomba's success is that it is in the same price range as a regular vacuum cleaner. With more advanced (and therefore potentially expensive) robots such as the RI-MAN, it will have to offer a service similar (or better) in quality at a comparable price.

Regarding normative beliefs, MATH [54] suggests that, following the technological trend, there will be social status gains or expectations associated with owning the newest technologies (including domestic robots) that may persuade people to adopt. Social pressures can also be manifested through concerned family members (such as children encouraging parents to adopt automatic vacuum cleaners [19]), a point which may be very influential given current concerns surrounding aging populations in western countries and Japan. However, some people are embarrassed by such automation technology, in that they are afraid to appear lazy to their peers. The Roomba is small enough to store in a closet and the nature of its work (i.e., it does the same task as a regular vacuum) makes it easy for an owner to conceal the fact that they have one, if they so wish. On the other hand, the Roomba has been marketed and designed as stylish, which may help overcome some of this issue.

Conversely, the the shear size and mass of the RI-MAN, as well as the nature of its work, makes it very difficult to conceal. This problem, however, may be short lived if adoption becomes more common. In the RI-MAN case necessity of assistance may overcome such concerns, similar to how canes and wheelchairs do for people who experience a loss of mobility.

Venkatesh and Brown [55] found the “obsolescence of technology” to be a very large factor for PC adoption. It is not clear how obsolescence concerns will map to the domestic robot. Conceivably, a robot is purchased for a particular purpose and will continue being useful until it breaks. This differs from the PC which can no longer execute software and perform the same basic tasks it was purchased for (such as sharing documents, checking email, etc.) long before it physically breaks, as software demands increase. Perhaps, then, robots will only be replaced when newer models offer a very large gain in capabilities and applications to new tasks. Perhaps the hardware/software model of robots may lay between the PC and traditional appliance, where it is generally not replaced until it breaks (appliance) but the software demands upgrades similar to how the PC does. Regardless, the resulting architecture will have a very large impact on the adoption of domestic robots.

MATH also points to a normative focus on perceived real barriers, including possible legislation controlling the use of a robot or lack of facilities in the home to deal with a robot. Currently, as Robots are not yet controlled by law, and they use standard household infrastructure (electrical outlets and internet connections) this does not seem to be an issue. However, we can expect legislation to emerge with the proliferation of robots for such things as confining their use and controlling their collateral impact.

6.2 Control and Safety Regarding Domestic Robots

The TPB model points to the importance of perceived behavioral control in forming opinions about technology [33] such as users believing they can control when and how technology operates, how adopting such a technology affects their social gains, perceptions by others, and all other factors of concern. TAM narrows this criteria and places emphasis on the perceived ease of use.

Which of the two emphasises, behavioral control or ease of usem is more accurate is subjective to the people involved and the nature of the particular robot. In either case, an important factor is the intersection of person's skill set and the perception of the skills required to operate a robot. Given that early adopters tend to be better educated [55], perhaps educated people have more confidence or skills around advanced technology. However, this may be less of a factor as there may not be many skills transferable from other technologies (such as the PC) to robots.

Although the ability to control the robot is important, we believe that the real key issue is personal safety. Despite safety tests and assurance by designers, the autonomous and physical presence gives the robot a 'life of its own' and can override users' perception of control. Just as with animals (or people), this fear will be a function of robot capability, size, and will be heavily influenced by experience. For example, similar to the Roomba, most people are not worried about a small kitten or a puppy as they feel they can control the animal if it gets out of hand. With larger animals, such as an untrained and wild large dog, a cougar or a wild horse, this confidence is more difficult (or impossible) to achieve. Even with smaller animals (or robots), capabilities are key: approaching a wild and panicking adult cat is a very scary venture as we know the cat has teeth and very sharp claws. The Roomba, however, has no claws, and is unable to hurt us as long as we keep our fingers away from the cleaning mechanism (a danger we are familiar with when using a regular vacuum), and so we feel safe around it. On the other hand, the RI-MAN is like a large trained animal: we can learn to trust it, but are still worried about what will happen if it breaks its training (programming).

The Roomba is marketed as a simple “clean with the touch of a button” device, a successful strategy where it only does a single task and only when commanded. Further, its small size and harmless capabilities make it easy to move or disable and the user can place easy-to-use *virtual walls* which restrict the Roomba to a particular room or region.

Regardless, people are worried about the Roomba bumping into furniture damaging it or knocking down breakables [19]. Until robots and artificial intelligence algorithms prove themselves to users, it is expected that this doubtful and wary approach will be a strong factor in peoples' considerations. The RI-MAN may have more difficulty with these control issues as it does complex tasks that may involve ambiguity and its physical size and weight make it impractical for an average person (let alone a needy user) to move or lift in a dangerous situation. Further, the strength of the robot's arms and its mobility makes the robot quite dangerous in a worst-case malfunction scenario. It is to be expected, then, that the damage-to-furniture type of concerns voiced regarding the Roomba will be dramatically amplified in the RI-MAN case.

6.3 Having Fun

MATH gives explicit consideration for hedonic gains, which have been shown to have shaped other technologies such as the PC in the past [43]. For example, the widespread success of the video game, which is primarily for hedonic purposes, supports the MATH claim that this is a strong consideration for domestic use. While the Roomba and RI-MAN do not directly address hedonic needs, they may do so indirectly: the Roomba saves time while the RI-MAN increases a person's mobility. Further, some robots are for aesthetic purposes only, much like dynamic art. For example the SONY Rolly [50], which moves and dances while playing music.

Robotic toys is another application that addresses users' enjoyment. Companies have marketed their remote control cars or other similar devices as robots, and, more recently there have been capable robots sold as toys. The prime example of this is the Sony AIBO robotic dog, a toy which can move around, sit, play with a ball or bone, can take pictures and send them to your email, and even has a complex behavioral and artificial intelligence model to mimic a real puppy. Despite this, however, the AIBO was not commercially successful, and Sony stopped production. The exact reason for the toy's failure is not clear, but it is likely related to the price and the dog's lack of movement capabilities. It sold for over $2000 USD, which is a steep price for a toy that has no direct utility or proven history, and it moved very slowly, got stuck easily, and could not traverse stairs. A more successful example is the line of affordable ($50–$100 USD) robotic toys from Wowwee [21], including the humanoid Robosapien and a flying robot called Dragonfly. These examples, however, are not really robots under the definition proposed in this paper: the Dragonfly is completely remote controlled, and the other models only have simple abilities and weak interpretation of their environment. Some of Wowwee's more advanced models, such as the Robopanda, are still extremely limited in their abilities. Because of this, these robots enter homes in much the same fashion as a remote-controlled car or battery-powered doll might. They have a modern feeling of novelty but to the average consumer they are still single-purpose toys that fit the existing *play* paradigms in the home. This contrasts strongly with video games, the internet, the PC, and the television, which provide a fundamentally different new dimension to the world of domestic fun.

As current robotic toys become more capable we may see a similar thing happen. For example, a Robosapien-like-robot that has just enough awareness of its surroundings to naively follow its owner and play simple games, help them fold the laundry, or even tell a few jokes, would be well beyond any toy available today. To many people, such a toy could become a kind of simple pet or companion, and would enable a whole new range of play possibilities not previously possible (as Isaac Asimov's short story Robbie [4] explores). With this in mind, then, presenting robots as toys may help to overcome understanding and acceptance barriers allowing people to categorize these new entities effectively and easily.

One type of emerging robot is the personal sex-service robot: various producers around the world are working on such products (such as the AndyDroid [3]). These will no-doubt be successful given the existing markets for a sexual devices including realistic dolls. The interesting question, however, is what will happen when these sex robots become increasingly capable of interpreting, understanding, and intelligently interacting within their environment. How far will the human mind allow the anthropomorphism of machines to go? Will people *fall in love* with their robot? How much jealousy will people feel if their partner decides to have sex with a robot? [30].

If these become successful, even within a minority of the population, such direct and personal experience with a robot may be a key component of the acceptance of robotic technologies. Someone who feels they have an understanding and trust of robots through their bedroom experiences will likely be more willing to bring alternate models in to clean, cook, or play with their children.

The idea of robotic companionship and friendship is a strong one. Given sociable robots, and the fact that people already anthropomorphize robots with human-like characteristics, it will be no surprise if people start to feel an attachment to them as already happens with material things such as sports cars, collectible items, teddy bears, or various other items that are important for personal reasons. Given the uniqueness and active role of robots, these kinds of bonds may perhaps become stronger and move closer to the kinds of bonds experienced between two people.

Particularly for robots such as the RI-MAN which has a human-like appearance, replaces a traditional human role, and provides a service that may result in a feeling of gratitude and perhaps emotional attachment from the owner, the development of a sense of companionship would be an almost-natural progression. This has happened, for example, in military settings [20]: an Army colonel canceled a mine-sweeping robot experiment as the robot was getting mutilated, stating that the test was *inhumane*, soldiers awarded robots *battlefield promotions*, and in one instance demanded that a damaged robot (in this case an iRobot Packbot [26] named Scooby-Doo) be repaired instead of replaced at a fraction of the cost.

(you left NOTE here, but no note...?) As intriguing as the idea of robotic companionship may seem, however, this idea will doubtfully have any initial impact on intention to adopt beyond what existing toys and electronics already offer. Robots are currently very limited, and people will likely not consider the deeper reaches of the companionship factor until there is experience and a cultural understanding of such a phenomena. Initially, at least, companionship may just be a secondary product of purchasing a robot.

7 Social Intelligence and its Role in Robotic Interface Design

The Roomba, although successful, is not explicitly designed to follow sociable robotics principles. It has a mechanical appearance and utilizes simple blinking lights for status messages, although the sounds it makes can be construed as *happy* or *sad*, and the newest models have a synthetic-speech introduction. Despite its extremely basic interaction design, however, people anthropomorphize and zoomorphize the Roomba anyway and gave it social, human-like characteristics [19]. In particular, its movements – although mechanical – are described using words such as *cute* or *pathetic*, and many people give the Roomba a name and talk to it while it cleans [19]. This suggests that in addition to being functionally useful, the Roomba can become a social part of the home and in a sense, a social participant in the family, not that different from, say, a pet hamster. Humans readily anthropomorphize objects which offer little more communication than movement and often attribute human or animal-like traits to robots; robots are perceived quite differently than existing in-home technologies. Therefore, gains such as familiarity and anthropomorphism generally attributed to social robotics may be obtainable through other design methodologies. However, it is also quite possible that the Roomba exhibits social principles (such as movement patterns) that are not-yet clearly defined or understood.

The RIKEN RI-MAN, on the other hand, is explicitly designed to have a human-like appearance: it has a human head, face and arms, has soft skin, has ears that listen and a mouth that speaks, and social programming that allows it to follow communication protocols such as gaze during conversation. It remains to be seen how this robot is received by general users, but this level of human resemblance puts the robot into risk of falling into the uncanny valley. Currently, the Roomba's approach shows promise for avoiding the uncanny valley and having a level of social interaction: it is somewhere in between the Roomba and the RI-MAN, where robots offer enough cues for in-depth social interaction but are still perceived as a mechanical entity, where we think that successful domestic robotic interfaces of the future will lay.

It is not yet understood how higher-level social savvy in a robot, that is, an ability to fit into the social and activity structures of the home, will affect the perception of the robot. Socially-ignorant technologies such as the PC and the Roomba (ones that offer no explicit model to interpret the social environment) suggest that active social understanding is not necessarily required for a technology to be successful in a domestic setting. The problem with this claim, however, is the simplicity of how these socially-ignorant technologies interact with physical environments. The goals of more advanced machines such as the RI-MAN require them to, with a large degree of autonomy and intelligence, actively interact in shared spaces with people. The robot must navigate environments and should have an understanding of what people are doing (such as a sleeping baby, a person using the washroom, or a child doing their homework) and alter its actions appropriately, with a calculated impact on the social fabric of the home.

We argue that social savvy is a secondary concern that is directly coupled with capability: the more intelligent and capable a robot is, the more people expect from it on all levels, including social understanding. This does not mean, however, that people are unhappy or impatient with unintelligent technologies, but suggests that robot designers may sometimes want to lower the intelligence, or appearance of intelligence, of their robot to lower users' social expectations. Perhaps people will be forgiving and will accommodate them in much the same way they do with pets or children, finding it simply natural that the robot does not understand. For example, a dog is taught not to bite or bark excessively as people know dogs can learn this, but fish are not trained in the same fashion: rather, signs that say "do not touch" are affixed instead. Similarly, parents simply apologize when infants pull other peoples' hair, but when the infant becomes a toddler they are (usually) scolded and instructed not to do so. While people may rationalize when the vacuum-cleaning robot interrupts their dinner, this comparison will likely break down for critical and dangerous scenarios, and people may have zero tolerance for domestic robots that break plates or flood the floor while cleaning. Following, in respect to using the model of the Victorian servant for robotic interface design [23], we argue that, although an excellent idea, such a complex level of social understanding may not be necessary.

8 Heuristics for Considering the Acceptance of Domestic Robots

Here we offer heuristics to represent and summarize what we have learned from social psychology in a way that is usable by designers of domestic robotic interfaces. The are two sets of heuristics: first, we discuss which factors we feel influence how domestic users perceive domestic robots, and second we outline which influences are key to forming these perceptions.

8.1 Factors Affecting Acceptance

We summarize below a list of key factors that will affect what users think of adopting domestic robots. These factors should in turn affect the ways that domestic human-robot interaction designers consider their design space.

Safety – Robots have an autonomous physical presence that, in a worst-case-scenario, can damage household objects or seriously injure and kill people. Robots provide a unique danger seldom experienced with other technologies in the past. Due to the seriousness of this concern it may veto any and all other gains and benefits.

Accessibility and usability – The apparent capabilities and complexity of robots raises serious accessibility concerns. Existing technology fears such as lack of knowledge, usability, and behavioral control, a large problem for PC adoption, will scale given the physical presence and dangers of robots. Other barriers include facilities and space requirements within the home, financial practicality (affordability, maintenance and obsolescence) and legal barriers and regulations.

Practical benefits – People really care about the utility gains promised by robots, and the potential impact on their quality of life. Robots must not only be useful, but need to fit properly into the social structures of a given particular lifestyle. At the same time, however, people may be dubious about the actual capabilities of robots.

Fun – Direct fun (and secondary gains such as more free time due to utility gains) is a very important consideration for domestic decisions. Robot designers have already recognized this and have introduced robotic technology satisfying this need. Further, companionship and comfort are basic human needs that robots may be able to meet. Perhaps, similar to the way games help drive PC technology, entertainment robots may serve as a catalyst for the entire domain.

Social pressures – Conflicting social pressures should be expected concerning domestic robots. As robots become common we expect social pressures to motivate adoption, for example in order to appear as a modern family. On the other hand, negative pressures such as appearing lazy or wasteful can also be expected.

Status gains – Being perceived as a cutting-edge person or family, or being a reference power, has been important for adoption of technologies in the past. It is unclear how this will relate to domestic robots, but science fiction and research hype has arguably created a fairly positive and luxurious image of robots for people to consider, an image designers can take advantage of.

8.2 The Perception of Factors Affecting Acceptance

As stressed throughout this paper, perception of factors is more meaningful to domestic users than the actual facts. Here we outline some of the key sources and points that influence how people shape their understandings of the factors presented in Section **??**.

Previous experience – This is a primary source (built from personal experience) for shaping peoples' perceptions of robots. Previous experiences may include personally-experienced lifetime actions and events and personally inferred beliefs. Education and initial exposure to robotic technology is large component of this factor. The unique properties of robots suggests that previous experience with animals and children may also be influential here.

Media – Peoples' previous experience with robotic technologies is very limited, so we expect them to strongly leverage media as an important source of information. This includes classic science-fiction-like literature, movies, and television, as well as more modern and fact-oriented news sources.

Personal social network – Opinions and perspectives offered by friends, neighbors, and family have a large influence on how people perceive robots. Although robots are new and as such the social network itself will be less informed, this will likely be an important factor nonetheless.

Robot design methodology – The design of a technology, its physical appearance, actions, interface, and all other aspects of design, directly influence which previous experiences people use when forming their understanding of a given entity. With robots, designers can leverage (or may want to hinder) peoples' tendency to anthropomorphize. Designers may also use the robot's dynamic physical presence as means to influence perception, for example, by limiting speed or agility in an attempt to convey a harmless or safe robot. Robots can use human social interaction (gaze, facial expression, physical proximity) in new ways that other, previous technologies are unable to. The uncanny valley phenomena may also be useful, to make users leary or uneasy around dangerous robots.

9 Conclusion

Social psychology offers an in-depth understanding of how people perceive technologies and how they build those perceptions. In this paper we discussed several of these theories, and presented a discussion and model which applies these theories in order to highlight domestic-robot-specific aspects. The model that we present and the examples we use are simple and arguably still shallow. Our analysis is by no-means complete, and we expect it to become obsolete as the social meaning of *domestic robot* evolves and changes, through artifact evolution [28].

We hope that this paper will provide practitioners with a new perspective to think from, and will offer insight and a set of theoretical tools that the community can use when exploring and analyzing domestic robots and robotic interfaces.

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