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Emotional Design in Human-Robot Interaction

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Preface

Design is a prosperous field. It reaches across the domains of science, stretching out into seemingly irrelevant fields such as robotics. Robots are becoming a part of human lives and, to an ever-increasing extent, will have an impact on human lives since the field of social robotics has been emerging rapidly. Social robots are expected to interact with people in various contexts. The emotional component plays an important role in the interaction with people.

The importance of emotion within practical and scientific design has increased significantly. People form emotional associations with the objects they use and emotions play a crucial role in people's capacity to comprehend and discover the world. Emotional design endeavors to make products that encourage positive emotions and is concerned with pleasure and usability as well as aesthetics, attractiveness and beauty. If people are engaged to specific products, the impact of positive emotions cannot be neglected. As such emotional design is essential within social robotics to create positive experiences for the people who will coexist with robots. Therefore, for the future involvement of social robots, more emotional cues should be introduced to communicate and respond to the perception of people interacting with them. Providing robots with emotions can be very useful for facilitating Human-Robot interaction. However, human's emotions toward social robots should not be neglected. Social robots can be designed to be human centric to interact with people and maintain a state of positive emotions.

The main emphasis of this book is the emotional component of social robot design, as a means of promoting successful Human-Robot Interaction. The successful social robot design is the ultimate fulfillment of creativity and multidisciplinary work. Social robots are designed by people and meant for people. This book highlights the multidisciplinary work and design for people.

The contents have been structured to achieve four main objectives: to promote emotional design for robotics; to highlight the fundamentals of design concerning the emotional component of social robots; to define the measures that can be used to identify the emotional component of robots used in the environment; and enrichment through case studies. This book makes a contribution to a very promising and challenging research field in which much needs to be done to develop social robots that are more affective, pleasurable, and satisfactory.

Lisbon, Portugal

Hande Ayanoğlu
Emília Duarte

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Part I
Understanding the Context

Chapter 1
Introduction

Hande Ayanoğlu and Emília Duarte

Over the past few years, significant technological development has been witnessed. This progress is visible not only in scientific and technological areas but also in social sciences and humanities (i.e., Design). Design, as a field of knowledge, is influenced by diverse disciplines such as Sociology, Philosophy, Psychology, Neuroscience, Geometry, Engineering, Robotics, among others. However, it was necessary to wait until the twenty-first century to attend to the greatest impacts in Design, one of which was suggested by Norman (2004) at the beginning of the new century. Norman suggested that assumptions from the field of Psychology related to the study about emotions are applicable to Design, specifically to product design. The author proposes and defends the importance of emotions in product design and how it is reflected in the user's interaction with the product or object. With this new argument, emotional design arises, which, over the last decades, has provided a big innovation in the way designers project and develop products, given the emotion and experience that they aim at triggering in the user. Van Gorp and Adams (2012) emphasize that over the last three decades, research that examines the relationship between design and emotion has steadily grown.

Another strong influence on the field of Design was Computer Science and Robotics. Computer Science technology boosted Design in the development of products that improve Human–Computer Interaction (HCI) (e.g., Norman and Draper 1986). In the meanwhile, Robotics was in its expansion and innovation phase. Initially, the objective of Robotics was the creation of industrial robots that would replace humans in the most dangerous and routine tasks (e.g., Paiva et al. 2014). As a consequence of technological development, other robots (e.g., companion robots) besides industrial ones were created which originated in the need for and focus on

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Human-Robot Interaction (HRI) (e.g., Breazeal 2002). Considering the growing number of robots designed to interact directly with humans, it has become necessary for the interaction to be able to be social. Within this scope, if robots are going to coexist with humans, then, better robot design is required (Kamide et al. 2014) considering more appropriate, desirable, suitable, and preferable interactions. Design is integral to the continued development of the field of HRI and it is in this sense that Design, Robotics, and Emotional Design should join forces for a superior HRI, namely for social robots.

According to Sanders (1992), product requirements are usefulness, usability, and desirability. Emotional design concerns with pleasure and usability, besides esthetics, attractiveness, and beauty (Norman 2004). According to Mokdad and Abdel-Moniem (2017) emotional design also takes users' emotions into consideration while designing or redesigning products by maximizing the good (positive) emotions and minimizing the bad (negative) emotions. If an emotional connection is necessary, pleasing and satisfying robots can build to strengthen the connection. To further the useful, usable, and desirable experiences in a relationship with robots, designers manipulate diverse characteristics of a robot (e.g., appearance, expressiveness, and behavior). The manipulations, familiar or unfamiliar, can result in triggering people's desires and create attraction and engagement to robots. Van Gorp and Adams (2012) state that the only familiarity can be enough to create pleasurable emotions and unfamiliar products are potentially unpleasant. In this sense, equipping robots with familiar features could lead to more desirable HRI through user testing to understand this connection for robots.

Emotion is an overriding influence in everyday life (Demasio 1994). Norman (in van Geel 2011) remarks that everything has a personality and sends an emotional signal. Van Gorp and Adams (2012) state that people tend to perceive a personality for each object and form relationships with each of them based on their perceived personality. In the case of robots, their personality can be represented by their characteristics. However, it should be investigated if the characteristics can evoke positive emotions and therefore lead to an engaging HRI.

Goris et al. (2011) suggest that the upcoming generation of robots will collaborate with humans in many aspects of daily life: from domestic tasks to health care with different population groups (e.g., children or elderly), whereby communication is essential. Different kinds of communication (e.g., using vocal expressions or gestures) can occur between humans and robots. Since emotions play a vital role in improving communication as well as in the mutual understanding between humans and robots (Buiu and Popescu 2011), Breazeal and Brooks (2005) suggest that interacting with a robot with the capability of giving social cues (e.g., by appearance or expressing emotions) is more natural and easier for people.

A person's psychological reactions toward robots can offer an important perspective on the investigation of expressions of emotions by robots. Fellous and Arbib (2005) declare that some aspects of emotions depend only on how humans react to observing behavior, some depend additionally on a scientific account of adaptive behavior, and some depend also on how that behavior is internally generated. Therefore, the main concern is how robots with emotions can improve the way they function, how people observe them correctly and feel more natural with them around. Moreover, people can more easily relate to a robot when they are able to connect with it on a personal level. As a result, the overall intent is not to create a robotic human, but rather to produce useful interactions by using emotions in autonomous robotic systems which can create positive emotions and lead people to define interaction with the robot as a desirable experience.

Emotions occur in every relationship from formal to the most intimate one; they can compel people to take action and influence their thoughts and decisions which can establish or ruin relationships. Arkin (2005) indicates that emotions provide two crucial roles for robots which are survivability and interaction. Survivability can be essential in a moment that does not allow for time to think nor react but emotions can help to modulate the situation and robots should interact effectively and efficiently with people in ways they are familiar and comfortable with. As emotions play an important role during interactions, incorporating emotions should be a key consideration in robot design.

When designing a robot that can be enjoyed and cared for over extended periods of time, it is essential that an understanding of not only Robotics but also emotional design be brought to bear. Emotional experiences with robots may be as important as the robot's task performance in terms of user acceptance and assessments of effectiveness. Understanding emotional design, how users feel, and what affects these feelings, is essential to provide better user experiences and interactions with robots. Some studies regarding emotions (e.g., Dautenhahn and Billard 1999; Breazeal 2002) provide support for effective interactivity between a robot and a human.

In the beginning, robots were nothing more than machines that people use to help and/or accomplish a task. Reeves and Nass (1996) emphasize that everyone responds, automatically and unconsciously, socially and naturally to media (i.e., robots). Accordingly, emotional meaning can become more important to a person than the functional meaning during an interaction. There are many robots in the market and although some of them are not particularly attractive, people still enjoy them. This can show that emotional meaning has a stronger effect on a person. Van Gorp and Adams (2012) mention connections which are created between people and robots that subconsciously affect the people. Hence, including emotional design is essential to provide meaning, connections, relations, and experiences with robots. Introducing emotions to robots is one way to ascribe positive meanings, create stronger connections, form desirable relations, and initiate effective interactions for enhancing HRI.

Social robotics has been gaining importance due to the increasing number of robots performing tasks where interaction with humans is a necessity. The ultimate goal of Social robotics is to communicate and interact with humans on an emotional level. Another goal of designing a social robot is that people should feel secure. How do people feel secure and comfortable while they are interacting with a robot—something that many regard as a threat to the human race? What kind of characteristics of robot design can help to overcome this association? What kind of process to elicit emotions is involved? How can we design a robot that is strong or weak, friendly or unfriendly, natural or unnatural? Another goal is to understand how people respond to robots emotionally. People should be able to interact with robots and this interaction should fit emotionally in terms of being engaged and having positive emotions toward them. Van Gorp and Adams (2012) suggest that a product must be emotional to be successful. Therefore, for successful HRI, emotions should be involved. In this sense, the main goal of this book is to present the process of designing a social robot, particularly focusing on its emotional component in order to create emotional connections and desirable and pleasurable experiences to improve the HRI. Moreover, the book helps to create robot designs that communicate emotions to fulfill users' needs by presenting the evaluation methods to test the emotions of the users.

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Chapter 2

A Motivational Case Study in Social Robotics

João S. Sequeira, Maria Isabel Aldinhas Ferreira, Ana Nunes Barata and Maria Filomena Pereira

Abstract Different social environments have been used, in recent times, as contexts for interaction by social robotics such as children in hospitals or classrooms with positive results. Recently, the MOnarCH project explored the formation of social relations between a robot and users, namely children, in the Pediatrics ward of an Oncological hospital. This robot can navigate autonomously in the available free space, interacting with basic verbal and non-verbal utterances, explicitly when someone is recognized or touches it. The chapter shows the design process of MOnarCH which is carried out in three phases: Conceptual, Production, and Deployment and Evaluation. The main intention is to understand how the system can be designed to best suit the people and the society who need to use it and include the necessary flexibility for a posteriori behavioral adjustment. Annotated video recordings and micro-behaviors that were used in some of the experiments asserts that MOnarCH is simply a playmate for a physically and emotionally fragile population, a new experience that does not replace healthcare professionals. The empirical evidence suggests that the vast majority of children surveyed had the correct perception that the robot was not alive. Nevertheless, children acknowledged the robot's presence in the Pediatrics ward and the liveliness features implemented positively.

Keywords Social robot · User-centered design · Design process · MOnarCH

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2.1 The Dawn of Social Robotics

By acquiring mobility and becoming robots, computers are nowadays required to engage in complex interactions with humans. The resulting momentum developed into social robotics, a blossoming area in the wide field of Robotics. Pragmatic economics, the aging of the population, and the intrinsic desire for a better Quality of Life (QoL) have been the underlying leitmotifs of this development.

Initially conceived to perform repetitive actions where human instructions were given a priori, robots are now starting to be assigned socially complex tasks. Creating artificial intelligence systems capable of acting as active partners, either being engaged in cooperative activities in a working environment or as coactors in multiple social contexts, is a highly complex endeavor. Its complexity challenges robotic engineering to go beyond primary concerns with the correctness of functional performance and compliance with basic safety rules, maximizing well-being and taking into account the specificities of the user, their needs, their expectations, and the way they feel and react to technology. In other words, as happens with all other artifacts, appliances or services, the figure of the user has come to play a central and determinant role throughout the design and production process.

Human-robot interaction is the natural follow-up to the initial stages of human-computer Interaction. People's perceptions of a robot resemble those involved in human–human interaction, with the distinctive feature that the robot still has a long road to go to achieve human-like sentiency.

Nevertheless, the growing integration of robots with social skills in society is leading to a worldwide expansion of the social robotics' field. Different social environments have been used as contexts for interaction by social robotics, e.g., children in hospitals (Shibata et al. 2001; Dautenhahn 2003; Dautenhahn and Werry 2004; Marti et al. 2013; Liu et al. 2008), children in classrooms (Tanaka et al. 2007; Kanda et al. 2009), adults in institutions and/or domestic scenarios (Turkle et al. 2006a, b), with positive results. Moreover, the existence of numerous projects targeting a diversity of populations shows the importance of the field (see a selection of projects in Table 2.1). All of these projects share common goals: well-being, moving robots outside labs, multimodal HRI, long-term HRI, understanding social environments, etc.

The number of projects in Table 2.1 is evidence of the maturity of robotics technologies, namely when operating in social contexts. The majority of these projects focus on (i) elderly people as end users and (ii) helping functionalities. Some of the robots in this summary have a dual purpose, as it is proposed they target different users (the elderly and children). The suggested bias toward the elderly population may be due to the fact that most elderly people like robots (Martín et al. 2013).

Studies have been carried out to discover elderly people's preferences regarding the design and features of a robot. The current results have shown that elderly patients prefer a robot that is smaller and with less humanoid features (Wu et al. 2012).

Zoomorphic robots have mostly been used to interact with elderly patients and results have been similar to those obtained with domestic animals (Bernabei et al.

Table 2.1 A summary of social robots and application domains

Link	Project Acronym	Robot/Application	End users
www.monarch-fp7.eu	MOnarCH	Edutainment for inpatient children in an Oncological hospital	Children
www.softbankrobotics.com	NAO	Humanoid robot of child size and full anthropomorphic features	Misc
www.softbankrobotics.com	Pepper	Humanoid robot, with anthropomorphic features, for generic people assistance	Misc
http://www.parorobots.com/	PARO	Seal cub robot with basic interaction capabilities and no locomotion	Elderly
www.aliz-e.org	Aliz-E	Artificial Intelligence for small social robots that interact with children using the NAO robot	Children
www.giraffplu.eu	GIRAFFPlus	Telepresence robot for remote monitoring	Elderly
www.chrisfp7.eu	CHRIS	Safe Human-Robot interaction within selected application domains	Misc
www.lirec.eu/project	LIREC	Building long-term relationships with artificial companions (lirec.eu/project)	Misc
www.cogniron.eu	Cogniron	Development of cognitive robots to serve as companions to humans	
humavips.inrialpes.fr	HUMAVIPS	Endow humanoid robots with audiovisual abilities such that they exhibit adequate behavior when dealing with humans (uses an NAO robot)	Misc
perso.ensta-paristech.fr/~tapus/HRIAA	HRIAA	Robot with social abilities and personality and emotions, using verbal and non-verbal and para-verbal communication (uses an NAO robot)	Misc
www.squirrel-project.eu	SQUIRREL	Human-robot interaction in a cluttered scene	Children

(continued)

Table 2.1 (continued)

Link	Project Acronym	Robot/Application	End users
strands.acin.tuwien.ac.at/	STRANDS	Long-term deployment of intelligent mobile robots in dynamic human environments. Understanding spatiotemporal structure of environment in different time scales.	Misc
www.dream2020.eu	DREAM	Autistic children (uses the NAO robot)	Children
www.companionable.net	CompanionAble	Personal assistant, for remote monitoring and aide memory services	Elderly
www.mobiserv.info	Mobiserv	Personal assistant, with some anthropomorphic features	Elderly
www.aal-europe.eu/projects/alias	Alias	Personal assistance in domestic and care homes	Elderly
www.aat.tuwien.ac.at/ksera/index_en.html	KSERA	Remote health monitoring robot	Elderly
rehabilitationrobotics.net/cms2/	Accompany	Personal assistant robot, for domestic use	Elderly
hobbit.acin.tuwien.ac.at	HOBBIT	Personal assistant robot for domestic use, with anthropomorphic features including manipulation	Elderly
mrl.isr.uc.pt/projects/socialrobot	SocialRobot	Personal assistant, with anthropomorphic features	Elderly
www.robot-era.eu	ROBOT-ERA	Personal assistant with anthropomorphic features	Elderly
rapp-project.eu	RAPP	Software platform for robotics apps	Elderly
www.ramcip-project.eu	RAMCIP	Personal assistant for domestic use, with dextrous manipulation and empathic communication capabilities	Elderly
http://www.growmeup.eu	GrowMeUp	Personal assistant using cloud computing and machine learning techniques. It is able to learn people needs in order to establish positive long-term relationships	Elderly
http://www.enrichme.eu	ENRICHME	Personal assistant for long-term monitoring and interaction	Elderly

(continued)

Table 2.1 (continued)

Link	Project Acronym	Robot/Application	End users
www.mario-project.eu	Mario	Personal assistant to address loneliness, isolation, and dementia effects.	Elderly
http://cordis.europa.eu/poject/rcn/206414:en.html	MoveCare	Personal assistant, using AI and machine learning, to propose exergames to people and detect risks	Elderly
http://cordis.europa.eu/project/rcn/206852_en.html	CARESSES	Robot able to autonomously re-configure their way of acting and speaking to match customs and etiquette of the person it is assisting	Elderly
https://www.heykuri.com	Kuri	Personal assistant with anthropomorphic features and lovable personality to play with children	Children
http://joyforall.hasbro.com/en-us	Joy For ALL	Robot pups (dog or cat) for companionship	Misc
http://www.aal-domeo.org	DOMEO	Personal Assistant for domestic use	Elderly

2013). Results show an increase in social activity, and less aggression and agitation, as well as fewer depressive symptoms (Giusti and Marti 2006; Šabanovic et al. 2013; Wada et al. 2013). Nutritional intake was also improved and the overall need for medication and medical follow-ups was reduced. At this moment, studies have not yet shown clear effects on patients' cognitive function.

In 2009, the U.S. Food and Drug Administration (USFDA) approved the PARO (see Chang et al. 2013; Moyle et al. 2013) robot as a class 2 medical device, for use with the elderly. This robot is currently being used in various countries, such as Germany, Denmark, and Japan.

In a pediatric hospital context, PARO has been used with children aged 2–15, whose communication improved as a result of the interactions between children and robot (Shibata et al. 2001). Another study measured brain activity in young adults through Functional Near-Infrared Spectroscopy (fNIRS) during interaction with this seal robot and the subsequent resting periods. Results showed that activity around the motor cortex decreased when PARO was turned off (meaning participants had no motivation to interact with it voluntarily), and there was also a decrease in the left frontal area activity after having interacted with PARO while it was turned on. This means that the area related to the recognition of emotional gestures as well as positive emotions had been activated while interacting with the robot (Kawaguchi et al. 2012).

Friedman et al. conducted a study with Sony's AIBO, the first consumer robot of its kind to be offered to the public (Aibo 2017). They looked into understanding people's relationships with AIBO, by analyzing the spontaneous postings in online AIBO discussion forums. The results showed that AIBO psychologically engaged this group of participants, particularly by drawing conceptions of technological essences, life-like essences, mental states, and social rapport (Giusti and Marti 2006; Friedman et al. 2003).

The companion robot cat from Hasbro (2017) has been used with people suffering from dementia and Alzheimer's in care homes. The social skills of the cat do not include walking, which is an important part of the animal's social behavior.

Current social robots include several commercial prototypes, some of which have already been used in real environments. The Chelsea and Westminster Hospital has been using an NAO robot "to assess whether these robots could help combat the social isolation experienced by many inpatients in hospital wards" (see NAO 2017).

The case of SoftBank Robotics' Pepper, used as auxiliary staff/receptionist at Ostend Hospital (see NAOb 2017) is an interesting example of technology that is still under development but, nonetheless, is profiting from its public usage. Pepper has also been "employed" in a maternity ward at a Belgium hospital, as an attempt to improve healthcare and putting a smile on patients' faces NAOb (2017). Other applications of this robot include very simple receptionist tasks in commercial environments.

Social robots are challenging the dichotomy between apparent living beings/artificial objects (at least from an epistemic point of view): people tend to recognize the robots as intentional agents even knowing they are not living entities, as a consequence of the natural human tendency to attribute intentional states to artificial objects (Giusti and Marti 2006).

2.2 A Case Study: The MOnarCH Project

Recently, the MOnarCH project explored the formation of social relations between a robot and people, namely children, in the Pediatrics ward of an Oncological hospital.

The MOnarCH robot (see Fig. 2.1) has an appearance consistent with the robot stereotype identified in a survey conducted with a set of children of ages up to 16 years old (Sequeira and Ferreira 2014). The robot is capable of navigating autonomously in the available free space, interacting with basic verbal and non-verbal utterances, namely when someone is recognized or touches it (see Fig. 2.2). It can also play simple games, such as a variant of the popular Flow Free commonly available in cell phones adapted to the slow dynamics of the inpatient children. It was assumed that adults (visitors and staff) could also be involved in casual interaction.

The paradigm underlying the MOnarCH project is that, even with technological limitations, a close human-like interaction mimicking some human communication features can be created. This is achieved by regulating the robot's activity/liveliness level according to the environment.

A typical scenario will be that of a robot wandering in open spaces, such as corridors or common rooms, socializing through various forms of greeting (e.g., Fig. 2.3 where the interaction with a child is depicted), until it is called to execute specialized tasks triggered by healthcare specialists.

Fig. 2.1 Young child exploring the robot (Credits: Exame Informática, 2016)

Fig. 2.2 Pre-teen interacting with the robot (Credits: Agência Lusa, 2015)

Fig. 2.3 A common reaction to the robot by a child in a hospital (Credits: José Oliveira and Revista Visão)

Fig. 2.4 The blueprint of the Pediatrics ward; the areas marked “classroom”, “playroom”, and “main corridor” can be used by the robot

2.3 The MOnarCH Environment

The environment accessible to the robot is essentially a flat area made up of a long corridor, a playroom, and a classroom (see Fig. 2.4).

During the project, video cameras were installed in static positions. These were used to estimate people’s positions in the ward, specifically the position of the children playing the Flow Free game variant (see Sequeira et al. 2015).

The areas accessible to the robot form a well-structured environment, where state-of-the-art localization techniques yield good results. Even in the presence of obstacles, the laser range sensors installed at the front and rear of the robot can acquire measurements that easily match an a priori defined map of the environment (see Ventura and Ahmad 2015 for details).

2.4 Designing a Social Robot—A User-Centered Framework

The term user-centered design was coined by Donald Norman and Stephen Draper in 1986 (Norman and Draper 1986) focusing the particular field of ergonomics in human–computer interaction. The approach explicitly highlighted the need, throughout the design process, to be aware of the potential user and the specificities of their physicality, as well as the nature of their experience using it. User-centered approaches have been reported, for example, in Wu et al. (2012).

The rich multidisciplinary framework involved in the process led some authors (e.g., Steen 2012; Giacomin 2012) to propose the term “Human-Centered Design” as more suitable for covering all aspects of what being a human means and not only those specifically concerned with usability. However, both user-centered design and human-centered design highlight the fact that all artifacts, including technological artifacts, are determined in their function and form by the anatomy and physiology of the user, by their psychology and life experience, by their expectations of technology, as well as by the specificities of the particular context of use.

Consequently, rather than expecting people to just adapt to a new technological artifact, learning how to handle or interact with it, robotic engineering has to be capable of thinking and anticipating how the system can be designed to best suit the people and the society who need to use it, or include the necessary flexibility for a posteriori behavioral adjustments.

In order to achieve this aim, one needs to identify the assumed end user and design for the variability represented in the population, spanning such attributes as age, size, strength, cognitive ability, prior experience, cultural expectations, and goals, thus optimizing performance, safety, and well-being.

Acknowledging the essential role played by the explicit understanding of the nature, status, and context of end users, the International Organization for Standardization has defined the six essential procedures to be followed throughout the production process (see ISO 9241-210 2010):

1. The design is based upon an explicit understanding of users, tasks, and environments.
2. Users are involved throughout design and development.
3. The design is driven and refined by user-centered evaluation.
4. The process is iterative.
5. The design addresses the whole user experience.
6. The design team includes multidisciplinary skills and perspectives.

2.4.1 The Definition of the User's Referential Framework

The particular characteristics of the users, all with their own special circumstances; the specific civilizational/cultural environment and the communicative context and conditions of use in the definition of the overall system and its expected performance play an essential part. This has therefore called for the definition of what we have designated the **User's Referential Framework—URF**.

The following factors, in some cases subsuming a small set of features, can be identified as constituting this referential framework:

1. Function/role to be performed by the system.
2. Universe of users.
3. Nature and Status.
4. Typical Environment: Scenario and Context of use.
5. Interaction Lifespan: Frequency and Duration.

Function/Role is determinant when conceiving an artifact. Whether it is technological or not, the overall architecture and all the design options are dependent on the function being performed.

Universe refers to the number of individuals supposed to interact with the artifact on regular terms. This interaction can involve a single individual, as in the case of an elderly person who has a service robot at home; or a multiple universe, as in the case of a service robot performing in a domestic environment and being assigned various tasks by the different family members, e.g., educational interaction with children, assisting adults in cleaning tasks, or entertaining grandma playing games.

Universe can consequently correspond to **a single individual or to multiple individuals**.

Nature and Status subsumes the variants (i) Age, (ii) Gender, (iii) Civilizational/ Cultural Context, and (iv) Particularities.

The age of the user and the specificities of their physicality are fundamental. Is the robot meant to interact with children, with adults or with both? The answer to this simple question will determine the dimensions of the robotic structure, the type of interfaces available, the overall appearance of the robot, and the materials to be used.

Besides the individual physical/chronological constraints when defining the system's architecture, designers have to be aware of important cultural differences in communities and societal groups that may determine the consumers' preferences in terms of the robot's appearance. For instance, it is well-known that the uncanny valley effect—the feelings of eeriness and revulsion experienced by most human beings when interacting with near-realistic humanoid objects (Mori 2012)—seems to be prevalent in the choice of a robot's appearance in western countries, though its effect is not so significant in the east (MacDorman et al. 2008).

One has to acknowledge the possible relevance of **Gender**, but we consider that this factor really places no constraints, although its specification just contributes to a possible customization of the artifact.

The Particularities factor relates to specific physical and mental user constraints that have to be considered by the design, for instance, any kind of physical impairment or psychological/mental condition.

Typical Environment: Scenario and Context of Use relates to the physical environment in which the system will be integrated, as well as the social atmosphere where it is going to be embedded and which it has to be responsive to. It involves questions such as Where is the robot going to operate? In the open air as, for instance, an agriculture aid? Will it operate indoors? For example, in collaborative contexts within industry; in institutional spaces and collaborative contexts such as assistive and care tasks; or in the domestic environment in edutainment activities for all the family? All these different options determine fundamental differences in terms of its overall architecture, namely, its physical robustness, mobility, perceptional awareness, navigation performance, as well as variations concerning interface definition and the forms of interaction available.

When we talk of **Interaction Lifespan**, we are assuming that every HRI taking place in a virtual timeline can vary according to its **frequency**, i.e., the number of times it occurs and according to its **duration**, i.e., how long it keeps going on. Regarding its **frequency**—it can be either **occasional**, such as the interaction between a robot and a museum visitor, or it can be **recurring**, as with a service robot in a domestic environment and the people that live there. Regarding **duration**, interactions can be either **short-** or **long-termed**. In a way, we can say that all occasional interactions are short-termed, while recurrent interactions are necessarily long-termed. The differences in interaction frequency and duration pose distinct problems. Occasional interaction, such as people suddenly coming face to face with a robot in a shopping center, requires the platform to swiftly attract and engage people, because the chance to interact happens in a snapshot. On the other hand, interactions that have a durative character, especially those that are long-termed, test the system's capacity for keeping the recipient's interest in the interaction. It must surprise them with new approaches/activities so that it doesn't become predictable and boring.

Table 2.2 sums up and organizes the main factors defining the User's Referential Framework.

2.4.2 The URF in the MOnarCH Project

The design of the MOnarCH robot is fully compatible with a user-centered design approach. Though it is anticipated that the robots might, and probably will, also interact with adults; children are the primary end users. Their interactions will be generally recurrent, though not necessarily long-termed, as the duration of the children's stay in hospital will vary.

Considering the relevant factors defining the User's Referential Framework (URF) as shown in Table 2.2, the following previous definition of the MOnarCH's end user profile is displayed in Table 2.3.

According to this referential framework the users, as mentioned above, will multiple, constituted by children and/or teenagers, mainly European and African. The interaction, either short- or long-termed (Ferreira and Sequeira 2015) according to the individual situations, will take place in the Pediatrics ward of a hospital, involving edutainment activities. The interactions will be generally recurrent though not necessarily long-termed, as the time span children are hospitalized will vary.

The activities included (i) helping to maintain the children in socially interesting dynamics and (ii) playing with the children. The assumption is that adults (visitors and staff) could also be enrolled in casual interaction.

The Pediatrics ward in MOnarCH is regulated by social norms established to preserve healthcare efficiency and the children's well-being. These norms implicitly limit the spatial areas a robot can use, and the admissible interactions. Consequently, specific behavior has been adapted to different areas of the ward. In a playroom, for example, the robot is able to play an interactive Flow Free game with a child; whereas in the main corridor of the ward, the robot can play catch-and-touch or simply wander around greeting people it recognizes.

Table 2.2 User's Referential Framework

Universe		Nature and status				Typical environment/scenario			Interaction lifespan			Functional role(s)
						Open air	Indoor					
Singular	Plural	Age	Gender	Particularities	Civilizational/ cultural context	Physical space	Institutional space	Domestic space	Frequency	Duration		
Individual user	Multiple users	Child -teenager	Gender specific, not gender specific	Disabled, other	European, Asian, American…	Public spaces, open institutional spaces, industry, agriculture	School, library, hospital, care house, industry	Flat, detached house	Recurrent	Short termed	Long termed	Edutainment, assistive and care, collaborative work

Table 2.3 MOnarCH URF

Universe		Nature and status				Typical environment/scenario Indoor	Interaction lifespan			Functional role(s)
Singular	Plural	Age	Gender	Particularities	Civilizational/ cultural context	Institutional space	Frequency	Duration		
~~	Multiple users	Child-teenager	Not gender specific	Inpatient children with severe physical condition	Mainly European	Hospital	Recurrent	Short termed	Long termed	Edutainment

2.4.3 *The Design Process*

The design process was carried out in three phases: Conceptual, Production, Deployment, and Evaluation. For the purpose of the present chapter, brief descriptions are given here of only the first two.

In Phase 1—the Conceptual Phase—the process started with an inquiry conducted in two public schools (to about 120 children and teens) of the suburban area of Lisbon in order to verify (i) the existence of a prototypical mental image corresponding to the concept of robot and (ii) the semantic consistency of this concept among children and teens.

Identifying the children's assumptions in terms of visual image (Fig. 2.5) and their expectations concerning the functions to be performed by a robot provided design guidelines that were important when defining an engaging and stimulating application capable of enhancing a fluent child/robot interaction.

As regards the visual image, the results of the above-mentioned survey pointed to a nearly generalized preference for anthropomorphic forms relative to all possible others, and a multi-functional capacity that body forms always reflected. Features such as eyes, mouth, and arms were present in most of the children's drawings (98%) and a particular emphasis was given in a significant percentage (35%) to a supplementary "tablet-like" interface on the chest area. As to the expected functionalities,

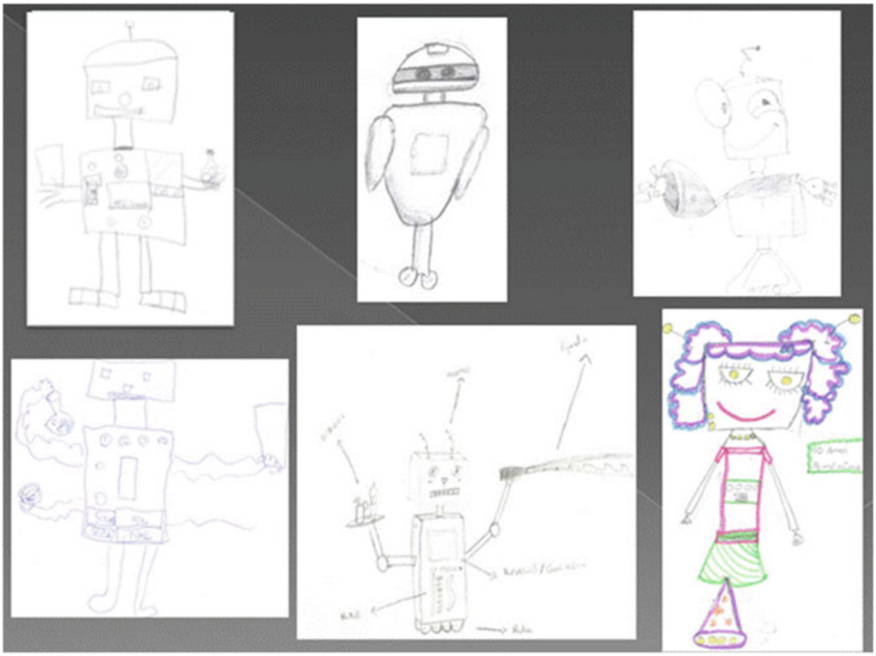


Fig. 2.5 Sample of children's drawings from the survey

edutainment and helping with domestic tasks, such as tidying up the bedroom were prevalent.

Some of the elements identified by the children were used by the design team. A set of preliminary drawings, shown in Fig. 2.6, was discussed by the MOnarCH team.

A merging of the options # 2 and # 3 features (Fig. 2.6, top left) was chosen, namely, because of their rounded, smooth surfaces, interface area in the belly zone, and expressive potential of the facial area.

The robot is 1.15 m tall, about the height of an 8–11-year-old child, in order to keep interaction with the children as close to eye level as possible (see Fig. 2.7). The robot weighs around 45 kg, fitting for a child's companion. It is equipped with a variety of sensors, including laser range finders and touch sensors (bumpers and soft touch). These enable the robot to estimate its localization with accuracy, so as to avoid obstacles and interact with the children.

The robot has an omnidirectional motion with linear velocities of up to 2.5 m/s, and is thus capable of walking beside a person at a moderately fast pace. The empirical evidence collected throughout the project suggested that there was no need for higher velocities. For some expressive capacity, the robot has got two 1-dof arms and a 1-dof neck, variable luminosity eyes and cheeks, a LED matrix for a mouth, loudspeakers, microphone, touch sensors placed in strategic places of the body shell, and a RFID tag reader. The 1-dof arms do not aim at any form of manipulation. Instead, they are useful, for example, to convey the perception of body movement when the robot circulates.

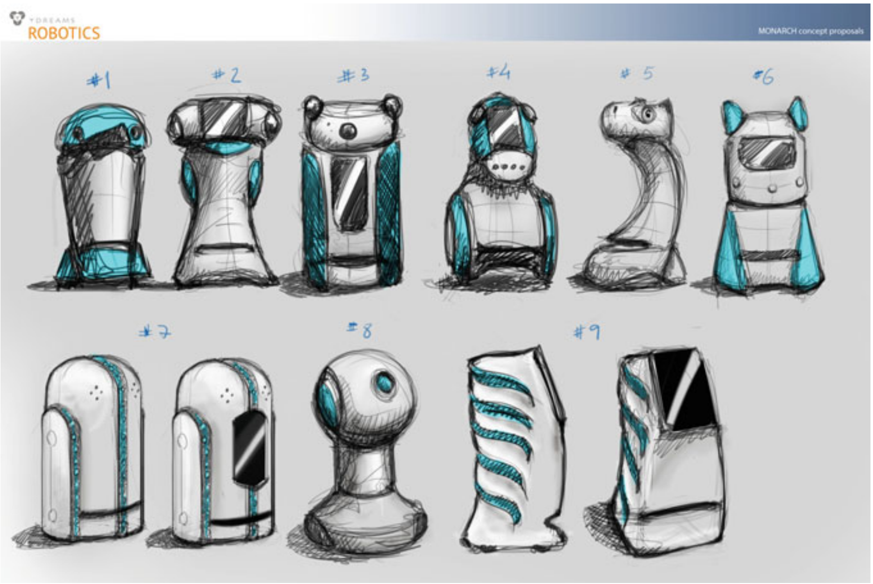


Fig. 2.6 The MOnarCH robot's appearance: initial studies conducted by one of the project partners

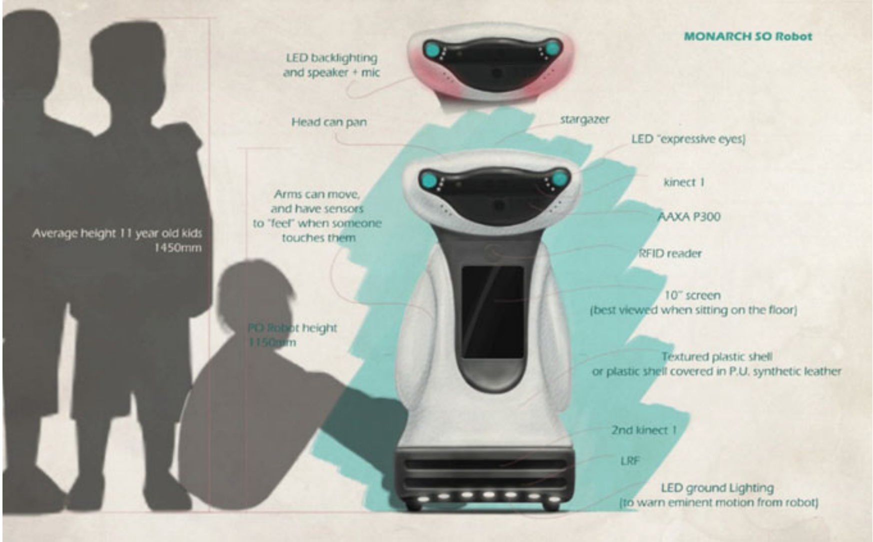


Fig. 2.7 Main features of the MOnarCH robot final version

Movement can be perceived by living organisms as expressive, in the sense of being meaningful, and body movements are generally interpreted among different species in specific ways. Just the way one walks carries a multitude of data comprehending for the observer: such different features as psychological state/attitude, mood, intention and also physical condition, or age.

The MOnarCH robot tries to convey the idea of lightness and cheerfulness with its soft and swift movements. Moreover, the smooth motion of the robot's body can sometimes be seen as "dancing" (see Fig. 2.8). This is just an example of expressive motion that contributes to the liveness of the robot. Similarly, when playing Flow-

Fig. 2.8 The MOnarCH robot using a "dancing" movement for expressivity (the sequence evolves from left to right)

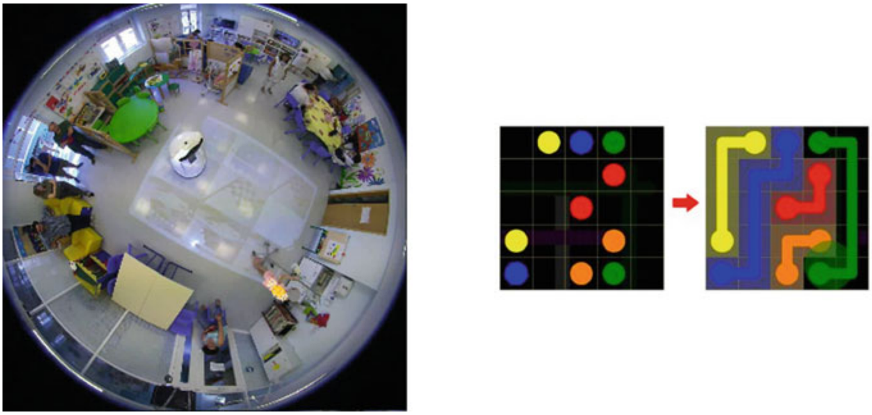


Fig. 2.9 Child playing the Flow Free interactive game with the robot (cell phone sample game on the right image)

Free (see Fig. 2.9) it is important to include small movements to convey a perception of liveness.

The two 1-dof arms are used to improve liveliness. A simple balancing of the arms, while the robot is moving, can easily convey the perception that the robot has a focus while moving or a goal location (as, for example, when playing “catch-and-touch”—see Fig. 2.10).

Also, the fact that the neck can rotate right or left (1-dof neck) conveys the feeling that it is looking at whoever it is interacting with or that it has a clear focus of attention, which contributes to interaction fluency (relevant in scenarios such as the Flow Free game of Fig. 2.9).

2.5 Technologies

The omnidirectional platform supports two laser-based range sensors, for obstacle avoidance and localization, with one computer in charge of the navigation and another to handle the interaction devices. These are the touchscreen in the chest, two LED eyes with color and intensity control, a LED matrix mouth, two RGB-D cameras, and a RFID reader inside the head. Touch sensors are available at the tip of the arms and around the shoulder area.

The laser range finders located at the front and at the back of the robot, at approximately floor level, provide 360° coverage around the robot with a 0.5° angular separation. Figure 2.11 shows the location of the robot in the ward (left-hand image) and the LRF measurements in the neighborhood of the robot (right-hand image). Regions of measurements (the red and blue points) aligned along with line segments, corresponding to walls in the corridor, are visible in the right-hand image. The dots in the close neighborhood of the front part of the head correspond to people

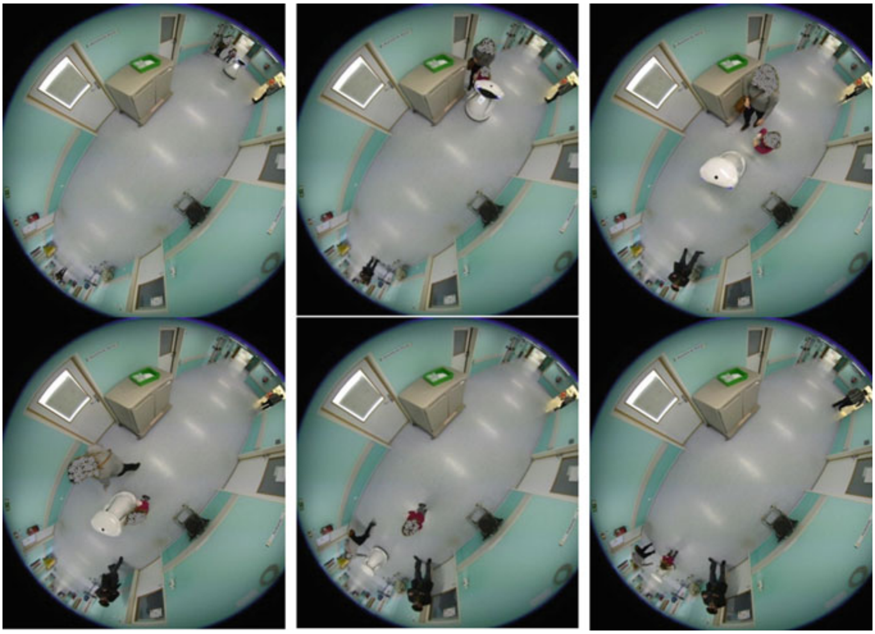


Fig. 2.10 Child playing catch-and-touch with the robot

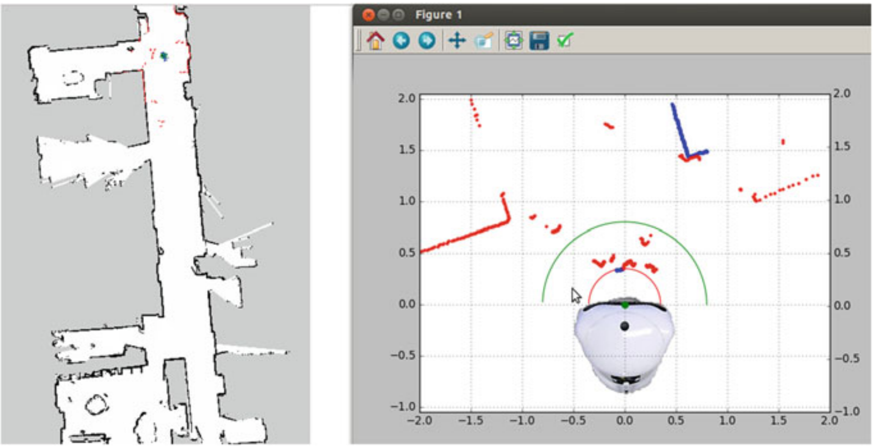


Fig. 2.11 A sample of laser range finder around the robot (the red dots stand for the laser range finder measurements)

standing in front of the robot (the legs of these people are visible as pairs of small sets of red points).

Primary interaction occurs through the facial expressions made through the eyes, mouth, and touch sensors. The legal restrictions on the use of video imaging discourage the use of the RGB cameras. Only the depth information is being used to detect people in the surroundings. Therefore, the robot does recognize or record RGB-D images but with no connection to databases maintaining inpatient health records.

The robot can operate either fully autonomously or using a Wizard-of-Oz strategy with various degrees of autonomy (see Fig. 2.12). Under full autonomy, the robot behavior is supervised by a finite-state machine that can be easily adapted to environmental changes (see Fig. 2.13).

Switching between the high-level behaviors is triggered through specific RFID tags detected by the reader inside the head of the robot. By default, the robot operates in the wander mode, moving around the main corridor without entering the inpatient rooms. The tags controlling the supervision state machine are only used by duly authorized staff members.

To account for emergency situations, the robot has a stop button (placed in a visible area at the back) that if activated stops all activity and allows anyone to push it out of the way.

People recognition is also made through the RFID technology. People wanting to be recognized must carry a small tag. This tag contains only information voluntarily waived by the user of the tag, e.g., a name, which does not need to have any relation with the person's real name.

The reader's antenna has a distinctive detection pattern (see Fig. 2.14) that is also used to provide a rough estimate of the angular position of a tag around the robot's head (Sequeira and Gameiro 2017).

Fig. 2.12 Wizard-of-Oz interaction using a smartphone

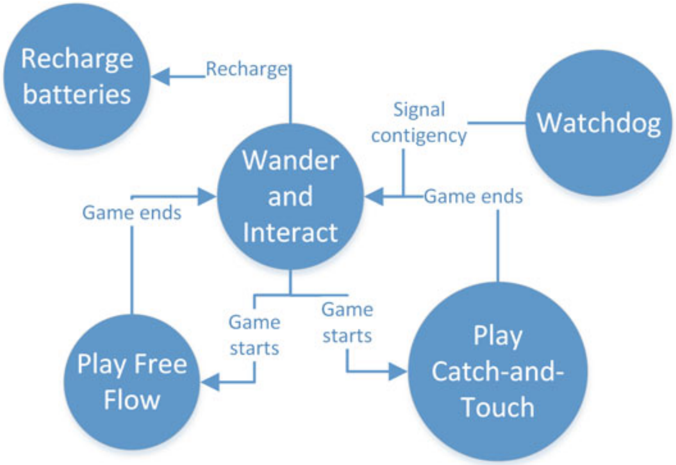
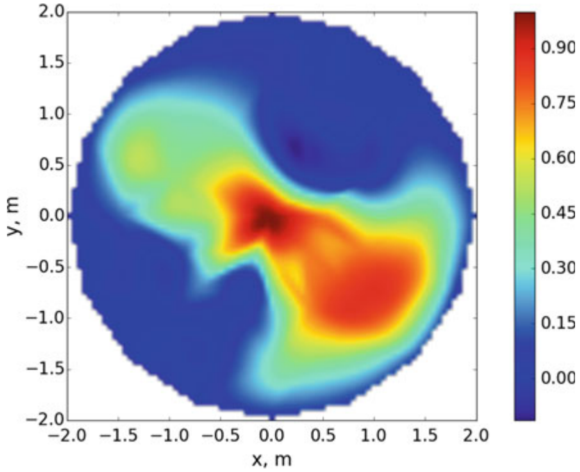


Fig. 2.13 An overview diagram of the high-level behavioral supervision state machine

Fig. 2.14 RFID antenna detection pattern (interpolated probability surface)



This rough estimate creates the interesting perception that the robot knows where a person carrying a RFID tag is, much like a normal person, i.e., often correct but failing sometimes.

2.6 Assessment

Developing metrics for social robotics' experiments have been a central topic in the field. The diversity of conditions makes the conclusions of one experiment not immediately applicable to another, even if seemingly equivalent.

The literature on the topic is extensive. For example, randomness has been recognized as helpful in some HRI scenarios (Holthaus et al. 2011), meaning that to properly compare different environments, uncertainty must be adequately estimated in them.

Moreover, assessing in-lab experiments may yield consistently different results than apparently equivalent out-lab ones (Weiss et al. 2011). In fact, standard techniques such as Likert questionnaires may easily introduce bias in out-lab experiments, e.g., by creating expectations about what is expected from people answering the questionnaire.

Annotation techniques, e.g., either directly or indirectly through video recordings, seem more appropriate for experiments in generic out-lab environments. With MOnarCH, annotated video recordings were used. Table 2.4 shows a list of micro-behaviors used in some of the experiments. These were selected to (i) be reasonably simple to identify, and thus minimize a priori misclassification of micro-behaviors and (ii) provide indicators that can be easily identified with the desired performance indicators, e.g., acceptance/rejection.

In MOnarCH, multiple indicators of micro-behavior relevance were used, namely, (i) direct counting of occurrences, (ii) activation rates, and (iii) functions of the time between occurrences (see Sequeira 2017 for details).

The activation rate, i.e., the number of micro-behavior occurrences per unit of time, indicates the micro-behavior relevance within a given time interval.

Counting the number of occurrences in an experiment allows for micro-behavior ranking and, hence, it is an indicator of their relative relevance.

The time between occurrences is intrinsic to the environment dynamics for which probabilistic models can be estimated.

In a sense, if the set of micro-behaviors to be annotated is rich enough, it will capture the environment dynamics, defined in terms of the timing of the micro-

Table 2.4 Sample of annotated micro-behaviors in a MOnarCH experiment

	Micro-behavior
1	Looking toward the robot, without direct interaction
2	Looking toward the robot and moving (around, ahead, and/or at the back of the robot)
3	Touching the robot
4	Aggressive movement toward the robot
5	Ignoring the robot
6	Following the robot
7	Compliant behavior toward the robot

behavior occurrence (the relevant events). Performance can then be assessed by looking at models of the environment and at any deviations from normal conditions.

As an example, experiments in MOnarCH yield aggregate countings, such as those in Table 2.5, found in two separate experiments. These occurred on different days with a 6-day interval in between, and with different children.

A ranking of micro-behaviors formed with these values, after normalization, suggests that (i) the robot does not significantly change the environment, as the micro-behaviors related to indifference are top rank and (ii) the robot is well accepted, as those related to acceptance are ranked next, while those related to non-acceptance are ranked bottom (see Sequeira 2017).

An example of the activation rates obtained in MOnarCH experiments is shown in Table 2.6. In this case, the set of micro-behaviors in Table 2.4 was used to annotate two different experiments on the liveliness exhibited by the robot.

A direct comparison between the two lines in Table 2.6 suggests that increased liveliness diminishes the relevance of micro-behavior 5, i.e., ignoring the robot. Furthermore, the values in the rightmost, micro-behavior 7, column suggest that people tend to be more compliant if the robot seems alive. People also appear to be less interested in following the robot if it shows improved liveliness. The differences between values relative to micro-behaviors 1–4 do not seem to be significant when drawing conclusions.

A major issue when assessing social interaction experiments in out-lab environments is the planning of experiments. To avoid introducing bias, experiments often cannot be scheduled in advance. Instead, they must occur at the environment's natural pace. The examples are the trials reported in Table 2.5. They had 6 days between them, as the team had to wait for the right environmental conditions.

Table 2.5 Aggregate counting for each of the micro-behaviors in Table 2.4, for two experiments

	1	2	3	4	5	6	7
Count 1	49	40	9	1	77	16	40
Count 2	50	18	1	0	97	0	65

Table 2.6 Activation rates ($\times 10^{-2}$) in two experiments (the micro-behavior list in Table 2.4 is used)

	1	2	3	4	5	6	7
Activation rate (low liveliness)	1	0.64	0.16	0.03	1.9	3.2	0.61
Activation rate (high liveliness)	0.86	0.78	0.16	0	1.1	0.23	0.82

2.7 Current and Future Challenges

In the near future, the widespread deployment of robots in different domains of human life will be one of the major technological and social challenges. There will, consequently, be a need for harmonious and sustainable coexistence between humans and embodied intelligent machines in shared physical, social, and cultural environments. So far, most of these new robotic applications have been conceived and tested in the lab, with their design process and evaluation being mainly guided by concerns with the functional correctness of their performance, e.g., when navigating, perceiving the surrounding environment, or grabbing things. There has been less concern about the need to produce autonomous artificial entities that are not only functionally efficient but also appealing and adequate for differentiated end user groups. If it is true that the process of incorporating a new artifact in society always involves the adaptation of human beings to it, it is also true that technology has to be user-friendly, so that it is easily accepted, understood, and smoothly incorporated in people's typical routines and environments. A user-centered approach, therefore, becomes essential throughout the design and production process. The identification of the potential end users and their corresponding characteristics, as well as the identification of the circumstances and contexts of use calls for the definition of what we designate the User's Referential Framework—URF.

The added value brought by a social robot, such as MOnarCH, must be assessed through long-term experiments. MOnarCH is simply a playmate for a physically and emotionally fragile population, a new experience that does not replace healthcare professionals. The empirical evidence collected suggested that the vast majority of children surveyed had the correct perception that the robot was not alive. Nevertheless, children acknowledged the robot's presence in the Pediatrics ward and the liveliness features implemented positively.

Ethical issues are currently gaining momentum, profiting from a media frenzy. MOnarCH followed the legal recommendations, namely (i) those from the National Data Protection Authority (CNPD), which severely restricts the usage of sensors, such as video cameras; (ii) the use of Informed Consents (EC 2017a) and (iii) the use of a code of conduct for the team members (Delvaux 2016; EC 2017b).

A Pediatrics ward is, by nature, a sensitive environment and requires extreme care in terms of the robot's behavior. From a physical point of view, people's safety in the Pediatrics ward was never an issue, with the current technology ensuring a collision-free operation. For approximately 18 months, the robot operated on a daily basis in two 1-h periods, one during the morning and the other in the afternoon. During these periods, several developmental stages were tested, always minimizing team member presence in the ward.

To continue improving inpatient QoL, it is paramount to innovate in perception techniques, namely avoiding ethics related issues. The real-time estimation of social environment models and the adjustment of robot behaviors to comply with any local social norms, especially related to multimodal communication to improve interaction with humans, are also topics of interest.

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Part II
Fundamentals

Chapter 3
Human-Robot Interaction

Hande Ayanoğlu and João S. Sequeira

Abstract Social robots are artificial socially intelligent partners, designed to interact with humans in various contexts. If well accepted by users, they can accomplish tasks (e.g., personal assistant/companion), which are particularly relevant when other humans are absent and improve the quality of life. As the main purpose of social robots is to interact with humans, they must have the ability to establish and maintain a relationship. In this context, the chapter introduces Human-Robot Interaction as interaction became more important, especially with social robots, due to the recent move of robotics from the industrial environment to the human environment. Various factors such as uncanny valley, proxemics, empathy, trust, engagement, and emotional design affect the interaction with a social robot and are explained in the chapter.

Keywords Human-Robot Interaction · Social robots · Influencing factors in HRI

3.1 Introduction

Human-Robot Interaction (HRI) is an area extensively covered in literature, often including the more general Human–Computer Interaction (HCI) or Human–Machine Interaction (HMI) areas (e.g., Carroll 2003; Dix et al. 2004). HRI is dedicated to understanding, designing, and evaluating robotic systems for use by or with humans (Goodrich and Schultz 2007). The design of a robot, namely its appearance, behavior and social skills, is highly challenging and requires interdisciplinary collaborations. Thus, HRI is a growing area of research that intersects many different fields such

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as Design, Psychology, Cognitive Science, Social Sciences, Artificial Intelligence, Computer Science, Robotics, and Engineering.

Dautenhahn (2013) mentions that researchers focus on the HRI field for a variety of reasons. Some may be roboticists, working on developing advanced robotic systems with possible real-world applications, e.g., service robots to assist people in their homes or at work, and they may join this field to find out how to handle situations where these robots need to interact with people, in order to increase the robots' efficiency. Others may be psychologists or ethnologists and take a human-centered perspective on HRI; they may use robots as tools in order to understand fundamental issues of how humans interact socially and communicate with others and with interactive artifacts. Artificial Intelligence and Cognitive Science researchers may join this field with the motivation to understand and develop complex intelligent systems, using robots as embodied instantiations and test beds of those. Last but not least, a number of people are interested in studying the interaction of people and robots, how people perceive different types (e.g., human-like, animal-like) and behaviors of robots, how they perceive social cues or different robot embodiments, etc.

Early robots were nothing more than clever mechanical devices that performed simple pick and place operations, whereas, nowadays robots have become more sophisticated and diversified to meet the ever-changing user requirements (Wang et al. 2006). Due to the fact that robots are involved with more users, there is a growing area of research interest regarding the HRI which highlights human-centered experiences in which people are the core focus (e.g., rescue, military, entertainment, hospital care). Besides robots and humans sharing the same context, sometimes they share the same objectives to achieve a task. Accordingly, it has become increasingly apparent that social and interactive skills are necessary requirements in many application areas and contexts where robots need to interact and collaborate with other robots or humans (Dautenhahn 2007).

While improving robot functions, evaluating the risks and benefits of interaction and collaboration is essential. In this sense, research in HRI is focusing on safe physical interaction (e.g., Lasota et al. 2017) but also on a socially correct interaction by building intuitive and easy communication with robot through speech, gestures, and facial expressions (e.g., Giambattista et al. 2016; Kanda et al. 2005). Depending on the roles and type of robots, interaction, and communication can have various forms.

HRI addresses the multidisciplinary aspects involved in all forms of communication, explicit and implicit, between humans and robots. In a sense, it encompasses social and nonsocial robotics. In the area of nonsocial robotics, there are numerous examples, with well-defined metrics, where the importance of carefully designed HRI is clear. Considering robotics strict sense, where a robot must have motion capabilities of its own (though it may not be autonomous), it is easy to construct an example where adequate HRI is paramount, e.g., warning the people in the surroundings that the robot is approaching by issuing verbal and/or nonverbal utterances (this is an especially relevant example in the context of autonomous/intelligent automobiles). For wide sense robotics, e.g., a cell phone that only moves jointly with its owner, it is important that the design of the interface maximizes a usability measure. Social robotics is specifically dedicated to equip robots to respond to the needs of people (Sekmen and Challa 2013). As there is more interaction/communication with social robots than nonsocial ones, it is important to focus more on the former.

3.2 Social Robots

The robot industry used to focus more on labor-intensive or hazardous tasks such as factory automation or military operation. Since robots have their roots in the industry, industrial robots are more focused on repetitive tasks. Siegel (2009) emphasizes that the robot industry has seen rapid growth in areas outside of industrial robots, and as a result of this transition robots are beginning to resemble those of our science fiction inspired imaginings, in that they are designed to function in a human environment.

The Japan Robot Association (2001) showed that there was a considerable expectation of a growing need for robots in houses, medical, and nursing care services to assist the aging society, both from a physical as well as a psychological point of view. Therefore, as research in robotics further, a shift occurred from industrial to more domestic, service-oriented and human-centered robots. The International Organization for Standardization defines a service robot as a robot that performs useful tasks for humans or equipment excluding industrial automation applications (International Organization for Standardization 2012). Litzenberger and Hägele (2017) indicate service robots are for professional and personal/domestic use in nonindustrial environments. A personal service robot or a service robot for personal use is a service robot used for a noncommercial task, usually by laypersons, such as a domestic servant robot, automated wheelchair, and personal mobility assistance robot. A professional service robot or a service robot for professional use is a service robot used for a commercial task, usually operated by a properly trained operator. The operator is designated to monitor and stop the intended task. Examples are cleaning robots for public places, delivery robots in offices or hospitals, fire-fighting robots, rehabilitation robots and surgery robots in hospitals.

After years of development, robots are being designed to serve in our daily lives as pets such as Sony's Aibo (Kubinyi et al. 2004) and Paro (Wada and Shibata 2007), servants like Kuri (Simon 2017) and ElliQ (Wilson 2017) or tour guides like Aggie (Wynne 2016). These robots are considered social robots due to their autonomous interaction with humans in a meaningful way. However, depending on their purposes service robots are not necessarily social robots. For instance, UV-Disinfection Robot (Robi-X Case 2018) is a mobile service robot that disinfects through a powerful UV-C light for hospitals. The robot requires virtually no human interaction and therefore has a minimal impact on the workflow of the hospital staff.

In accordance with this definition, the consumer market for service robots that are designed for personal and domestic use is also growing at an increasing rate (World Robotics 2013). This shows that robots are increasingly becoming an integral component of our society and they have great potential in being utilized as social companions. According to Dautenhahn and Billard (1999) social robots are embodied agents that are part of a heterogeneous group: a society of robots and humans. Therefore, robots need social skills to enable them to perform a task. Breazeal (2002) defines a social robot as a robot that is socially intelligent in a human-like way and interacting with it is like interacting with another person. According to the author, creating social robots will require an understanding of how humans respond to them, and in what ways our understanding of human interaction applies to HRI. It is noticeable that social robots are already supporting various tasks of our lives such as care and service providers (e.g., help elderly and disabled people), educational partners (e.g., help children to learn a new language), and entertainment (e.g., play games).

Social robots can be classified as animal-like such as Leonard (Breazeal et al. 2005), Probo (Saldien et al. 2008) and AIBO (Kubinyi et al. 2004), human-like such as KASPAR (Dautenhahn et al. 2009) and SAYA (Hashimoto et al. 2006), character-like such as eMuu (Bartneck 2002), Teo (Bonarini et al. 2016), and Mung (Kim et al. 2009) or machine-like such as Nao (Beck et al. 2010), EMYS (Ribeiro and Paiva 2012), and QRIO (Tanaka et al. 2004). These new generations of robots will be used in close collaboration with people in a wide spectrum of applications (Goris et al. 2010). As social robots become more utilized and routine in everyday situations, people will be interacting with social robots in a variety of contexts (e.g., hospitals, homes, museums). There are robots which were not designed only to operate in a human environment, but also to function with a social component by interacting with people. Siegel (2009) indicates that robots are expected to interact with humans in the very same way that humans interact with each other and this may prove to be an ideal form of communication for robots. Goetz et al. (2003) found that people expect a robot to look and act appropriately depending on the task, form follows function. Thusly, if a robot acts like a human, then it should have a human-like appearance. Moreover, Dautenhahn et al. (2005) highlight that people prefer a robot to perform specific roles and tasks in addition to the desired behavioral and appearance characteristics. In other words, some robots will appear in different forms, not for reasons of aesthetics, but because it is the most effective design for the task (Norman 2004).

Fong et al. (2003) explain that a social robot should show emotions, have capabilities to converse on an advanced level, understand the mental models of their social partners, form social relationships, make use of natural communication cues, show personality and learn social capabilities. Interaction is the most serious difference between industrial robots and robots which serve in daily environments (Kanda and Ishiguro 2013). Therefore, if social robots are sharing environments with people, it is important to understand what the interaction with them looks like.

3.3 Interaction

The success of robots in the assistance of humans depends on the extent to which they are able to interact with humans at a social level (Lewandowska-Tomaszczyk and Wilson 2016). Therefore, having robots be able to autonomously interact with humans, in a context where they would have to continuously adapt to novel and unstructured scenarios, is considered as a significant milestone in HRI (Tanevska et al. 2017). It is important to understand how the interaction should be. The technology which is implemented in robots has been used to enhance the quality of human life which requires more natural and intuitive ways of interaction. Interaction is defined as a reciprocal action or influence (*oxforddictionaries.com* 2018). Therefore, any action between a human and a robot is considered as an interaction. Robots can participate in various forms of interaction by mimicking facial expressions, gestures, body postures, sound, touch, etc., in which the form of communication depends on the context of interaction. Haddadin (2014) points out that HRI is divided into two: cognitive and social HRI, and physical HRI.

As the integration of social robots in human social spaces increases, HRI is subject to challenges similar to those in Human–Human Interaction (HHI). Successful HRI in a social context seems highly dependent on quality estimation, (e.g., recognition and generation of a number of features, e.g., emotions, speech, perception from artificial vision, and touch sensing), and also on architectural aspects of the physical systems (e.g., external sensing and supporting communication infrastructures). Psychological/emotional factors also play a key role. For example, Kanda and Ishiguro (2013) report the positive influence of robot–robot interactions in the acceptance of robots by humans. Sodnik and Tomažič (2015) specify that the interaction with modern devices (i.e., robots) is most commonly done through a visual, auditory, or tactile user interface.

The interaction between humans and robots requires communication which can take place in several forms, largely influenced by whether humans and robots are in the scope adjacent to each other or not, like most other technologies, robots require the user interface to interact with people or humans (Siregar et al. 2017). Nejat et al. (2009) describe noninteractive robots as providing support for surgical, rehabilitation, and medication delivery purposes, whereas highly interactive robots can provide more cognitive, affective, and social support. In recent years, people have become more exposed to robots (e.g., toy robots) in their daily lives due to increasing availability. Therefore, in the daily environment, robots are expected to interact with humans along performing their task since these require encountering humans. Rather, one of the main tasks of robots will be interaction for which it has become increasingly apparent that social and interactive skills are necessary requirements in many application areas and contexts (Dautenhahn 2007). Comprehending more about the HRI process in the everyday context is an important consideration for researchers (Holmquist and Forlizzi 2014).

In fact, in many studies, robots are being equipped with faces, speech recognition, or other features (e.g., gestures, emotions) in order to make the interaction more human-like (e.g., Breazeal and Scassellati 1999; Zecca et al. 2009). Also, it is argued that a humanoid form is easier to interact with since they provide a more intuitive interface and contain more social cues (Breazeal and Scassellati 1999; Brooks et al. 1999). Also, Kanda et al. (2013) remark that the physical appearance of human-like bodies of humanoid robots enable humans to intuitively understand their gestures and cause people to unconsciously behave as if they were communicating with humans, that is, if a humanoid robot effectively uses its body, people will communicate naturally with it. The term humanoid is mostly associated with the human-like physical appearance of a robot, rather than to its human-like capabilities, whereby it is fundamental that the robot's appearance matches its cognitive capabilities. Moreover, Adams et al. (2000) suggest that robots should be designed to interact socially with people by exploiting natural human social cues, i.e., robot interact with people in the same way as people interact with each other. According to Fong et al. (2002), although socially interactive robots have already been used with success, much work remains to increase their effectiveness, for instance, in order for socially interactive robots to be accepted as natural interaction partners, they need more sophisticated social skills, such as the ability to recognize social context and convention.

Interaction moments can also be important. For instance, during the initial interaction with robots, people are more uncertain, anticipate less social presence, and have fewer positive feelings (Edwards et al. 2016; Spence et al. 2014).

According to Mehrabian (1968), more than 60% of human communication is nonverbal, mostly through facial expressions and gestures, 7% of information is transferred through spoken language, while 38% is transferred through paralanguage and 55% is due to facial expressions. Humans convey intent through the direction of their gaze, posture, gestures, vocal prosody, and facial displays (Breazeal and Scassellati 1999). Adams et al. (2000) support that for many social interactions a vocal exchange is an important part. Therefore, it is important to develop those capabilities during communication in order for the robot to become social (Goris et al. 2010). Dautenhahn (2007) states that a primary goal of research in the HRI area has been to investigate 'natural' means through which a human can interact and communicate with a robot. Since the mid-2000s, anthropomorphized robots in various forms have been developed, with faces, arms, and mobile devices or tablet interfaces attached to their chests. Even though some robots, such as Monarch (Sequeira et al. 2013), IROBIQ (Han 2012) and Pepper (https://www.ald.softbankrobotics.com/en/cool-robots/pepper), use displays on their bodies which can provide multiple interface services, they are different from computers and mobile devices, namely they have characteristic appearances, names, personalities, and are capable of social relations. These robots are notable in their capacity for nonverbal communication, such as facial expressions, gestures, postures, and mimics, while coexisting with users in a real environment.

Also, speech is relevant both in verbal and nonverbal forms. Sounds, tones, and music influence the effective expression and can be used in multicultural environments, where verbal language rules may be understood by everyone (see Luengo et al. 2017) for a system that generates meaningful nonverbal sounds). Better social interaction for social robots, interactive dialog and interactive motion planning can be included, though are still relatively unexplored areas. Furthermore, Hoffman and Ju (2014) declare that movement is critical to conveying more dynamic information about the robot, therefore, designing robots with movements which accurately express the robot's purpose, intent, state, mood, personality, attention, responsiveness, intelligence, and capabilities should be considered for better interaction.

The ability of robots to interact with humans in ways that resemble HHI becomes increasingly more relevant, as robots progress from very controlled settings in laboratory environments and are deployed in homes and social contexts (Breazeal 2009). The environment represents a natural challenge for any HRI system. People without a robotics background may a priori have unknown expectations about the behavior of a social robot. This reinforces the importance of experimenting away from laboratory conditions (see, Kanda and Ishiguro 2013, Chap. 2). According to Picard (2000), HRI is only effective if the robot is able to express emotions, in this sense, emotions are essential for a better HRI. Overall, successful HRI systems tend to mimic HHI. Speech, body posture, facial expressions, eye gaze, and deictic and representational gestures, are extensively used by humans and highly valuable in social robots (e.g., Admoni and Scassellati 2017; Cameron et al. 2015a, b; Deshmukh et al. 2016; Mutlu et al. 2012; Salem et al. 2012; Shimada and Kanda 2012).

3.4 Contributing Factors to Human-Robot Interaction

The use of social robots in daily life has been increasing, so interaction between people and social robots has been progressively gaining relevance. If well accepted and as a part of the daily routine, robots can have a positive influence on people's quality of life. However, in spite of the many signs of progress made and the strong pieces of evidences on the benefits of using social robots, the interaction between humans and robots has not, yet, reached the quality that was expected. In this sense, HRI continues to be studied depending on various contributing factors to human acceptance of robots and eventually how well the human can act comfortably in human-robot spatial relationships.

3.4.1 Uncanny Valley

Although it is quite common to imitate HHI with robots appearing human-like, Mori (1970) introduced the concept of Uncanny Valley which suggests that robots can look like a human up to a certain level or humans can be uncomfortable with or disgusted by them. As the robot's appearance reached the maximum degree of similarity, the perceived oddness reverted to dislikability. On one hand, research exists supporting the Uncanny Valley (e.g., DiSalvo et al. 2002; Schindler et al. 2017; Woods et al. 2004), on the other hand, there are some studies (e.g., Kraft 2017) indicating that there are no real indications as to where within the Uncanny Valley the appearances actually fall. Cheetham (2017) and Kätsyri et al. (2015) emphasize that Uncanny Valley is not a hypothesis in the scientific sense of an empirically testable statement.

Stein and Ohler (2017) mention that research exploring the phenomenon emphasized specific visual factors in connection to evolutionary psychological theories or an underlying categorization conflict, though recently, studies (e.g., Mathur and Reichling 2016; Yamada et al. 2013) have also shifted focus away from the human-like appearance, exploring their mental capabilities reached as the basis for the user's discomfort.

3.4.2 Proxemics

In HHI, there is a personal space that is maintained between people, which is called proxemics (Hall 1966). There are several elements influencing the proxemics, namely, among others, personality, the relationship between people, social rule, and cultural rules (Argyle 1975). Some studies have revealed that proxemics is also important in HRI (e.g., Walters et al. 2005). To enable socially integrated HRI, a robot should display appropriate interaction, and both understand and control proxemics in the human's environment. Studies (e.g., Mumm and Mutlu 2011; Takayama and Pantofaru 2009) have shown that people tend to stay closer to robots than to other people. Proxemics effect can be analyzed from the robot's and from the human's perspective.

Regarding the human's perspective, studies (e.g., Walters et al. 2005) have shown that children tend to stay further away from robots than adults, and with women keeping more distance from robots than men (e.g., Takayama and Pantofaru 2009). The proxemics during HRI is also affected by some of the characteristics of robots (Takayama and Pantofaru 2009), namely voice and form. In relation to the voice of the robot, studies have revealed that in the interaction with robots with synthesized voice, humans tend to a greater distance by comparison with the proximal maintained with robots without voice or with female or male voices of high quality (Walters et al. 2008).

From the robot's perspective, since human proxemics preferences with respect to a robot can change during the interaction, this change has a significant impact on the performance of the robot's automated speech and gesture recognition systems (e.g., Mead and Matari 2016a, b; Tapus and Matarić 2008).

3.4.3 Empathy

Empathy is important in HHI. Plutchik (1987) denotes that empathy bonds individual to each other. Paiva (2011) indicates that empathy is the capacity to perceive, understand, and experience others' emotions. Therefore, emotions can be used to achieve empathy in communication (Nishida et al. 2010). Also, Beck et al. (2010)

support that robots should display rich emotions to be socially accepted and generate empathy. Empathy can also be demonstrated through words, tone of voice, facial expressions, posture, and physical gestures.

Given the strong role of empathy in shaping the way of communication, it is obvious that to create better interactions with robots, empathy is a major element (Paiva et al. 2017). Research shows that humans feel empathy with machines (e.g., Breazeal 2002; Cañamero and Fredslund 2000; Demers 2012; Kozima et al. 2004). Furthermore, some studies (e.g., Cramer et al. 2010; Fan et al. 2017) showed a robot with high empathy would lead it to be more trustworthy, which is another important factor in HRI.

3.4.4 Trust

Every day, people make decisions about whether to trust machines. Some studies have shown that humans do not readily trust robots by showing some reluctance to conform to their suggestions and to accept them as partners in social tasks (Gaudiello et al. 2016) because they consider robots to be socially ignorant (Young et al. 2009). Trust that the human has in a robot is however fundamental in HRI (Cameron et al. 2015a, b; Hancock et al. 2011; Salem and Dautenhahn 2015; Salem et al. 2015). According to Freedy et al. (2007), the confidence that the human has in the robot influences the acceptance or not of suggestions and information given by the robot.

As reported by Hancock et al. (2011), the factors that influence trust in robots are divided into human-related factors, robot-related factors, and environment-related factors. Therefore, depending on these factors, trust level during interaction can change which can eventually affect engagement.

3.4.5 Engagement

According to Sidner and Dzikovska (2005), engagement is a process that two (or more) individuals establish, maintain, and end during their perceived connection to one another. O’Brien and Toms (2008) suggest that engagement is a quality of user experiences with technology (i.e., robots), which is characterized by various attributes such as challenge, aesthetic and sensory appeal, feedback, novelty, interactivity, perceived control and time, awareness, motivation, interest, and affect.

Being engaged with a robot can be the sole purpose of HRI. In certain interactions with robots (e.g., a smile for greeting), a person can allege that the purpose is to be connected. Making a natural experience between a robot and a human requires understanding the nature of engagement and applying similar types of human engagement behavior to a robot.

Aylett et al. (2011) claim that believability of a robot would convey user engagement in which users display appropriate affective behavior and robots respond appropriately to the user's affective behavior.

3.4.6 Emotional Design

Due to the users' variability and the variety of designs and purposes (e.g., pets, toys), the understanding of which factors contribute/influence most to proper HRI is not easy and immediate for all robots. Models about the acceptance of technologies were developed and some studies indicate that the ease of use and usefulness are the two strongest factors in the acceptance of robots (e.g., Heerink et al. 2010). However, the influence of other factors as robot's appearance, facial expressions, or body movement (e.g., Hoffman and Ju 2014; Hwang et al. 2013; Kulic and Croft 2007; Nehaniv et al. 2005) are also well known. This can be related to the importance of the expression of emotions (e.g., Picard 2000) in the establishment of an empathic relationship. Moreover, additional facial features can provide more expressive capabilities (e.g., including facial muscles, using eyelids).

In this context, the emotional design (see Norman 2004; Desmet 2002) of the robot can facilitate HRI since it will prompt the design of products with the main intention of evoking and/or prevent the induction of certain emotions (Demir et al. 2009). The availability of guidelines about the robot's design features (e.g., appearance), behaviors (e.g., movements, facial expressions), and affective/emotional features while in social interaction, could be very informative for designers and/or developers.

3.5 Conclusion

Robots are not only integral to industrial life but are entering human's everyday life. Particularly social robots are integrating more and more seamlessly in daily tasks, in this sense, these robots should be designed to respond to meaningful interactions with humans and employ natural communication.

Most, if not all, of the social robots currently actively assume some degree of passivity by humans. This means that the robots are not problem solvers, that is, end-users cannot expect that the robot solves problems in an intelligent manner, e.g., requiring complex deduction skills. However, expectations can be boosted if some novelty is introduced in the interaction from time to time. For example, Alonso-Martín et al. (2015) discuss a dialog system capable of maintaining the coherence of the interaction and introducing new topics. Maintaining natural interactions with end-users for significant periods of time is a clear indicator of the success of a social robot and the quality of its interaction skills. Being able to control this time may be the ultimate goal of Human-Robot Interaction (HRI); this is a process often difficult even for socially experienced humans.

Other factors influencing the interaction between a robot and a person include uncanny valley, proxemics, trust, empathy, engagement, and emotional design. One factor can have an impact on the other (e.g., empathy on engagement). Hence, it should be important to consider these factors, not only individually but also together, while designing a social robot's appearance and behavior to create better and more engaging interactions.

People need engaging interactions that lead to affective user experiences. The experiences can be related either to the functionality or the usability of a robot. Effective understanding of people's emotions during interactions can help to create pleasing robots. Therefore, emotional design can be a strong ally for HRI. The meaning of pleasure in the use of robots can be complex. With regards to recent years, where robots are integrating more into human lives, if the application of emotions toward robots and pleasurable/joyful interaction is considered, emotional design becomes a necessity. Moreover, by applying emotional design, better user experience could be expected.

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Chapter 4
Emotions and Emotions in Design

Magda Saraiva and Hande Ayanoğlu

Abstract This chapter discusses and clarifies the concepts and definitions of emotion, feeling, and mood. Although they refer to distinct phenomena, these concepts are normally used indiscriminately when someone refers to emotions. This is followed by a brief review of the literature on the main theories applied to the study of emotions. This reference to the study of emotions will serve as the basis for the introduction and exploration of the concept, purpose, and application of Emotional Design.

Keywords Emotions · Emotion theories · Design

4.1 Introduction

Emotions play a key role in an individual's behavior within the social context (Plutchik 1991). The study of emotions and their influence on human behavior took a leap forward in 1872, when Darwin published *The Expression of Emotions in Man and Animals*. However, and despite emotions having been studied for almost a century and a half, there is still no consensual definition. For example, Plutchik noted in 2001 that there were more than 90 definitions of emotions (Plutchik 2001a).

Over time, various theories and models about emotions have emerged, based on different perspectives, such as the evolutionary theory (e.g., Darwin 1872), the physiological theory (e.g., James 1884) and the cognitive theory (e.g., Schachter and Singer 1962), among others. The different theories of emotions are supported by other existing theories of Psychology (among other areas) and, due to this, differ in

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their definitions, as well as on the role and importance they play in the life of the individual.

However, before presenting some of these theories, we shall discuss and clarify some concepts: emotion, feeling, and mood. Although they refer to different phenomena, these concepts are used by all of us as if they referred to a single one—emotion.

4.2 Emotions, Feelings, Moods, and Sentiments

Before focusing on emotions and their main theories, it is important to define and clarify other concepts. Individuals usually refer to feelings, moods, or sentiments as if they were emotions (e.g., Beedie et al. 2005; Ekman 1994a). However, these three concepts refer to different phenomena.

Feelings can be defined as the subjective experience of emotions (e.g., Scherer 2005). They are states of mind, which derive from the evaluation that the individual makes about an event, such as the level of its pleasantness or unpleasantness (e.g., pain) (TenHouten 2007). According to Damásio (2003), feelings occur after emotions. In this sense, feelings are less visible at the behavioral level than emotions, and are therefore considered more private than emotions (TenHouten 2007). The duration of a feeling is short, usually seconds, and is less intense than an emotion (Damásio 2003).

According to Ekman (1999), the emotions are the result of a specific cause (i.e., specific event). However, mood may or may not ensue from a specific cause (e.g., Ekman 1990; Beedie et al. 2005). Contrary to emotions, moods can have a long duration (i.e., hours, days) (e.g., Ellis and Ashbrook 1988), change frequently, alternating with other mood states (Desmet 2015), and have a medium intensity (e.g., Morris 1992; Scherer 2005). Frijda et al. (1991) explained moods as continuous feeling states without a specified object. However, both emotions and moods have a high impact on the individual's behavior, since they can stop one behavior and start another one that is more effective for that event (Scherer 2005).

Turner (1970) called sentiments a socially defined complex of feelings that vary across cultures. Frijda et al. (1991) defined sentiments as emotional dispositions to a certain product. Nass and Brave (2007) argued that sentiments are not a person's state but characteristics that are designated to a product; and while emotions last for seconds and moods for hours/days, sentiments can remain indefinitely.

The concept of emotion has been described in a varied way by different authors, according to the theory they follow. The emotions correspond to a construct that the individual creates, allowing for the emotional evaluation of the event, and because of this, the emotions are relatively constant for each individual (Lazarus 1999). Emotions, it is argued, trigger a set of behavioral (e.g., run), physiological (e.g., sweat), and cognitive responses (e.g., evaluation of the event), and these changes allow the individual to adapt and respond appropriately to an event (e.g., Nesse 1990). From all these definitions, we identify with and have adopted the definition proposed by Frijda (1987), which defines emotions as the tendency that the individual has to establish, maintain, or terminate a relationship with the environment or with others. According to this author, emotions are characterized by high intensity and short duration (i.e., seconds, minutes) (Frijda 1994).

Although, as mentioned earlier, there are several theories about emotions, there is agreement on the two dimensions for measuring them: *Arousal* and *Valence* (e.g., Lang et al. 1997; Russell and Barrett, 1999). *Arousal* refers to the psychophysiological condition caused in the individual by the presence of a stimuli, product, or object (Lang 1995). It may be high when the stimulus produces a high activation in the subject (e.g., seeing a snake) or low when the stimulus produces low activation (e.g., listening to music for relaxing). *Arousal* is characterized by an activation of the autonomic nervous system (e.g., running away), and the activation of the endocrine system (e.g., increased heart rate) enabling the individual to respond appropriately to the stimuli. *Valence* concerns the positivity (e.g., happiness) or negativity (e.g., sadness) that a stimulus or situation elicits in the individual (e.g., Lewin 1935).

As mentioned above, the definition of emotion depends on the theoretical current that the authors follow. Over the years, various theories about emotions have emerged. The next section presents the basic principles of what we consider to be the most significant theories in the field.

4.3 Theories About Emotions

This section is not intended to be exhaustive. It has a selection of the theories considered most influential or controversial in the study of emotions: Psychoevolutionary Theories of Emotion; Physiological Theories of Emotions; and Cognitive Theories of Emotion.

4.3.1 The Psychoevolutionary Theories of Emotion

According to Darwin (1872), emotions are not a specific characteristic of humans, since other animals, even insects, have them. In his studies about emotions, Darwin (1872) concluded that their function was to ensure the adaptation, communication, and survival of species in different environments. It is on the basis of this assumption that the first great theory in the area was created: the Evolutionary Theory of Emotions.

One of its main followers was Robert Plutchik, who developed The Psychoevolutionary Theory of Emotion (Plutchik 1962). Plutchik, like Darwin, argues that emotions play an important role in the evolution of species and supports the principle of antithesis.

According to this theory, emotions result from a cognitive interpretation/evaluation that is made in relation to a particular event or stimulus. It is this interpretation that triggers a physiological reaction, which enables the action (e.g., running away) (Plutchik 1977). In the light of this theory, emotions are adaptive responses to dangerous events/situations. Some situations or events that jeopardize the survival and adaptation of the individual cause imbalance, and the function of the emotions is to reestablish that balance. For Plutchik (2001b), the emotions are activated in response to four types of problems that are commons to all species: temporality, identity, hierarchy, and territoriality.

For Plutchik (1979, 1980), the first problem, temporality, is related to the reproduction of the species. For humans, it is related to the building and continuity of the family and its community, involving positive emotions such as joy if the mission is accomplished, and sadness if not.

The problem of identity corresponds to the fact that individuals/animals accept (or not) other individuals/animals as being part of the same species. Although the definition of this problem has not been thoroughly explored by Plutchik, he has associated it with acceptance and disgust emotions. In other words, the solution of this problem is the acceptance or rejection of other members of the species.

The problem of hierarchy is related to power and dominance within the same species. The strongest/dominant members have privileged access to food or sexual partners, ensuring the survival of the species. To overcome this problem, humans/animals have two possible solutions: to fight and to resist, which is expressed through the emotion anger; or give up, expressed through the emotion fear.

Finally, territoriality concerns the struggle for control and defense of a space that is safe for the species, ensuring its survival. For Plutchik, this problem has two possible solutions: spatial control by thinking ahead of the enemy—anticipation or losing control of that space to the enemy—surprise.

Plutchik (1980) argues that there are eight basic emotions—two per problem: joy, fear, anticipation, acceptance, anger, sadness, disgust, and surprise. In the same year, Plutchik created the Wheel of Emotions model to explain the relation between the emotions (see figure XX). According to this model, the eight basic emotions follow the principle of antithesis, with each emotion having an opposite emotion: joy versus sadness; fear versus anger; disgust versus trust; anticipation versus surprise. Each of the basic emotions can manifest itself in different intensities and form combinations with other emotions (e.g., disgust and sadness = remorse).

Along with the eight emotions, Plutchik (1980) considered the existence of 24 secondary emotions that derive from the various possible conjugations between the basic emotions: ecstasy, admiration, terror, amazement, grief, loathing, rage, vigilance, serenity, acceptance, apprehension, distraction, pensiveness, boredom, annoyance, interest, optimism, love, submission, awe, disapproval, remorse, contempt, and aggressiveness.

Another author who based his theory of emotions on Darwin's arguments and on the evolutionary theory of emotions is Paul Ekman. Ekman (1994b) argues that there are basic emotions that play an important role in the adaptation and evolution of species. In 1969, Ekman et al. argued for the existence of six basic emotions: sadness, happiness, fear, surprise, disgust, and anger (as Darwin had argued in 1872). For the authors, these emotions are innate, present from birth and universally recognized.

In this sense, each emotion has a specific function that allows adaptation to certain contexts (Ekman 2003). According to Ekman (1973), the basic emotions are manifested through facial expressions, which distinguish them, and each expression is universal. Darwin (1872) had argued that some emotions had a universal facial expression and were also expressed in animals. Based on this argument, Ekman dedicated himself over the years to the study of the facial expression of emotions in humans (e.g., Ekman 1972, 1992, 1994b). The facial expression of emotions will be explored in more detail in Chap. 7.

Although the importance of evolutionary theory in explaining emotions is undeniable and is still argued by some authors, other explanatory theories of emotions have emerged over the years. In the nineteenth century, William James and Carl Lange argued that emotions result from physiological responses to external stimuli. This idea runs counter to the Psychoevolutionary argument that emotions are the response to an evaluation made in relation to a stimulus.

4.3.2 The Physiological Theories of Emotions

4.3.2.1 The James–Lange Theory

In *Psychology: The Briefer Course*, published in 1892, William James distinguished emotions from instincts. For James, instincts are considered the tendency to act, whereas emotions are defined as the tendency to feel, although these are also expressed through the body.

James (1884) argued that bodily changes (visceral and muscular) derive from adjustments that the nervous system makes in response to stimuli, and it is the awareness of those changes that constitutes an emotion. According to this theory, if the individual is in the presence of a snake, the individual is not afraid of the snake. They are afraid because they tremble: the individual is aware of the bodily changes that the presence of the snake has triggered.

Thus, physical changes (i.e., emotion) are felt immediately upon contact with the stimulus that triggers it and prior to its cognitive perception. It is possible to distinguish between different emotions because each of them has a different bodily change (James 1892: 245).

James was not an apologist for experimental methodologies, so all his investigations were made on the basis of self-observation, strongly based on personal memories of the mental processes experienced. This approach was highly criticized, since phenomena based on self-observation could not be replicated by other researchers. James' theory is counterintuitive because the emotion is not interpreted as a response to a stimulus but rather as the awareness of the physiological changes that this stimulus has provoked.

In 1885, Carl Lange presented his theory of emotions. Although they worked independently, Lange and James built similar theories about emotions, and so their theories became known as the James–Lange Theory. In addition, for Lange (1885), when a stimulus is presented, there is a physical arousal and the reaction of the nervous system to that arousal is an emotion. This theory has been criticized because, for James and Lange, emotions do not have any function (e.g., Damásio 1994; Plutchik 1962), and it ignored the influence of previous experience in the evaluation of emotions, in other words, the cognitive dimension of emotions (e.g., Damásio 1994).

One of the main critics of the James–Lange Theory was Walter Cannon (1914), a student of William James. According to Cannon, the brain played a vital role in the emotional process. For this author, (together with Philip Bard), the James–Lange Theory presents some problems, such as the fact that the body takes between 1 and 2 s to respond to a stimulus, so the physiological changes associated with an emotion are not immediate. Furthermore, the fact that many emotions produce similar visceral responses means it is not possible to distinguish and recognize emotions through physiological response/change. The Cannon–Bard Theory emerged as an attempt to deal with these problems.

4.3.2.2 Cannon–Bard Thalamic Theory of Emotions

In the first decade of the 1990s, Cannon devoted himself to the study of emotions in healthy animals, measuring their physiological changes, and strongly influenced by the James–Lange Theory. This approach resulted in the distinction between sympathetic visceral patterns and parasympathetic visceral patterns. According to Cannon, emotions can be distinguished through these two visceral patterns, i.e., if visceral expression of an emotion (body changes) occurs in the thoracic-lumbar zone, it belongs to the sympathetic visceral patterns; whereas if it occurs in the cervico-sacral zone, it belongs to the parasympathetic visceral patterns. As the nerves constituting the autonomic nervous system are antagonist, the emotions expressed by each of these patterns are also antagonistic (Cannon 1914).

In 1925, Cannon and Britton began studying emotional expression in animals that had had a part of the cerebral cortex removed. They thus determined that the thalamic region was responsible for emotional expression, since some emotional expressions were compromised or disappeared when the thalamus was removed.

Later, Cannon (1927) and Bard (1928) investigated the level at which emotional expressions were integrated into the brain, which would give rise to the Cannon–Bard Thalamic Theory of Emotions. These authors verified that there was no significant alteration in the emotional response of animals that had had a part of their sympathetic nervous system removed. In other words, the emotional response is not a merely visceral process as argued by the previous theory.

Moreover, Cannon and Bard found that viscera are less-sensitive structures than James and Lange believed (e.g., during the digestive process we do not account for all responses and visceral movements that occur) (Cannon 1927).

This theory argues, as already mentioned, that there is an area of the brain (the thalamus) responsible for emotional expression. In addition to this idea, the authors also argued that arousal does not have to be prior to emotion. On the contrary, arousal and emotion occur at the same time, which contradicts the key idea of the

James–Lange Theory of Emotions. Thus, in the presence of a stimulus, the receptors are activated and send the information to the cortex, where the response to that stimulus is decided. This response will activate the thalamus, producing an emotional expression at same time as the bodily and visceral changes occur (Cannon 1927).

However, other studies soon demonstrated that the thalamic region was not the center of control of emotional expression, or at least it was not the only area of the brain involved in that process. An example was Papez (1937), who created a circuit of emotion. For Papez (1937), the emotions and their expression come from the interconnections between some brain structures, such as: hypothalamus, anterior thalamic nuclei, gyrus cinguli, and hippocampus. The expression circuit is due to the fact that Papez argued the emotional process begins and ends in the hypothalamus, traversing a circuit between different structures constituting the limbic system.

Although these theories have contributed significantly to the understanding of the emotional process from the physiological and neurological point of view, the cognitive component of emotion was neglected or even ignored. In the second half of the twentieth century, however, some theories began to emerge based on the importance of cognition in the emotional process. An example was that of Schachter and Singer.

4.3.2.3 Schachter-Singer: The Two-Factor Theory of Emotions

Contrary to the theoretical currents about the emotions that had emerged based essentially on their physiological component, Schachter and Singer (1962) argued that emotions are the result of physiological arousal but also of cognitive factors. According to these authors, physiological arousal and physiological changes are not sufficient to distinguish emotions, since some of them produce very similar physiological changes. This theory argues that emotion depends on two factors: physiological arousal, and the way that arousal is interpreted—cognition. Thus, when our body undergoes some physiological change, we are able to perceive these changes and through them, perceive the emotion we are experiencing. In this sense, the emotions result from the individual's interpretation of internal and external changes.

To test this theory, Schachter and Singer (1962) developed a complex experiment. Some participants were injected with a placebo substance (i.e., did not produce any arousal), while others were injected with a drug that produced physiological arousal. Some of the participants injected with the drug were informed about its effects and others were not. The results revealed that participants who received information about the effects of the drug did not experience emotions because, according to the authors, participants interpreted the physiological changes as an effect of the drug and not as an emotion. That is, emotion does not depend only on physiological changes. In contrast, participants who received no explanation about the effects of the drug experienced physiological arousal and interpreted it cognitively as an emotional state. That is, emotional experience depends on the cognitive interpretation given to physiological changes.

This theory constituted a change in the paradigm of the study of emotions. If until then, the focus had been on the physiological changes, from here onwards, cognition gained relevance, in particular the importance of the thought for the emotional process.

4.3.3 Cognitive Theories of Emotion

4.3.3.1 Appraisal Theories of Emotions

According to this theory, emotions derive from the evaluations and interpretations that individuals make of a stimuli, i.e., appraisal. The emotion thus stems from the appraisal, with no physiological arousal being necessary. Emotions are regarded as an adaptive response of individuals to the environment. Over the years, several authors have contributed to the development of these theories (e.g., Arnold 1960; Lazarus 1968; Frijda 1986). Since appraisal may differ between individuals, the same stimuli may have different emotional responses; but if the appraisal is the same, the expressed emotion is the same. It was Arnold who introduced the term appraisal of emotions with his Appraisal Theory of Emotions (Arnold 1960). According to this author, individuals, when faced with a stimuli, evaluate it automatically and immediately as good or bad, and stimuli evaluated as indifferent are ignored. This evaluation is made on the basis of past experiences (i.e., memory) with the same or similar stimulus. In this sense, appraisal represents the tendency for the individual to act in a certain way when faced with a situation. According to Arnold, whenever this tendency is strong, an emotion is being expressed. So appraisal is the beginning of emotional experience followed by physiological changes.

In 1968, Lazarus carried out a set of studies whose main objective was to understand the determinants of appraisal. As a result of these studies, Lazarus argued for the existence of three types of appraisal: primary, secondary, and re-appraisal. Primary appraisal corresponds to the recognition of the stimuli and their importance for the well-being of the individual. Secondary appraisal is the analysis the individual makes of the resources that can be used to respond to the stimulus. Finally, re-appraisal is the changes that the individual makes to the primary and secondary appraisals after interaction with the stimulus. This process of continuous (re) evaluation attributes a continuous and nonstatic character to emotion (Lazarus 1968).

Another researcher who contributed actively to the development of this theory was Frijda, who argued that emotions are cognitive states representing action dispositions (Frijda 1986). For this author, the emotions also correspond to responses to stimuli appraised as relevant for individual concerns (Frijda 1986). By concerns, Frijda (1986, 1988) means the individual's motives and values. Emotions initially involve the perception of the stimulus, which follows an evaluation (i.e., appraisal) made on the basis of the individual's concerns, which activates a set of actions (i.e., arousal). Emotions, therefore, involve all these stages of preparation for action (Frijda 1986).

Finally, another author who made important contributions to this theory was Scherer. For him, the emotions are a set of synchronized changes between several subsystems in the organism of an individual (Scherer 2001). For Scherer (1984), emotions have five components: appraisal, physiological changes, motor expression (e.g., facial expression), action tendency and subjective feelings (i.e., emotional experience).

As has been seen, a number of theories on emotions have appeared over the years, although we have only referred to those that we consider most significant. While some theories are based on evolutionary arguments (e.g., Plutchik 1962), others are based more on physiological (e.g., James 1884) or cognitive arguments (e.g., Scherer 1984). However, other theories that were not mentioned here are based on cultural (e.g., Malatesta and Haviland 1982), social (e.g., de Rivera 1977), or developmental (e.g., Giblin 1981) factors. If, on the one hand, the interest in the study of emotions has served areas such as Psychology, Philosophy, or Sociology; since the beginning of this century, we have seen an increased interest in the role of emotions in Design, as we explore next.

4.4 Design and Emotions

The combination of design and emotion has been gaining interest within design practice and design research over the last 20 years (e.g., Desmet and Pohlmeyer 2013; Fokkinga and Desmet 2012; Yoon et al. 2014 and Yoon et al. 2016). Emotions play an important role in the generation, development, production, purchase, and final use of products that we surround ourselves with. When an object or a product is idealized, it should take into account not only its usability and functionality, but also the user's pleasure (Jordan 2000). Aesthetically pleasing objects attract people, and it is sometimes possible to establish an emotional connection between the individual and the object (Helander and Khalid 2006).

One of the first authors to be interested in studying the importance of emotions in design was Pieter Desmet. Basing his approach on the *Appraisal Theory of Emotions,* he began studying the emotional connection between the user and the product. Desmet (2002) argues that individuals extract meaning from their relationship with the product. Therefore, products that contribute to the well-being of the user trigger positive emotions and pleasure. Besides this, when the user's relationship with the product is assessed as harmful or unpleasant, negative emotions are triggered. According to Desmet, it is the designers' purpose to develop products capable of eliciting positive emotions from the user, or to avoid certain negative emotions (e.g., sadness).

Desmet (2003) proposed five categories of product emotions (i.e., instrumental, aesthetic, social, surprise, and interest emotions). Instrumental emotions relate to the function of a product. Aesthetic emotions address the physical characteristics of a product. Social emotions are associated with products that are used by a specific group. Surprise emotions astonish users by novelty/innovation in products. Interest emotions are the result of products that stimulate and motivate users into producing a creative action or thought.

Although Desmet categorizes product emotions, he also states (2003; 2004) that products can elicit all kinds of emotions and that they are elicited not only by the product's appearance, but also by its function, brand, behavior, and associated meanings. Desmet (2004) also argues that individuals experience different emotions about the same product because they are personal and one product can elicit mixed emotions simultaneously. For Desmet (2012), users can experience 25 positive emotions during their interaction with objects/products. These emotions are: sympathy, kindness, respect, hope, surprise, anticipation, energized, pride, confidence, courage, dreaminess, admiration, love, lust, desire, worship, euphoria, joy, amusement, satisfaction, relief, relaxation, fascination, inspiration, and enchantment.

Producing objects capable of eliciting emotions (particularly positive emotions) in the user is therefore the main objective of Emotional Design (Norman 2004). Emotional design, sometimes also referred to as hedonic design, affective design, affective human factors design, human-centered design, and empathetic design is, in a simple way, the inclusion of emotions as an influencing factor in the way that individuals interact with objects and products (Aumer-Ryan 2005). Throughout this book, the term Emotional Design refers to the emotional component involved in the interaction between human and product (i.e., robot).

Based on a neurobiological theory of emotions, Norman (2004) proposed the existence of three levels in Emotional Design: visceral, behavioral, and reflective. According to Norman, it is not possible to design without all three levels. The visceral level is about the initial impact of a product, about its appearance, touch, and feel. The behavioral level concerns the pleasure and effectiveness of use, the experience with a product. Experience, however, has different facets: function (i.e., what the product is meant to do), performance (i.e., how well the product carries out the desired functions) and usability (i.e., how easily the user can understand how it works and how to get it to perform). Finally, the reflective level is related to the rationalization and intellectualization of a product (e.g., creating good memories for the user).

For Aumer-Ryan (2005), emotions are quick at the visceral level (e.g., fear and disgust); at the behavioral level, emotions coincide with bodily activity, and include such feelings as frustration, aggravation, and annoyance; finally, at the reflective level, emotions, are removed, contemplative, and include feelings such as pride, embarrassment or guilt.

Though interest in studying the emotions in the design process is still recent, its principles have now been applied not only to object design but also to robots, in order to facilitate Human-Robot Interaction (HRI). We will return to the theme of Emotional Design in that context, in Chap. 8, in particular to its HRI application.

4.5 Conclusion

Emotions play a key role in an individual's behavior within the social context (Plutchik 1991). Over time, various theories and models about emotions have emerged, based on different perspectives, as explored at the beginning of this chapter.

Although the earliest theories about emotions date back to the nineteenth century, only recently, have emotions come to be regarded as an important component of cognitive functioning (e.g., decision-making), and not just as something that negatively affects rational thought (e.g., Damásio 2003; Goleman 1995; Norman 2004). Norman (2004) suggested that the Psychology assumptions related to the study of emotions were applied to Design, specifically product design. Therefore, this author argues for the importance of emotions in product design, and how this is reflected in the user's interaction with the product/object. Emotional Design arose out of this new argument that, over the last decade, has proved to be a major innovation in the way designers conceive and develop their products: hence the recent history of emotions in the design field. In recent years, there has been an increase in the importance of emotions applied to this area—Emotional Design. Emotional Design aims to elicit (e.g., pleasure) or prevent (e.g., displeasure) determined emotions during the human product interaction. In other words, it regulates the emotional interaction between the individual and the product. One of the most significant developments of emotion in technology was to create products, objects, and machines capable of expressing, recognizing and feeling/showing emotions. The importance of the individual establishing an emotional and empathetic relationship with the products through design has become evident, thus giving rise to Emotional Design.

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Chapter 5
On the Origins and Basic Aspects of User-Centered Design and User Experience

Rodrigo Hernández-Ramírez

Abstract Over a decade after the iPhone was first commercialized, screen-based tactile interfaces have become our primary means for interacting with computational technologies; although thanks to recent developments in Machine Learning (ML), gesture and voice control mechanisms will become more common. Smart technologies and what we end up defining and recognizing as robots will determine the practical principles, and the type of experience designers will be able to shape. To understand where the future of User-Centered Design and User Experience will take us, we need to understand how we got to where we are. The main goal of this chapter is clarifying what may be understood by User-Centered Design and User Experience. To do so, it will look at the period between the late 1960s and early 1980s, when Personal Computing and the ensuing democratization of technology forced designers to think about their users honestly.

Keywords Aesthetics · Artificial agents · Human–computer interaction · Human-centered design · Pragmatism · Technology · User experience · User experience design

5.1 Introduction

Over the last four decades, computers went from being rare tools for specialists to ubiquitous personal, intimate devices.[1] Nowadays, computational technology has already been—or can be potentially—integrated into every other artifact, including cars, telephones, vacuum cleaners, stoves, thermostats, or toilets. Thanks to high-speed data transfer, the increasingly potent sensors, and processors embedded within

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[1] As Kay (2002, p. 124) notes, when he first began to conceive the "personal" computer, the idea he had in mind was "intimacy".

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these artifacts can gather and receive vast amounts of data. Some of these datasets, in turn, are used alongside new algorithmic methods to train so-called "smart" software systems. These Machine Learning methods are behind the third "boom" or "wave" (Garvey 2018; Lee 2018) of Artificial Intelligence (AI), which can take raw visual and auditive information such as images and voice directly as input. This type of AI is powering a new generation of smart appliances that we would normally refer to as artificial agents (AAs) or robots.[2] Paradigmatic examples of the latter include autonomous vehicles, the highly publicized robotic humanoids, and quadrupeds developed by Boston Dynamics, and AI-powered personal assistants[3] such as Apple's "Siri", Microsoft's "Cortana", or Google's Assistant.

These devices have increasing agency[4] and autonomy[5] thanks to ubiquitous computing, which has "enveloped"[6] our environment, making it more accommodating for AAs (Floridi 2014). Our world, which until recently harbored only "dead" objects, will be further populated by responsive, interactive, and interconnected systems. As this Internet of Things (IoT) trend continues, more aspects of concrete reality will be incorporated into our informational environment or "infosphere" (see Floridi 2002). Consequently, hitherto meaningful boundaries between the (linear, Newtonian, and inert) offline world and the (post historical, informational, alive) online world will become irrelevant. Our interaction with information technologies (ITs) will stop being primarily mediated by screens and instead will be embedded in our environment (Lee 2018). This situation brings a host of issues, but also possibilities for Interaction Design (IxD) and User Experience (UX) at large, not to mention that some of the principles behind User-Centered Design (UCD) will need to be revised and updated to meet the challenges of new Human–AA relationships better.

Both UCD and UX are tied to Donald A. Norman and the work he developed as an academic and as a design consultant working for major technology companies. Many of the principles and methods comprising UCD can be traced back to Gould's and Lewis (1985) article "Designing for Usability" and the Project on Human–Machine Interaction from the Institute for Cognitive Science at the University of California in which Norman played a central role (see Norman and Draper 1986). In terms of design

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[2] Paraphrasing Bryson (2009, 2019), a robot is any nonhuman artificial agent that transforms perception into action; any artifact that senses and acts in the physical world, and in real time. Thus, under this broad definition, smartphones, smart speakers such as Amazon's Echo ("Alexa"), and even "Roomba" vacuum cleaners count as robots, but so do disembodied AAs such as chatbots. In this chapter, the terms "robot" and "artificial agent" will be used indistinctly.

[3] According to Danaher (2018), a "personal AI assistant" is any software system that can act autonomously in a goal-directed manner. That is to say, any software that can receive instructions (usually by voice) as input and provide specific output, such as directions to a place, selecting among a range of options.

[4] Understood as the capacity to decide to act (or not), to choose the means to do so, and to apply those means to bring about specific changes in the world (Bunnin and Yu 2009, p. 19).

[5] In the context of AI, "autonomy" has a distinctive, more restrictive, meaning of a system being capable of achieving a given goal without having their course of action fully specified by a human (Johnson and Verdicchio 2017).

[6] An envelope or "reach envelop" refers to the three-dimensional bounded space in which a robot can reach (Floridi 2013).

practice, there is a growing number of methodologies based on UCD principles. Some of the most influential approaches are Norman's (2013) own Human-Centered Design (HCD) and Goal-Directed Design by Cooper et al. (2014).[7] Whereas more recent iterations include Wright's and McCarthy's (2010) Experience-Centered Design, Karjaluoto's (2013) "knowledge-led, systems based" Design Method, and perhaps the most well-known of all, IDEO's Design Thinking[8] (Brown 2008, 2009; Meinel et al. 2011).

The term UX was allegedly invented by Norman in the early 1990s while working at Apple's Advanced Technology Group (Buley 2013; Merholz 2007; Norman et al. 1995). Norman contended that "user experience" would better characterize an expanding area of design practice that could no longer be described through interface design and usability (Merholz 2007). Hassenzahl's (2013) entry in the *Encyclopedia of Human-Computer Interaction*, as well as his book, "Experience Design" (2010), provide thorough descriptions of UX principles. Wright and McCarthy (2010), and McCarthy and Wright (2004) also give a good account of UX design focusing on its philosophical and aesthetic roots. Besides providing a host of practical insights Saffer's book, *Designing for Interaction* (2010) contains a widely distributed cartography of the various disciplines associated with UX. UCD and UX are the two dominant paradigms in contemporary design practice. Nonetheless, a decade after popularizing the term, Norman lamented that UX and HCD, along with usability and "even affordances" have turned into buzzwords (see Merholz 2007). That people now use these terms with little or no awareness of their, origin, history, and the actual meaning.

This chapter takes the circumstances previously discussed as a starting point. Its main goal is clarifying what may be understood by UCD and UX. Its primary assumption is that to understand how these concepts will change as nonhuman agents further populate our environment, we first need to understand their origins. To do so, we need to look at the period between the late 1960s and early 1980s, when technical means and the cultural environment converged to allow the crystallization of the Personal Computer (PC) and the emergence of contemporary HCI.

5.2 Before There Were UCD and UX

Nowadays, the idea that computers are personal and even *intimate* devices are taken for granted, and so is the fact that we interact with them primarily through Graphical

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[7] Cooper et al. (2014, pp. 13–14) make a point of distinguishing their approach from Norman's, which they claim is heavily inspired in Activity Theory, a conceptual framework initially developed by Russian psychologist Aleksei Leontiev (see Kaptelinin 2013; see also Kaptelinin and Nardi 2012).

[8] It is essential to distinguish between design thinking as an epistemic domain halfway between logical rationality and artistic intuition—i.e., as understood by Archer (1979) and Cross (2011)—and Kelley's and Brown's five-step general methodology for problem-solving (see Hernández-Ramírez 2018).

User Interfaces (GUI). This was not always the case. Before the 1970s, computational technology was not accessible to everyone, instead it was rigidly controlled by the government, educational, and private institutions. Even within universities, access to computers outside certain institutes was only possible through time-sharing,[9] which could be quite expensive.[10] Interacting with computers required at least basic knowledge of programming since the only way to work with them/issue commands was by inputting text through a terminal.

Since the mid-1950s, the United States Military (mainly through DARPA) had been financing research to improve the usability of computers. The public and private institutions doing it mostly followed ergonomic principles. Hence, as a distinctive field of research, Human-Computer Interaction (HCI) only emerged in the 1980s, around the same time computers became PCs, that is, consumer products for the general population (Carroll 2013). HCI marked a profound shift in the way engineers who had been developing computational technology in the last decades regarded end-users: they realized that nonspecialists had "functioning minds" and that understanding those minds would determine the way people would relate to computers in the future (Kay 2002). This shift had been gestating since the late 60s but arguably only turned paradigmatic once all the necessary components that are now familiar in every computer came together: microprocessors, pointing devices, and the GUI.

The icons and graphical representations comprising the GUI enabled every potential user to conceptualize computational process in more familiar terms through visual metaphors of "real life" objects and actions. While pointing devices allowed them to interact with computers more intuitively, by selecting and "touching" objects in the screen. The principles behind the GUI were based on intuitive learning and creativity; they contemplated and made explicit a factor which had hitherto been absent from interface design: the aesthetic dimension. To understand the origins of HCI and later, of UCD and UX, we need to make a short digression to look at the origins of the GUI and the notion of personal computing in general.

5.3 Early HCI and Interface Design

The origins of the GUI can be traced back to Ivan Sutherland's "Sketchpad" (1964), a computer program he developed during his Ph.D. that would revolutionize HCI, computer graphics, and the very notion of the computer. The primary goal of Sketchpad was allowing users to generate graphics not by writing code but by directly "drawing" over the monitor with a light pen. With Sketchpad, Sutherland introduced a new paradigm of interactivity, wherein by manipulating an image displayed on

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[9] Time-sharing allowed multiple users to work on the same computer using different terminals, receiving alternated "slices" of computer execution time as they became available (Alesso and Smith 2008, p. 61).

[10] One hour of time-sharing could cost between 10 and 20 USD (Campbell-Kelly et al. 2014), that is, between 50 and 100 USD in today's money.

the screen, a person could directly change "something in the computer's memory" (Manovich 2002, p. 104).

Among the people influenced by Sketchpad was Douglas Engelbart. Engelbart was the founder of the Augmentation Research Center at the Stanford Research Institute. Inspired by Bush's (1945) seminal article, "As We May Think",[11] Engelbart had been attempting since the mid-1950s to develop a computer-based "personal information storage and retrieval machine" (Campbell-Kelly et al. 2014, p. 258). In late 1962, Engelbart obtained funding to develop what he and his research team called the "electronic office", a computer system capable of integrating for the first-time text and pictures (2014, pp. 258–259). Five years later, Engelbart's group was already prototyping what would arguably become their most lasting contribution to HCI: the computer mouse. After extensive testing, this peripheral showed to be more effective than the "light pen" used by Sketchnote and other joystick-like devices (Ceruzzi 2003). On December 9, 1968, at the Fall Joint Computer Conference in San Francisco,[12] Engelbart and about a dozen other people—including Stewart Brand, editor of the highly influential zine *The Whole Earth Catalog*—staged what came to be known as "The mother of all demos". Using a video projector to enlarge a computer screen to six meters, Engelbart showed the mouse, hypermedia, and teleconferencing; all of the features that would end up defining the contemporary computing environment.

Engelbart's electronic office system was too expensive to be commercialized due to a lack of cost-effective technology,[13] but the demo made a profound impression on the emerging HCI research community. Engelbart and his group conceived the feasible technological means for interacting with the computer beyond inputting text with a keyboard. But it was a group of researchers from the University of Utah—where Sutherland was a professor at that time—who conceived the software, and the visual language that eventually allowed computers to become personal tools. And arguably the most influential of them was Alan Kay.

As a doctoral candidate at the University of Utah, Kay pursued an ambitious project that would culminate in his thesis, *The Reactive Engine* (1969). In the thesis, he specified a new programming language called FLEX, as well as an early prototype for a personal computer that he designed along Ed Cheadle. According to Kay, the computer used a pointing device, a high-resolution display for text and animated graphics, and used the concept of multiple windows, but the interface, nonetheless, "repelled end-users" (2002, p. 123).

In 1972, Kay joined the recently founded Xerox Palo Alto Research Center (Xerox PARC) along with many of Engelbart's former colleagues (Ceruzzi 2003). This laboratory would be responsible for developing the Ethernet, laser printing, Object-Oriented programming, as well as the concept of the contemporary personal

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[11] See Engelbart (1962) for his account of Bush's influence.

[12] For a full account, see "A research center for augmenting human intellect" (Engelbart and English 1968).

[13] At that time, even so-called "mini-computers" would cost several thousand dollars. The Intel 4004 microprocessor, which powered the new generation of PCs, only entered the market in 1971.

computer. By 1973, Kay and his team had developed a prototype computer called the “Xerox Alto”, whose operating system and configuration owed considerably to FLEX. The Alto was a desktop machine, it had a custom-built bitmap screen roughly equivalent to a letter-sized sheet of paper (215.9 by 279.4 mm) but oriented in portrait instead of landscape mode. The alto displayed documents that “look[ed] like typeset pages incorporating graphical images” (Campbell-Kelly et al. 2014, p. 260), and each one of the visible elements on it could be manipulated. Users could “scale letters and mix text and graphics on the screen” (Ceruzzi 2003, p. 262), which meant editing was effectively “what-you-see-is-what-you-get” (WYSIWYG). Having refined Engelbart’s design, Kay and his team incorporated the mouse into the alto, along with the “now-familiar desktop environment of icons, folders, and documents” (2014, p. 260). However, the Alto was never commercialized; at 18,000 USD a piece — about 90,000 USD in today’s money (Ceruzzi 2003, p. 261)—it was simply too expensive.

In 1979, Steve Jobs visited the Xerox PARC and was so impressed by the Alto that he convinced his partners (Steve Wozniak and Ronald Wayne) to incorporate the GUI paradigm into Apple computers. According to Kay’s account (2017a) Jobs was so amazed by the GUI that he missed the fact that the Alto had already incorporated networking (ethernet) and Object-Oriented Programming, two features that are indispensable in contemporary systems.

In 1981, Xerox introduced a commercial version of the Alto, the “Xerox 8010 Star System”, which was targeted at business users. Besides having a mouse and network connection, it was the first commercial computer to use a GUI based on the office “desktop” metaphor simulating interactable objects such as documents, folders, trash bin, rulers, pencils, “in” and “out” boxes, etc. (Brey 2008). The operating system allowed the user to treat *everything* that was displayed on the monitor (images, characters, words, sentences, paragraphs) as “objects” and thus select and manipulate them individually. Object integration was system-wide so that a document could hold charts, tables, and image modules along with the text. Moreover, the system incorporated generic commands (such as move, copy, open, delete, and show properties) that could be used on *every* object selected, using dedicated keyboard buttons. These features liberated the user from having to remember specific commands (e.g., Ctrl + C) to apply changes (Johnson et al. 1989).

The Xerox Star was conceptually and technically superior to every other office machine available at the time, but it was a commercial failure (Campbell-Kelly et al. 2014; Ceruzzi 2003). It was too expensive (it sold for approximately 16,500 USD), almost five times the price of other computers available at the time (Johnson et al. 1989; Smith and Alexander 1988). Furthermore, to take advantage of the Star’s distributed (Ethernet-based) networking, the potential buyer had to acquire at least two or three workstations along with a file server and one or two laser printers. That meant spending between fifty and a hundred thousand USD (almost a quarter of a million USD in today’s money). But the other major obstacle the Star faced was *conceptual*, and those responsible were Xerox’s salespeople as well as the potential buyers themselves.

5.4 The Computer Becomes Personal

As previously noted, before the mid-1970s, the very idea of a personal computer was not mainstream. The Star was advertised depicting an executive making calls, writing, and sending documents while sitting at his desk. Somehow the marketing department at Xerox failed to see that in those days' executives rarely, if ever, carried out any of those tasks (Ceruzzi 2003, p. 263). And even if a technologically curious executive would be willing to try a computer, he or she could buy and experiment with a far cheaper one (Smith and Alexander 1988). In contrast to Xerox's strategy, other brands (such as the now-defunct Wang Laboratories) aimed their products precisely at the people whose work conditions could be improved by using a PC: secretaries and office clerks. By then, the PC had been defined physically as an artifact, conceptually, however, it remained unclear why anyone would be interested in having one at home or work. The cultural environment was not yet ready for advanced personal information systems.

At that time, computers were still regarded as single-task devices meant for institutions. While in theory, the computer is a universal machine (Turing 1937), in practice mainframe and "mini" computers were fixed, and their reprogramming required specialized knowledge and hardware adjustments. For that reason, large companies such as IBM not only sold (or rather leased) computers but also "business services". Mainframe computers were custom-designed and programmed to meet a client's specific computing requirements; the software was hard-coded into the machine so, along with selling the equipment, IBM included the services of its engineers for a yearly fee. Minicomputers, on the other hand, were usually sold without engineering support, they were not customized and had to be programmed by whoever bought them. Consequently, the idea of a computer being used by a single person was unthinkable at that time. What ended up making the PC appealable for consumers was not the hardware that early computer hobbyists were so fond of tinkering with, but *software*—along with IBMs (cautiously skeptical) decision to finally enter the PC market.

PCs were from the outset all-in-one general purpose machines "ready to run" (Byte 1995, p. 100). By late 1977, the pioneering "trinity" (see Byte 1995; Williams and Welch 1985) of personal computers— the Apple II, the Tandy/RadioShack TRS-80, and the Commodore PET —had opened the market for a new class of cultural product: *software applications* for business, education, and entertainment. A whole new industry emerged around software—particularly around computer games—that would end up redefining human culture at large.[14] The consumer software industry would play a crucial role in the emergence of the UCD paradigm and UX.

In August 1981, IBM officially entered the PC market; this meant personal computing was finally legitimized by a "serious" (i.e., conservative) corporation willing to bet on the new technology. Whereas the "trinity" had certainly gained followers

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[14] Arguably, the software industry continues to play a critical role in technological adoption. We should remember the success of smartphones depends mainly on the fact that they allow users to run myriads of "apps" controlling an equal amount of services.

in the electronics enthusiasts and educational markets before IBM introduced the Model 5150 PC most business users who had hesitated to buy an Apple or a Tandy (the Commodore was seen mainly as an educational device) were finally convinced. To the news media, unaware of the cultural origins of this technological shift, the computer was an overnight phenomenon whose success surprised even IBM itself (Campbell-Kelly et al. 2014, p. 248).

Engelbart's "electronic office" and Kay's Alto were two technological models that joined to form not only the modern GUI but also the paradigm of contemporary HCI (Campbell-Kelly et al. 2014, p. 259). Companies such as Apple and Microsoft capitalized on these innovations, "liberating" consumers from having to interact with the command line and creating a market for software applications which brought new challenges for the field of HCI and set the stage for the emergence of UCD and UX as disciplines. Before looking at the origins of these design paradigms, it is critical to focus on the ideas behind the GUI, in particular on its pedagogical imperatives, for it is there that we will find the reason why HCI researchers stopped treating the actual needs of end-users as an afterthought.

As we will see further along the way, one of the tenets of contemporary design practices following UCD approach (particularly Interaction Design) is creating technological solutions that are not only usable but *useful*. The goal is providing users with the means to accomplish something better; the technical solution is, therefore "just" an enabler, an affordance that will improve a user's experience while carrying out a task. To achieve this goal, designers need to understand the role of products in the context of meaningful activities, this means learning not only what kind of tasks a user engages in, but why she does it.

5.5 The Pedagogical Role of the GUI

Kay's goal was offering people, particularly children, not (just) a multipurpose tool, but a "metamedium" (Kay and Goldberg 1977) for constructing knowledge. Whereas other HCI pioneers such Engelbart and English (1968) had focused on improving HCI to "augment human intellect", Kay was looking instead to develop an *enabling* device for personalized *learning* (Coyne 1995, p. 33). Kay's vision highlighted the nature of the computer as prefigured by Alan Turing. Turing (1937) imagined his machine as capable of simulating, or rather of "computing"[15] any machine that was computable. Kay thought this universality—this capacity to simulate—could be extended to sound and images (Manovich 2013). Hence, he made simulation the "central notion" guiding the design of his prototypes, particularly, of the *Dynabook* (Kay and Goldberg 1977, p. 36).

If Kay and his team spent over a decade researching the computer's potential as "a medium for expression through drawing, painting, animating pictures, and compos-

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[15] Turing never used the word "simulation" in his paper, the term is the product of later interpretation of Turing's ideas.

ing and generating music" (1977, p. 31), it was not due to artistic inclinations. Kay was interested in improving human learning potential through computational technology, but he disagreed with the prevailing rationalist conceptualizations of knowledge shared by most HCI researchers. For them, computers could be at best devices for capturing and retrieving information (Bush 1945) or machines for automating routine work (Licklider 1960). Whereas Kay regarded the computer as a "culture machine"—to borrow Manovich's formulation (2013); as a medium through which active learning and experimentation could be significantly amplified by simulation.

Influenced by the ideas of Jerome Bruner, Seymour Papert and Marvin Minsky, Kay, and his group at Xerox PARC imagined the computer interface as something that should be equally approachable for anyone regardless of age and prior cognitive skills and knowledge. In 1968, as a graduate student, Kay met the ideas of Papert through Minsky (Kay 2017b). Papert, who studied with developmental psychologist Jean Piaget, had realized that children under 12 years old are not well equipped to do "standard" symbolic mathematics, but they nonetheless could do other kinds of mathematical thinking when presented in a way that matched their current capacities (Kay 2002). Kay later came into contact with Jerome Bruner's interpretation of Piaget's ideas on children's cognitive development and came to believe that interaction with a computer interfaces should take advantage of the three "mentalities" (modes of representation) Bruner had identified: enactive (manipulate objects), iconic (recognize things), and symbolic (abstract reason); as opposed to merely stimulating the symbolic mentality like the traditional command line interface (CLI) did (Kay 2002; see also Manovich 2013, pp. 97–98). Kay condensed his vision in the slogan "doing with images makes symbols" (2002, p. 128), which culminated in the Alto's GUI.

Early programmers and HCI researchers were mostly mathematicians and scientists, their approach to interface design and programming, in general, was based on mathematical logic. A shift in paradigm required, to borrow Kay's formulation, "a new class of artisan" (1984, p. 54). These artisans understood the role aesthetics plays in cognitive processes, specifically one that privileged simplification via visual metaphors and analogies over abstract logical descriptions. To embrace this new paradigm required accepting that people are different from computers; that human behavior is far more complex than any logical model would admit. Therefore, a new design approach was required. One that was "pluralist" (interdisciplinary) enough to accommodate all the nuances of human behavior, and sensitive enough to place the human needs rather than the system's needs at the start and the core of the design process. This approach was UCD.

5.6 User-Centered Design (UCD)

The origins of UCD date back to the early 1980s, to the Project on Human-Machine Interaction from the Institute for Cognitive Science at the University of California, San Diego. At the time, a group of researchers from AI and psychology, among them Donald A. Norman, put together an interdisciplinary team of researchers and organized a series of conferences and workshops that culminated in the book *User Centered System Design* (1986). Both the name of the book[16] and the holistic approach it advocated grew in popularity among HCI practitioners and researchers and has since then become the dominating paradigm, particularly in Interaction Design (IxD). Another key document is “Designing for usability” by Gould and Lewis (1985), an article that outlined the main ideas and reasons for adopting an empirical approach in what was then called system design, that includes user research and intensive cycles of prototyping and testing.

The emergence of UCD is arguably a continuation of the ideas that led to the GUI in the first place, albeit more pragmatic and with the benefit of having computers already transformed into consumer products. Its origins may be attributed to HCI practitioners and researchers realizing that computers are not (just) about technology but about people using them. These researchers recognized that “computation is a social act”—to borrow Turkle’s (1980, p. 22) words, and hence, that the computer could be understood as a social tool (Norman et al. 1986, p. 2) that influences social interactions and policy. They understood that the computer could and should be viewed “from the experience of the user”, which is itself influenced by the nature of the task, the user herself, and the context of use.

The ideal driving the shift toward UCD was giving users “the feeling of ‘direct engagement’” (Norman et al. 1986, p. 3). That is, the feeling that the computer itself receded to the background while letting the task at hand, whether it involved sound, words, or images to come to the forefront. This stance was radical insofar as it proposed completely subordinating the interface to “social concerns”: to the various ways in which the computer could be use, rather than the other way around—as had been the case until then. So much so that Gould and Lewis (1985, p. 301) note that while they had been promoting these principles since the 1970s and many designers claimed not only that they applied them but that these ideas were “common sense”, the reality is they did not even understand them. It has been more than 30 years since Gould and Lewis and Norman and Draper (1986) outlined the core principles of UCD, but only in the last decade or so have they been accepted and implemented in product design (Still and Crane 2017, p. 19).

5.7 What Is UCD

UCD developed from many different sources; it is related to Interaction Design (IxD) and User Interface Design (UID),[17] but whereas these are “artifact driven” notions, UCD is better understood as a comprehensive *process* (Wallach and Scholz

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[16] The name “User Centered System Design” was originally an alliteration of the abbreviated name of the University of California, San Diego (UCSD). Norman and Draper (1986 iX) credit Paul Smolensky with having come up with the idea.

[17] UCD is informed by these two design areas but also by cognitive science, user research psychology, HCI, and ergonomics (Still and Crane 2017).

2012)—although not as ample as UX. UCD is a *cluster*[18] of operations comprising a framework that implicitly recognizes the interface of a computational device as a sociotechnical intersection. That is, as something where "many different kinds of things: people, machines, tasks, groups of people, groups of machines, and more" (Norman et al. 1986, p. 5) come together. As Wallach and Scholz (2012) note, there is little doubt that Gould and Lewis (1985) laid the foundational concepts and general approach on which current UCD practices are still based. This is no small feat, considering that in terms of technological development, three decades is a significant time span. Their central claim was that "[a]ny [computational] system designed for people to use should be easy to learn (and remember), useful, that is, contain functions people truly need in their work and be easy and pleasant to use" (1985, p. 300). They were, in short, advocating that to provide learnability, usability, and "delightful" experiences (see Cooper et al. 2014; see also Norman 2013), designers[19] ought to first and foremost *understand* their potential users.

Gould and Lewis do not define "usability",[20] however, their claim is echoed in the International Organisation for Standardisation (2018), according to which:

usability
[is the] extent to which a system, product or service can be used by specified users to achieve defined goals with effectiveness, efficiency, and satisfaction in a specified context of use.

Gould and Lewis (1985, p. 306) were prescient enough to recognize that in this age the product is not (just) the device but the *interface*. They understood the need to develop a robust methodology to increase usability, which undoubtedly would have a powerful impact on the emerging market of computational devices. They advocated three principles that are now obvious for anyone acquainted with UCD, but which at the time seemed if not foreign, at least superficial. First, that "systems designers" should engage in "interactive design" (1985, p. 302), that is, they should focus on the users and their tasks from the outset, understanding who they are and the nature of the work they engage in by studying their behavior through *direct contact*. Second, carry out empirical measurement while testing prototypes with actual users early in the design process, focusing on their reactions and suggestions. Third, embrace iterative cycles consisting of design, testing, and redesigning.

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[18] A "cluster" is best understood as "a number of things growing naturally together" (Harper 2019).

[19] It is important to remember that, at the time, there was no such thing as a "user interface designer". The people designing interfaces were mostly self-taught programmers and scientists with little or no training in design. Design as practice continued to be primarily analogical and divided along two traditional branches: graphic and industrial.

[20] For thorough discussions on the history and broader meanings of the term see Johnson et al. (2007) and Sullivan (1989).

5.8 Understanding Users

Gould and Lewis further clarify that by understanding “typical users”[21] they do not mean identifying, describing, or stereotyping. They argue contact with them should be direct, preferably through interviews carried out *before* the actual design cycle begins because it is at that moment that the information gathered can influence the outcome of the design. This process stands in stark contrast to what inexperienced designers (mainly students) attempting to follow an empirical approach do: conducting user research *after* creating the prototypes thus falling into the trap of post hoc rationalization that forcibly attempts to validate design decisions that were already implemented. Gould and Lewis (1985, p. 302) note this type of user involvement resembles participatory design, a methodology that originated in Scandinavia and which advocates direct user involvement throughout the entire design process (for a thorough discussion see Luck 2018; see also Spinuzzi 2005).

Regarding “empirical measurements”, Gould and Lewis are talking about testing and measuring variables such as learnability and usability with a user interacting with a prototype, rather than carrying out simple analytical questions. In other words, they warn against attempting to “sell” a finished interface to a potential user. Usability testing helps overcome the problem of designers being too used to their product and hence not being able to see all the potential pitfalls and untested assumptions in their project. Usability testing makes explicit the differences between the ways a designer and a user think about the interface.

Gould and Lewis understand iterative prototyping as an effective way to address the unpredictability of user’s needs, which often lead to fundamental changes in design. Prototyping should be based on user testing, for the latter can reveal that even the most thoughtful design might prove to be inadequate. This implies that the implementation should be as flexible as possible, extending throughout the system. An essential aspect of iterative prototyping is that designers need to be capable of accepting (and reacting upon) test results that call for radical changes in the design and be prepared to “kill their darlings”. In sum, testing prototypes can help designers to reliably identify critical problems in what they create; hence, it should not be treated as a luxury or unnecessary waste of time.

5.9 Norman’s Approach

Gould’s and Lewis’ principles are aligned with one of Norman’s most influential works, *The Design of Everyday Things* (2013). Norman argues his approach concerns three major areas of design: Interaction Design, Industrial Design, and Experience

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[21] Gould and Lewis (1985, p. 302) suggest user research should be conducted for example with secretaries and clerks: from a historical standpoint this suggestion is interesting because it reveals an understanding of who the actual users of personal computers were. A knowledge that contradicts the naive assumptions that some computer manufacturers such as Xerox had at the time.

Design. However, whereas Gould and Lewis claim their approach could increase "usability marks" (and therefore make systems easier for users to learn and use), Norman's approach is more holistic; he sees the users from a broader perspective. He talks about human–technology relations, not restricting his approach to a specific technology or context of use. Norman's vital contribution is suggesting that designers not only provide a given product or service but a whole *experience*; something with an active aesthetic component. Experience, Norman (2013, p. 10) contends, is critical because it determines how people are going to internalize their interaction with a given technology.

For Norman, the design is ultimately a humanistic activity; a form of mediation. As he puts it, "[a]ll artificial things are designed" (2013, p. 4); the design is concerned with how things work and how they are controlled, and thus how humans interact with them. But while people build machines, their behavior is limited (procedural and literal) and may often seem alien to the users. Traditionally, it was users who had to adapt to the situations presented by the machine, but that should not be the case any longer. Instead, machines should adapt to people's needs and circumstances, and it is the designer's task to make sure that happens. The problem, Norman contends, is that the people in charge of designing the technologies are experts in the machines, not in people's behavior. Furthermore, they are often convinced that logic is the most appropriate way of thinking, whereas human thought is far more complex. The technological design thus stands at an intersection between humans and machines; its task is bridging the gap that separates the two. For Norman (2013, p. 9) UCD, or rather HCD is not only an approach but a design *philosophy* that relies primarily on (scientific-like) observation of people. Because specifying what is going to be defined is the most challenging aspect of the process UCD/HCD instead iterates potential approximations to the solution. UCD is a methodology that can be employed by different design areas, regardless of their specific focus (e.g., Interaction, Communication, Industrial products).

In the decade since Norman and Gould and Lewis first promoted their ideas UCD/HCD has been expanded and adapted by many design practitioners, leading to somewhat different methodologies which, nonetheless, maintain the same basic principles: understand the user before designing and incorporate insights from user research throughout the design process; test prototypes in recursive iterative cycles and be prepared to make changes after each cycle, regardless how radical they need to be.

In summary, UCD is a process or rather a set of processes that emphasize an approach to design that breaks from the traditional product-centric/technological approach by taking care of the whole experience of the user. It is a humbling method that highlights the uncertain nature of design, and the complexities of its various stages, putting a humane focus throughout the design process. UCD is above all iterative; it implicitly addresses a vital issue for design practitioners, which Parsons (2015) calls the "epistemological problem" or difficulty of design: the question of how a designer can know her solution is going to solve the intended problem (see also Galle 2011). UCD tackles this problem by adopting a fundamentally empirical method to gain as much information from the users as possible to craft a unique experience. How this concept should be understood in the context of design and what is its relationship with aesthetics will be the focus of the next section.

5.10 User Experience (UX)

Contemporary design practices address complex problems that involve difficult sociocultural issues and reveal the deep entanglement between human behavior and technologies. If we lend credit to Norman, designers today are more like applied behavioral scientists than applied artists. New design areas such as interaction or product design require a deep "understanding of human cognition and emotion, sensory and motor systems, and sufficient knowledge of the scientific method, statistics, and experimental design" (Norman 2010). Traditional design skills such as drawing, sketching, and modeling are supplemented and sometimes replaced by programming, and scientific methodologies for gathering and analyzing data. Design products and what is expected from them have thus become significantly more complex.

The emergence of UX is arguably the result of the technological shift discussed in the first section of this chapter, which led designers from "merely" designing concrete objects (i.e., "stuff") to designing the *conditions* that may elicit a positive and complex response from users. In the early and mid-decades of the past century, designers mainly focused on "external" aspects of products, i.e., their form, function, use, and materials (Buchanan 2001). However, with the arrival of the PC and consumer software, designers began to move their focus away from "visual symbols and things" and onto understanding products "from the inside" of the humans interacting with them in specific social and cultural circumstances. Computational technology opened an uncharted space for a design where form, function, use, and materials are still important, but they are re-conceptualized through research attempting to understand what is it that makes a product useful, usable, desirable and delightful (2001, p. 13).

Defining UX in general terms is a difficult if not impossible task. It can be a practice or area of focus in contemporary design but also the *result* of a design process.[22] It is an umbrella term that attempts to describe all the complex things that a user undergoes when interacting with a designed artifact. Hence, while it is a relatively novel concept, it describes phenomena that have been discussed for a long time by designers under other names, such as ergonomics, affordances, or anthropometrics. The main distinction, however, is that unlike previous notions, UX explicitly acknowledges that whatever happens between a human being and a designed artifact has a strong aesthetic component.

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[22] From this point onwards, UX will be used to designate the result of a design process, whereas UXD will refer to the activity aiming to achieve it.

To the best of our knowledge, Norman was among the first one to use—if not the inventor[23] of—the term "User Experience" (Norman 2013, xiii–xiv) in the early 1990s while he was the head of the "User Experience Architect's Office" at Apple. Norman implicitly defines experience as "the aesthetics of form and the quality of interaction" provided by a given product (Norman 2013, p. 4). This implies the product is not only usable but useful; that its features are immediately discoverable and understandable to the user. This succinct definition is a good starting point. Nonetheless, to fully grasp what experience stands for in a contemporary design, we need to look at its origins and evolution as a concept and its relationship with aesthetics. But also, to its usage within a philosophical school (American pragmatism) and, particularly, in the work of John Dewey. This we will do before turning our attention to the ways experience influenced computer system design, HCI, UCD, and IxD.

From a (traditional) epistemological standpoint, an experience is that which contrasts to what is thought or to what is accepted based on authority or tradition; it is what we perceive through our senses; information that comes from external sources (or through inner reflection) (Bunnin and Yu 2009, p. 240). In this sense, the experience is associated with empirical observation. Because it concerns sensory perception experience is closely linked to aesthetics, which was initially understood as "the science of sensitive knowing" (Bunnin and Yu 2009, p. 17), from the Greek *aisthitiki*, "perceived by the senses" (Fishwick 2006).

Although aesthetics is usually associated with art, there is an essential distinction between the two. Aesthetics may be concerned with works of art, but it is not restricted to art or beauty or the beautiful (Nake 2012, p. 66). Aesthetics is also concerned with value and with our experience of the environment (both natural and artificial); it is an autonomous branch of philosophy concerned with the analysis of problems relating to perception. It was initially conceived as a companion and complement to logic, and thus its focus was human cognition. Whereas logic studied discursive and rational cognition, aesthetics focused on holistic sensory cognition (*cognitio sensitiva*), that is, cognition experienced and practiced through our senses, tied to our physical capacities (Proudfoot and Lacey 2010). There are many approaches to aesthetics, but the one that interests us, due to its lasting influence on contemporary design practices and areas of specialization such as interaction design and User Experience Design (UXD) is by the American Pragmatist philosopher, John Dewey.

5.11 Dewey and Pragmatism

Pragmatism is a philosophical school that emerged in the United States in the late nineteenth century. Unlike other philosophical strains in the Western Tradition, pragmatism evaluates claims (e.g., concerning meaning, truth, knowledge, or morality)

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[23] Norman admitted to having "invented" the term because usability and human interface seemed too narrow to account for everything that happened when a person interacted with a system (Merholz 2007).

not in terms of perennial axioms or syllogisms but in terms of the consequences that a given action has (Dusek 2009). Pragmatism rejects dualism (mind vs. body distinction) and the separation of theory and practice; it embraces the materiality of the world, the embodiment of knowledge, the interaction of the senses, and the formative power of technology in everyday life (Coyne 1995, p. 17). Pragmatism is anti-essentialist; it emphasizes practice, not representation (Ihde 2009). For pragmatism, experiences are crucial for creating knowledge. Their view of experience is holistic and dynamic, according to it, humans do not merely (passively) receive individual sense impressions but actively engage with the world through active habits; hence we continuously transform our experience of it (see Pihlström 2011, p. 31).

According to Coyne (1995, pp. 38–41) Dewey understood facts, ideas, and concepts *as tools*; he regarded theoreticians as technicians. Tools are not universally useful; their applicability changes according to the situation. Thus, he did not grant any special privilege to reason or inference—he regarded science as just another form of practice, albeit highly specialized. Knowledge cannot exist outside of doing, knowing is "knowing *how*" instead of "knowing that". Humankind, for Dewey, is not above nature but always involved *with* nature and in constant interaction with it; life happens not only in an environment but within it. More important, and because he emphasizes (human action) Dewey regarded perception not as analytical or passive but as a participatory activity, and this is key for his understanding of aesthetics.

For Dewey aesthetic artifacts such as works of art have no intrinsic, essential features, the "art" is in what the object does *within an experience*. To understand the aesthetic value of an artifact, we need to look at ordinary, "in the raw", everyday aesthetics. That is to say, for example, that if we want to understand the Parthenon, we first must understand the cultural context of Athenian society (Leddy 2016).

In Dewey's view, aesthetic experiences begin in happy absorption in an activity (poking fire in a campfire, or watching a baseball game), so a crafty mechanic fixing a car may be in this sense "artistically engaged" (see Granger 2006). Organisms (including humans) engage in a dialectical relationship with their environment: every creature has needs, their life flows are a constant rhythmic resolution of tensions between requirements and their satisfaction; between disunity and a unity (balance) (Leddy 2016). For humans, this rhythm is conscious. Direct experience is a function of the interaction between us and our environment. The aesthetic experience involves a drama (narrative) where actions, feelings, and meaning play a part. The most intense aesthetic experiences happen in the transitions between the disturbance of needs and the harmony of balance when needs are met. Happiness is the result of deep fulfillment; when every aspect of our being is adjusted to the environment (in full balance). Experience is the result of active engagement with these tensions when we infuse them with conscious meaning through communication (Leddy 2016). Consequently, the experience is not only the result of the interaction between subject and environment but the subject's reward when it transforms mere interaction into active (meaningful) participation.

Dewey's book (1980) *Art as Experience* and, in particular, the chapter "Having an experience" has had a longstanding influence on contemporary design practices, particularly on IxD (Buchanan 2009). Dewey's book was compulsory reading in the Industrial Design course at the New Bauhaus in Chicago (Findeli 1990). It later informed HCI research at Xerox PARC and continues to elicit much discussion among IxD researchers (Dixon 2019).

For Dewey, in "an experience" the material of experience is fulfilled or consummated, e.g., when a game is played, or a problem is solved (Leddy 2016). As we saw before, Dewey understands life as a collection of histories, each one with a unique quality. In an experience, every one of its components follows in an unbroken chain without sacrificing their identity; each part is a phase of an enduring whole. A good example of experience is an artwork; in it, separate elements participate in forming a unity; their particular identity is not diluted but enhanced.[24] For Dewey, no experience has unity without aesthetic quality, although this does not imply that *all* experiences can be reduced to aesthetic experiences (Leddy 2016). Emotion is the unifying quality that distinguishes an aesthetic experience from other kinds of experiences (Buchanan 2009).

5.12 Experience as Design

Dewey's influence is palpable in the work of Hassenzahl (2010, pp. 5–30), who describes experiences in terms of unique *emergent* qualities that are not reducible to (nor explainable by) their constituting elements and processes. Nonetheless, these elements are open to study and deliberate manipulation; experiences can thus be shaped through carefully modifying their elements. Experiences are lived episodes comprising sights, sounds, feelings, thoughts, and actions; they are stories emerging from the "dialogue" of a person with her surroundings. Experiences are holistic, situated, and dynamic; they arise from the activation of perception, action, motivation, and cognition at a given place and moment, and they extend over a certain timespan. Experiences may occur in infinite variations, but, in Hassenzahl's view, there are universal psychological needs that are essential constituents of experience (2010, p. 57).

UX is a sub-category of experience that is deliberately elicited and shaped through an (interactive) product (Hassenzahl 2013). UX is not unlike experience at large; the difference being that it focuses on a person's attention on that specific product. The product is not the experience per se, but a facilitator, a mediator that can shape or influence what and how we experience a given activity (2010, p. 8). The emergence of a given experience cannot be guaranteed; however, careful application of knowledge about how experiences are elicited can make them more likely, that is precisely the task of UXD.

Although for UX, the interactive product is a necessity, UXD is *not* about the technology itself, but about transcending its materials, about making it an instrumental

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[24] Artworks may be understood as integral complex informational systems, wherein each element is necessary for the aesthetic content to emerge, a slight change in the configuration may alter the whole meaning of the piece (see Hernández-Ramírez 2016).

and yet almost transparent presence. The technologies are the canvas, the pretext for the UX designer. Given that the majority of these products are digital, an excellent way to understand UXD is in terms of narratives, or “material tales” narrated through digital objects (Hassenzahl 2013). Because experiences are dynamic and happen over a timespan, any given moment within that timespan can impact the overall experience. Designers can influence that experience by manipulating order and timing; by *scripting* interactions among the elements (Hassenzahl 2010, pp. 29–30).

Products fulfill needs, but to do so, they need to be “instrumental”, i.e., able to shape the user’s experience as intended (Hassenzahl 2013). Products need to be functional, useful, discoverable, and understandable to satisfy a particular need; it is only then that a (good) experience emerges. Functionality and usability, however, need to be contextualized, and that means being meaningful. A genuinely unique experience requires that not only the engineering, manufacturing, and ergonomic aspects are met, but also the aesthetic ones; interaction with the product should also be delightful and enjoyable. It is only with this holistic satisfaction of needs that truly unique experience can emerge (Hassenzahl 2010; Norman 2013).

5.13 Concluding Remarks

Pervasive computation and general advances in hardware and software have allowed us to transform artifacts that were traditionally “dead” into alive devices. Computational objects have come a long way since the dawn of HCI, UCD, and UX. While ergonomics and HCI emerged almost at the same time as computational technology, only with the democratization of computers, it became a necessity for designers to honestly think about their users. Smart technologies and what we end up defining and recognizing as robots will determine the practical principles, and the type of experience designers will be able to shape.

Robots should be able to enhance and improve our experience of the world, improve our living standards, liberate us of chores and burdens so we can dedicate ourselves to cultivate meaningful activities. Robots and our technologies, in general, are reflections of what we are, how we understand them and design them reflect our understanding of ourselves. Designing should always consider the human–technology relationship as complementary, not in terms of substitution. We need artificial agents that highlight what is valuable and enjoyable about being human. Ultimately, and given the broader objectives of the volume to which this chapter belongs, it is fundamental to pay attention to the core principles behind UCD and UX. It is crucial to listen to the core ideal of UCD and UX: to focus on the human in her context, not in decontextualized technology for the sake of technology.

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Chapter 6
"I Love You," Said the Robot: Boundaries of the Use of Emotions in Human-Robot Interactions

Eduard Fosch Villaronga

Abstract This chapter reflects upon the ethical, legal, and societal (ELS) implications of the use of emotions by robot technology. The first section introduces different cases where emotions play a role in human-robot interaction (HRI) contexts. This chapter draws particular attention to disparities found in recent technical literature relating to the appropriateness of the use of emotions in HRIs. These examples, coupled with the lack of guidelines on requirements, boundaries, and the appropriate use of emotions in HRI, give rise to a vast number of ELS implications that the second section addresses. Recent regulatory initiatives in the European Union (EU) aim at mitigating the risks posed by robot technologies. However, these may not entirely suffice to frame adequately the questions the use of emotions entails in these contexts.

Keywords Emotions · Human-robot interaction · Ethical, legal and societal (ELS) issues · Guidelines · Law · Ethics

6.1 Introduction

Over recent years, social interactions have expanded from mere human interactions to technology-mediated human interactions. What is more, technology enables humans to interact with information and with the world. Technology can be, thus, not only a means of communication but also an end in itself; an end to which humans are addicted (Kardaras 2016). Companies invest time and resources in improving user interfaces to make them more appealing and functional both for trivial (making you click on the advertisements that financially support the company) (Vance 2011) and meaningful interactions (e.g., in cognitive therapies for people with dementia) (Tapus et al. 2009).

The more users mingle with screens, computers, and increasingly with robots, thus, the more these machines need to be appealing, useful, and interactive to be adopted by users. The High-Level Expert Group on AI (HLEG AI) of the European Commission (2019) believes that robot and AI technologies also need to be trustwor-

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thy. In the context of personal care, that includes assistance with dressing, feeding, washing, and toileting, but even encouragement and emotional and psychological support (Elderly Accommodation Counsel of the UK), this would translate in robots that are trustworthy, appealing, useful, and integrate a social interface that promotes engagement. Robots fail to integrate a social, trustworthy, dimension in this context risk not being fully adopted.

The technology used in industrial environments, where safety standards reduced human contact for obvious reasons, has not experienced such an evolution—user-friendly, appealing, and trustworthy technology results from the increasing development of technology that directly interacts with users. As the novelty effect soon wears off (Kanda et al. 2004), the technology requires continuous "improvements" to continue being attractive to users once they get used to the technology. One way to "improve" such systems is to make the technology exhibit human social characteristics. Social robots, for instance, perceive/express emotions, communicate in high-level dialogue, establish/maintain social relationships, use natural cues (gaze, gestures), exhibit distinctive personalities and characteristics, and can learn and develop social competencies (Fong et al. 2003). Because people treat computers in the same way they treat other people (Cañamero 2001), they do the same with robot technology (Darling 2016). The exhibition of such characteristics in robots ensures their believability and their aliveness, improving, thus, the effectiveness of their interaction with humans (Hudlicka 2011).

This tendency is leading users to interact increasingly more with technology than with other humans. As a consequence, "the more human attention and learning effort is absorbed by the virtual variety of proximity, the less time is dedicated to the acquisition and exercise of skills which the other, non-virtual kind of proximity requires" (Bauman 2013). The problem is that the readiness level of technology is not quite there yet. In the words of Yang et al. (2018), "a robot that expresses excitement when the death of a family member is being discussed, one that shouts at inappropriate times, or one that takes a coffee mug before it is empty will not find itself welcome in the home or workplace." This article, therefore, wonders what are the implications of the recent and increasing use of emotions in HRI given that the systems created for "social" interactions fall behind in accuracy, preciseness, and reliability levels. This type of concern has yet to be reflected in the technical, legal, and robot ethics literature.

This chapter reflects upon the ethical, legal, and societal (ELS) implications of the use of emotions by robot technology. The first section introduces different cases where emotions are used in human-robot interaction (HRI) contexts. Special attention is drawn to disparities found in recent technical literature relating to the appropriateness of the use of emotions in HRIs. These examples, coupled with the lack of guidelines (Barco and Fosch-Villaronga 2017) on requirements, boundaries, and appropriate use of emotions in HRI, give rise to a vast number of ELS implications, which the second section addresses. Recent regulatory initiatives in the European Union (EU) aim at mitigating the risks posed by robot technologies. However, these may not entirely suffice to frame adequately the questions the use of emotions entails in these contexts. Some conclusions at the end of the chapter raise awareness regarding the importance of integrating ELS aspects into the design of emotions not as an afterthought but as an integral and essential part of the life-cycle design, implementation, and use of robot technology.

6.2 The Use of Emotions in Human-Robot Interaction

Emotions play a significant role in human behavior, communication, and interaction (Fong et al. 2003). However, the community has come no further than the Ancient Greeks in reaching a consensus on what emotions are (Scarantino 2016). It seems that "everyone knows what an emotion is until asked to give a definition" (Fehr and Russell 1984). However, this has not impeded advances in the understanding of the nature and extension of emotions from the perspective of different disciplines, including philosophy, music, sociology, and neuroscience (Barrett et al. 2016).

The computing that "relates to, arises from, or influences emotions" is called *affective computing* (Picard 1995), and has been used in many applications, including helping people with disabilities, for domestic use or lately to help people mourn. In physically embodied computing, aka robots, emotions relate to the capability of displaying facial expressions, body and pointer gesturing, and vocalization and they are typically used to provide the user with information about the robot's internal state, goals, and intentions, to act as a control mechanism, but also to make the interaction more believable (Fong et al. 2003). Robots also exhibit personality, which provides affordances to understand robot behavior and can range from tool-like to pet-like or even human-like. The robot embodiment can convey this personality, but also its motion or the tasks that it performs (Fong et al. 2003). This section compiles different cases of the use of emotions in HRI contexts that will help illustrate their ELS implications.

a. Therapeutic contexts

The insertion of robot technology in healthcare settings is accelerating. Typical examples of such cyber-physical systems are cognitive therapeutic robots (for autism, traumatic brain injury or dementia patients), physical rehabilitation robots (lower-/upper-limb exoskeletons), mobile assistants (servants), and surgery robots. Other less typical examples include sexual robots for the elderly in care homes, or disabled people (Martin 2016). Of all of these systems, socially assistive robots (SAR), those that assist people in a non-physical way, through non-contact interaction to support patients (Feil-Seifer and Mataric 2005) are those that generally integrate emotions into their interaction design. Sexual robots allow users to choose different traits and emotions that the users feel are appealing (Sharkey et al. 2016). In sensitive contexts, the use of emotions is crucial in the caregiver–receiver relationship. This extends to SAR.

The inclusion of emotions into the design of the robot derives from the need to maintain and support long-term interactions, but also from the need to manage the emotions that the interaction with the human arouses. One example is the "Traumatic

Brain Injury (TBI) Project" (Barco et al. 2013). Some researchers in Barcelona used a social robot to help improve the effectiveness of neuropsychological treatments for children with TBI. The robot included several activities defined by neuropsychologists to recover the functionalities most affected by TBI. After six months of the rehabilitation process, the researchers found out that the engagement was fragile, and decided to add personalization features to the robot to match the children's likes and dislikes. The conclusions of their study show an increased interaction given the personality trait adjustment and accordingly better performance of the children. Years later, one of the authors acknowledged that the personality adjustment had some drawbacks: there was increased dependence on the robot, and the emotional bond created between the robot and the child was powerful (Fosch-Villaronga et al. 2016). When the robot's behavior is more personalized, the emotional engagement with the user is stronger. Two consequences derive from this: that the task performance of the robot may entail the management of user emotions too; and that because the HRI is safe at the physical level, it does not mean that it is safe at the emotional level.

In another project called "Rehabibotics," some researchers went one step further in the personalization of the robot and created an emotional adaptation model to help generate empathic responses to improve the interaction between the robot and dementia patients (Shukla et al. 2015). They collected sensorial data including physiological, eye-tracking and ambient video recording, a database containing information about the user (preferences, physical/mental abilities), algorithms to predict the users' emotional state, and a user-learning model containing user performance records and information about the user, such as degradation and memory level. Although they collected valuable information about the user and improved the interaction, they acknowledged errors in the prediction of the user's emotional state. Taken together with the possibility that user's feedback may be non-existent, as they have dementia, and may not be aware of these errors, the predictive analysis of the user's behavior and the subsequent robot action may mismatch, if not endanger the effective HRI. The researchers claimed a lack of guidance on the boundaries for the use of emotions in HRI.

b. Domestic contexts

If a robot exhibits personality, the engagement with the user accelerates (Lee et al. 2006). In a study with the iRobot's Roomba, the robotic vacuum cleaner, the users reported increased pleasure, willingness to share it with others, and even making an effort to make room for the robot only by developing intimacy with it (Sung et al. 2007). If the robot is friendly, it also elucidates better responses from the users. For instance, Jibo—considered one of the best inventions of 2017 (Time Staff 2017) but that never hit the market—has such human-like expressions that users report saying "thank you" and "please" more often than with other devices (Stern 2017). The way a robot behaves and interacts with users affects users' behavior. In a way, technology becomes a filter and, at the same time, an agent determining how users see the world (Fosch-Villaronga et al. 2018a; Verbeek 2015).

Sometimes the construction of robot personalities is not transparent to the user. In 2015, Google patented the development of robot personality drawn from cloud computing capacities (Google 2015b). The patent covers the creation of robot personalities from collected information (from the user, user devices, environment, or social network sites) or modifiable from a default-persona. As they announce, “the robot can build emotion models or access emotion models on the cloud to determine an appropriate reaction to a situation.” If the robot prepares a meal with peanut oil and the user has an allergic reaction, then (the patent explains) the robot will understand scolding the robot as a negative feedback response for the action carried out. Using the emotional reaction of the user as reinforcement learning in real environments, thus, may seriously compromise the safety of the user (Fosch-Villaronga and Albo-Canals 2018). Instead, there should be testing beds for the appropriate assessment of the safety, efficiency, and efficacy of robot technology.

Technology marketed directly to children offers other reasons to worry. Hello Barbie or IXI-play from WittyWorX that has a lifelike body movement and posture, animated eyes and sounds to express emotions and support a playful interaction (WittyWorX 2017) are just some examples of robotic devices targeted to children. Companies like Google aim at developing devices in the form of dolls or toys with embedded anthropomorphic queues, exhibiting emotions to elucidate an emotional response from the user. A Google patent explains that “in order to express interest, this anthropomorphic device may open its eyes, lift its head, and/or focus its gaze on the user (…) to express curiosity (…) tilt its head, furrow its brow, and/or scratch its head with an arm. To express boredom (…) defocus its gaze, direct its gaze in a downward fashion, tap its foot (…) an anthropomorphic device may use other non-verbal movements to simulate these or other emotions” (Google 2015a).

In the same way that the sugar industry is not particularly interested in the health of its consumers, it is uncertain how worried these companies are about the implications of the continuous use of their technologies, especially if they can “store, or have access to, a profile for each resident of the house” (Google Patent 2015a). Having access to all these data using innocent dolls means feeding large corporations with the behavioral surplus they need to predict the behavior of vulnerable parts of the society for their benefit (Zuboff 2019). While corporations may use some of these data to improve the user experience of these children, they inevitably encourage more device usage. Advances in related research, however, show that the overexposure to technology (in the case of the research, screens) activate a system of rewards in the brain that releases dopamine, which leads to an unhealthy addiction involving irritability, anger, aggression, and violence (Lezhaen 2018). Other effects include brain damage (Zhou et al. 2011).

Research has yet to prove how these impacts translate into HRI contexts. Still, recent industry-driven legal documents focus on how the use of AI fosters human nature and its potentialities, thus creating opportunities; how the underuse creates opportunity costs; and how the overuse and misuse creates risks (Floridi et al. 2018). The overfocus on use, of the industry and the policy documents, aligns with the so much needed return of investment, the extraction of behavioral surplus for predictive behavioral analytics and modifiers, and blurs the understanding of long-term consequences that might affect human nature (Zuboff 2019).

c. Griefbots

The quoted patent of Google reads, “the robot may be programmed to take on the personality of real-world people (e.g., behave based on the user, a deceased loved one, a celebrity) to take on character traits of people to be emulated by a robot” (Google 2015b). Although very nuanced and only appearing once in the patent, it seems to imply that storing personalities in the cloud may allow users to speak with people that pass away. A similar idea inspired a whole episode of Black Mirror entitled “Be right back.” After her husband dies, a woman decides to hire the services of a company that, in order to help mourners, collects all the data from those that have passed away to create synthetic replicas. She can speak to him on the phone and, after an upgrade, she embeds his (synthetic) self in a “sleeve” that looks the same as him.[1]

Although seemingly very futuristic, there are already real cases trying to solve immortality. Eugenia Kuyda used an artificially intelligent chatbot to recreate the conversations she had with her friend that passed away (Newton 2017). She founded Replika.ai, an artificially intelligent system that uses neural networks to have a conversation with users and learn, over time, to speak like them. Other companies provide similar services. Under the promise to “become virtually immortal” Eterni.me is a company that generates digital avatars from pictures, videos, and memories of the users to allow a permanent virtual presence of humans.

If there is enough information about a person, it is already possible to create his or her digital simulation—a simulation that other users could use to talk with that person once s/he dies (Ahmad 2016). Interacting with a digital avatar of a deceased person connects with the idea of “continuing bonds,” where the process of grieving is not about detaching oneself from the deceased but establishing a new relationship with them (Klass et al. 2014). These AI systems, also called *griefbots*, could activate the grieving process more efficiently and accurately than people’s memories and objects, and speed up the stages of such a process: denial, anger, bargaining, depression, and acceptance (Godfrey 2018).

6.3 Implications of the Use of Emotions in Human-Robot Interaction

By now, the reader may already imagine that the use of emotions in human–machine interactions has implications at various levels, including ELS level. Typically, the general opinion differs between those who think that robots should embody empathy

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[1] The sense of the word sleeve has been taken from the TV Series “Altered Carbon.” This refers to the human-like body that carries human consciousness, two things completely separated in the series.

and emotions for different applications, including care, medical, or social applications. Others, in contrast, may completely oppose to that idea (Fung 2015). Part of the scientific community may think this has nothing to do with them, that they merely work on the detection and simulation of facial expressions to improve user experience and support long-term engagement. Another part of the community may think this is worth paying attention to because current safeguards for ensuring a human-robot safe interaction do not include guidelines on how roboticists should implement it, and that this may have tremendous implications at various levels.

In 2003, Fong et al. already wondered whether there should be ethical issues linked to the sophistication of social robots. They mentioned that detailed user modeling could involve privacy concerns and might not be acceptable, and wondered to what extent a robot should take action when detecting human error (Fong et al. 2003). In 2016, Ahmad wrote, "Given that one is trying to simulate a deceased person, several ethical questions arise, and, e.g., if one can interact with a Simulacrum of the deceased, does that diminish the significance of bereavement? How will children respond to such a Simulacrum? At what age do children have the cognitive apparatus to appreciate the difference between a real person and a Simulacrum of that person? Most importantly, even if the technology to create a simulation of a deceased person exists, is it ethically correct to do so? (Ahmad 2016).

The use of emotions in HRI contexts gives rise to distinct legal and ethical implications; however, the legal literature has not yet reflected on this topic. Legal research on emotions has typically focused on how emotions can bias legal reasoning (Popovski 2016), or on how emotions influence the behavior of the people that commit offenses (Karstedt et al. 2011). The newest research deals with the legal and regulatory implications of advances in emotion detection technologies used for advertising and marketing (Clifford 2017). The legal community has not addressed questions concerning the boundaries in emotion robot embedment, or the safeguards implemented to ensure a safe emotional human-robot interaction yet. The titles of the following subsections describe the implications or issues arising from or connected with such uses, followed by an explanation.

a. Disagreements in the technical literature impede clear discernment of the importance of associated ethical, legal, and societal (ELS) issues.

Petisca et al. (2015) highlight that "more social and emotional behavior may lead to poorer perceptions of a social robot." In a similar study, Kennedy et al. (2015) also showed how embedding social behavior to robots may negatively affect child learning. In their study, Petisca et al. (2015) used an autonomous robot that played a game against a participant while expressing some social behaviors. They wanted to see whether the emotional sharing of the robot affected how its users perceived it. To the surprise of the researchers, and contrary to their hypothesis, they found that in the non-sharing condition, participants rated the robot more "conscious, lifelike, and nice." At the end of their paper, they highlight the importance of being cautious when embedding social behaviors in HRI; and claim that more research is needed to understand in which contexts the emotional sharing of the robot provides it with better social capabilities and in which such sharing should be avoided (Petisca et al. 2015).

Some researchers argue that by allowing the robot to show attention, care, and concern for the user (Turkle 2006), as well as being able to engage in genuine, meaningful interactions, socially assistive robots can be useful as therapeutic tools (Shukla et al. 2015). Others, however, suggest that the emotional sharing from the robot to the user does not necessarily imply feeling closer to it (Goetz et al. 2003). This context-dependent division may suggest that there could be a "purpose limitation." In law, purpose limitation refers to one of the principles relating to the processing of personal data. It states that a data controller has to collect data for specified, explicit, and legitimate purposes and that they cannot use it for other purposes. In this case, however, it would relate more to the establishment of a limitation in the contexts where emotions are used. For instance, and based on the given examples, the use of emotions in therapeutic contexts could improve the interaction of the users.

Still, the use of emotions (personalization or emotional adaptation) raises other types of questions concerning how appropriate the use of emotional data from patients is under certain clinical conditions. How error-tolerant should the technologies used for the detection of the mood and emotional state of the users be? What lines should the industry not cross? Knowing the impacts, benefits, and limitations of the use of emotions in HRI is essential to understand what safeguards policymakers need to devise to ensure a human-robot safe interaction.

b. The lack of standardized procedures and guidelines impedes the establishment of a clear safeguard baseline for safe emotional human-robot interactions.

Although the majority of the scientific community agrees on their importance, there are currently no guidelines on the use of emotions in HRI, child-robot interactions (Barco and Fosch-Villaronga 2017), and cognitive HRI (Fosch Villaronga et al. 2016). This concern relates to the intangibility of "emotions." Current standards and guidelines governing service robot technology are not well suited for robots that have zero contact with humans (Fosch-Villaronga 2017). Indeed, these standards typically establish safety requirements that aim at mitigating the risks related to physical HRIs, typically concerning various internal and external design factors, i.e., robot shape, emotion, correct decision-making; but also environmental aspects (ISO 13482:2014). However, there is not much research on the non-physical but psychological, cognitive part of the HRI. ISO 13482:2014 concerning personal care robots, for instance, mentions "stress" as a human-related hazard but other aspects such as how to address the fear of falling from an exoskeleton or conversational privacy are not addressed (Fosch-Villaronga et al. 2018a).

The European Parliament (EP) stressed this aspect on its resolution with recommendations to the European Commission (EC) on Civil Law Rules on Robotics (2017). This resolution is a non-binding regulatory initiative that stresses that the designers of robot technology "should draw up design and evaluation protocols and join with potential users and stakeholders when evaluating the benefits and risks of robotics, including cognitive, psychological and environmental ones" (European Parliament Resolution 2017). This is of crucial importance because, although "robotics combines [...] the promiscuity of information with the capacity to do physical harm" (Calo 2015), when mental and emotional communication is practically the only channel of communication between the user and the robot, physical safeguards may not suffice to provide a comprehensive protection to the integrity of the user (Fosch-Villaronga and Virk 2016). In this regard, and because the law protects both the physical and the mental integrity of the person via Art. 3 of the European Charter of Fundamental Rights, the EP resolution claims that the users "are permitted to make use of a robot without risk or fear of physical or psychological harm," and that designers should "respect human frailty, both physical and psychological, and the emotional needs of humans."

The fact that there are not well-established and community-supported guidelines that detail the boundaries, limits, requirements, and procedures has an impact on the design of emotions for robot technology. Indeed, the establishment of a safeguard baseline is not straightforward, which further challenges the establishment of a benchmark to be followed by developers assessed in a testing zone. Still, although this could help improve legal certainty concerning what is called "certified safety" is not clear how perceived safety should be addressed (Salem et al. 2015).

The community working on emotions should make an effort to draw interdisciplinary guidelines (from lessons learned, for instance) that could, over time, be fully respected by all roboticists designing and implementing emotions in the robot design. This effort does not need to be titanic. Instead, it could be a gradual, progressive, and scalable process, where different research institutes share their lessons learned, write down common/agreed protocols and, gradually, ask others to join forces and improve their benchmark (Fosch-Villaronga and Heldeweg 2017, 2018). These efforts would be an excellent first step to ensure that HRI is safe both physically and psychologically.

c. There is little awareness regarding the consequences of the use of emotions in HRI and their creators' level of responsibility.

After attending the Conference "Scientific Aspects of Development and Implementation of Emotionally Intelligent Human-Inspired Robots—Enthusiasm and Skepticism" organized by Prof. Dr. Aleksandar Rodić from the Mihaljo Pupin Institut in Belgrade, an email popped in my email box:

> Good Morning Eduard,
>
> Thanks for your email (...) It [was] a pleasure to meet you and [learn] about the field you are working in. It is really interesting to hear about the ethical, legal and safety issues regarding robotics. To be honest, I [had] never thought about it. But your talk, in which you highlighted "Who implements emotions?" is really a point which interests me a lot. Since I am implementing algorithms and emotions for the robot for specific situations, there is definitely a question there: whether [I am] the right person to decide 'How robots should behave' or should there be an expert who tells me about this information. I found [out on a] relatively smaller scale that emotions that I code/implement [in] the robot sometimes doesn't appear natural to some other subjects. The reason is I am implementing them based on my view or opinion about situations which more often than not [differ] from others. For me, it is quite informative and somehow opens a new perspective [on] my work.[2]

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[2] *See*: https://twitter.com/eduardfosch/status/942710206932357121.

Designers and creators of robotic and artificial intelligent systems may work in silos, without receiving interdisciplinary feedback, with no formation on the impacts their work might have. As Asaro (2006) explains, roboethics involves the ethics of the people that interact with robots, the ethical systems of people who design robots, and the ethical systems built into robots. Designing robotic systems that interact with users implies, thus, careful multifold thought about what implications this system has for the user and society.

The responsibility of the designer is a significant factor here. In "Concrete problems in AI safety," Amodei et al. (2016) refer to the designer's problems. In their words:

- the designer may have specified the wrong formal objective function;
- the designer may know the correct objective function, or at least have a method of evaluating it (…), but it is too expensive to do so frequently, leading to possible harmful behavior caused by bad extrapolations from limited samples;
- the designer may have specified the correct formal objective, so that we would get the correct behavior were the system to have perfect beliefs, but something bad occurs due to making decisions based on insufficient or poorly curated training data or an insufficiently expressive model.

What often lacks in these discussions is the question whether from "those who design, use, and control this kind of robot should also be required moral agency and emotion." (Coeckelbergh 2010). Designers tend to overlook internal biases that may be projected into the robot and may lead to regrettable scenarios (Campolo et al. 2017). The ongoing debate on whether robots should receive legal status (in the form of an electronic person according to EP Resolution, 2017) offers an unsatisfactory solution in this regard, as humans create robots, and they may project their inherent bias onto the robot. Openly opposed by some researchers, there is a push for "at least the most sophisticated autonomous robots [to have the legal] status of electronic persons responsible for making good any damage they may cause, and possibly applying electronic personality to cases where robots make autonomous decisions or otherwise interact with third parties independently" (European Parliament Resolution 2017). Although it is society, who decides how to address technology and not technology itself (Johnson 2015); some authors already highlighted electronic personhood might not be an ideal construction (Bryson et al. 2017).

The EP also seems to push for the establishment of the accountability principle, stating that "robotics engineers should remain accountable for the social, environmental and human health impacts that robotics may impose on present and future generations." Similarly found in Regulation 2016/679 on data protection (General Data Protection Regulation, GDPR), the accountability principle currently reigns in the European Union. This principle changes the burden of proof, with the robotic engineer being responsible for showing that s/he took reasonable steps to ensure user safety. That is why the EP is also promoting the establishment of codes of conduct for robotic engineers, although typical questions concerning code of conduct are going to arise once again: who writes such codes, to what extent are they binding and what are the consequences for someone that has not followed them. In this respect, complex relationships generated by the use of cloud services are going to exacerbate the issue of who is responsible for what (Millard 2013).

d. The use of emotions may undermine privacy and data protection

Ahmad already mentioned that “an important open question to consider is […] what kind of data should be collected for this project for the eventual use [of] a person who is still alive but will inevitably be dead, and thus a simulation may be needed to interact with such person” (Ahmad 2016). Very similar questions arise in the general use of emotions in HRI, as it will be unclear how much data is needed to achieve the desired interaction, clashing with the data minimization principle. It is also unclear what constitutes training data, what safeguards are implemented to protect the data of the users, and who should be the one to implement those.

For now, it is unclear what *emotional data* is. While the concept of personal data has been expanded in recent years and reflected accordingly in the GDPR, it is uncertain whether emotions *stricto* sensu are covered. *Lato* sensu emotions commonly refer to biometrical and physiological data. However, due to the intimacy and delicate nature of the processing of such information concerning the essence of the user. While it remains uncertain whether emotional data may be considered one day a specific category of data worth of protection (Fosch-Villaronga and Albo 2019) if emotions are currently biometrical data, which are a special category under the GDPR, the data controller will have to assess the impacts of the processing of these data. In such an assessment, the controller will have to explain what steps s/he took to mitigate associated risks.

There are many principles enshrined in the GDPR, and addressing them is beyond the scope of this paper. There are some articles and principles, however, worth considering. A lesson learned from PbD is that the design of technologies has a severe impact on privacy. Art. 25 GDPR obliges the data controller ‘at the time of the determination of the means for processing and at the time of the processing itself, to implement appropriate technical and organizational measures, such as pseudonymization, which are designed to implement data protection principles, such as data minimization, in an effective manner and to integrate the necessary safeguards into the processing in order to meet the requirements of this Regulation and protect the rights of data subjects. The default part of the article refers to the processing in which “only personal data which are necessary for each specific purpose of the processing are processed.” In the case of emotions, this may be difficult to determine as much data is being collected and the real intentions of the company processing such data rich in behavioral content are often unknown (Zuboff 2019).

PbD can be an excellent approach to follow if it provides engineers with concrete recommendations that use their everyday language. In this respect, Tamò-Larrieux (2018) proposes a way to think about PbD in terms of integrating security, autonomy, anonymity, and transparency tools. Other authors, like Mulligan and King (2011) even re-envision privacy by design more as an alignment with value-sensitive design.

One principle to take into account will be the principle of data minimization. There is a common understanding that more data leads to more accurate results. At this moment, it is unclear, however, how much data designers need to process to develop their emotion-based models. Some may use weather data to infer the mood of a user, and others may use facial expressions to identify a preset of emotions. However, those collecting and processing the data should only process the data needed for the performance of the task to which the users agreed.

As the collection of data is dynamic and progressive, however, the demand for life-cycle protection becomes evident. In this respect, other rights will also play an important role. For instance, the GDPR also grants the user the right "to receive the personal data concerning him or her, which he or she has provided to a controller, in a structured, commonly used and machine-readable format and have the right to transmit those data to another controller without hindrance from the controller to whom the personal data have been provided" (art. 20, GDPR). However, it is still unclear how this can be realized as standards for cloud robotics are still missing (Fosch-Villaronga and Millard 2019).

Another right is the "right to obtain from the controller the erasure of personal data concerning him or her without undue delay, and the controller shall have an obligation to erase personal data without undue delay. This right is called the right to be forgotten, and it has been proven very difficult to realize in artificial intelligent environments without seriously endangering the consistency of the environment (Fosch-Villaronga et al. 2018b). Although there might be many robots, the dynamic, progressive learning of the robots happens in one place, mainly in the "brain" of the robot, often offloaded to the cloud. Such global cloud-based learning empowers a single robot to perform tasks more efficiently. Still, the identification of the single emotional model that contributed to the overall learning of the robot might be challenging to differentiate from the rest and to be eliminated without endangering the consistency of the learning environment of the robot.

There is an ongoing debate on the importance of making robotic system actions explainable in everyday language, which is connected to the transparency principle, trust, and accountability (HRI 2018; Felzmann et al. 2019). The explainability and intelligibility of the robot's action differ from the right to an explanation of the GDPR—if that even exists (Selbst and Powels 2017; Edwards and Veale 2018; Kaminski 2019). Given the complexity and opacity of information processing in information technologies, there will be an increasing need to accommodate an ideal balance between meeting legal requirements, the efficiency of the operation of the robot and the respect of user's rights, which will require interdisciplinary collaboration between legal, social science, and technology experts (Felzmann et al. 2019).

e. Emotions can be used very differently, especially by industry, and the ethical committee cannot do anything to prevent it.

Before conducting a study, a researcher may typically approach the ethical committee of the university. Upon approval, the researcher may proceed with the experiment. However, ethical committees may not offer enough protection to users. Although this committee may protect the rights of the user involved in the study, it may not ensure the ethicality of the created application/system. Moreover, there have already been cases where the ethical committee had asked for the consent form of some participants when these "participants" were just very well done facial representations of humans (Chen and Jack 2017).

Ethical committees usually work on a standalone basis, and their decision process is not often very transparent. What is more, their decisions are not published and shared with the community or with other ethical committees to gradually develop guidelines on the topics they address. If policymakers could create a shared data repository of ethical committee decisions, the collected knowledge could mainly improve and ease the production of guidelines in this domain.

The industry does not wait for any of this to happen. Most of the time, it is not interested in following any of these aspects, unless there is a transparent business model behind it. For instance, consumers did not adopt biological and ecological products fully until the demand for those products was an apparent gain for the industry. Similarly, only when the protection of user rights (and the assurance of that in a transparent manner) is a business model (already seen in many privacy-friendly applications) will it be pursued. One of the consequences of the fast development of technology is that public policymakers struggle to develop policies that adequately frame the technology impacts, challenges, and opportunities in time (Fosch-Villaronga and Golia 2018). Difficulties in catching up with the speed of the technological change favor private actors who develop their standards decentralizing this way the power to regulate from policymakers. This decentralization is evident after the appearance of ethical standards, namely BS 8611:2016 Guide to ethical design of robot technology or the IEEE 7000 series. While the majority of these standards costs money—which may entail the privatization of the law (Fosch-Villaronga and Roig 2017), one may wonder to what extent society should allow private actors to develop their standards, in particular, if they deal with the ethics of these systems.

f. The use of emotions can have broader legal and ethical implications

When someone buys a t-shirt, it is not the t-shirt that adapts to the individual; but the individual adapts to the t-shirt. For many years now, t-shirt sizes range from XS to XXL. The procrustean design of technology constraints how robots perform their tasks (Fosch-Villaronga and Albo 2019). The continuous use and development of emotional models may result in the creation of standard emotion models, and behavioral patterns, into which individuals may fit. Is society prepared to have standardized human emotions?

It seems society has a little say in this. Technology usually works in an "Accept Terms and Conditions" basis, which makes difficult the understanding of whether society truly accepts the way certain technology is deployed. Indeed, there is an art in hiding relevant information that affects users to users. Seen how companies have replicated this way of doing in different domains (Zuboff 2019), it is difficult to imagine this is going to be different in the deployment of "emotion-as-a-service" models.

For a while, it seemed only those repetitive tasks were subject to replacement. However, the improvement of technology that uses empathy and emotions is increasing day by day, and this poses the question of whether robots could perform cognitive-based and social tasks. Virtual tutors, socio-educational companions, and empathic avatars in virtual reality are just some examples of possible applications of emotional-based that robots and AI technologies could use. Some authors believe that robots are just doing the job that should have already been carried out by them in the very first place (Pistono 2014). However, which job-related tasks dignify a person, and which not? Should automation replace part of the therapeutic tasks of human therapists working with children under the autism spectrum disease?

6.4 Conclusions

The use of emotions in HRIs entails several implications that need careful consideration from designers, policymakers, and users. Since "there is urgency in coming to see the world as a web of interrelated processes of which we are integral parts so that all of our choices and actions have consequences for the world around us" (Mesle 2008); this article calls for interdisciplinary efforts to understand the boundaries of the use and development of robot and AI technologies that use emotions.

The definition of a robot is still, according to the Merriam-Webster dictionary, "a machine that looks like a human being and performs various complex acts (such as walking or talking) of a human being; also: a similar but fictional machine whose lack of capacity for human emotions is often emphasized." However, this article stresses the fact that robots can express and perceive human emotions and exhibit human social characteristics, including personality, to the humans with whom they interact. Indeed, it is essential to acknowledge the "psychological/cognitive" dimension to ensure a safe HRI. In this respect, the EP claims that "human dignity and autonomy—both physical and psychological—is always to be respected." Although often disregarded not only by the law but also by designers, the implementation of safeguards at the cognitive/emotional level is of fundamental importance. Indeed, safety is like a body with two legs, without which it cannot walk: one leg relates to physical safety, and the other leg to cognitive safety, which typically relates to psychological aspects and perceived safety.

Designers should take into account both technical aspects and legal and ethical considerations to promote responsible use and development of robots using emotions. Available studies suggest that designers should think carefully about the extent to which robots could use emotions in HRI contexts and where it should be prohibited. Policymakers may want to make use of this evidence to consider the implementation of a purpose limitation in this respect.

In the end, "if things go this way, it will not be a natural evolution of technological development. Rather it will be because in the negotiations about the technology, certain actors pushed in that direction, were able to enroll others in the way of thinking, and together they won the day in terms of design and responsibility practices" (Johnson 2015).

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Chapter 7
Ethics in Human-Robot Interaction

João S. Sequeira

Abstract As social robotics becomes ubiquitous so is the range of ethics questions involving human-robot interaction (HRI). Though Ethics is a well-established field, the human-robot mix is raising questions on the human and robot conditions that exponentiate with the increase in the number of robots in human societies. Safeguarding the human quality of life and well-being is at the core of current legislative efforts on robots. The chapter reviews some of these efforts and points to the need for an educational effort that clarifies the role of technologies, namely robotics, in societies.

Keywords Ethics · Technology · Robotics · Human-Robot Interaction

7.1 Introduction

Ethics is often referred to as Moral Philosophy (Rachels 2003), or, in a Socratic sense, the way people should live. The translation into the Robotics' context means making robots replacing in a socially acceptable manner when interacting with humans.

Interactions among humans are subject to a wide variety of rules, e.g., linguistics, proxemics, and cultural. These rules may have multiple representations, be rigid, or allow for some flexibility. This easily generates subjective, ill-posed, scenarios that challenge rigid moral constructions and hence are hard to materialize in the computational frameworks underlying most of robotics constructs.

Initial references to Ethics in Robotics can be found, for example, in the literature on robot control architectures (see Koplowitz and Noton 1973; Meystel and Albus 2002). For a broad coverage of Ethics issues in Robotics, see also Ferreira et al. (2017).

The literature on social robotics has highlighted health care (Lee and Lau 2011; Kahn et al. 2012), the use of lethal actions (Asaro 2009; Lin et al. 2009), and the manipulation of human emotions (Sullins 2012; Lin et al. 2012), as the key areas

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involving Ethics issues, namely (i) privacy, (ii) contention, (iii) deception, (iv) liability, and (v) psychological damage (Sharkey and Sharkey 2006).

The rapid progression of social robotics has fostered the recent developments in Ethics-related legislation. Moreover, the media frenzy about the possibility of a singularity is both (i) nudging the general public toward fear of social robots, and (ii) raising awareness of the ethical issues in social robotics. Overall, there is a net effect of amplifying those fears.

In the healthcare domain, the most sensitive area, regulations tend to be strict. The recommendations from the World Health Organization (WHO) and from the World Medical Organization (WMO), point to the need for robots to comply with national regulations. These tend to enforce absolute transparency concerning the end users, meaning that any interaction must be consented to. In fact, the use of Informed Consent (IC) forms is a standard practice to ensure that anyone interacting with the robot has access to any relevant information (EC 2017).

Lethal actions by robots are, in general, discouraged. Many people still think that there must always be a human-in-the-loop and that delegating lethal actions to robots may be immoral (Kukita 2014). However, the dynamics of a decision involving humans tends to be slower than that of a fully autonomous system. In life-or-death decisions, this means, both, (i) that lives can be lost because of a split-second delay in a decision, and (ii) that decision errors can cost lives (see examples in HRW 2012). In a sense, this problem is mapped into the Ethics of decision error management.

Human emotions represent an effective communication strategy, saving bandwidth in complex interactions. In simple interactions, not including hidden meanings, people will generally have a clear perception of the robot's role. However, robots may be used to manipulate human emotions, e.g., robots can be used to tell people bad news (a problem akin to having a medical doctor to avoid explaining a terminal condition to a patient) or even inducing maternity feelings through a companion baby robot (see Toyota 2016).

Besides the people normally interacting with the robots, those involved in development and maintenance also need to be accounted for. The recommendations in Delvaux (2016), namely §6 and §7, seem to suggest that everyone in the team be bound (i) to a code of conduct specific to the project (to be detailed in the Consortium Agreement), and (ii) to any codes of conduct enforced at the participating institutions. These also match the recent European Parliament resolution (EP 2017).

A key EU regulation on Ethics is the Directive 2001/20/EC of the European Parliament and of the Council of April 4, 2001, on the approximation of Member State laws, regulations, and administrative provisions relating to the implementation of good clinical practice in the conduct of clinical trials on medicinal products for human use JEC (2001). Additional principles and legislation of interest for Robotics R&D can be found in ECPO (2013), ECPO (2012) and JEC (2006).

EU-funded projects provide extensive material both on generic, health- and robotics-related Ethics issues. The expected outcome of Project RoboLaw is regulations for robotics developments. Project Linked2Safety aimed at developing a secure and ethically compliant exchange of medical and clinical information in the

European zone. Social networking, interactive media technologies, including augmented reality and content production, were addressed in the Experimedia project.

Additional documents of interest used by the EU legislators are those produced by the Working Parties, namely ECDPO-131 on the processing of Electronic Health Records and ECDPO-187 on the definition of "consent"; ECDPO-171, on behavioral advertising, may also still be relevant given that the key project information is disseminated through broad media such as the web.

7.2 Technology and Interaction

HRI is the operational side of social robotics. Ethics compliant HRI means matching the technology capabilities with the social norms enforced in each environment.

The capabilities of the current technologies enable robots to be equipped with sensing systems providing information with a quality approaching that of human physical senses. These sensors are capable of acquiring information sensitive from a privacy perspective.

The privacy issue is at the center of Ethics-related questions with the usage of, for example, imaging technologies. Current computer vision is already able to produce interesting performances in facial and body recognition (see, for instance, airport technologies already in place at passport control points). Using facial recognition from a machine (robot) that moves anonymously in a social environment is, in general, prohibited/discouraged on the grounds of Ethics. However, people recognition by other people will, in general, be tolerated. This paradoxical behavior by humans interacting with robots, exponentiated by the (human) legislator is justified by some authors on biological grounds (see Adolphs 2013). Similar concerns apply to other sensing information, e.g., speech recognition. Though frameworks claiming to solve such issues may be found in the literature (see, for instance, the "ethical regulator" of Shim and Arkin 2017), its efficacy remains to be demonstrated. Moreover, algorithms processing the information acquired through these sensors can generate processed information in which people's anonymity cannot be ensured.

Besides anonymity, HRI has the capability to influence the actions of humans interacting with a robot. Exerting direct authority, from robots toward humans, is frequently not well received by humans. Advising/counseling is likely to produce the best results. Indirect suggestions, e.g., nudges (see, for instance, Sunstein 2014) also play a valuable role.

Deception may arise in multiple interactions, either on purpose or inadvertently, and is often morally inadmissible. However, similar to human–human interactions, there are situations in which deception may be ethically acceptable/indicated, e.g., when smoothing bad news to someone that it is likely to become disturbed by it. See, for instance, Matthias (2015) for morally permissive deception criteria. A taxonomy for the benefits of deception in HRI can be found in Shim and Arkin (2013).

Regarding liability, the recommendations in Delvaux (2016), namely §27; and also, in EP (2017), can again be followed by logging every relevant interaction so that causal links involved in liability questions can be verified. The use of meaningful validation metrics may prevent liability situations. The healthcare domain is a sensitive area, with numerous cases of medical errors caused by poorly designed interaction interfaces available in the literature (see, for instance, Fairbanks and Caplan 2004).

As the complexity of the interactions increases, the Informed Consent principle may be expanded, providing full information on (i) how the interfaces work, (ii) expected behaviors, and (iii) contingency situations. The educational role (i) is preventive and, simultaneously, (ii) makes robot integration smoother. This enforces some degree of transparency, as suggested in IEEE (2016).

7.3 Conclusion

Designing behaviors for social robots from Ethics principles is a difficult problem, as it requires humanizing the robots (see the discussion in MacDorman and Cowley 2006) and must account for advances in Psychology that some authors argue might be impossible to be applied to HRI (Kahn et al. 2006).

The creation of sentient robots appears to be a long-term objective of mankind (Sharkey and Sharkey 2010), which means Ethics-related issues will either converge on, or extend, arguments used in human-only societies. Education to prioritize Ethics when designing robots, or, more generally, HRI, is thus of paramount importance (IEEE 2016). This however must adopt a cautious strategy, not focusing on media trends, and, instead, taking an educational approach to explain that a dystopian society due to robots is a fallacy and that humans have the power to stay in control at all times. Knowledge on technologies is a fundamental part of this.

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Part III
Robot Design Process

Chapter 8
Emotional Design and Human-Robot Interaction

Magda Saraiva, Hande Ayanoğlu and Beste Özcan

Abstract Recent years have shown an increase in the importance of emotions applied to the Design field—Emotional Design. In this sense, the emotional design aims to elicit (e.g., pleasure) or prevent (e.g., displeasure) determined emotions, during human product interaction. That is, the emotional design regulates the emotional interaction between the individual and the product (e.g., robot). Robot design has been a growing area whereby robots are interacting directly with humans in which emotions are essential in the interaction. Therefore, this paper aims, through a non-systematic literature review, to explore the application of emotional design, particularly on Human-Robot Interaction. Robot design features (e.g., appearance, expressing emotions and spatial distance) that affect emotional design are introduced. The chapter ends with a discussion and a conclusion.

Keywords Emotional design · Human-robot interaction · Emotion expressions · Facial expressions · Vocal expressions

8.1 Introduction

Some products have positive traits (e.g., appealing, engaging, exciting, tempting) while others have negative traits (e.g., repulsive, displeasing, undesirable, unattractive), thus, products can evoke several different emotions. Although, studies on product design focused on more functionality and utility of the product than emotional

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factor (Khalid and Halander 2006), for sustained interaction it is vital to make experiences pleasurable and enjoyable (Wensveen and Overbeeke 2003). Pleasure can make the importance of emotions more apparent.

Tielman et al. (2014) indicate that expressive behavior (e.g., emotions) is a crucial aspect of human interaction. Emotions can allow humans to establish a relationship with others as well as the environment (e.g., objects, machines). In this sense, interaction with technology (i.e., robots) should be guided by the same principle (Valli 2008). Currently, robots are designed to become a part of people's lives and creating emotional engagement with robots can shape the involvement of people during an interaction. In particular tasks (e.g., entertainment and playing), the robot will interact closely with people in their daily environment. Within this context, it is essential to create natural, engaging, pleasurable and intuitive communication between humans and robots.

Walter (2011) emphasizes that emotional experiences (positive or negative) make deep influences on people's long-term memory. Negative emotional experiences can cause unpleasant and unappealing interaction with the products, whereas positive emotional experiences can cause pleasure and enjoyment. Pleasure and enjoyment have a critical role to make an appropriated bridge between people and robot's feature and characteristics which support a continuous interaction. The main concern during an interaction between a robot and a person is how the person feels about the experience which can be positive or negative. Is the person happy, satisfied, scared, or stressed? Another concern is how the robot can reveal a positive or negative experience by its appearance, behavior, expressions. In order to comprehend these concerns, first emotional design will be introduced followed by its applications in Human-Robot Interaction.

8.2 Emotional Design

Gorp and Adams (2012) explain emotional design as directing the attention of a person to create an emotional response to the right thing at the right time. Emotional design is mostly about creating positive emotions and preventing negative ones. According to Norman (2004), as aesthetics, attractiveness and beauty collaborate so do pleasure, and usability within the emotional design. Designing emotionally meaningful products can change the experience with the products. Personal experiences and emotional meanings complete the appearance and functions of a product.

Walter (2011) indicates that emotional design captivates ordinary people, thus they would be ready to tell others about their positive experience.

There are also other terms which seek to build an emotional connection with people: affective design, pleasurable design, and hedonomics. Helander and Khalid (2012) define affect as the judgmental system and emotion as the conscious experience of affect. According to Demirbilek and Sener (2003), affect is the user's psychological response to product design.

According to Picard (1997), machines and robots, in particular, should associate intelligence with emotion, thus giving rise to affective computing. The field of artificial intelligence aims to study how machines (e.g., computers, robots) can process and express emotions. According to Norman (2004), affective computing is an attempt to evolve machines which can sense the emotions of the people and respond accordingly. Hence, affective design arose from affective computing which endeavors to improve human–computer interaction with emotional information that is communicated by the users in a natural and comfortable way.

Jordan (2003) defined pleasure as the emotional, hedonic and practical benefits related with products where the emotional benefit is how things related with a product affects people's emotions, hedonic benefits refer to the sensory and aesthetic appreciation whereas practical benefits are outcomes of tasks that the product is for.

Tiger (2000) proposed a framework that classifies positive emotions into four type types of pleasures. First, the physical pleasure derives from the five senses (e.g., touching a robot during interaction). Second is the social pleasure that is related to relationships (e.g., social interactions with a robot). The third one is the psychological pleasure which refers to people's cognitive and emotional reactions (e.g., robots stimulating interaction for a certain satisfaction). The last one is the ideological pleasure that expresses the values that a product represents (e.g., robot made of sustainable material). The four pleasures can be useful to design pleasurable robots, thereby, motivate people to enhance HRI.

Hancock et al. (2005) defined hedonomics as the scientific study which is dedicated to promote pleasurable human–technology interaction. Mokdad and Abdel-Moniem (2017) noted that ergonomics was more focused on the physical and cognitive aspects of a system, though later ergonomists became enthusiastic about making the human–machine system pleasurable. Helander (2002) denotes that hedonomics concerns with pleasurable products and tasks. Each product can evoke various emotions and depend on the emotions, a person can enjoy using/interacting with the product.

Desmet (2002) explained three characteristics concerning product emotions, which are personal (i.e., people differ and consequently so does the emotional response toward the same product), temporal (i.e., a person can have different emotions independent of time toward the same product), and mixed (i.e., a person can have various emotions toward a product). Gorp and Adams (2012) state that emotions can be effective in inducing people to alter attention and change their behaviors. Also, experiences and realities are dominated by emotions and emotions play a role in human reasoning (Demasio 1994).

8.3 Emotional Design in HRI

Changing emotional states of people can increase the possibility of performing the desired behavior (e.g., securely approaching a robot). Creating positive emotional states/experiences between people and robots would eventually influence the interaction between them.

Gorp and Adams (2012) supports that whatever the desired behavior, emotional design can guide people's attention to the right place at the right time to initiate and extend the interaction into a relationship. A relationship can be created between people and robots for cogent interactions.

Emotional design is also relevant in the robot design process because people's needs must be taken into account and the most important features from their point of view, thus facilitating greater user acceptance of the robot (Hameed et al. 2016). Demirbilek and Sener (2003) state that for high-tech products (i.e., robots) emotional needs have been a basis. Moreover, Norman (2004) emphasizes the importance of robots to display emotions for successful interaction.

Helander and Khalid (2012) refer that there are two purposes to understand the emotions and affect. The first purpose is how to measure and analyze human reactions (i.e., emotions) to affective and pleasurable design. Limited studies (e.g., Rosenthal-von der Pütten et al. 2013) can be found dedicated to measure emotional reactions of people toward the design of robots though mainly behavior and attitudes toward robots. In Chap. 9, methods to measure people's emotions are detailed. The second purpose is how to produce affective design features of a product (e.g., robots). Constituting affective/pleasurable robots, besides appearance (e.g., human-like robots), is mostly fulfilled by making them capable of expressing emotions. Though emotions need to appear as natural and ordinary as human emotions or they look fake and will be more irritating than useful (Norman 2004).

There are different interaction scenarios where in some cases, people need to touch robots (e.g., Nakata et al. 1998; McGlynn et al. 2017) which can influence emotional design in HRI. Emotional design can be affected by various characteristics of robots, i.e., in order to create positive emotions and experiences on a person, robot design features (e.g., appearance, expressing emotions and spatial distance) can be manipulated. Moreover, the robot's design features are crucial for attaining HRI.

8.3.1 Appearance

Emotional design can be affected by various components of the appearance of a robot. Leite et al. (2013) emphasize that embodiment can play an important role in the first impressions and future expectations about a robot. Campa (2016) supports that the appearance is fundamentally important, due to interacting with humans on an emotional level, and this type of interaction is grounded in visual and tactile perception no less than in verbal communication.

Robots can appear in different forms, sizes, colors, and even genders, age, ethnicity, and outfits due to having anthropomorphous (e.g., humanoids and androids) features. Mori (1970) states that when the appearance of a robot is similar to a human, emotional response to the robot becomes positive until a point in which the robot looks too much like a human. It is still desirable for natural interactions that robots share some physical characteristics with humans. The appearance of a robot is important to distinguish social expectations. Bartneck et al. (2008) state that appearance can evoke expectations (e.g., human-like robots are expected to listen and talk) and that if the robot is not able to fulfill those expectations it can cause disappointment.

The form of robots can be categorized into four classes: human-like, semi-human-like (i.e., limited lower body movements), pet-like, and character-like. Concerning the resemblance of characteristics of a human, social robots, mostly, have a torso, hands, and head. On one hand, Dautenhahn (2004) indicates that anthropomorphism might create incorrect expectations related to the cognitive and social abilities that the robot cannot perform. On the other hand, several authors (e.g., Bartneck et al. 2010; Kanda and Ishiguro 2013) point out that human brain does not react emotionally to artificial objects but reacts positively to the resemblance to the human likeness. As such, robots should be designed taking into account their behavioral and social capabilities, as well as the robot's functions (Leite et al. 2013).

8.3.2 Expressing Emotions

Expression of emotions allows for the existence of a realistic HCI and/or HRI, and for this reason, HRI currently aims to provide robots with human characteristics. Some studies have revealed that humans are able to establish an empathic relationship with human-like robots (Riek et al. 2009) easier than with nonhuman-like robots (e.g., Bartneck et al. 2010). In HRI, it is effective and necessary that the robot, no matter what it looks like, is able to express emotions, and also recognize the emotions expressed by humans and respond to them appropriately (e.g., empathetically, complicit) (Picard 2000).

A robot should be capable of interacting naturally with humans as a social partner and adapt its behavior according to the given states. Fong et al. (2002) support that the robot must manifest believable behavior such as establishing appropriate social expectations, regulating social interaction (using dialogue and action), and following social convention and norms. Emotions are also an important factor in reflecting the given states. However, it should be noted that when referring to the robots that recognize emotions, this recognition is not the same as in humans. That is, a robot is unable to attribute meaning or analyze cognitively an experience or interaction as a human does (e.g., Blow et al. 2006). Thus, Picard and Klein (2002) defined two types of requirements for interaction between users and machines (which can refer to robots): (1) emotional needs (e.g., empathy); (2) emotional experience (e.g., frustration). It is at the level of emotional experience that machines play an important role. With its artificial intelligence and endowed with affective computing, machines help the user to have a positive experience while interacting, allowing the user to not have a negative experience and preventing frustrating situations (Klein et al. 2002).

Equipping machines with the ability to respond to emotions and to express them is a way to create intelligent machines (artificial intelligence) (Picard 1997). Thus, the biggest challenge is to build machines (i.e., robots) that are able to infer emotional states through behaviors and emotional expressions of the user and respond to them appropriately. According to Picard (1997), there are four factors that explain the need for robots to present emotions: (1) the presence of emotions facilitates the communication (emotional communication) with the user; (2) the need to develop applications that control emotional information; (3) growing interest in developing robots with social and emotional skills, and; (4) the presence of emotions in robots makes the interaction with user, a more interesting experience and less frustrating for the user. These components are particularly important when referring to service robots. Service robots are autonomous systems equipped with artificial intelligence, which enable them to perform many of the daily activities carried out by humans (Khan 1998). This type of robots which provide assistance are having an increased focus recently, due to uncertainties in the industrialized world (e.g., increasing number of the elderly, diseases). These robots are intended to help people in their daily tasks but also to be, for example, companion robots for the elderly without family. Currently, there are some robots which are able to express emotions and/or recognize emotions expressed by humans while doing their tasks.

From a design perspective, the emotion system would implement the style and the personality of a robot, encoding and conveying its attitudes and behavioral inclinations toward the events it counters (Breazeal and Brooks 2005). Designing robots with personality may help provide people a good mental model (Breazeal and Brooks 2005), similar to what occurs in the interaction between humans. Breazeal (2002) discusses an important and related aspect in HRI which is the readability of the behavior. The author supports the fact that the robot's behavior and manner of expression (facial expressions, shifts of gaze and posture, gestures, actions, etc.) should be well matched to the robot's cues and movements so that people would understand and predict its behavior (e.g., their theory-of-mind and empathy competencies). For better readability, the robot anthropomorphizes itself to make its behavior familiar and more understandable.

It is in this context that social robots appear and are able to express and recognize emotions and human behaviors. Adams et al. (2000) discuss that two skills are required for a social robot to have an emotional model that understands and manipulates the environment around it. First is the ability to attain social input to understand the cues which humans provide about their emotional state. Second is the ability to manipulate the environment, which can be done by the robot expressing its own emotions. Therefore, expressing emotions can be the key to improved interaction.

Bartneck (2001) states that for humans one of the ways to express emotions is by using body language (i.e., facial expression, gesture, and body movement). Picard (1997) also supports that emotions can be expressed through body movement, facial expressions, and physiological responses. Since some social robots' bodies are built to resemble human's, this allows more natural interactions while using their body language. Breazeal (2003) declares that robots should have a social interface which naturally employs human-like social cues and communication modalities. According to DiSalvo et al. (2002), the addition of a nose, eyelids, and a mouth gives a robot more human characteristics. On one hand, robots are expected to resemble human for natural interactions, on the other hand, it is also encouraged that robots should maintain as much of a robotic appearance feeling as possible while remaining human-friendly in order to avoid an uncanny valley effect (Mori 1970).

Expressiveness of robots can be a key to keep natural interactions in HRI. Robots can use facial expressions, vocal expressions, and body movements while expressing emotions similar to a human.

8.3.2.1 Facial Expressions

Facial expressions are particularly important in the communication between humans because it allows easily identifying emotions through small changes in the face (e.g., Russell 1997; Plutchik 1984; Woodworth 1938). Facial expressions provide a basic means by which people can detect emotion (Ekman et al. 1972) and are used in nonverbal communication. There are distinctive clues of the face to each basic emotion though depending on the intensity and the meaning more areas can be involved and according to intensity signals are adapted (Ekman 2003a, b). Facial expressions can be reduced to changes in eyes, eyebrows, mouth, nose, and so on.

Argyle (1994) specifies that facial expressions work better as a way of providing feedback on what the other person is saying. According to the author, the eyebrows provide a continuous running commentary; the mouth area adds to the running commentary by diversifying between turned up (i.e., pleasure) and turned down (i.e., displeasure); eye movements (e.g., eye contact, eye gaze, blinking, pupil size) have an important role in sustaining the flow of interaction between humans. While a person is in a conversation with another person, eye movements are a natural and important part of the communication process. Eye movements such as eye gaze, blinking, and pupil size can be implemented to robots as ocular behaviors to express emotions. Eye gaze is especially important while approaching a person and should be implemented to robots for natural interactions (e.g., Yamazaki et al. 2008; Mutlu 2009; Mohammad et al. 2010).

Since nonverbal emotional feedback plays a very important role in human interaction (Salichs et al. 2006), it should be extended to HRI as well. If a similar type of human–human communication is anticipated to be interpreted by robots, the facial expressions and the corresponding emotions should be clearly defined so that they are recognized reliably. Usually, the programming of facial expressions in robots (e.g., Loza et al. 2013) is based on FACS (Ekman and Friesen 1978), which is validated (in humans) for the six basic emotions. Instead of visualizing emotions in a static manner, dynamic methods and additional visualization methods (e.g., blinking, blushing) can be used to generate robot emotions. Some common features to include robot expressiveness can be making direct eye contact (e.g., prolonged eye contact can cause distress) or averting gaze (e.g., this might indicate distraction or discomfort), blinking (e.g., often or rarely, rapid or slow), or dilated pupils (e.g., highly dilated eyes can indicate interest or arousal).

8.3.2.2 Vocal Expressions

Vocal expressions can be divided as linguistic (e.g., speech) and nonlinguistic vocalizations (e.g., laughing, crying, yawning, whispering sounds). Douglas-Cowie et al. (2000) indicate that vocal expression is linked to facial expression, gestures, and verbal content.

Speech is the most natural method of communication between human and the same method can apply to human and machine (Feil-Seifer and Mataric 2005; El Ayadi et al. 2011). Speech is also used as a way to transmit emotional state for humans (e.g., Engberg et al. 1997; Amir et al. 2000). According to Burkhardt et al. (2005), emotional cues in speech gained attention due to new developments with respect to human–machine interfaces that see applications of automatic recognition and simulation of emotional expression within reach. Moreover, speech emotion recognition is useful in human–machine interfaces (El Ayadi et al. 2011). Feil-Seifer and Mataric (2005) suggest robots may use synthetic speech generation or preloaded human voice, which is another factor to change the emotional design.

Darwin (1872) described various nonlinguistic vocalizations for specific emotions such as deep sighs for grief, snorts for contempt, and little coughs for embarrassment. Russell et al. (2003) hypothesize that since there are different variations of laughter, different types of laughs correspond to different emotional states. Depending on the expressed emotion the sound can be slower/faster or have a lower/higher pitch. There are studies (e.g., Schröder 2000; Sauter and Scott 2007; Simon-Thomas et al. 2009) about vocal bursts (e.g., “yeeey” for amusement, “ahhh” for fear) while people are expressing emotions. These studies support the fact that most vocal expressions are accurately categorized for the intended emotion. Furthermore, Kraus (2017) found that hearing (i.e., voices) may be more reliable than sight (i.e., facial expressions) to accurately detect emotions.

For more natural interactions, robots are expected to mirror or mimic humans. Thus, during interactions, robots can use diverse vocal expressions with or without facial expressions to show their emotional states. Thereby, it would be easier to identify the emotions that the robot is representing and, people can react accordingly.

8.3.2.3 Body Movements

De Gelder et al. (2015) specify that historically the human body has been perceived primarily as a tool for actions, there is now increased understanding that the body is also an important medium for emotional expression. Montepare et al. (1999) emphasized that research on the communication of emotion has generally supposed that the perception of emotion is more engaged with facial or vocal expressions than with body movements. Bodily emotion communication is an old though neglected topic in emotion research regarding humans (Dael et al. 2012). Although movement of the body or its parts makes a considerable contribution to nonverbal communication for humans (e.g., Atkinson et al. 2004; Zieber et al. 2014), there is conclusive support that specific facial expressions exist for certain emotions (e.g., Ekman et al. 1972).

Atkinson et al. (2004) found that exaggerating body movements increase both the recognition of emotions and intensity. Wallbott (1998) denotes that there is evidence that specific body movements accompany specific emotions and, also, movements might be the indication of the intensity of emotion. Moreover, Aviezer et al. (2012) found that peak emotions are detected more accurately from body movements than facial expressions.

Body movements can be divided into two for robots: movements of parts of body and translocation. Compared to other machines, body movements are one of the most distinguishing features of robots. Hence, introducing body movements in robots could support the emotion that is indicated by facial expressions. Furthermore, it is necessary to understand robot abilities/limitations to use the movement information to distinguish different emotions.

Mobility (i.e., translocation) is an important feature for robots to execute tasks. Most of the social robots are mobile (e.g., Bonarini et al. 2016). Robots can use location change as an additional component to reveal the emotional state, though, using only translocation to express emotions can be inefficient and strange. Hence, it should be introduced with other expression methods.

8.4 Spatial Distance

Hall (1966) categorized the distance people keep with each other in four: intimate, personal, social, and public. According to Hall, the distance between people is determined depending on what they do, the relationship between them, mutual feelings, and culture. According to Gillespie and Leffler (1983), age, gender and place are also factors that affect the distance.

Feil-Seifer and Mataric (2012) suggested that if a robot is to be an effective socially, its actions, including interpersonal distance, must be appropriate for the given social situation. van Oosterhout and Visser (2008) stated that when one interaction partner is a robot, it is not well known to what extent the different factors of human distances still apply and what new factors play a role. Though, robots should still follow similar distances to interact with people (Yamaji et al. 2011) in order not to make people uncomfortable or disturbed and cause miscommunication. Walters et al. (2005) found out that when approaching a robot, or when being approached by a robot, prefer approach distances that are compatible with those expected for human–human interaction. van Oosterhout and Visser (2008) defined possible factors that influence the spatial distance in HRI: robot type (i.e., to know the intention), person's height, gender, and age, and occupancy of the interaction space (e.g., crowded). Therefore, the spatial distance would change according to the robot.

The spatial distance can have an impact on emotional design. Based on the distance between a robot and a person, people can have negative or positive emotions toward robots. Furthermore, the way and speed of approaching could also influence emotional design. Kato et al. (2015) defined two types of approaches. The passive approach is when a robot waits until a person initiates interaction with the robot which can cause hesitation or uncertainty for the person. The proactive approach is when a robot seeks people to initiate conversation (e.g., Satake et al. 2009) in which people can feel annoyed or disrespected.

The direction of approach can also be important in HRI. For instance, Dautenhahn et al. (2006) found out that when people are seated, they preferred a robot to approach from either the left or right side and they found frontal approach uncomfortable, impractical, and even threatening or confrontational. Moreover, sometimes, interactions require a robot to follow (approach behind) its human companion (e.g., Hüttenrauch et al. 2006; Hu et al. 2014). Sünderhauf et al. (2018) define person-following scenarios as the result of a common task in which a robot needs to follow a person. The spatial distance during the interaction should also be taken into account to perceive the emotions of the person followed.

Furthermore, if the spatial distance is too close between a robot and a person, this might end up with physical interaction. In most healthcare cases (e.g., Mukai et al. 2010; Chen et al. 2011; McGlynn et al. 2017), physical contact is needed in which the robot is in the intimate space of a person. Physical contact can affect the emotional state of the people, though it depends on other variables such as whether the robot or the person initiates the contact, cause of the contact and forms of touch that Weiss (1992) referred such as the location, intensity, modality, and duration of the touch. Additionally, psychological discomfort caused by any factors, as well as a robotic violation of social conventions and norms during an interaction, can also have serious negative effects on people over time (Lasota et al. 2017).

8.5 Related Studies

As mentioned, several theories on the existence and nature of basic and fundamental emotions have been proposed (e.g., James 1884; Plutchik 1980; Schachter and Singer 1962). At the same time, robots are mainly expected to help and assist during activities of daily living and to achieve the outcome, personal robots should be capable of human-like emotion expressions (Endo et al. 2008).

Different studies were performed to assess emotions in HRI. Studies about expressions of emotions by robots (e.g., Cañamero and Fredslund 2000; Breazeal 2003; Blow et al. 2006; Sosnowski et al. 2006; Hashimoto et al. 2006; Salichs et al. 2006; Endo et al. 2008; Zecca et al. 2009; Beck et al. 2010; Oh and Kim 2010; Cohen et al. 2011; Giambattista et al. 2016) and human reactions and attitudes toward robots (e.g., Bruce et al. 2002; Nomura et al. 2004; Woods et al. 2004, 2006; Ray et al. 2008) are presented.

In this sense, the studies about the expression of robot emotions can be differentiated as follows: (a) form; (b) emotion stimuli; c) ways of emotion expression; (d) robot stimuli; (e) participants in the study; (f) measures; and (g) results revealed.

(a) Form. Human-like robot examples are Feelix (Cañamero and Fredslund 2000), iCub (Beira et al. 2006; Tanevska et al. 2017), KASPAR (Blow et al. 2006), Kismet (Breazeal and Aryananda 2002; Breazeal 2003), Nao (Beck et al. 2010; Häring et al. 2011), Saya (Hashimoto et al. 2006), Kobian (Zecca et al. 2009, 2010), Tiro (Oh and Kim 2010), Doldori (Kwon et al. 2007; Lee et al. 2007), Eddie (Sosnowski et al. 2006).
Semi human-like robots examples are Ifbot (Kanoh et al. 2005; Kato et al. 2004), Maggie (Salichs et al. 2006), Monarch (Giambattista et al. 2016; Ferreira and Sequeira 2017), Pepper (Dignan 2014), WE-4RII (Miwa et al. 2004; Endo et al. 2008).
iCat (Kessens et al. 2009; Cohen et al. 2011), Probo (Saldien et al. 2010) and Sparky (Scheeff et al. 2002) have a pet-like appearance while eMuu (Bartneck 2002) is an example of character-like.

(b) Emotion Stimuli. The emotions that are implemented in many robots as stimuli (e.g., Ifbot, Eddie, Probo, Doldori) correspond to the ones known as the six basic emotions (Ekman et al. 1972) which are joy, sadness, fear, surprise, anger, and disgust. Furthermore, there are some robots that exclude the disgust emotion (e.g., Feelix, iCat) or used extra emotions such as calm, pride, excitement and perplexity (e.g., Saya, Kobian, Nao) or sorrow, interest, and curiosity (e.g., Tiro, Kismet, Monarch) additional to the 6 basic emotions. It is worth to mention that there is a common use of a neutral emotion in many studies.

(c) Ways of emotion expression. Four different ways of emotional expression can be found which are implemented to a robot: (i) facial expressions; (ii) body movements; (iii) translocation; and, (iv) vocal expressions. These ways are used by themselves or simultaneously. The first and most common way is to manipulate facial expressions. Most of the robots use their eyes and mouth (e.g., Ifbot, eMuu) to express emotions. Changing color in facial features, such as eye color (see Chap. 10) or, cheek color (WE-4RII), is an extra feature for adapting different emotions.
Additionally, to these features, some robots use the eye brows (e.g., Feelix, iCat) or the eyelids (e.g., Saya, WE-4RII, Maggie). Nose (e.g., Probo) and ears (e.g., Kismet and Eddie) are used when the robots resemble a character. The second way of expression is by using body movements. Arm rotations are extensively used for several robots (e.g., Maggie, Kaspar), while, rotation of the head is also frequently applied (e.g., Doldori, Monarch). Even though many of the robots lack legs, some are using leg movements to express emotions (e.g., Kobian, Nao). Translocation is the third way in which robots express emotions, by changing their positions while expressing an emotion (e.g., Kobian, Monarch). Furthermore, some robots are also using tablets on their body (e.g., Monarch, Pepper) as an extra element to interact with people. Care-o-Bot 4's head is working as a touch screen besides expressing facial emotions (Kittmann

et al. 2015). While vocal expressions are not studied in detail, there are some robots which can talk to communicate (e.g., Breazeal and Aryananda 2002; Salichs et al. 2006; Dignan 2014) or use various sounds (e.g., an animal or weather event) to express emotions (e.g., Wagner 2015).

(d) Robot stimuli. In the studies about expressions of robot emotions, it is possible to verify that there are, at least, four different ways of presenting robots in tests with participants: (i) the robot itself—the real robot was used (e.g., Eddie, eMuu, Feelix, iCat, Ifbot, Nao, Probo) to express emotions; (ii) images—the robot's expressions were photographed (e.g., Kismet, Saya) and shown to participants; (iii) videos—the robots performed an expression and this video was recorded (Kaspar, Kismet, Kobian, Saya) and presented to participants; and (iv) virtual models—the robot was demonstrated as a computerized 3D model (e.g., Probo, Monarch).

Some of the studies (e.g., Tsui et al. 2010) did not use any particular robot and focused on the idea of the robots specialized in different tasks (i.e., service robots, medical robots, military robots).

(e) Participants. The expressions of emotions in robots has been studied with participants of different ages including children aged between 5 and 14 years old (e.g., iCat, Probo, Feelix, Kismet, Eddie, Tiro), adults aged 15–58 (e.g., Kaspar, Saya, Kobian, Nao), and elderly (e.g., Kobian). Moreover, some studies (e.g., Feelix, Eddie, Kismet) had two groups of participants, namely, children and adults.

(f) Measures. There are essentially three forms of measure in the studies: (i) Free test in which the participants observe the robot's performance to express a sequence of emotions and then identify the emotions that were expressed (e.g., Feelix); (ii) Multiple choice in which participants are asked to label a sequence of expressions, but this time they are given a list of emotions (e.g., Feelix, Eddie, Kismet, Kobian, Nao, Probo, Saya); and (iii) Likert scale in which the participants rated, on a scale, the level of the emotion expressed by the robot (e.g., Kaspar).

(g) Results. Many of these studies (e.g., Kismet, eMuu, Eddie, Nao) were done in labs, though there are some studies (e.g., Tiro, Monarch) that took place in different contexts (e.g., school and hospital) or contexts that were given as stories (e.g., iCat). Results related to context revealed that emotions expressed in a specific context were significantly better recognized than emotions expressed without a context (e.g., iCat).

In terms of robot stimuli, the data showed that in studies with videos, participants using had an overall stronger recognition of emotions performance than with static images (e.g., Kismet, Saya). Another result (e.g., WE-4RII, Kobian) showed the importance of combining different cues (e.g., face and body) to promote the recognition of emotions expressed by the robot. The most recognized emotions are happiness, sadness, and surprise (e.g., Saldien et al. 2010; Giambattista et al. 2016) and fear is the least recognizable emotion for many robots (e.g., Breazeal 2002; Zecca et al. 2004; Kanoh et al. 2005). If disgust is included in the list of emotions expressed, it also has a lower rate (e.g., Kanoh et al. 2005; Saldien et al. 2010). Furthermore, in some studies (e.g., Ifbot, Kismet, Monarch), there are some emotions that are confused with others. For instance, the surprise was confused with fear or despair and fear was confused with disgust, anxiety, or sadness.

As it was referred, many robots are expressing the emotions in their own ways. However, the interest should also focus on the emotions of the human toward robots. There are some studies that concern about human emotions which can be recognized by robots (e.g., Maggie, Pepper). Furthermore, studies concerning human reactions/attitudes toward robots can be found as well (e.g. Woods et al. 2004, 2006; Nomura et al. 2006; Syrdal et al. 2009). Nomura et al. (2004) created the NARS scale (Negative Attitudes Toward Robots) to measure human attitudes toward robots in various studies (e.g., Nomura et al. 2009; Wang et al. 2010; Riek and Robinson 2011; Schaefer et al. 2012; Nomura 2017). The NARS scale consists of 3 subordinate scales, 5-point Likert scales, which are negative attitudes toward situations of interaction with robots, negative attitudes toward the social influence of robots, and negative attitudes toward emotions in interaction with robots. Besides the NARS scale, questionnaires were also used to collect data about attitudes toward robots (e.g., Khan 1998; Fong et al. 2003; Woods et al. 2004; Ray et al. 2008; Sanders et al. 2017).

8.6 Discussion and Conclusion

The chapter provides information about emotional design and how it is applied to Human-Robot Interaction (HRI). Appearance, expressing emotions, and spatial distance are defined factors that can influence emotional design. Displaying emotions is the most common and effective way to affect the emotional design, through facial expressions, vocal expressions, and body movements. Manipulating the expressiveness of a robot's emotions can lead to pleasurable and enjoyable experiences during HRI. Also, studies related to emotional design in HRI, namely, expressions of emotions by robots and human reactions and attitudes toward robots, are presented.

Spatial distance should be considered as another factor affecting the emotional design. Mumm and Mutlu (2011) emphasize that robots must be designed to follow societal norms of physical and psychological distancing to seamlessly integrate into human environments. Also, Kim and Mutlu (2014) emphasize that robots which are deployed in a social setting should be aware of the social norms (i.e., social distance). Though, if the distance is not as expected, people may experience negative emotions (e.g., anxiety, annoyance, fear, frustration) which is another research branch to be considered/included in HRI concerning emotional design.

The expectations of people regarding robots are changing due to robots increasingly participating in daily life. Besides functionality, usability, and safety, people would desire robots to enhance their lives and evoke emotions. Also, DiSalvo et al. (2004) support the idea that people look for more dimensions that go beyond usability and the necessity to create an emotional resonance between people and products (i.e., robots) increases. In fact, in many products, designers are challenged to manipulate the emotional impact. Likewise, Cupchik (1999) claims that the emotional process begins with an initial impression (i.e., appearance) of a product and continues with experiences of usage and culminate with an emotional attachment to it. Hereby, appearance can be a very powerful affirmative approach and encourage experiences between people and robots. Bartneck et al. (2008) suggest that the emotional response becomes positive as the appearance and movements of robots become less distinguishable from those of a human. Moreover, Fong et al. (2003) state that the physical appearance biases interaction and most research in HRI is not focused on the design of the robot. Additionally, Koay et al. (2007) revealed that humans let robots without human traits approach themselves more than humanoid robots. Therefore, the design of the robot is quite important to achieve a substantial emotional experience and it is essential to include design areas (e.g., product, graphics, and interaction design) to the field of HRI.

Emotional design, creating positive emotions and pleasurable experience, is an important approach in HRI. Norman (2004) indicates that emotional expressions of robots would notify people about their motivations, desires, accomplishments, and frustrations which increase people's satisfaction and appreciation. Desmet (2002) states that people are expert at interpreting emotional expressions. In this sense, introducing emotional design in HRI should, first, demonstrate the interpretation of expressed emotions by robots. One way to manipulate emotions elicited by the design of a robot is to implement emotions to robots. Generating emotions in robot design can be implemented by using facial expressions, vocal expressions, body movements, and spatial distance. Ekman et al. (1972) denote that as sound and speech are intermittent, the face can be informative. The studies in the HRI field support that the most common way used to convey emotions is by manipulating facial expressions. Eyes and mouth are mainly studied due to the limitations of robots (i.e., not having more facial features). However, with more facial features to convey emotions, they could be easier for people to perceive (e.g., Kühnlenz et al. 2010) and, accordingly, interaction becomes less effortful. The main issue is to find realistic and accepted combinations of modalities during emotional expression.

There are various robots functioning in diverse environments. Depending on the context and functions, robots may/should be designed to address specific emotions. Desmet et al. (2007) found that it was possible to design products that target specific types of emotions by measuring emotional responses. Moreover, understanding the context might enhance and stimulate the emotional experience and make the experience more pleasing, agreeable, and favorable.

Emotions, obviously, play an important role in people's lives. Triberti et al. (2017) state that emotions are cognitive processes with a significant influence on the overall quality of interaction and accordingly new technologies (i.e., robots) can be treated as opportunities to manipulate, enhance and trigger different discrete, and even complex emotional states. Helander and Khalid (2012) denote that there is not a neutral design, thus any design will reveal emotions. Though, DiSalvo et al. (2004) specify that products cannot be designed to generate specific emotional experiences and according to Desmet (2002) designers can only predict the emotional impact of a design. While many studies (e.g., Fong et al. 2003; Dautenhahn 2004) support that robots should behave in a socially acceptable manner to increase acceptance in human-occupied environments, the analysis of the impact of robot designs during HRI is a lacking area of HRI research. Hence, including people is essential when designing HRI trials (Koay et al. 2007) whereby it is essential to consider that accurately foreseeing emotional responses is difficult for various factors and emotions are not dependent on the instant perceptual situation (Helander and Khalid 2012).

With advanced technology, it is easier to achieve usability as well as encourage pleasure for people. Designers are advised to thoughtfully address the link between emotions and HRI. This would facilitate communication and interaction with robots; consequently, it would lead to the desired experience. As HRI employs emotional design more effectively, better and more positive experiences will emerge, though, as Walter (2011) emphasizes the emotional design should never interfere with usability, functionality, or reliability.

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Chapter 9
Subjective and Objective Measures

Hugo Alexandre Ferreira and Magda Saraiva

Abstract One of the greatest challenges in the study of emotions and emotional states is their measurement. The techniques used to measure emotions depend essentially on the authors' definition of the concept of emotion. Currently, two types of measures are used: subjective and objective. While subjective measures focus on assessing the conscious recognition of one's own emotions, objective measures allow researchers to quantify and assess the conscious and unconscious emotional processes. In this sense, when the objective is to evaluate the emotional experience from the subjective point of view of an individual in relation to a given event, then subjective measures such as self-report should be used. In addition to this, when the objective is to evaluate the emotional experience at the most unconscious level of processes such as the physiological response, objective measures should be used. There are no better or worse measures, only measures that allow access to the same phenomenon from different points of view. The chapter's main objective is to make a survey of the main measures of evaluation of the emotions and emotional states more relevant in the current scientific panorama.

Keywords Emotions · Measures · Emotional response · Arousal · Valence

9.1 Introduction

The biggest challenge in the study of emotions is to measure them because they are related to internal states of the individual. First, it is noted that the emotional response may be of several types, for instance, verbally, through facial expressions, body movements and/or physiological responses. Although there are several theories about emotions, there is agreement on the two dimensions for measuring emotions:

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Arousal and *Valence* (e.g., Lang et al. 1997; Russell and Barrett 1999). *Arousal* refers to the psychophysiological condition caused in the individual by the presence of a stimulus, product or object (Lang 1995). It may be high when the stimulus produces a high activation in the subject (e.g., see a snake) or low when the stimulus produces low activation (e.g., listening to music for relaxing). *Arousal* is characterized by an activation of the autonomic nervous system (e.g., fight or flight reaction), and the activation of the endocrine system (e.g., increased blood cortisol levels) which enable the individual to respond appropriately to the stimuli. *Valence* (Lewin 1935) concerns to the positivity (e.g., Happiness) or negativity (e.g., Sadness) that a stimulus or situation elicits in the individual.

Existing instruments for measuring emotions can be divided into two major groups: subjective measures (e.g., questionnaires) and objective measures (i.e., psychophysiological).

9.2 Subjective Measures

One way to measure and evaluate emotions and emotional states is using subjective measures. This type of measures is essentially based on self-reports or questionnaires. A range of different subjective measures is available which reflects the variety of ways in which emotion has been conceptualized. Next, some of the most commonly used subjective measures are described.

The subjective measure most used to measure emotions against a given product is PrEmo. This instrument was created by Desme et al. (2000) and aims to measure the pleasantness or unpleasantness that one product elicits in the user. It consists of eighteen cartoon-like images, each image representing an emotion: 9 positive emotions (inspired, appreciative, pleasantly surprised, enthusiastic, attracted, desiring, fascinated, content, and softened) and 9 negative emotions (bored, contempt, aversive, disgusted, disappointed, dissatisfied, indignant, vulnerable, and disillusioned). The cartoons represent the facial expressions and body postures of each emotion.

The application of this instrument consists of showing the products to the participants. After the interaction with the product, the participant must choose which cartoon(s) best characterize the emotion felt in the presence of the product. This instrument has a great advantage for the evaluation of emotions elicited by products. Participants do not need to verbalize the emotion felt, since they only have to identify it visually through the cartoons represented in PrEmo. This feature is very important for this type of measures since verbally expressing emotions can prove to be a very difficult task since not all individuals have the necessary vocabulary to do it (e.g., Desmet et al. 2000).

Another widely used instrument for emotion self-reporting is the SAM (Self-Assessment Manikin) proposed by Bradley and Lang (1994). SAM evaluates the valence, arousal and also the emotional dominance (subjective feeling of control regarding the emotional event). The three dimensions are represented by a pictogram rating system: the valence is evaluated on a scale ranging between negative and positive dimensions (sad, neutral and happy faces); the arousal varies between calm and active (e.g. from a small beating heart to a heart beating with an explosive/flash appearance); and the dominance varies from submissive to overwhelming dominance (e.g. a picture element that is much larger than the rest). The participants only have to indicate the option that best applies to their emotional experience with the object/product, for each dimension. It should be noted that this test only allows access to the general emotional state of the individual, so for this reason, it is advisable that this test should be applied in conjunction with other measures (e.g., physiological measurements). This test has the main advantage that it is easy to administer, answer and analyze, and, also, the fact that it is cheaper and may be applied on paper or computer. SAM has often been used in human-robot interaction (e.g., Mussakhojayeva et al. 2017).

Other examples of self-report instruments are: PANAS—*Positive and Negative Affect Schedule* (Watson et al. 1988) which is a self-reported questionnaire consisting of two 10-item scales to measure positive and negative affect with different versions developed for different purposes (e.g., PANAS-C, PANAS-X); STAXI—*State-Trait Anger Expression Inventory* (Spielberger 1988) which was developed to measure intensity of anger and the disposition to experience angry feelings (current version STAXI II, Spielberger 1994); STEM—*State-Trait Emotion Measure* (Levine et al. 2011) which assesses stable and current emotions at workplaces; Affective Slider (Betella and Verschure 2016) which is a digital self-reporting tool to measure arousal and pleasure on a continuous scale; among others. In fact, there are studies in human-robot interaction area which have used PANAS (e.g., Bucci et al. 2017; Mutlu et al. 2009).

Many other techniques have been used in the measurement of emotions, such as the analysis of facial expressions proposed by Ekman and Friesen (1978) and Ekman et al. (2002) called *Facial Actions Coding System* (FACS). FACS is a tool to measure facial expressions by dividing facial expressions into individual components of muscle movements. Some robots (e.g., Tutsoy et al. 2017) are detecting human's emotions by using FACS technique while others (e.g., Loza et al. 2013) use FACS to define their own facial expressions.

Ten Emotion Heuristics (Lera and Garreta-Domingo 2007) is another technique which is dedicated to help measuring the affective dimension in the user evaluations. The heuristics are based on different theories such as FACS (Ekman et al. 2002) and The Maximally Discriminative Facial Moving Coding System (MAX) (Izard 1979).

Furthermore, other techniques such as analysis of the body movements (e.g., Tracy and Robins 2004) and vocal expressions/speech analysis (e.g., Juslin and Scherer 2005) can be used to assess in a more qualitative or quantitative manner.

Only recently, emotions came to be regarded as an important component of cognitive functioning (e.g., decision-making), and not just as something that negatively affects rational thought (e.g., Damásio 2003; Goleman 1995; Norman 2004), hence the recent history of emotions in the field of Design and Engineering. In this sense, one of the most significant developments of emotion in technology was to create products, objects, and machines capable of expressing, recognizing and feeling/showing emotions. That is, it became evident the importance of the individual establishing an emotional and empathetic relationship with the products, through its design, thus giving rise to emotional design.

Despite the relevance of the subjective evaluation of emotional states, it is sometimes necessary to evaluate the individuals' emotional experience in a deeper way, i.e. accessing the internal, cognitive and physiological mechanisms that individuals are not able to report subjectively.

9.3 Objective Measures

The instruments previously discussed are subjective in nature as they rely on self-reporting. Consequently, what is being assessed with these instruments is the conscious recognition of one self's emotions, i.e. emotions are to certain extends "rationalized". As such, the unconscious emotional processes which can, in some sense, be regarded as "truther" are not being clearly evaluated. Additionally, although such self-reporting measurements are based on scores, they only provide a semi-quantitative assessment of emotions.

The use of objective physiological measures comes then to both quantify and assess the conscious and unconscious emotional processes (e.g., Ekman et al. 1983; Lang et al. 1993; Scherer and Wallbott 1994; Stemmler et al. 2001). As before, the two-dimensional model for emotions: *Arousal* and *Valence* are considered and are now correlated to quantitative physiological measures.

Understanding which physiological measures to consider, one has to understand how emotions are "generated". This issue has not yet a definite answer, is a topic of discussion and research for generations, and often dwelling into the realms of philosophy. Scientifically though, the processes are starting to be understood and have their bases in neuroscience.

The nervous system is an intricate and complex information and communication system (see Table 9.1) (Kandel et al. 2013). It gathers information from the external environment by making use of senses (sight, hearing, touch, taste and smell) and, similarly, from the internal environment by making use of various bodily sensors such as muscle spindle sensors that provide information regarding proprioception (knowledge of body parts/movement) and pain (e.g. inner organs malfunctioning such as in a heart attack). Stimuli information from the external and internal environments is then communicated to the brain directly via nerves (e.g. optic nerve and facial nerves) or to the spinal cord via peripheral nerves. Information at the spinal cord is then forwarded to the brain (the brain and the spinal cord comprise the central nervous system) where it is processed and interpreted in complex cognitive and emotional processes, from which result in action that is communicated to other brain regions (e.g. storage of an event into memory), to the face (e.g. triggering the mimicry muscles for smiling) or to the body via peripheral nerves (e.g. informing the hand's muscles to wave goodbye or increase heart rate during running).

Unlike, cognitive processes (e.g. memory, calculus, navigation, executive functions), which are regarded as being held solely in the brain, emotional processes do

Table 9.1 Simplified organization and roles of the nervous system and its components

System level	Role
Central nervous system	Information gathering, processing, interpretation, translation into action and communication
Brain	High-level (cognition and emotion) processing, interpretation and translation into action
Organs of senses (sight, hearing, taste, smell) and sense of touch of the face)	Gather information from the external environment and forwards it directly to the brain via cranial nerves; gather information from touch, proprioception and pain from the trigeminal cranial nerve; facial mimicry via the cranial facial nerve
Spinal cord	Low-level (muscle and osteotendinous reflexes) processing, gathers/sends information from/to the peripheral nervous system
Peripheral nervous system	Gathers information from the rest of the body to the spinal cord or to the vagus nerve (autonomic information)
Somatic	Gathers information from the sense of touch, proprioception and pain from the body; convey conscious/voluntary and unconscious/involuntary motor information; also convey motor information to the pharynx (speech)
Autonomous	Gathers information and acts upon visceral organs (e.g. heart, lung, gut, bladder), glands, and sex organs; conveys conscious information; regulates pupil diameter
Sympathetic	Conveys "fight or flight" information; increases pupil diameter; sweating
Parasympathetic	Conveys "rest/maintenance" information; decreases pupil diameter; increases secretion of salivary and lacrimal glans

For a more complete view of the nervous system explained in a joyful yet complete way it is suggested the reading of "Clinical neuroanatomy made ridiculously simple" by Stephen Goldberg

have a bodily translation (e.g. when feeling anxious the palms get sweaty and the heart is pounding). In the event of an external (e.g. listening to the favorite music; touching a rose petal) stimuli or internal process (e.g. thought of the loved one), information is further processed in the brain where is emotionally interpreted and then translated into a bodily response.

The emotional communication between the brain and the body is then mediated via the spinal cord and the peripheral nervous system, which includes the somatic and the autonomous nervous systems.

The somatic nervous system communicates both conscious and unconscious brain processes, such as voluntary and involuntary movements. Emotional content is, nonetheless, more often perceived from involuntary movements such as body movements (e.g. gestures, body stances, and postures). The autonomous nervous system, on the other hand, communicates unconscious brain processes only (see Fig. 9.1).

Emotional processing of stimuli in the brain often makes use of evolutionary older brain structures such as the diencephalon (hypothalamus and basal ganglia) and the limbic system but also of evolutionary newer brain structures such as the neocortex. The emotional output is then communicated to the autonomous nervous system which is comprised of sympathetic and parasympathetic systems, which have "opposite" effects. The former system is related to a "fight or flight" or stress reaction, in the sense that prepares the body for action. The latter system is related to a rest reaction as it prepares the body for "maintenance" (e.g. digestion and sleep).

The effect of sympathetic activation (or parasympathetic inactivation) results for instance in increased pupil diameter, heart rate, blood pressure, breathing rate, and sweating as the body prepares to better assess the nature of a threat (increased visual acumen) and makes resources available for action (increased blood flow delivered to skeletal muscles, heart, and head that results in increased local temperature and blushing). The effect of parasympathetic activation (or sympathetic inactivation)

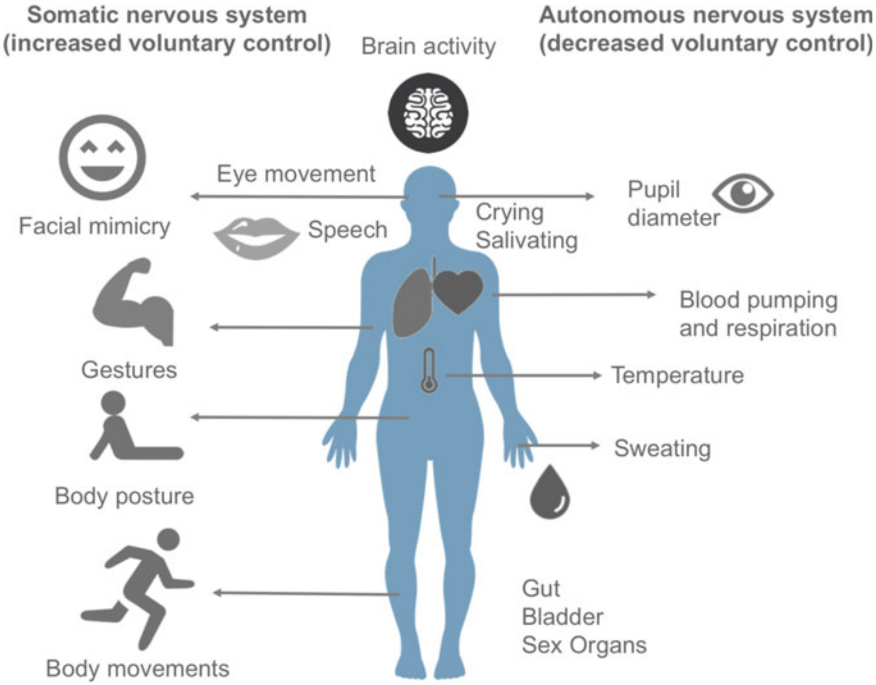

Fig. 9.1 Representation of physiological measures/actions and their relations to the somatic and autonomous nervous systems

oppositely results in decreased pupil diameter, heart rate, blood pressure, breathing rate as the body is being set to a rest state, and also increased secretion of salivary and lacrimal glands.

The autonomous nervous system is a system that can react fast to changing environments and therefore to emotional processes. These processes also elicit the response of the endocrine system which has a much slower but long-lasting effect. For instance, in the event of chronic stress, there is a sustained increase in blood cortisol levels, a process which is mediated via the endocrine system.

Arousal is then understood as a degree of alertness/excitement, and therefore is more directly related to the activation of the autonomic nervous system and the endocrine system, but also to some extent to the somatic nervous system. Consequently, arousal can then be measured more directly in the body. Nonetheless, aspects of arousal can also be translated into facial mimicry (e.g. surprise)

Valence, on the other hand, does not have a simple correlation to the activation of the autonomic nervous system, as stimuli strongly positive or negative could provide similar autonomic reactions. *Valence* can be better perceived from facial mimicry (e.g. disgust) and speech and overall from the somatic nervous system body movements/posture and gestures. Also correlates of valence have been described regarding the brain activity, such as pre-frontal alpha wave asymmetry (see below).

As such, *Arousal* and *Valence* can be perceived via different physiological measures which can be assessed using different techniques. A resume is shown in Table 9.2.

Although less studied, the dimension of emotional dominance has also been correlated to physiological measurements, such as beta wave power in the midline brain, a measure of brain electrical activity.

The different techniques to assess the physiological measures are mostly optical, and electrical/electrode or sensor-based (here, chemical methods of assessment of emotions via analysis of bodily fluids such as blood and saliva are not discussed). In particularly, when the brain or body electrical activities are assessed it is referred to electrophysiological techniques, which will be described in more detail below.

Optical techniques include the use of visible or infra-red video cameras, which may have 3D depth perception, to assess facial mimicry, gestures, postures, and movements. These cameras can further be combined with markers placed on the body for increased precision.

When used for facial mimicry these cameras are combined with recognition/computer vision algorithms based on the Facial Action Coding System (FACS) method. This method codes facial expressions, depending on involved muscles and was developed by Paul Ekman and Wallace V. Friesen in 1976. Nowadays, companies such as Affectiva offer software development kits that facilitate the development and deployment of facial mimicry recognition applications. For the assessment of body movement, other algorithms are used instead. Microsoft's Kinect is one of the first and most well-known system for body movement recognition and more recently Leap Motion developed its controller which recognizes gestures with greater accuracies.

The same Kinect or other video cameras can make use of an algorithm called Eulerian Video Magnification to magnify subtle changes of color of the skin at

Table 9.2 Emotional dimension, physiological measure and assessment technique

Dimension	Physiologic measure	Suggest assessment technique
Arousal	Pupil diameter	Eye tracking
	Eye movement patterns	Eye tracking; EOG
	Facial mimicry	Video facial recognition; EMG
	Speech	Voice/sound analysis; EGG; IMU
	Heart rate; Heart rate variability	ECG; PPG; video
	Breathing rate and pattern	Piezo/Force/pressure sensors; EMG; PPG; Oximetry
	Blood pressure/BVP	Pressure sensor/PPG
	Temperature	Thermometer; IR; thermographic cameras
	"Sweatiness"	GSR/EDA
	Brain activity	EEG; other neuroimaging/physiological techniques (see overall)
Valence	Facial mimicry	Video facial recognition; EMG
	Speech	Voice/sound analysis; EGG; IMU
	Body movements	VIS/IR video (w/ or w/o markers); 3D depth cameras
	Brain activity	IMU; EMG EEG; other neuroimaging/physiological techniques (see overall)
Dominance	Brain activity	EEG; other neuroimaging/physiological techniques (see overall)
Overall	Neurophysiologic/neuroimaging correlates	fMRI; fNIRS; MEG; PET; BCI; tCS; TMS

BCI, brain-computer interface; *BVP*, blood volume-pressure; *ECG*, electrocardiography; *EDA*, electrodermal activity; *EGG*, electroglottography; *EMG*, electromyography; *EOG*, electrooculography; *fMRI*, functional magnetic resonance imaging; *fNIRS*, near-infrared spectroscopy; *GSR*, galvanic skin response; *IMU*, inertial measurement unit (accelerometer ± gyroscope ± magnetometer ± barometer); *MEG*, magnetoencephalography; *PET*, positron emission tomography; *Piezo*, piezoelectric sensors; *PPG*, photopletysmography; *tCS*, transcranial current stimulation; *TMS*, transcranial magnetic stimulation; *VIS/IR*, Visible/infrared. Invasive techniques that require bodily fluid collection such as blood or saliva (e.g. for cortisol level measurement) are not here considered each heartbeat: due to increased blood flow in the face, the skin is slightly redder. In this manner, it is possible to assess heart rate in a contactless manner (Gambi et al. 2017).

Other sophisticated infrared systems are eye trackers, which have been fundamental in the Design process. These instruments allow to perceive the points in an image or video in which users focus their gaze and also enable the measurement of pupil diameter, thus informing on the cognitive processes of exploration of an image of a product for instance and the arousal levels such product elicites in the users (Poole and Ball 2006).

The use of the eye tracker already has more than a century of history, existing records of its use in Javal (1878). However, the first eye trackers were very invasive and dangerous measuring instruments, because to measure the ocular movement, they had to be in contact with the cornea.

It is estimated that the first non-invasive eye tracker was created in 1901 by Dodge and Cline. However, this instrument was very limited (e.g., participants could not move their heads). Over the years, the eye tracker technique has been improved and used primarily in research and studies on reading.

Its evolution was such that in 1948, Hartridge and Thompson, created the first head-mounted eye tracker. Over the years and as the technology improved, eye trackers have extended their use to other areas of knowledge, such as human-computer interaction (e.g. Josephson and Holmes 2002; Reeder et al. 2001).

Eye movements allow the individual to maintain or shift the gaze between various visual areas (Goldberg and Wichansky 2003) by capturing information that is then transmitted and processed in the brain.

This set of information collected through the eye tracker may prove to be fundamental for the designer to identify the points of the object that most catch the attention of the user, and thus increase them.

Simpler optical systems comprised of light emitting diodes (LEDs) and photoresistors or other photodetectors are used to assess blood-volume pressure (BVP) signals, a technique called photoplethysmography (PPG). BVP signals translate the amount of blood flowing through a vessel and can be used to compute the heart rate and heart rate variability, but also the breathing rate, and a correlate of the blood pressure. In fact, just after a heartbeat, excess blood flow is observed in tissues in a pulsatile manner which will reflect or transmit light differently, enabling it to be detected.

Further development of these systems which include both red and infrared LEDs is oximetry. Besides the former measures discussed above, it can also provide oxygen saturation, translating increased or decreased oxygenated blood flow in the brain that may result from an emotional response. Finally, temperature can also be assessed using an infrared LED or infrared cameras, as well as with other methods.

Other physical sensors include piezoresistors, and other force and pressure sensors may be used to measure breathing rate and breathing patterns via a flexible sensor strap placed around the thorax. Pressure sensors are typically used for assessing blood pressure, or as microphones can also be used to capture speech, which is then classified by specialized algorithms.

Inertial measurement units (IMUs) typically comprise accelerometers, gyroscopes, magnetometers/compass and, also, more recently barometers. IMUs are used to assess both voluntary and involuntary movement and may be used also to assess speech, by measuring the vocal box vibrations.

Electrophysiological techniques, on the other hand, are used to measure a large variety of brain and body electrical signals (see Fig. 9.2), especially associated to emotions and the autonomous nervous system but also to cognitive processes and to the somatic nervous system.

Since it was invented by Hans Berger in 1929 (Berger 1929), electroencephalography (EEG) has been the neurophysiological technique by excellence, as it measures the electrical activity of the brain. Both EEG signals and their frequency components (delta, theta, alpha, beta and gamma) have been associated with arousal, valence and dominance (Reuderink et al. 2013):

– Delta (0.5–4 Hz): a power increase in the posterior right hemisphere is associated with increasing arousal;

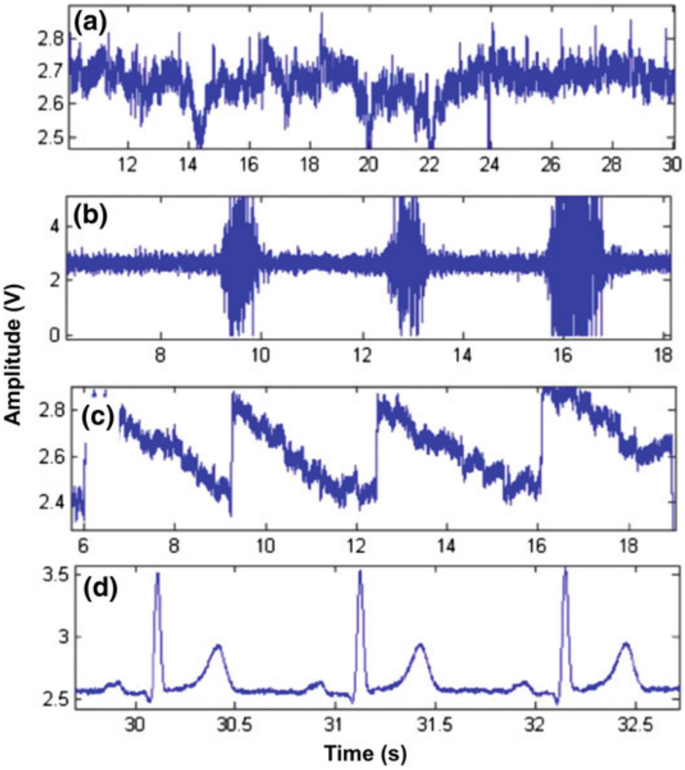

Fig. 9.2 Example of electrophysiological signals tracings: A—Electroencephalography; B—Electromyography; C—Electrooculography; and D—Electrocardiography. Adapted from Ribeiro et al. (2014)

- Theta (4–8 Hz): a power decrease in the frontal cortex is associated with increasing positive valence and to attention;
- Alpha (8–13 Hz): a global power increase is associated with increasing arousal; additionally, a frontal left-right hemispherical asymmetry correlates with valence with a decrease in power in the left/right hemisphere for positive/negative emotional information, respectively;
- Beta (13–30 Hz): a correlation in the midline with dominance;
- Gamma (>30 Hz): asymmetry in the temporal cortex was found associated with valence.

Additionally, EEG signals have been shown to assess attentive/focused and meditative/resting states. In attentive/focused states an increase in beta power and a decrease in alpha power are observed (Marrufo et al. 2001). In meditative states, an increase in alpha power in the occipital cortex, and an overall increase in both theta and beta powers were observed as well (Ahani et al. 2014).

Electromyography (EMG) is a technique that translates skeletal muscle activity. It is therefore related to the somatic nervous system and can translate both conscious and unconscious cognitive processes. EMG sensors are typically placed over the facial muscles in order to detect expressions related to facial mimicry (Bartlett et al. 1996), but they can also be placed in the upper or lower limbs to perceive movement or event jitter associated to an anxious state (Haag et al. 2004). Finally, EMG sensors can also be placed over respiratory muscles in order to assess the breathing rate, which is under control by the autonomous nervous system. Fast breadths can be associated with high arousal states while slow shallow breadths can be associated with low arousal states. Here, the deepness of breadth (as assessed by the amplitude of breathing) can further discriminate between emotions, whereas fast and deep breading can be related to an excited state, which can be positive or negative in valence, fast and shallow breading can be related to tense anticipation. Also, slow and deep breading can be related to a relaxed state, whilst a slow shallow breathing may be associated with depressive syndromes or calm happiness (Haag et al. 2004).

Electrooculography (EOG) measures the electrical activity associated with eye movements. EOG may be used as a complement to EEG for instance for the detection of EEG signal artifacts but can also be used to monitor eye movements as scanning of a particular visual stimuli, and detect blinking rate (Calvo and D'Mello 2010), which may help translate a particular emotional state (e.g. anxiety, withdrawal) and also be used to detect facial mimicry around the eyes (Setz et al. 2009).

Electroglottography (EGG) measures the electrical flow across the larynx which is increased when focal cords are closed. It can be used to depict the emotional content of speech (Hui et al. 2015).

Electrocardiography (ECG) measures the electrical activity of the heart and therefore measures the activity of the autonomous nervous system. It is perhaps the most widely used technique for assessing emotions using physiological signals. These signals can be measured using electrodes over the chest or even on the fingertips using a two-electrode setup. Heart rate (HR) and heart rate variability (HRV) can be easily computed from ECG signals and can translate a state of relaxation when the HR is decreased and the HRV is increased and a state of anxiety/stress when the HR is increased and the HRV is decreased in regards to baseline values (Haag et al. 2004). Finally, ECG signals can also be used for artifact removal in EEG signals.

Finally, the electrodermal activity (EDA), also known as, galvanic skin response (GSR) is also a widely used electrophysiological signal for emotion recognition. It translates skin conductance, which changes accordingly to the skin sweat, as already first studied by German physiologist Emil Heinrich Du Bois-Reymond in 1849. EDA then assesses the autonomous nervous system, especially the arousal level. As such, EDA has been found to be a useful way to assess stress and to differentiate between conflict/no-conflict situations. The main drawback of this technique is its dependence on external factors such as temperature (Haag et al. 2004).

All these signals have been used individually, but multimodal approaches have shown improved accuracies in emotion detection (Kim et al. 2004). This type of measures involves the application of sensors and electrodes in the individual, so that, although painless and harmless, these methods are more intrusive and more expensive than self-report instruments, but also much more powerful.

So far, considering what was discussed, EEG is the only technique that directly measures brain electrical activity. The other techniques mostly measure the outcome of brain processes communicated to the peripheral nervous system.

More recently, other more complex and expensive neurophysiological and neuroimaging techniques have been used to study emotional processes in the whole brain. In this regard, besides EEG, the magnetoelectroencephalography (MEG) technique is being used for the study of emotions within the millisecond time-scale (Giorgetta et al. 2013). Moreover, when both EEG and MEG are used for high-density recording their output may result in functional images, which may provide advantageous views on the data.

Other functional neuroimaging techniques include functional near-infrared spectroscopy (fNIRS), functional magnetic resonance (fMRI) and positron emission tomography.

fNRIS uses similar technology to oximetry, but sensors are spatially arranged in order to provide increased spatial information. Nonetheless, fNRIS does not provide a direct measure of brain activity, as EEG does. Instead, it assesses the local increased arterial blow flow resulting from the increased demand of local neurons for oxygen and glucose during stimuli processing or during a task (Nishitani and Shinohara 2013).

fMRI works similarly as fNIRS, as it depends also on local increased arterial blow flood. In this case, though, it makes use of the proton properties of tissues, not the optical properties. fMRI as an imaging technique is able to provide better spatial localization of the brain processes, although being a more expensive and less available technique (Phan et al. 2002).

The PET technique is the most specific of all, as radiotracers can be designed and used to address a particular metabolic route or neurotransmitter receptor. In this manner this technique as the greatest potential to enable a deeper understanding of molecular and cellular functional processes. Nonetheless, when comparing to fMRI, a number of disadvantages has to be equated, such as the invasiveness/need to inject a contrast agent, use of ionizing radiation, longer scan times, smaller temporal and spatial resolutions, smaller market availability and higher costs.

These techniques are all related to the measurement of cognitive and emotional processes. Nonetheless, it is possible to study these processes by modulating/manipulating the brain and observing the outcomes. These interventional techniques include EEG-based brain-computer interfaces (BCI) which operate via neurofeedback, exposing the user to a translated version of his/her own physiological measures and enabling the progressive control of such measures (Johnston et al. 2011).

Other interventional techniques include transcranial current stimulation (tCS) and transcranial magnetic stimulation (TMS), which both modulate tissue electrical excitability via the application of electrical currents (in the former) and magnetic fields (the latter) (Martin et al. 2018; Notzon et al. 2017). As being interventional and more recent, there is still a great investment in assessing the safety profiles and effectiveness of such techniques, but their potential, particularly in combination with the other measurement techniques, is enormous.

9.4 Conclusion

Emotions are ever more a topic of research and, correspondingly of application. As more and more studies put in evidence the critical role of emotions; in what makes us humans like and dislike, love and hate, and motivate, lead and decide; the more important is to have awareness of the subjective and objective tools and techniques that are available and that are being developed for measuring (and also for modulating) emotions. That is so more important in the Design field, as the designer makes use of his/her emotions to dream and create, and the user, as more than a recipient, also co-participates in the design process guided by his/her own emotions, aesthetics and purchasing decision.

In this chapter, besides subjective measures, neural-correlates of emotions, related physiological measures, and assessment techniques are described, hopefully in with the right mix of overall perspective and detail. We further hope to have given our reader, the designer (and other related professionals), additional tools to create evermore valued products and services.

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Part IV
Case Study

Chapter 10
Human-Robot Interaction: Exploring the Ability to Express Emotions by a Social Robot

Hande Ayanoğlu, Magda Saraiva, Luís Teixeira and Emília Duarte

Abstract Robots should have characteristics that make the interaction effective and fluent for a successful Human-Robot Interaction (HRI). Since the emotions play a fundamental role in the human interaction process, many robots are introduced facial expressions, speech, body movements, among others to deepen the HRI. This chapter presents the exploration, design, and evaluation of the recognition of emotions displayed by a social robot. Initially, a pre-experiment was done to program the emotions in a virtual prototype. Afterwards, a pilot study and two experiments were conducted by manipulating the robot facial expressions and body movements to evaluate the recognition of the emotions. The results show that joy, surprise, and sadness have higher correct recognition and fear, disgust, and anger reported as lower recognition. Further study is needed regarding body movement and displacement of the robot for disgust, fear, and anger. Moreover, a robot should be introduced in a specific context to increase the recognition of emotions.

Keywords Human-Robot Interaction · Emotional design · User experience · Robot emotions · Basic emotions

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10.1 Introduction

It is expected to increasingly penetrate social robots to everyday life (e.g., Graaf and Allouch 2013). Until a few years ago industrial robots were occupying a prominent place, currently, social robots play an increasingly important role in the lives of humans. On one hand, industrial robots were created with the aim of helping, or even replace, the human in routine and dangerous tasks (e.g., blasting bombs). On the other hand, social robots are designed to interact and accompany humans in their daily tasks (Siegel et al. 2009). This type of robot operates autonomously while performing tasks and interacts with humans contributing to the human's well-being (Schraft and Schmierer 2000; Siegel et al. 2009).

When a human interacts with another human, this interaction is guided by a complex set of characteristics (i.e., verbal and nonverbal) which make it effective. One of the most important characteristics for the interaction between humans is the expression of emotions (e.g., Frith 2009). Although there is not a single, universal definition of emotions, this can be defined as the tendency that humans have to start, maintain and finish an interaction with the environment and/or with another human (Frijda 1986). Emotions are considered subjective experiences (because they vary from individual to individual in terms of intensity, arousal, and such) and are commonly accompanied by biological changes (i.e., changes in the nervous system) and behavioral reactions (e.g., start or stop one behavior), which allows the individual to adapt to a particular situation or event (Levenson 1994). In this sense, emotions play an important role in human life. However, different theories ascribe different functions. Thus, the physiological theories (e.g., James 1884) argue that when an individual experience an event, the nervous system generates a physical reaction in relation to this event (e.g., crying), which causes an emotional reaction (e.g., sadness). This means, according to these theories, that the emotion is the result of the interpretation that the individual makes about physical reactions caused by an event.

In addition, cognitive theories (e.g., Schachter and Singer 1962) argue that there are two key factors for the emergence of emotion, arousal, and cognitive label. The arousal is the psycho-physiological condition caused by an event. This condition is derived from the activation of the endocrine and autonomic nervous system. After this, the individual seeks environmental clues to assign a label to that activation.

Finally, the most common theory about emotions is the evolutionary theory (e.g., Darwin 1872; Ekman et al. 1982). For authors who advocate this theory, some emotions are innate and universally recognized, which allows the individual to identify, in their interaction with others, potential dangers to their survival. According to Ekman et al. (1982), there are six basic emotions (i.e., joy, sadness, fear, disgust, surprise, and anger) that are expressed and recognized universally (through facial expressions), regardless of cultural and social factors. In this sense, it is easy to understand that emotions play a key role in human's life, allowing them to interact effectively with others.

Reeves and Nass (1998) argue that humans tend to apply social rules in their interaction with computers, similar to those that apply in their interaction with other humans, for example, assign gender, name or personality (e.g. Nass et al. 1997). The same can be true for Human-Robot Interaction (HRI). In the case of robots, their interaction with humans is influenced by several factors, such as robot appearance, facial expressions, body movement, among others (e.g., Hwang et al. 2013; Kulic and Croft 2007; Nehaniv et al. 2005). In this sense, there are some authors who argue that HRI is effective only when an empathic relationship between human and robot is created, which is possible through the expression of emotions (e.g., Picard 2000). This is the reason that an increase in the number of robots is seen, particularly social robots, able to express and recognize emotions (e.g., Blow et al. 2006; Breazeal 2003; Zecca et al. 2009, 2010). Expressing and recognizing emotions are important features of social robots, as these features allow them to respond adequately to the needs of its user (Picard 2000). Depending upon the sort of the robot, the tasks it performs, the context and its social life, the robot needs to express emotional state as well as the emotions of the people it interacts (Norman 2004). However, it should be noted that when referring to the robots that present emotions, the expression is not the same as in humans since robots are not humans and they do not have human cognitive abilities (e.g., assigning a meaning to an interaction) (Blow et al. 2006) and can also have diverse limitations (i.e., people's faces are rich in muscles).

Norman (2004) denotes that in order to increase people's satisfaction and appreciation emotional expressions of robots are needed to inform people about robots' motivations, desires, accomplishments, frustrations which increase people's satisfaction and appreciation. Therefore, the main objective of this study was to explore and evaluate the recognition of emotions displayed by a social robot. The ability of participants' recognition of emotions by a robot (i.e., a virtual replica of a social robot) was tested. Accordingly, a pre-experiment (in order to program the emotions in the virtual prototype), a pilot study, and two experiments were conducted.

10.2 Pre-experiment

This part was mainly to define the characteristics that the virtual robot which presented the facial expression, movement, and displacement, to represent eight basic emotions: joy, trust, fear, surprise, sadness, disgust, anger, and anticipation (Plutchik 1980). Pre-experiment was divided into two phases: Definition; and Design (Giambattista et al. 2016).

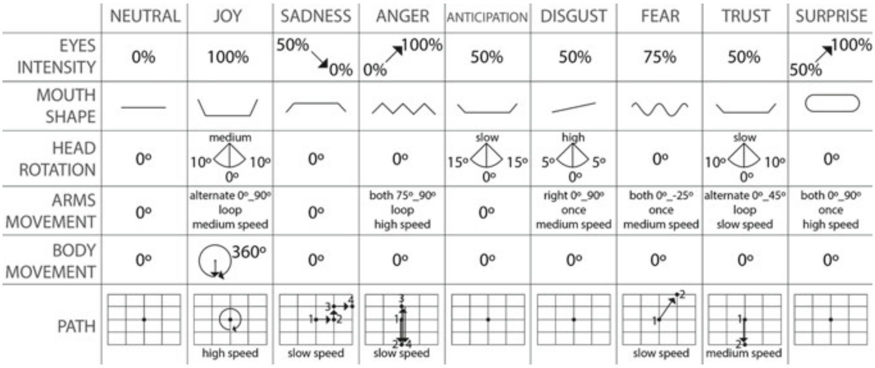
10.2.1 Definition Phase

The objective of this phase was to define a combination of characteristics, i.e., facial expressions, body movements, and displacement) to represent 8 emotions (i.e., joy, trust, fear, surprise, sadness, disgust, anger, and anticipation). The study was conducted with 10 students who tried to simulate a robot's behavior, namely Monarch (Ferreira and Sequeira 2017) to express emotions, by using two cardboard arms (Fig. 10.1). The students were informed about the limitations of the robot's movements: they could move their arms only up and down, walk forward backward and move sideways, rotate their head and body to the left and right, but they could not bend their body.

The participants were voluntaries and that they consented the video recording of their participation in the experiment. The procedure took place in a photography studio/lab and the performance of the participants was video recorded. In the lab, the participants could perform each emotion in a limited area which was marked on the floor as 2 by 2 meters. Before performing each emotion, they were asked to perform training in which they were shown an emotion besides the 8 emotions. If they accomplished this session as requested, then they were asked to start performing the 8 emotions in which each was written on a sheet of paper. The order of the emotions was randomized and after each performed emotion, the participants were asked to clarify some facial expressions and movements that are not clear to the researchers.

The videos were analyzed by two researchers to identify the characteristics of each emotion, based on the criteria defined and given to the participants, with a focus on the characteristics (e.g., eyes, mouth, arms and body movements) that the virtual robot would be able to reproduce. A table was filled in which each emotion was identified by various features (Fig. 10.2).

Fig. 10.1 A student is imitating the robot with cardboard arms



	NEUTRAL	JOY	SADNESS	ANGER	ANTICIPATION	DISGUST	FEAR	TRUST	SURPRISE
EYES INTENSITY	0%	100%	50% ↘ 0%	0% ↗ 100%	50%	50%	75%	50%	50% ↗ 100%
MOUTH SHAPE									
HEAD ROTATION	0°	medium 10° 10° 0°	0°	0°	slow 15° 15° 0°	high 5° 5° 0°	0°	slow 10° 10° 0°	0°
ARMS MOVEMENT	0°	alternate 0°_90° loop medium speed	0°	both 75°_90° loop high speed	0°	right 0°_90° once medium speed	both 0°_-25° once medium speed	alternate 0°_45° loop slow speed	both 0°_90° once high speed
BODY MOVEMENT	0°	360°	0°	0°	0°	0°	0°	0°	0°
PATH		high speed	slow speed	slow speed			slow speed	medium speed	

Fig. 10.2 Each emotion's variables which were implemented to the virtual robot

10.2.2 Design Phase

In the Design phase, a Virtual Environment (VE) was created. The VE was a 5 m long hospital corridor, and the virtual robot was placed at the end of the corridor. The context was chosen due to the Monarch's case study's aim (Messias et al. 2014) which is improving the quality of life of inpatient children. Both VE and virtual robot were created using Rhinoceros, then exported to Unity 3D to program and represent the emotions that robot would express. The VE was simple and neutral since the aim of the study was that the participant focuses on the robot performance and not on the environment (see Fig. 10.3). Participants were seated during the procedure. The virtual robot was presented to participants in 3D, and for this, a 3D projection-based virtual reality system with a 1280 × 720 pixel resolution at 120 Hz was used.

Fig. 10.3 Robot's neutral emotion in the VE

Surprise Sadness Trust Fear

Anticipation Disgust Anger Joy

Fig. 10.4 Static images of the eight target emotions with facial expressions and body movements for the pilot study

Eight target emotions; i.e., joy, trust, fear, surprise, sadness, disgust, anger, and anticipation were selected, gathered from Plutchik's theory (1980). An animation was created for each emotion that was based on the results of the Definition phase. The static images of the emotions are shown in Fig. 10.4. In the animation, before each emotion, the robot showed the neutral emotion first and then the target emotion.

10.3 Pilot Study

This study's main objective was to understand whether the 8 emotions programmed into the virtual robot model was correctly recognized by the participants. To this end, all materials developed in the Design phase were tested.

10.3.1 Participants

Thirteen participants volunteered in this experiment. Seven were female (53.8%) and six males (46.2%) aged between 19 and 37 ($M = 24.6$; $SD = 5.02$) years old.

10.3.2 Stimuli and Materials

8 emotions (i.e., surprise, sadness, trust, fear, anticipation, disgust, anger, and joy) were used proposed by Plutchik.

Initially, the participants answered to some demographic's questions (e.g., age, education) and were asked about the previous experience/contact with social robots. If participants had already had contact with a robot of this type, they should indicate the context and the frequency of interaction. Then it was presented a questionnaire to the participants. The questionnaire was divided into four sub-questionnaires: (a) Technological Attitude Scale—before the interaction with the robot; (b) Perception Scale about Robots—before the interaction with the robot; (c) Emotion Recognition Task—during the interaction with the robot; and (d) Perception Scale of the Virtual Model—after the interaction with the robot. The stages are described below:

a. Technological Attitude Scale (based on Lakatos et al. 2014)—this scale aims to understand the relationship that the participants have with technology, in general. It consists of 7 affirmations (e.g., *my technological knowledge is excellent*), and the participant must, in a 5-point Likert scale (1—*I Strongly Disagree*, 2—*I Disagree*, 3—*Undecided*; 4—*I Agree*; 5—*I Strongly Agree*) choose the answer that best applies.
b. Perception Scale about Robots (based on Nomura et al. (2006)—it is a scale that aims to evaluate the participants' perception about robots (e.g., *I worry that the robots can be a bad influence on children*). It consists of 10 affirmations and it was used the same 5-point Likert scale used previously.
c. Emotion Recognition task—it is composed of a list of 16 emotions (8 main emotions and 8 distracting emotions): joy, trust, fear, surprise, sadness, disgust, anger, anticipation, anxiety, irritation, shame, contempt, guilt, pleasure, despair, proud, and the option "*none of the above emotions is correct*". This task aims to understand if participants would correctly identify the emotions expressed by the virtual robot. To this end, after the robot expressed each emotion, the participants selected in this list, the emotion that thought to have been expressed by the robot.
d. Perception Scale of the Virtual Model—this scale aims to analyze the perception that participants have about the virtual robot. To this end, participants must, a 5-point Likert scale, report their opinion for three affirmations: 1—*I would feel comfortable if I had to interact with this robot*; 2—*I would not like to have this robot in my house*; 3—*I would feel sorry if I had to destroy this robot*. In the end, the participants were asked about the robot's gender (i.e., female, male, without

defined gender) and one question about the functions that the robot could perform (e.g., tourist guide).

10.3.3 Procedure

The procedure took place in a dark room (user experience laboratory), with ideal conditions (e.g., controllable light, temperature conditions) for the use of virtual reality and had a maximum duration of 15 min. When participants arrived, they were informed about the general objectives of the study and they signed informed consent. Also, they were warned for the possibility of slight negative effects due to the use of 3D glasses (e.g., possibility of nausea due to simulator sickness). Then, participants answered the demographic's questions, the Technological Attitude Scale, and the Perception Scale about Robots.

Thereafter, participants were told that the virtual robot would start its performance, i.e., to express emotions. Participants sat at a distance of 1 m from the wall screen and put the 3D shutter glasses. After that, the robot appears in the virtual environment, with a neutral expression. In the neutral expression, the mouth of the robot was represented by a simple line, arms rested, and the eyes were lit but without any level of glow. Then, the robot moves in a straight line towards the participant. This phase was designed to accustom the participant to the virtual environment, the robot, and the 3D shutter glasses.

The researcher tells the participant that the robot would start its performance, expressing one emotion at a time. Each emotion was displayed for 10 s, after which, the participant had to recognize the emotion expressed by the robot in the list of 16 emotions presented. After expressing an emotion, the robot returned to the starting position (i.e., in front of the participant, where it started the performance). The robot remained still as it was turned off (i.e., mouth and eyes off, and arms down) until the following emotion expression that began with a key press by the researcher.

Emotions were presented to the participants in one of two sequences: Sequence 1—surprise, sadness, trust, fear, anticipation, disgust, anger, joy; Sequence 2—sadness, fear, trust, joy, surprise, anger, anticipation, disgust. All the emotions were placed in a website to generate several ordered lists and two were chosen.

After the performance of the robot, that is, at the end of the six emotions expression, participants answered the Perception Scale of the Virtual Model questionnaire and a question about the gender of the robot and its function. In the end, the researcher asked the participants some possible changes in the robot in order to improve the expression and recognition of emotions. After that, the participants were thanked, debriefed and dismissed.

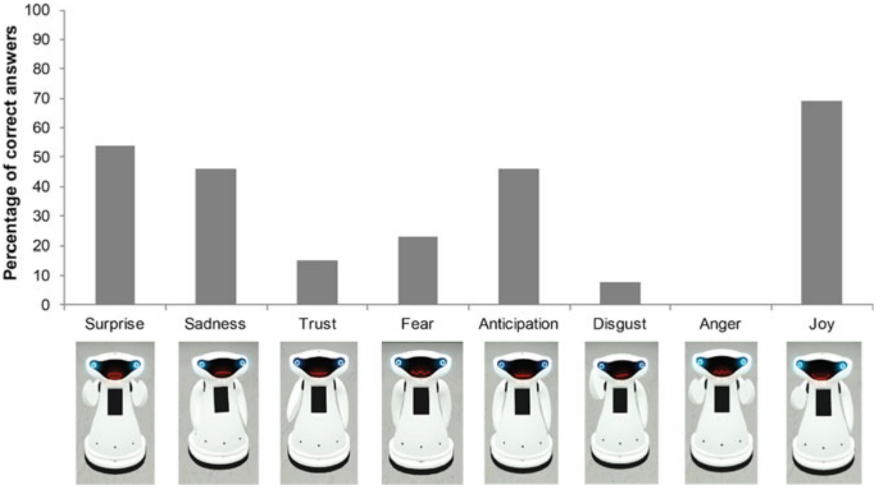


Fig. 10.5 Percentage of correct responses for each emotion for Pilot Study

10.3.4 Results

The main objective of the pilot study was to understand if participants were able to recognize 8 emotions correctly which were expressed by the robot. Therefore, only the results for Emotion Recognition Task are presented. In this sense, results revealed that participants had some difficulty in recognizing correctly the emotions expressed by the robot (33% correct answers). Figure 10.5 represents the percentage of correct answers for each presented emotion. The results revealed that joy (69%) and surprise (54%) were the ones with a higher percentage of correct answers, followed by sadness (46%) and anticipation (46%). The other emotions presented a percentage of accuracy below 25%: fear (23%), trust (15%), disgust (8%) and anger (0%).

These results showed that some of the emotions are confused with others (e.g., trust was confused with joy in 46% of cases), which shows the need to implement some changes in the expressions of emotions by the virtual robot, making them easier to recognize. For more information about the results of this pilot study please see Giambattista et al. (2016).

10.4 Experiment 1

In the pilot study, the correct recognition of the emotions expressed by the virtual robot was quite low. This result revealed the need to make significant changes in the programming of emotions in order to increase its correct recognition. In this sense, also the theoretical approach to emotions was altered. Thus, in the following experiments, the 6 basic emotions (i.e., joy, sadness, fear, disgust, surprise, and anger) based on evolutionary perspective, proposed by Ekman et al. (1982) were used. There are several studies (e.g., Bartneck 2002; Kanoh et al. 2005; Hashimoto et al. 2006; Saldien et al. 2010) identifying the characteristics of the emotions for robots in terms of facial expression which can be combined with the features that was classified in Definition Phase.

10.4.1 Participants

The sample consists of 20 volunteered students, 17 (85%) were females and 3 (15%) were male. The ages vary between 18 and 22 years ($M = 19.75$, $SD = 1.04$). The participation was voluntary. The participants did not receive course credits or any monetary compensation for participating in this study.

10.4.2 Stimuli and Materials

As mentioned before, this experiment used the 6 basic emotions proposed by Ekman (1999) instead of the 8 emotions proposed by Plutchik (1980), this means that the emotions trust and anticipation are not part of this experiment. In this experiment the same VE, virtual robot and questionnaires were used. However, since two emotions (i.e., trust and anticipation) were eliminated, the Emotion Recognition task has been slightly modified. In this sense, Emotion Recognition task is composed of a list of 12 emotions: 6 basic emotions and 6 distracting emotions: despair, anxiety, shame, anticipation, contempt, and trust; and the option "*none of the above emotions is correct*".

Considering the results of the pilot study, some changes were made in the programming of the emotions that had a low hit rate. The emotions joy and surprise were not changed, while the remaining four emotions suffered small adjustments in motion (i.e., anger and fear), shape of the mouth (i.e., anger, disgust, and fear), and eyes color (i.e., anger—red; fear—yellow; disgust—green; sadness—purple).

These changes were suggested and defined by a multidisciplinary team of researchers (e.g., designers, psychologists, engineers) taking into account the analysis and study of the expression of emotions in humans and robots, as well the opinions and suggestions of some participants who were subject to some tests of emotion recognition with the virtual robot. Figure 10.6 shows the expression of the six basic emotions by the virtual robot in a static manner.

10.4.3 Procedure

The same procedure as in the Pilot Study was followed.

Surprise | Sadness | Fear

Disgust | Anger | Joy

Fig. 10.6 Static images of the six target emotions with facial expressions and body movements for Experiment 1

10.4.4 Results and Discussion

A qualitative analysis of the results is shown that was obtained for the different scales used and for the recognition of emotions expressed by the robot. The mode was calculated for each answer for all scales since they are ordinal scales. 18 out of the 20 participants mentioned they had never been in contact with a social robot before participating in this experiment.

a. Technological Attitude Scale

On this scale, most participants declared they liked to explore new technological devices (Q1) while assuming that their technological knowledge is not excellent (Q2). On the other hand, participants revealed that they could imagine having a social robot in your home (Q3) and agreed that they liked to have a social robot to help them (Q4). Also, in this sense, participants said they would like to try new robots (Q6) and they completely agreed that social robots were useful (Q7). In relation to question 5 (Q5—*I am afraid that robots are used for bad purposes in the future)*, the responses mode of participants was 3, or undecided.

b. Perception Scale about Robots

In this questionnaire, the participants revealed that they felt comfortable if robots would express emotions (Q1) and if they had to talk with them (Q3). Furthermore, the participants agreed that if the robots had artificial intelligence, something may go wrong (Q2). Regarding the questions related to the interaction that participants would be able to establish with robots, participants declared that they would not be able to establish a friendship with a robot that expresses emotions (Q5), they would feel nervous if they had to obey an order given by a robot (Q6), or if they depended on a robot to perform tasks (Q8). For the question "I would feel uncomfortable if I was given a job where I have to interact with robots" (Q4), participants were undecided about their response. This questionnaire also revealed that participants are undecided about the influence of robots could have on children (Q9) and about the domain of the robots in the future (Q10). Finally, participants agreed that they would not like if the robots were able to make judgments about different subjects (Q7).

c. Emotion Recognition task

Regarding the ability of the participants' correct recognition of the emotions expressed by the virtual robot, the results revealed that the success rate was 46%. This result was significantly higher than the results obtained in the pilot study (33%). However, these results were not comparable since two emotions (i.e., trust and anticipation) from the pilot study were removed, and the virtual robot has been reprogrammed. Figure 10.7 represents the percentage of correct answers for each of the six presented emotions.

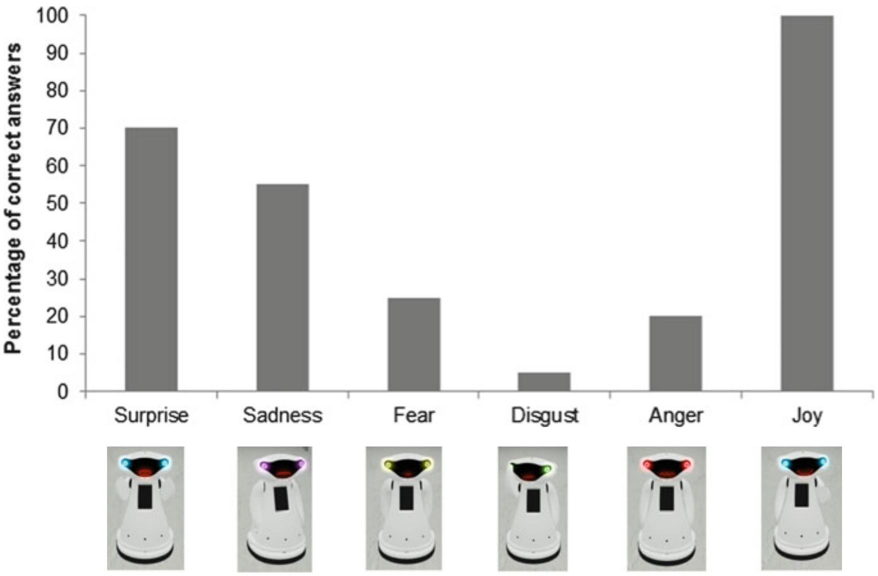


Fig. 10.7 Percentage of correct responses for each emotion for Experiment 1

The emotion joy had a 100% success rate, i.e., all 20 participants recognized correctly this emotion. The other two emotions that also had a higher success rate were surprise (70%) and sadness (55%). Fear was correctly recognized in 25% of the cases and anger in 20% (which represents an improvement in relation to the pilot study result). Additionally, the emotion disgust had a low success rate (5%).

As mentioned before, participants could choose an emotion from 16 possible (6 target emotions and 6 distracting emotions) and also had the option "none". Regarding the association between the displayed emotions and the emotions listed, we found that participants identified some emotions from these distracting ones. In this sense, the emotion surprise was wrongly recognized in 20% of the cases as despair, anxiety, anticipation or trust, and 2 participants selected the option "none". Despite this false recognition, surprise was the second most easily recognized emotion.

Besides, sadness was confused in 30% of cases with fear, which can be explained by the fact that the robot performed a backward movement which might have represented fear. This emotion was still confused in 5% of the cases with shame and 10% with disgust.

Fear was confused in 35% of cases with shame, which may be explained with the backward movement made by the robot and with a fast and rhythmic head shaking (i.e. disagree). In 30% of cases, the participants selected the option "none" or despair, and anxiety or surprise in 10% of cases. This distribution of participants' responses by different options reveals the difficulty experienced in recognizing emotion.

Disgust was confused with shame in 70% and fear in 15% of cases. This result may be due to the fact that the robot raised an arm to hide the face. This arm movement was intended to simulate repulsed by something but could be confused with shame or fear, because it might look like the robot was hiding from something or someone. In 10% of cases, the participants chose the option "none" or contempt.

Anger was confused in 50% of cases with despair and in 25% of cases with fear. This result may be due to the fact that the robot moved quickly from one side to the other which may mean despair like the robot did not know what to do. On the other hand, this rapid movement could be interpreted as being to flee from something (i.e., fear). In the remaining 5% of cases, the participants chose the option anxiety.

d. Perception Scale of the Virtual Model

In this questionnaire, the participants revealed that they would have felt comfortable to interact with the displayed robot (Q1) and they would have liked to have the robot at home (Q2). Participants also revealed that they felt sorry if they had to destroy the robot (Q3) which suggested that an empathic relationship with the robot was established. About the gender of the robot, 75% of participants said that the robot did not have a defined gender, and 20% reported that it was male. Finally, most of the participants suggested that the function of the robot was to help humans in housework.

It was possible to understand, compared to the pilot study, that some emotions, particularly anger, had a higher success rate of recognition. However, success rates remained low, especially for fear, anger, and disgust. This result reinforced the need to continue to make changes to the virtual robot in order to improve the correct recognition.

10.5 Experiment 2

Some of the emotions expressed by the virtual robot in experiment 1 were not correctly recognized. The low success rate for the emotions anger, disgust and fear can be an example of this. In this sense, in experiment 2, our objective was to make some changes in the programming of these emotions in the virtual robot and to test if these changed increased the success rates.

10.5.1 Participants

The sample consisted of 20 students, 11 (55%) were females and 9 (45%) were male. The ages of participants varied between 18 and 27 years ($M = 20.95$, $SD = 2.16$). As in the previous experiment, the participants were volunteers and did not receive course credits or any monetary compensation for participating in this study.

10.5.2 Stimuli and Materials

The same VE, virtual robot, questionnaire and emotions from Experiment 1 were used.

In terms of emotions, some changes were done in the virtual robot. In this sense, the emotion fear has changed the shape of the mouth and the robot moves backward and slightly to the left side. Regarding the emotion disgust, the arm movement was removed (in the previous version the right arm of the robot was raised parallel to its head) and the shape of the mouth was changed. In the emotion sadness the movement of the robot was removed, that is, the robot had only facial expressions (the same as in Experiment 1). Finally, in the emotion anger, the shape of the mouth was changed to simulate the existence of teeth. The robot raised both arms simultaneously at the level of the head and the robot moved from one side to the other. Figure 10.8 shows the expression of the six basic emotions by the virtual robot in a static manner.

10.5.3 Procedure

Similar to Experiment 1.

Fig. 10.8 Static images of the six target emotions with facial expressions and body movements for Experiment 2

10.5.4 Results and Discussion

Same data analysis was applied as previously in Experiment 1. Fifteen out of the 20 participants mentioned they had never been in contact with a social robot before participating in this experiment.

a. Technological Attitude Scale

On this scale, most participants declared that they liked to explore new technological devices (Q1), while they revealed to be undecided about their technological knowledge (Q2). As in Experiment 1, participants revealed that they could have imagined having a social robot at home (Q3) however they were undecided in relation to the question "I would like to have a social robot to help me" (Q4). Most participants agreed that they were afraid that robots could be used for bad purposes (Q5), but they would have liked to test new robots (Q6), and they agreed that social robots were useful (Q7).

b. Perception Scale about Robots

In this questionnaire, participants revealed that would have felt comfortable if robots expressed emotions (Q1) or if they had to interact with a robot during work (Q4).

However, participants proved to be undecided in the response to questions “Something wrong could happen if the robots have artificial intelligence” (Q2), “I would feel comfortable speaking with a robot “ (Q3), and “I would feel nervous if I had to obey an order given by a robot in front of other people” (Q6). The results of this questionnaire revealed that participants would be able to establish a friendly relationship with the robots if they had emotions (Q5), they liked the robots that were able to make judgments (Q7), and they did not feel nervous if they were dependent on a robot to perform tasks (Q8). Finally, participants said they worried about the robots could influence children badly (Q9), and they were convinced that society would be dominated by robots in the future (Q10).

c. Emotion Recognition task

The success rate for the recognition of emotions expressed by the virtual robot was 51% on average. Figure 10.9 shows the percentage of correct answers for each of the six presented emotions.

As for the emotions joy and surprise, no changes were made since a similar success rate was expected as Experiment 1. This hypothesis was confirmed with the joy getting a success rate of 95% and surprise getting 70% of success. Regarding sadness, it was possible to observe an increase in the success rate (85%) when compared with the result of Experiment 1 (46%).

Anger also increased in success rate (40%) when compared with Experiment 1 (20%). However, participants confused anger with despair in 40% of cases, which can be due to the robot’s movement from one side of the wall to the other. This may indicate some level of despair. In the remaining 20% of cases, participants confused anger with fear (10%), anxiety (5%) or contempt (5%).

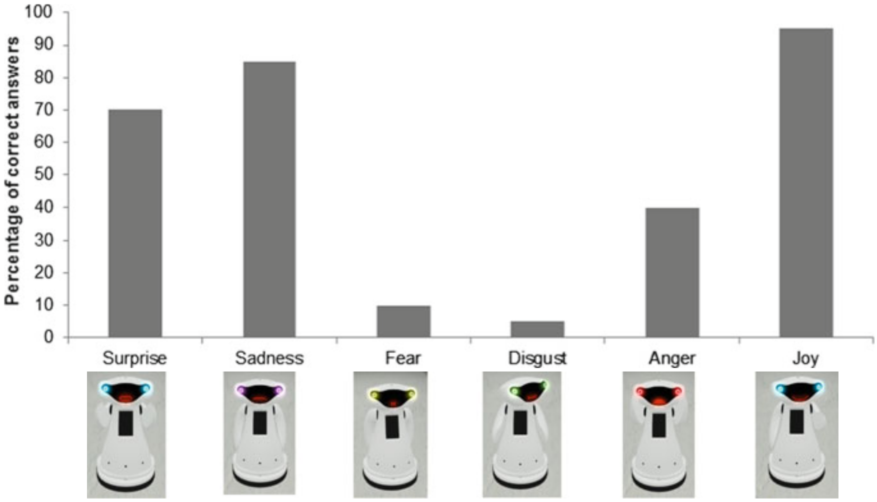


Fig. 10.9 Percentage of correct responses for each emotion for Experiment 2

On the other hand, the results for the recognition of fear decreased in success rate in Experiment 2 (10%) compared with Experiment 1 (25%). In 80% of cases, participants confused fear with shame. This result may be due to the movement that the robot makes to one side of the wall. Participants interpreted the robot's movement as hiding from something or someone as if the robot did something wrong. This result revealed the clear need to implement new changes in the virtual robot to make the recognition of this emotion easier. Some participants suggested that the eye color should be changed from yellow to white, and the motion should be changed. In this sense, it has been suggested by participants that the robot should move backward instead of moving to the side. However, this was the movement that the robot was in Experiment 1, and as verified then, the success rate was also low (25%). this shows that the difficulty in recognizing fear was not only related to the movement, but more changes and tests are required.

Finally, despite the changes made in the expression of disgust, the success rate remained very low (5%) as in Experiment 1. Participants confused disgust with all other emotions, except joy, anger and trust: sadness (5%), despair (5%), surprise (5%), anticipation (5%), fear (5%), anxiety (10%), shame (15%), and contempt (25%). In the remaining 20% of the cases, the participants chose the option "none". The fact that the participants indiscriminately chose other emotions, without any pattern, was indicative of the difficulty in recognizing the emotion disgust.

d. Perception Scale of the Virtual Model

In this questionnaire, the results of Experiment 1 were replicated, i.e., the participants showed that they would have felt comfortable to interact with the displayed robot (Q1) and they would have liked to have the robot at home (Q2). Participants also revealed that they would have felt sorry if they had to destroy the robot (Q3). Regarding the gender of the robot 80% of participants said that the robot does not have gender, and 20% reported that it is male. Once again, the participants suggested that the function of the robot was to help humans in housework.

10.6 Conclusion

The expression of emotions allows humans to communicate their internal states to others that through empathic responses understand and react adequately to their needs. Cañamero (2005) discussed that modeling emotions in robots can offer several valuable contributions to emotion research regarding human perception of emotions although the field is still in its infancy. Thereby, the main objective of this study was to design the emotions expressed by a social robot and test the correct recognition of participants when they interact with the virtual robot. For this purpose, a pre-experiment was done in order to design and program the emotions for the virtual robot. Then, a pilot study was performed to understand whether the 8 emotions programmed into the virtual robot model were correctly recognized by the participants. The results showed that some emotions were easily recognized (e.g., joy) while others had a very low recognition rate (e.g., disgust, anger). In this sense, taking into account the feedback from participants in the pilot study and the experience of the research team, some changes were done in the robot's expressions. One of the changes was theoretical in which the next two experiments would use Ekman's theory of emotions because the facial expressions for the six basic emotions in humans are well documented in the literature and this could be an important help to design the emotion representation of the robot.

These two experiments were conducted to make changes in the expressions of low recognized emotions in the virtual robot, and to test if these changes increased the success rates of recognition. The results showed that the emotions that have higher correct recognitions were joy, surprise, and sadness. Moreover, fear, disgust, and anger were emotions with lower success rates. For these three emotions, several changes were done, though, participants always revealed that they were hard to recognize correctly. However, it is important to note that the success rate for anger increased significantly between Experiment 1 (20%) and Experiment 2 (40%). This means that changes made to the virtual robot worked as expected. It should also be noted that participants confused anger with despair, which may be due to the robot's movement which had signs from other emotions as well.

Furthermore, relative to disgust, some studies with humans have shown some problems in its correct recognition (e.g., Bullock and Russell 1984; Widen and Russell 2008; Panksepp 2007). Between humans, the recognition of that emotion is difficult, therefore, between human and robot, it should be expected to be even harder since a robot has more limitations in terms of facial expressions and body movements than a human while expressing an emotion. Especially in this case of study, the virtual robot has several limitations: it was only possible to change the intensity of light and the color of the eyes; light on/off LEDs panel to draw the mouth; move arms up/down; move forward/backward, left/right. Also, usually, in humans, the expression of disgust involves the act of spitting (e.g., Widen and Russell 2008), and this expression is impossible to program in the robot, because of the limitations, mentioned above.

Regarding fear, the success rate in Experiment 1 was higher than in Experiment 2. The difference between the two experiments was the robot's body movement. While in Experiment 1 the robot walked back simulating moving away for something, in Experiment 2 it moved to the left side in the direction of the wall. However, in Experiment 1 the success rate was higher than in Experiment 2, but it was still low (25%). Therefore, the movement of the virtual robot was also more problematic than the facial expression in this emotion as well.

Also, it is worth to mention that in many projects with robots, the recognition of fear in facial expressions tends to be the most difficult (Fairchild et al. 2009; Saldien et al. 2010). Since the robot had the most limitations related to face, it was expected to have a lower rate in correct recognition.

During the study, the robot was presented in a neutral context and it expressed all the emotions in sequence. However, in a real context, emotions arise in response to a stimulus, person or event in a given context, in a specific moment (e.g., Ekman 1999; Frijda 1986; Lazarus 1999). All these circumstances are clues to the correct recognition of emotions. Due to the limitations, the robot could not express all the emotions successfully by using its facial expressions and body movements. However, a given context, and/or a scenario could help the success rate go higher for lower rated emotions. In this sense, it is important that in future studies, the virtual robot is presented in a context, accompanied by a narrative that allows participants to contextualize each emotion. Besides, further study is needed for body movements and displacement for the robot in particular emotions (i.e., disgust, fear, and anger).

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Part V

Future Developments

Chapter 11
Artificial Intelligence in Human-Robot Interaction

Edirlei Soares de Lima and Bruno Feijó

Abstract Human-Robot Interaction challenges the field of research on Artificial Intelligence in many ways, especially regarding the complexity of the physical world. While physical interactions require Artificial Intelligence techniques to handle dynamic, nondeterministic, and partially unknown environments, the communication with humans requires socially acceptable responses and common-sense knowledge to handle a broad variety of situations with complex semantics to interpret and understand. In the context of emotional design, different Artificial Intelligence techniques are necessary to allow robots to express, understand, and induce emotions as part of the interaction process. This chapter explores Human-Robot Interaction from the Artificial Intelligence point of view, presenting the main challenges, techniques, and our particular vision for future developments in this research area.

Keywords Artificial intelligence · Robotics · Human-robot interaction · Machine learning

11.1 Introduction

In the emotional design of Human-Robot Interaction, we should consider the connections that can form between humans and robots, and the emotions that can arise from them. In this context, the most central technological question is the intelligence of the machines. What is Artificial Intelligence and what are its limitations?

Over the last decades, Artificial Intelligence (AI) has emerged into the public view as an important frontier of technological innovation with potential influences in many areas. The first use of the term Artificial Intelligence is attributed to John McCarthy, who created the term in his 1955 proposal for the 1956 Dartmouth Conference (Russell and Norvig 2009), which is considered the seminal event for Artificial Intelligence as a field. Today, applications of Artificial Intelligence are all around us

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(virtual assistants, recommendation systems, robotics arms in assembly lines) and there are more to come in the near future (autonomous vehicles, autonomous drone delivery services, robot assistants, etc.).

The term Artificial Intelligence can have different definitions depending on the context and the intended application. The English Oxford Dictionary defines it as "the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages." (Stevenson 2010). A more general definition is given by the Merriam-Webster dictionary: "a branch of computer science dealing with the simulation of intelligent behavior in computers." (Merriam-Webster 2016). Similarly, The Encyclopedia Britannica states that AI is "the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings." (Encyclopedia Britannica 2003). However, all these definitions do not consider the fact that intelligence itself is not very well defined or understood.

In general, Artificial Intelligence can still be considered a young discipline, and its structure, concerns, and methods are less clearly defined than those of more mature sciences (such as physics).

Many different disciplines contributed to the development and establishment of the field of research on Artificial Intelligence, including Philosophy, Mathematics, Psychology, Neuroscience, Linguistics, and Computer Engineering. The general goal of the research on Artificial Intelligence is to create the technology necessary for computers to work in an intelligent manner. Over the past years, several techniques have been proposed and successfully applied for a variety of different tasks, such as market analysis, medical diagnosis, speech recognition, simulation, training, weather forecasting, emotion analysis, facial recognition, and robotics.

There are many approaches and methods to creating intelligent systems, including search and optimization, logic and planning, probabilistic reasoning, and machine learning. Some approaches are becoming synonyms of AI, such as machine learning, which gives computers the ability to learn without being explicitly programmed to solve a specific problem (Russell and Norvig 2009). Machine learning techniques are employed in a vast range of computing tasks, where designing and programming explicit algorithms with good performance is difficult or infeasible (Mitchell 1997).

Human-Robot Interaction represents a challenge for the field of research on AI (Lemaignan et al. 2017). Most classical AI techniques were not designed to handle the dynamic, nondeterministic, and partially unknown environments of the physical world. Over the last decades, the most successful applications of robots were limited to simple tasks that involve predictable situations (e.g., packaging, welding, and spray painting). Robot automation obtained a huge commercial success because it is usually applied to highly repetitive processes that hardly vary and require little dexterity, such as those done in industrial plants. However, physical interactions and communication with humans require socially acceptable responses and common-sense knowledge to handle a broad variety of situations with complex semantics to interpret and understand.

Robots that interact with humans are very different than those used in assembly lines: they require more intelligent behavior than simply following a set of instructions to complete repetitive tasks. As a result, robotics is moving into areas where sensor input becomes increasingly important and the AI must be robust enough to anticipate and handle a range of different situations (Thrun et al. 2005). Robotics, thus, is increasingly becoming a software science, where the goal is to develop robust software that enables robots to handle the challenges that arise when dealing with complex and dynamic environments.

Human-Robot Interaction requires intelligent robots able to recognize, understand, and participate in communication situations, both explicit (e.g., the human addresses verbally the robot) and implicit (e.g., the human points to an object). In addition, an intelligent robot must be able to take part in joint actions, both proactively (by planning and proposing resulting plans to the human) and reactively (by following the human instructions) (Lemaignan et al. 2017). All these actions must be complemented with the robot's ability to move and act in a safe, efficient, and legible way, considering all social rules relevant to the situation. This kind of behavior requires more than just AI algorithms; it requires support from Psychology, Philosophy, Interaction studies, and General computer engineering.

11.2 Artificial Intelligence in Robotics

From the Artificial Intelligence point of view, robots are physical agents that perform tasks by manipulating the physical world (Russell and Norvig 2009). They are equipped with effectors (e.g., legs, wheels, joints, and grippers) and sensors (e.g., cameras, lasers gyroscopes, and accelerometers). While the sensors allow the robot to perceive the environment, effectors are used to asserting physical forces on the environment.

In the physical world, robots must interact with environments that are partially observable, nondeterministic, dynamic, continuous, and multiagent. Partial observability, continuously, and non-determinism are the result of dealing with a large and complex world. Most robot sensors cannot see around corners, and motion commands are subject to uncertainty due to gear slipping and friction (i.e., it is not possible to guarantee that all planned actions will have the desired results). The physical world is also dynamic, so it can change while the robot is planning or performing an action, which requires real-time responses from the robot. In addition, some robots can interact with other robots or with humans, which adds the multiagent characteristic to the environment.

Figure 11.1 illustrates a general robot interaction process. First, the robot sensors capture raw signals from the environment (e.g., visual signals, audio signals, and tactile signals). Then, feature extraction methods are used to obtain meaningful data from the raw signals. Based on the extracted features, Artificial Intelligence and Computer Vision techniques are performed to procedure a semantic understanding of the current situation (e.g., object recognition, object tracking, and emotion recognition). With this information, the robot can plan and perform the most appropriated actions, such as movements, gestures, and speech.

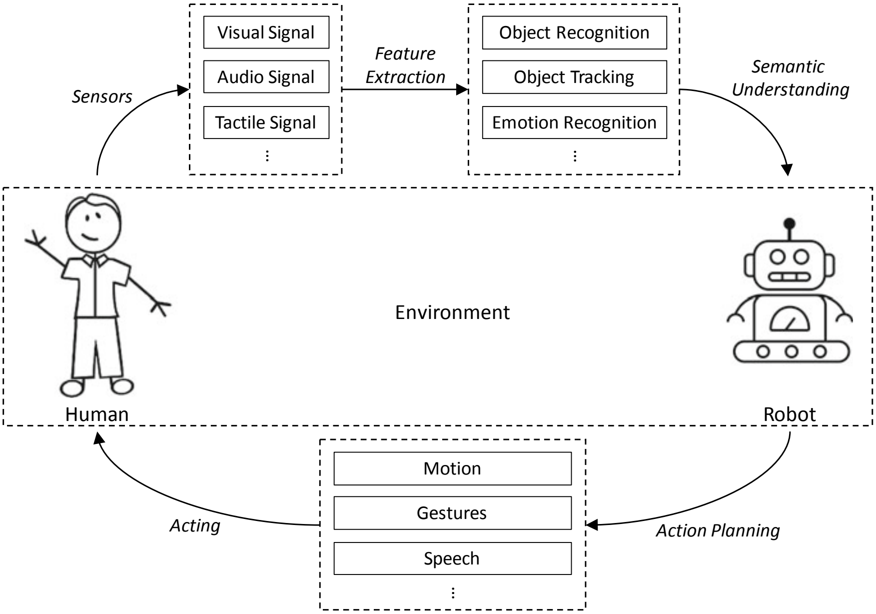

Fig. 11.1 General robot interaction process

Perception is one of the key elements when designing robots that interact with complex environments (Russell and Norvig 2009). It consists of the process of mapping sensor measurements into internal representations of the environment. The perception process can be divided into two steps: (1) feature extraction, which has the objective of converting the raw signals from sensors to feature descriptors for subsequent understanding tasks; and (2) semantic understanding, which aims at inferring the objects or human behaviors from the extracted features. Typical semantic understanding tasks include object detection and recognition, human tracking and identification, speech recognition, emotion recognition, and touching detection and recognition.

One of the most basic perceptions a robot requires is localization, which is used to determine where things are in the environment (including the robot itself). This kind of knowledge is the key element of any successful physical interaction with the environment (Thrun et al. 2005). For example, robot manipulators must know the location of objects they seek to manipulate, navigating robots must know where they are to find their way around, and assistant robots must know where their human subjects are.

Localization has received a lot of research attention in the past decades and, as a result, significant advances have been made on this front. The most common method used to determine the position of the robot in the environment is called Monte Carlo localization (MCL) (Dellaert et al. 1999). The MCL algorithm estimates the position and orientation of a robot as it moves and senses the environment (Thrun et al. 2005). The algorithm uses a particle filter to represent the distribution of likely states (each particle represents a possible state, that is a hypothesis of where the robot is). Initially, the particles are uniformly distributed based on prior knowledge. Whenever the robot moves and senses something new, the particles are resampled using a recursive Bayesian estimation (Berger 1985). This process repeats until all the particles converge toward the actual position of the robot. In some situations, no map of the environment is available. In these cases, the robot must acquire a map while navigating through the environment. This problem is known as simultaneous localization and mapping (SLAM) (Thrun and Leonard 2008). Usually, this problem is solved using probabilistic techniques, including the extended Kalman filter (Jetto et al. 1999).

Not all robot perceptions are about localization. Social robots also need to recognize objects, identify humans, recognize gestures, track subjects, recognize emotions, and so on. Motivated by the fact that most information received by human beings are visual signals (Castleman 1996), most robot systems use visual signals to simulate human-like perceptions (Yan et al. 2014). Most of these visual signals are usually obtained using traditional or stereographic camera sensors. Then, Computer Vision techniques are used to extract meaningful information from the captured images.

Different tasks usually require different features and specific techniques to extract them. The field of research on Computer Vision provides a vast repertory of techniques for feature extraction, including color, texture, shape, and motion. Color can be used to detect objects with distinct color components (Khan et al. 2012). It can also be used to efficiently detect human skin and identify the presence of human subjects (Darrell et al. 2000; Wang et al. 2008). However, color can be easily affected by illumination conditions, which requires special treatment. Visual texture is another important property for object and face detection. The Local Binary Pattern (LBP) (Wang and He 1990; Ojala et al. 1996) and the Scale Invariant Feature Transform (SIFT) (Lowe 1999) are both popular texture descriptors for feature representation that have been widely used in object recognition, robotic navigation, video tracking, and image matching. The shape is also a useful feature for visual signal representation, especially for facial image analysis and human detection. Popular shape descriptors include the snake model (Kass et al. 1988), which can capture features like lines and edges; and the Hu descriptors (Hu 1962), which are based on non-orthogonalized central moments that are invariant to image rotation, translation, and scale. Another important visual feature is motion, which is widely used for object tracking. Optical flow is a typical motion feature that represents the distribution of velocities of brightness patterns' movement in an image (Horn and Schunck 1981; Brox et al. 2004; Bab-Hadiashar and Suter 1998).

Motivated by the fact that speech is an important communication channel for human beings, audio signals are also an important source of information for robots that interact with human subjects. By analyzing the collected audio signals, robots can acquire more information related to their interaction subjects, such as their positions, commands, and emotional states (Yan et al. 2014). In addition, audio signals are essential to establish a communication channel between humans and robots through speech recognition and speech synthesis.

With all relevant features extracted from the sensors' signals, semantic understanding tasks must be performed in order to generate semantic knowledge to be used by the robot to plan future actions. For these tasks, Artificial Intelligence techniques—especially machine learning methods—are essential for general solutions. While some simple tasks can be solved only with Computer Vision techniques (such as human tracking), most of the semantic understanding tasks require machine learning algorithms (e.g., object recognition, emotion recognition, human identification).

11.3 Machine Learning

Machine learning tasks are typically classified into three categories, depending on the type of data available to the system: supervised learning, unsupervised learning, and reinforcement learning (Russell and Norvig 2009). In supervised learning tasks, the system learns a function that maps an input (features describing an instance of a problem) to an output (the correct answer for the instance of the problem) based on examples of input–output pairs. There are several algorithms for supervised machine learning, including artificial neural networks (Priddy and Keller 2005), decision trees (Rokach and Maimon 2014), support vector machines (Steinwart and Christmann 2008), k-nearest neighbors (Altman 2012), etc. In contrast, unsupervised learning tasks require from the system the ability to learn patterns in the input even though no explicit output is supplied. Algorithms for unsupervised learning include clustering methods (Aggarwal and Reddy 2013), artificial neural networks, and latent variable models (Loehlin 1998). In reinforcement learning tasks, the system learns from a series of reinforcements (rewards or punishments). The system does not know which actions to take, but instead, it must discover which actions yield the highest rewards by trying them. Algorithms for reinforcement learning include Q-learning (Watkins and Dayan 1992) and State-Action-Reward-State-Action (Szepesvári 2010).

Artificial Neural Network is a very popular machine learning algorithm used in robotics for a variety of tasks. Inspired by the biological neural networks that constitute biological brains (Russell and Norvig 2009), artificial neural networks comprise several artificial neurons interconnected with each other to form a network with input, hidden, and output layers (Fig. 11.2). Neural networks "learn" by example and can be trained to extract patterns and detect trends.[1]

Over the last years, several works explored the use of neural networks to solve robotic tasks. Seemann et al. (2004) presented a method for estimating a person's head pose using neural networks trained with grayscale and disparity images from a stereo camera. Ge et al. (2011) described a neural network to estimate human motion intention based on the desired trajectory in human limb model. Yin and Xie

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[1] In a nutshell, given a set of training points (x_i, y_i), a system that learns by example tries to find a function f that maps a given x to its corresponding y (within a certain error tolerance). In a neural network, this function is represented by numerical weights associated with each node. During training, these numbers are continually adjusted until training data with the same labels consistently yielding similar outputs.

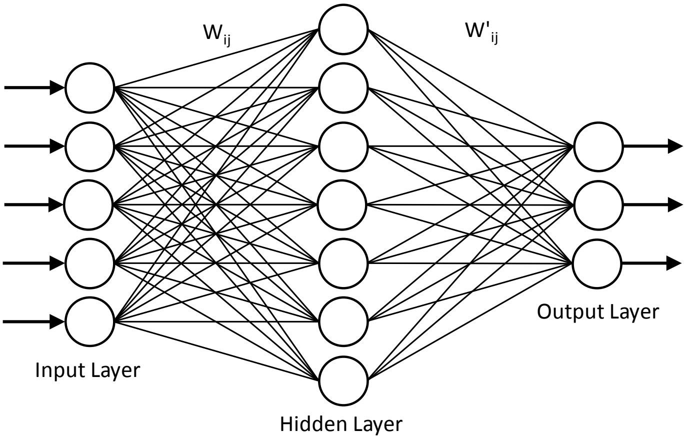

Fig. 11.2 Structure of an artificial neural network. Each neuron is connected to all neurons in the next layer and each connection has a numeric weight (W_{ij} and W'_{ij}) that determines the strength and sign of the connection

(2007) proposed a hand posture recognition system for humanoid robots that uses neural networks trained with topological features extracted from the silhouette of the segmented hand. Ito et al. (2006) used a dynamic neural network model to allow a small humanoid robot to learn object handling behaviors. Other authors proposed solutions for general problems that also exist in robotics using neural networks. Maturana and Scherer (2015) proposed a real-time object recognition method that uses a supervised 3D convolutional neural network capable of recognizing hundreds of objects per second. Bhatti et al. (2004) presented a language-independent emotion recognition system for the identification of human affective state in the speech signal using a neural network. Lawrence et al. (1997) presented a hybrid neural network for human face recognition that combines local image sampling, a self-organizing map neural network, and a convolutional neural network.

11.4 Future Developments

Future developments in Artificial Intelligence in HRI should be mainly driven by breakthroughs in deep learning. However, a realistic assessment and a solid understanding of these new possibilities require a review of the core of what Artificial Intelligence means and what are its most challenging problems.

If we take the claimed goal of AI seriously—i.e., the production of AI—then we shall specify the most important features of intelligence. There is no consensus in the AI community about the most adequate theory of intelligence, mainly because this depends on the context. For the purposes of the present writing, we can assume that intelligent behavior arises from the ability to learn, to adapt behavior to new and challenging environments, and to be creative.[2] Alternatively, we can suppose that intelligent behavior arises from the balance of the following abilities: (i) the ability to evaluate, analyze, and compare information; (ii) the ability to generate invention and discovery; (iii) the ability to apply what have been learned in the appropriate situation. This is exactly the Triarchic Theory of Successful Intelligence proposed by Cianciolo and Sternberg (2008). However, no matter which intelligence theory we adopt, the challenge of producing Artificial Intelligence is enormous.

The story of AI consists of successes and failures, ups and downs, abundance and scarcity of investments.[3] From a theoretical viewpoint, this story is marked by the rivalry between two lines of thought: *logic-based AI* (also known as *logicism* or *symbolic AI*) and *machine learning* (mainly, artificial neural networks). In the first line, cognition involves operations on symbols. In contrast, neural networks exhibit intelligent behavior without processing on symbolic expressions.

Logicism was the predominant theory within the AI community until the mid-1980s, when neural networks, genetic algorithms, and other machine learning paradigms started producing impressive results. Currently, in the late 2010s, after almost 20 years of experiencing slow development, AI innovation has exploded and deep learning (mainly in the form of neural networks) has been dominating the AI scenario.

A deep learning algorithm (also known as hierarchical learning) attempts to learn in multiple levels, corresponding to different levels of abstraction. Deep learning requires extremely large datasets (called big data), which are complex sets to process, manage, and maintain. Furthermore, current deep learning models also require training datasets that are labeled (i.e., data that have been classified or categorized by humans).

Deep learning typically uses artificial neural networks leading to the so-called deep neural networks (DNNs). In a DNN, there are multiple layers to process features, and generally, each layer extracts some piece of information. In this architecture, higher level features are defined in terms of lower level ones. Deep neural networks can have hundreds of millions of parameters (LeCun et al. 2015), allowing them to model complex functions such as nonlinear dynamics. They form compact representations of states from raw, high-dimensional, multimodal sensor data commonly found in robotic systems.

The current burst of AI advances occurred due to the emergence of powerful GPUs (Graphics Processing Units) [4] being used for complex computations of deep learning models, and the availability of big data. Deep learning has achieved astonishing performance in many complex tasks like language translation (Wu et al. 2016),

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[2] Apart from being "creative", this is totally aligned with early psychological theories, such as the one by Edward Thorndike in the very ending of the nineteenth century (Thorndike 1911), which are one of the first references on learning mentioned by researchers of artificial neural networks (also known as connectionists) (Knight 2017; Ertugrul and Tagluk 2017).

[3] A fun but complete and accurate history of AI until the early 1990s can be found in Crevier (1993).

[4] GPUs are designed for rendering graphics by having a large number of simple process units for massively parallel calculation. However, we can use GPUs to perform any sort of computation (e.g., deep learning computation). We can use multiple GPUs to increase processing power.

strategic games playing (Silver et al. 2016), and self-driving cars (Bojarski et al. 2016). Although deep learning has been successful in perception and classification problems, it is far from solving real reasoning problems. The next AI revolution is when *deep reasoning* becomes effective. Cognitive robots[5] rely not only on deep learning but also on deep reasoning. Deep reasoning is required for cognitive tasks, such as common sense, dealing with changing situations, planning, remembering, and making complex decisions. Robots and other Artificial Intelligent systems are still far from real deep reasoning. Yet there are even more complex issues that current technology cannot deal with, such as *consciousness* (especially the ability to obtain and process information about ourselves) and *ethics*. An interesting approach to machine consciousness can be found in Dehaene et al. (2017). The present authors believe that logicism and machine learning should cooperate with each other to deal with these challenging questions and the situation of AI safety in general. A deep discussion about AI safety is presented in Amodei et al. (2016).

While disruptive solutions for deep reasoning are yet to come, important improvements in deep learning can be pursued: (i) to train systems on less data ("small data"); (ii) to use unlabeled training datasets (unsupervised learning); and (iii) to open the black box of deep learning systems—the interpretability problem (Lipton 2017). These subjects are somewhat intertwined, and we may envisage a future system that can attain rapid learning from small unlabeled data and, in case of an accident, can track down the cause.

The use of small data is necessary not only because developing AI systems using big data is a costly and time-consuming task (or because extremely large sets of data are not available in many domains) but also because an AI system must quickly adapt to single unexpected observations. Many situations require rapid inference from small quantities of data. As pointed by some researchers of Google DeepMind (Santoro et al. 2016): "in the limit of 'one-shot learning', single observations should result in abrupt shifts in behavior." The use of statistical models (e.g., Gaussian process and Bayesian optimization) to deal with the problems of small data and interpretability have been reported by the media (Metz 2017). In a different approach to interpretability, a recent work by Google Brain explains how a deep neural network can make decisions by combining feature visualization (*what is a neuron looking for?*) with attribution (*how does it affect the output?*) (Olah et al. 2018).

The second research direction mentioned above efers to the use of raw, unlabeled data to train AI systems with little or no human intervention (known as unsupervised learning). The use of massive labeled dataset training presents many drawbacks: it is costly, consumes time, and introduces human bias into the systems (either unintentionally or caused by malicious attackers). One of the first experiments with large-scale unsupervised learning was presented by Google and Stanford University (Le et al. 2012). We can reduce the use of labeled data if we use *transfer learning*, a technique in which the first layers of a network are a copy of the first layers of another network (Yosinski et al. 2014).

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[5] Cognitive robots, different from industrial robots, are robots that reason, remember, learn, anticipate, plan, and communicate with humans and with each other.

The next AI breakthrough can be driven by new hardware currently under development. The two most promising new hardware paradigms are *neuromorphic chips* and *quantum computing*, according to current media reports (Knight 2018).

A review of deep learning in robotics can be found in Pierson and Gashler (2017). These authors argue that large training data, long training times and unsupervised learning for critical robotic systems[6] are the main barriers to the adoption of deep learning in robotics. They also claim that a promising perspective is crowdsourcing training data via *cloud robotics* (Pratt 2015). However, as we have mentioned in the present section, advances in small data, unsupervised learning, and interpretability can also lower the barriers to adoption of deep learning in robotics.

As far as HRI is concerned, deep learning is of ultimate importance for communication and assistance. For example, deep neural networks can recognize spontaneous emotional expressions (Barros et al. 2015), which is essential for Human-Robot Interaction. Assistance has been considered a premium goal in AI systems, in the sense that AI should be used to augment human intelligence. In this case, we should create user interfaces that let us work with the representations inside machine learning models (Carter and Nielsen 2017). As a general prognosis, future developments in AI systems must maintain a strong adherence to the concept of creating an interactive and intelligent conversation between a human and a machine.

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[6] Such as aerial vehicles, where a single failure is catastrophic.

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