

UNIVERSITÉ PARIS-SACLAY

DOCTORAL THESIS

ED n° 575 INTERFACES

Field of Study: Informatics

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# Lifelong Learning, Adaptation, and Adjustability for Personalized Human-Robot Interaction

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Thesis defended at Palaiseau, DAY Month 2017

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# Declaration of Authorship

I, Arturo CRUZ-MAYA, declare that this thesis titled, “Lifelong Learning, Adaptation, and Adjustability for Personalized Human-Robot Interaction ” and the work presented in it are my own. I confirm that:

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- Where I have consulted the published work of others, this is always clearly attributed.
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- I have acknowledged all main sources of help.
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*“Thanks to my solid academic training, today I can write hundreds of words on virtually any topic without possessing a shred of information, which is how I got a good job in journalism.”*

Dave Barry



## Abstract

Doctor of Philosophy

by Arturo CRUZ-MAYA

[illegible]





## Resume

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# *Acknowledgements*

The acknowledgments and the people to thank go here, don't forget to include your project advisor. . .



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# List of Abbreviations

**LAH** List Abbreviations **Here**  
**WSF** What (it) **Stands For**



*For/Dedicated to/To my...*





# Chapter 1

## Introduction

### 1.1 Companion Robots

About companion robots, their purpose.

### 1.2 Robot Adaptation in Human Robot Interaction

About lifelong learning, adaptation and adjustability.

### 1.3 Motivation and Existing Problems

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### 1.4 Major Contributions

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## **1.5 Thesis organization**

## Chapter 2

# Theoretical Foundations

The first step in answering my research question, "How to achieve lifelong learning, adaptation, and adjustability for personalized Human-Robot Interaction?", was to do a research on the Human-Human interaction literature.

In this chapter I will present the theories in which this work is based. This is of great importance in aim of the thesis question in order to integrate different paradigms in a robotic system, which is intended to interact with people in their everyday life.

I will begin by examining the most known Behavior Theories, which have been proposed by the psychology field by many years so far. I then explain the Personality Theories. As there are many models in the literature about personality traits, I chosed the Big Five Personality Trait. I will explain each of these topics, arguing that these theories and model were the most suitable approach to provide answers to my research question.

After explaining the models of personality, I will describe the Social Cognitive Theory, and how this helped to define the different parts of our framework.

I will follow by briefly explaining the main Emotion Theories, describing the Non-Cognitive Theories and the Cognitive Theories, arguing that the Cognitive approach is more suitable for the purpose of this work. This decision leads to another decision, about the cognitive emotion model to use, I chosed the OCC Model, which I will describe, as well as the reason why I used this specific model.

Also, another topic of vital importance for a system of lifelong learning is the memory system, for which I will mention the diferent kinds of memory that are known. I then will focus on the Episodic Memory to explain how it works and why I used this memory on the proposed framework.

## 2.1 Behavior Theories

The aim of this work is to create a framework to achieve a longterm Human-Robot interaction. For this reason, the robot would have to adapt to its users. Nevertheless, the human nature presents differences between one individual to another. Each person has different preferences, then, a robotic behavior that can be seen as a good behavior for one person, can be seen as a bad behavior for another person.

As social entities, we tend to treat computers and other medias as if they were also social entities, as stated by Reeves and Nass in the Media Equation (Reeves and Nass, 1997). In certain occasions we talk to computers even if they do not understand us. This happens because of our need to communicate in a natural way. This would be accentuated by robots who have a body and can talk to us. Then, if we want to achieve a natural interaction between humans and robots, we should need to base our work on the study of human behavior.

The problem of understanding human behavior have been studied for many years by the field of Psychology. One of the first attempts to explain human behavior was done by Freud, in his the psychoanalysis theory and his studies on the unconscious (Freud, 1915), Freud compare the mind as an iceberg, where in the surface is the conscious mind, below of that is found the preconscious, which are the thoughts that can be retrieved by memory, and finally, the biggest region is the unconscious mind, where are found all our internal desires and primitive wishes, which govern our basic behavior.

Another theory of human behavior, called behaviorism, was developed by John Watson in his article "Psychology as behaviorist views it" (Watson, 1913). This theory, rejects the idea of the consciousness and focus on observable behavior, which can be measureable in an objective way.

Behaviorism was detracted by other researchers, who stated that using experiments with humans creates an artificial environment and low ecological validity, this approach is called Humanistic psychology, which also states that humans can make their own decisions and do not follow a deterministic approach (Rogers, 1963).

Gordon Allport was one of the first psychologists who developed a personality trait theory (Allport, 1937). This approach states that a person can be described by terms called traits. A trait can be seen as a behavior pattern that keeps constant through space and time. The combination of different traits and the different degrees of these, is what gives to an individual an specific

personality. I will describe this theory in section 2.1.1

Other grand theory of human behavior is the Cognitivism theory, also called Social Cognitive Theory, was developed by Albert Bandura (Bandura, 1989), this theory focuses on the mental process of learning and the dynamic interplay between person, behavior and environment. I will explain this theory in more detail in the section 2.1.2.

### 2.1.1 Personality Trait Theories

We decided to focus on this group of theories because it gives a categorization of different kinds of personalities, and at the same time provides a differentiation between individuals. Also, this has been widely studied before in the field of Human-Computer Interaction (HCI), in order to provide with personality to virtual agents (e.g. André et al., 2000, Allbeck and Badler, 2002, Egges, Kshirsagar, and Magnenat-Thalmann, 2004). In social robotics, this has been also a topic of interest to provide robots with a personality that best fit with their users (e.g. Woods et al., 2005, Tapus, Țăpuș, and Matarić, 2008, Hendriks et al., 2011).

The personality trait theory has evolved with the pass of the years. I will briefly explain some of the most recognized theories in this domain.

One of the first models of personality traits, is the Gordon Allport's Trait Theory, this theory classify the traits in three classes: Cardinal traits, Central traits, and Secondary traits. According with this theory, Cardinal traits are the traits that are developed by a person (i.e. kindness, greedy, honesty). Central traits are seen as common to all people and we have different degrees of them (i.e. friendliness, generosity, anxiety). Secondary traits are considered to be related with attitudes or preferences and only appear under certain situations. The total number of traits was of over 4000.

Eysenck proposed a model of only 3 personality trait (Eysenck, 1953): Introversion/Extroversion, Neuroticism/Emotional stability, and Psychoticism. This model was critized for using a small sample and only self reporting as source.

Raymond Cattell reduced the number of traits from 4000 to 16 using factor analysis using different sources, he also developed a questionnaire to measure these 16 traits, called the Sixteen Personality Factor Questionnaire (16PF, Cattell, 1957).

A model emerged from these previous ones, called The Five Factor Theory of Personality, also called the Big Five personality trait. This model has

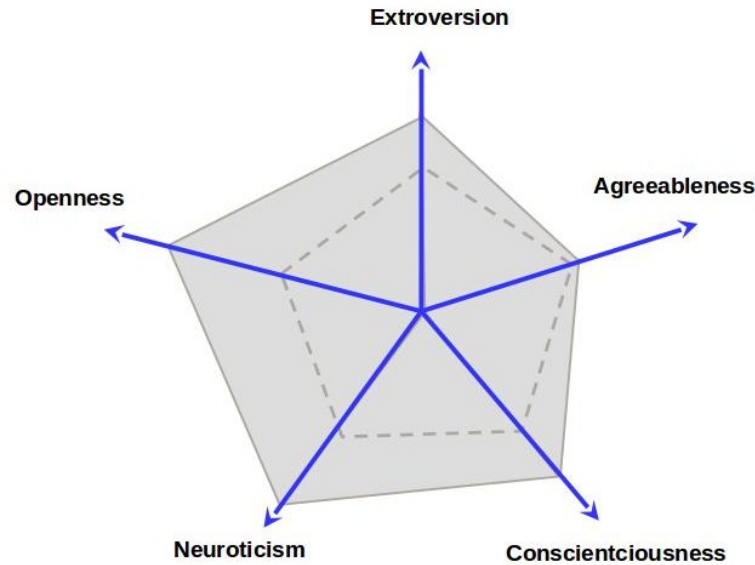


FIGURE 2.1: Big Five Personality Trait

5 traits: Extroversion, Neuroticism, Agreeableness, Conscientiousness, and Openness. I will describe this model in more detail in the following section.

### Big Five Personality Trait

The first researcher who argued the existence of 5 traits of personality was Fiske (Fiske, 1949), after that, a number of researchers have converged to the existence of 5 orthogonal factors (Norman, 1963, Goldberg, 1993, Digman, 1996). Even when there is no general consensus on a definitive theory of personality, this theory is the more accepted in the contemporary literature.

Researchers, who defend this theory, state that any reasonable large sample of English trait adjectives will elicit a variant of the Big Five factor structure, and then, all such terms can be represented within this model. It is important to note that each trait can be seen as a dimension, each dimension has to facets, and each facet represent a group of adjectives. An example of the uniqueness of a personality, conformed by the five traits of this model, can be seen in Fig. 2.1.

This model is also sometimes called OCEAN by the initials of the traits. In the following I will list some of the adjectives grouped on each trait.

- Openness (Intellect):
  - High Openness: Intellectuality, depth, insight, intelligence, creativity, curiosity, sophistication.

- Low Openness: Shallowness, unimaginativeness, imperceptiveness, stupidity.
- Conscientiousness:
  - High Conscientiousness: Organization, efficiency, dependability, precision, persistence, caution, punctuality, Decisiveness.
  - Low Conscientiousness: Desorganization, negligence, inconsistency, forgetfulness, indecisiveness.
- Extroversion (Surgency):
  - High Extroversion (Extroversion): Playfulness, expressiveness, spontaneity, talkativeness, animation, courage, optimism.
  - Low Extroversion (Introversion): Silence, reserve, shyness, inhibition, passivity, lethargy, pessimism.
- Agreeableness:
  - High Agreeableness: Cooperation, amiability, empathy, generosity, courtesy, flexibility, modesty.
  - Low Agreeableness: Belligerence, bossiness, cruelty, pomposity, irritability, prejudice, volatility.
- Neuroticism (Emotional Stability):
  - High Neuroticism: Insecurity, fear, instability, emotionality, envy, gullibility, intrusiveness.
  - Low Neuroticism: Placidity, independence.

A self-reported questionnaire, to measure the five personality traits of this model, was proposed by John and Srivastava, which consisted of 44 items in a likert scale from 1-5 (John and Srivastava, 1999), such questionnaire has been used (or modifications of this) to perform numerous experiments on personality traits in social sciences and also in social robotics.

### 2.1.2 Social Cognitive Theory

In the last section, I described the personality traits theories, which explain the differences and similarities between different individuals. Nevertheless, these theories do not explain how these differences are generated. For this

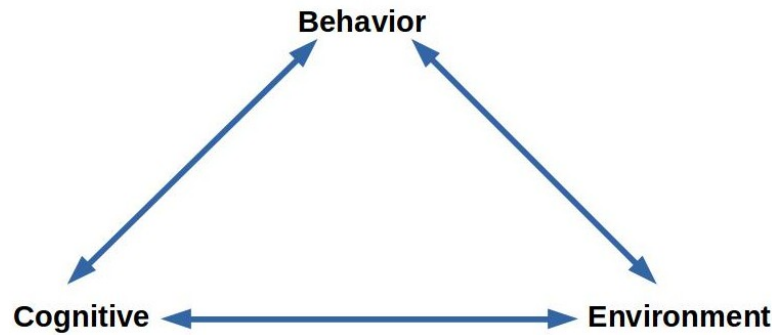


FIGURE 2.2: Triadic reciprocal determinism

reason, we include a theory that attempts to give a reason of the differences on behaviors between individuals.

This theory sees the human development as a life-long process, where diversity in social practices produces substantial individual differences in the developed capabilities and the ones that remain underdeveloped (Bandura, 2011).

Social Cognitive Theory presents a model of a triadic reciprocal determinism (see Fig. 2.2), where cognition and other personal factors, behavior, and environment, all influences each other bidirectionally, operating as interacting determinants. This interactions can have different strenghts, and occur in different times.

Persons are characterized in terms of basic capabilities, which are mentioned below:

- **Symbolizing Capability:** Humans have the capacity to process external information thanks to the capacity to use symbols. Cognitive factors partly determine in which events we will focus, the related meaning and emotional impact, and how we will organize and use this information on the future.
- **Specialized Cognitive Competencies:** Different domains of activity have different structures. Social factors play an influencial role in cognitive development, because of the rapid growth of knowledege, human acquisition of specialized cognitive competencies relies on modeled expertise.
- **Vicarious Capability (Observational learning):** Much social learning occurs by observing the behavior of others and the consequences for them.



- Forethought capability: People not simply react to their immediate environment, nor are restricted by past experiences. Most human behavior, is regulated by forethought. People motivates themselves and guide their actions anticipatorily.
- Self-regulatory Capability: Sucessful socialization requires the presence of internal controls and direction. People possess self directive capabilities that give them some control over their thoughts, feelings, and actions.
- Self-reflective Capability: This capability allow humans to analyze their experiences and to think about their own thought processes. This characteristic acts like a mechanism of adaptation of the thoughts, judging the results of ideas and adequating the thoughts accordingly.

This theory, was of great help to integrate the elements of our framework for a robotic system in a social context, even if we don't create specific subsystems for each human capability of the model. For the symbolizing capability, we need a memory system wich also can be combined with the forethought capability, to learn from experiences and adapt the behavior of the robot in future actions. Also an emotion system linked with the memory system is of great importance. The specialized cognitive competences, can be represented by the different task the robot can do, also the information about each user personality and how to act accordingly.

In the following section I will explain some of the main theories of emotion and the one we used in our framework.

## 2.2 Emotion Theories

For many years, psychologists have been trying to decide what are the emotions and what are their roles, which remain as open questions until our days. Many theories of emotions has been proposed (For a review, see Moors, 2009), which can be grouped in two categories: Cognitive theories, and Non-Cognitive theories.

### 2.2.1 Non-Cognitive Theories

This group of theories was first developed by two authors independently, William James and Carl Lange (James, 1884 , Lange, 1885). They stated that

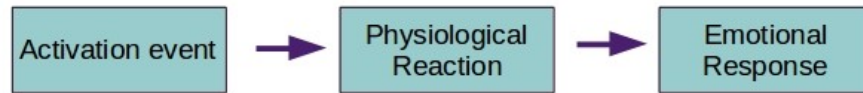


FIGURE 2.3: James-Lange Theory

an emotional experience is a mental state of bodily response to external stimulus (i.e. "we feel afraid because our body trembles because of a bear"). Williams James considered the emotion as the feeling of the bodily changes that follow the perception of an exciting fact (see Fig.2.3). Lange argued that if we remove of all the bodily sensations, there is nothing left of the emotion, only pure rational knowledge of the event that caused the emotion.

Posteriorly, Paul Ekman developed what is considered the standard of the Non-Cognitive process of emotions. Ekman adopted an evolutionary point of view, where a group of six emotions (happiness, sadness, fear, anger, disgust, and surprise) that he called "basic emotions" (Ekman, 1992), evolved in response to ecological conditions, and each emotion is linked with a specific neurological circuit. Accordingly to Ekman, the characteristics which distinguish these basic emotions are: Distinctive universal signals, distinctive physiology, quick onset, automatic appraisal, brief duration, unbidden occurrence, distinctive thoughts, and distinctive subjective experience. Also, Ekman stated that each of these basic emotion can be distinguished by different facial expressions (Ekman and Oster, 1979).

### 2.2.2 Cognitive Theories

This group of theories states that emotions are a cognitive process. The precursors of this theories are Walter Cannon and Philip Bard, today known as Cannon-Bard Theory (see Fig. 2.4). They stated that we feel emotions and experience physiological reactions at the same time. This theory emerged as a critic of the James-Lange Theory (Cannon, 1927). Cannon proposed that emotions can be experienced even when physiological reactions are not present, and also that different emotions can present similar reactions (like increasing heartbeat in response to fear or anger).

Other cognitive theory is the Schachter-Singer Theory (also known as two-factor). This theory proposes that physiological arousal occurs first, but these reactions are often similar to different emotions, then such reactions should be cognitively labeled as a specific emotion (Schachter and Singer, 1962).

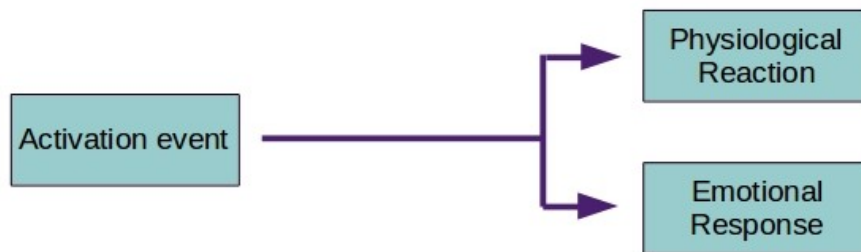


FIGURE 2.4: Cannon-Bard Theory

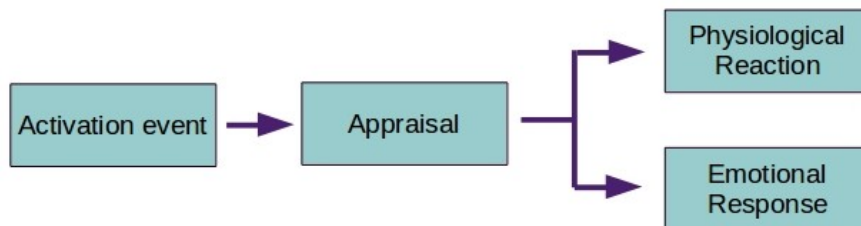


FIGURE 2.5: Cognitive-Mediational Theory

Richard Lazarus proposed the Cognitive-Mediational Theory (Lazarus, 1991), where the appraisal mediates between the stimulus and the emotional response (see Fig. 2.5). This appraisal is the interpretation we give to a particular situation, it can be good or bad, and can be different in different people. Also, Lazarus, distinguish two types of appraisal: 1) primary appraisal, which try to give a meaning to an event, and 2) secondary appraisal, which is the ability to deal with the consequences of an event.

A contemporany theory is the one of Antonio Damasio, called by him the somatic marker hypothesis (Damasio, Everitt, and Bishop, 1996), he states that the emotion process starts with the perception of an stimulus, which provokes a cognitive evaluation, and this generates a bodily response, followed by a perception of a certain body activity (see Fig. 2.6). Also, Damasio proposes a link between the cognitive evaluation and the perception of activity in the body, called as-if-loop (as if the body were active).

Damasio

## OCC Model

## 2.3 Learning and Memory

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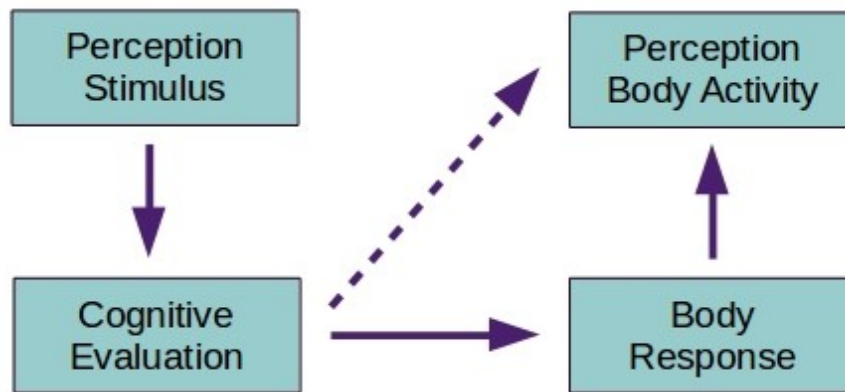


FIGURE 2.6: Damasio's Theory

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### 2.3.1 Memory Types

#### Episodic Memory

## 2.4 Conclusion

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## Chapter 3

# State of the Art

### 3.1 Robots with personality

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### 3.2 Robots showing emotions

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### 3.3 Robots with Episodic-Memory

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### 3.4 Conclusion and Horizon

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## Chapter 4

# Intregating a Framework for Human-Robot Interaction

### 4.1 Social Issues of Human-Robot Interaction

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#### 4.1.1 Social Facilitation

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### 4.2 Choosing an Emotion Model for the Robot

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### 4.3 Giving an Episodic-Memory to the Robot

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### 4.4 Testing the Framework in a Game-Like Scenario

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### 4.5 Contributions and Conclusion

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## Chapter 5

# Need of a User Pattern for a Personalized Interaction

### 5.1 Choosing a Personality Model

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### 5.2 Differences between Introverts and Extroverts

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### 5.3 Differences between People with High Conscientiousness and People with Low Conscientiousness

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### 5.4 Study-Case: Office-Like Scenario with a Robot Giving Reminders

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### 5.5 Contributions and Conclusion

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## Chapter 6

# Effects of Stress and Personality in Human-Robot Interaction

### 6.1 Robots Used for Teaching

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### 6.2 Multimedia Learning

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### 6.3 Neuroticism Trait Related with Learning

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## 6.4 Study-Case: Teaching Nutrition by using Multimedia with a Robot

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## 6.5 Contributions and Conclusion

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## Chapter 7

# Predicting Users Preferences using Personality and Gender

### 7.1 Similarity Atraction Theory

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### 7.2 Complementary Needs Theory

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### 7.3 Learning a Model of Users Preferences of Robot Behavior

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### **7.3.1 Chosing the Features to Create the Model**

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### **7.3.2 Configuring the Episodic Memory**

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### **7.3.3 Adapting the OCC Model**

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## **7.4 Study-Case: Learning Users' Preferences and using them with New Users**

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## 7.5 Contributions and Conclusion

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## Chapter 8

# Conclusion

### 8.1 Our Contributions

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#### 8.1.1 A Framework for Human-Robot Interaction

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### 8.2 Limits and Future Work

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## Appendix A

# Evaluation Documents

### A.1 Big Five Questionnaire

The color of links can be changed to your liking using:

```
\hypersetup{urlcolor=red}, or
\hypersetup{citecolor=green}, or
\hypersetup{allcolor=blue}.
```

If you want to completely hide the links, you can use:

```
\hypersetup{allcolors=.}, or even better:
\hypersetup{hidelinks}.
```

If you want to have obvious links in the PDF but not the printed text, use:

```
\hypersetup{colorlinks=false}.
```

### A.2 Game-Like Scenario Post-Questionnaire

The color of links can be changed to your liking using:

### A.3 Office-Like Scenario Post-Questionnaires

The color of links can be changed to your liking using:

### A.4 Multimedia Scenario Post-Questionnaire

The color of links can be changed to your liking using:

### A.5 Learning Users' Preferences Post-Questionnaire

The color of links can be changed to your liking using:



## **Appendix B**

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