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Companion Robots Behaving with Style

Towards Plasticity in Social Human-Robot Interaction

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"Les conduites des individus se caracterisent à la fois par leur plasticité et par leur unité."

Michel Huteau [Huteau, 1987]

"Individuals' behaviours are caracterised by both their plasticity and unicity."

Michel Huteau Translated by Wafa Johal

Résumé

De nos jours, les robots compagnons présentent de réelles capacités et fonctionnalités. Leurs acceptabilité dans nos habitats est cependant toujours un objet d'étude du fait que les motivations et la valeur du compagnonnage entre robot et enfant n'ont pas encore été établies. Classiquement, les robots sociaux avaient des comportements génériques qui ne prenaient pas en compte les différences inter-individuelles. De plus en plus de travaux en Interaction Humain-Robot se penchent sur la personnalisation du compagnon. Personnalisation et contrôle du compagnon permettraient en effet une meilleure compréhension de ses comportements par l'utilisateur. Proposer une palette d'expressions du compagnon jouant un rôle social permettrait à l'utilisateur de "customiser" leur compagnon en fonction de leur préférences.

Dans ce travail, nous proposons un système de plasticité pour l'interaction humain-robot. Nous utilisons une méthode de Design Basé-Scenario pour expliciter les rôles sociaux attendus des robots compagnons. Puis, en nous appuyant sur la littérature de plusieurs disciplines, nous proposons de représenter ces variations de comportements d'un robot compagnon par les styles comportementaux. Les styles comportementaux sont définis en fonction du rôle social et grâce à des paramètres d'expressivité non-verbaux. Ces paramètres (statiques, dynamiques et décorateurs) permettent de transformer des mouvements dit neutres en mouvements stylés. Nous avons mené une étude basée sur des vidéos, qui montraient deux robots avec des mouvements stylés, afin d'évaluer l'expressivité de deux styles parentaux par deux types de robots. Les résultats montrent que les participants étaient capables de différentier les styles en termes de dominance et d'autorité, en accord avec la théorie en psychologie sur ces styles. Nous avons constaté que le style préféré par les parents n'était pas corrélé à leur propre style en tant que parents. En conséquence, les styles comportementaux semblent être des outils pertinents pour la personnalisation social du robot compagnon par les parents.

Une seconde expérience, dans un appartement, impliquant 16 enfants dans des interaction enfant-robot, a montré que parents et enfants attendent plutôt d'un robot d'être polyvalent et de pouvoir jouer plusieurs rôle à la maison. Cette étude a aussi montré que les styles comportementaux ont une influence sur l'attitude corporelle des enfants pendant l'interaction avec le robot. Des dimensions classiquement utilisées en communication non-verbale nous ont permises de développer des mesures pour l'interaction enfant-robot, basées sur les données capturées avec un capteur Kinect 2.

Dans cette thèse nous proposons également la modularisation d'une architecture cognitive et affective résultant dans l'architecture Cognitive et Affective orientées Interaction (CAIO) pour l'interaction social humain-robot. Cette architecture a été implémentée en ROS, permettant son utilisation par des robots sociaux. Nous proposons aussi l'implémentation des Stimulus Evaluation Checks (SECs) de [Scherer, 2009] pour deux plateformes robotiques permettant l'expression dynamique d'émotions.

Nous pensons que les styles comportementaux et l'architecture CAIO pourront s'avérer utiles pour l'amélioration de l'acceptabilité et la sociabilité des robot compagnons.

Abstract

Companion robots are technologically and functionally more and more efficient as technological advancement progresses. The capacities and usefulness of companion robots is nowadays a reality. These robots that are now more efficient, are however not accepted yet in home environments as the *worth* having such robots and companionship hasn't been established. Classically, social robots were displaying generic social behaviours and not taking into account inter-individual differences. More and more work in Human-Robot Interaction goes towards the personalisation of the companion. Personalisation and control of the companion could lead to better understanding of the robot's behaviour. Proposing several ways of expression for companion robots playing roles would allow user to customize their companion to their social preferences.

In this work, we propose a plasticity framework for Human-Robot Interaction. We used a Scenario-Based Design method to elicit social roles for companion robots. Then, based on the literature in several disciplines, we propose to depict variations of behaviour of the companion robot with behavioural styles. Behavioural styles are defined according to the social role with non-verbal expressive parameters. The expressive parameters (static, dynamic and decorators) allow to transform neutral motions into styled motions. We conducted a perceptual study through a video-based survey showing two robots displaying different styles allowing us to evaluate the expressibility of two parenting behavioural styles by two kinds of robots. We found that participants were indeed able to discriminate between the styles in terms of dominance and authoritativeness, which is in line with the psychological theory on styles in general. Most importantly, we found that the styles preferred by their parents for their children were not correlated to their own parental practice. Consequently, behavioural styles are relevant cues for social personalisation of the companion robot by parents.

A second experimental study in a natural environment involving child-robot interaction with 16 children showed that parents and children were expected a versatile robot able to play several social role. This study also showed that behavioural styles had an influence on the child's bodily attitudes during the interaction. Common dimensions studied in non-verbal communication allowed us to develop measures for child-robot interaction based on data captured with a Kinect2 sensor.

In this thesis, we also propose a modularisation of a previously proposed affective and cognitive architecture resulting in the new Cognitive, Affective Interaction Oriented (CAIO) architecture. This architecture has been implemented on the ROS framework, allowing it to be used on social robots. We also proposed instantiations of the Stimulus Evaluation Checks of [Scherer, 2009] for two robotic platforms allowing dynamic expression of emotions.

Both behavioural style frameworks and the CAIO architecture can be useful in socialisation of the companion robots and improving their acceptability.

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Chapter 1

Introduction

The research described in this thesis is about the adaptability of a companion robot's behaviours according to the user's social preferences. The underlying assumption of this work is that the social personalisation of the companion's robot behaviour improves the acceptability of the users. The interest in the personalisation of companion robots comes from the assumption that users want a more socially intelligent robot while keeping a certain controllability of their home assistant. It is also assumed that social robots should display comprehensive behaviours for the user - in its decision and expressions. For this, its reasoning processes should be made explicit to the user providing a level of understanding. Customisation of the behaviours on the other hand can improve the user's feedback as well as the controllability of his companion robot. Researchers in Human-Robot Interaction (HRI) have agreed that acceptability in home environments will come only via sociability[1] of the robots.

Human-human communication is a large detailed field of study. Some signals sent between human interlocutors are subconscious while still having been processed by their cognition. Subconsciously, humans emit social signals that shows their intentions and their goals. These abilities are parts of what is called the social intelligence. Several research fields, from human-computer interaction, affective computing, social signal processing, human-robot interaction, human activity recognition etc. are now working on enabling new technologies with social intelligence in order to make them more user-friendly and acceptable. Researchers in HRI [Tapus et al., 2007, Dautenhahn, 2007b] have also noted that robots need not only to be competent in the task but also socially intelligent.

The perspective taken in this thesis is to propose a way for the user to chose the manner their companion robot would behave. This aims to contribute in both

[1] ***Sociability*** *is the ability to perceive, understand and express social cues of communication in a human-understandable way. It is also the ability to create and maintain social relationships; the ability to learn and develop social competencies* [Dautenhahn, 2007b].

acceptability of the companion and to make the relationship and social bounding easier with the companion. In particular, the goal for this thesis is to investigate how the personalisation of the social robot's behaviour in context based on *style* can be designed and evaluated in a realistic context and can contribute to *social adaptability* of the companion robot's behaviour.

The challenge of the social adaptability of a robot's behaviour can be approached from different perspectives. The design of companion robots requires an understanding and a model of the *plasticity* as well as reasoning and developing communicating vector of this adaptation. Our work takes concepts from several disciplines, aiming to benefit from various approaches of plasticity. As the research went along, this work used notions from socio-psychology, cognitive sciences, artificial intelligence and affective reasoning, human-machine interaction, computer sciences and human-robot interaction.

Another focus of research presented in this thesis is to take into account the user's perspective in the development process. Understanding the needs and expectations of a user's interaction with a companion robot and the value and worth of HRI for children has been a constant goal.

From a more technical point of view, the variations in the ways social roles that a social robot has to play can be seen as styles applied to a predefined script. The notion of style and social role are important in this thesis: the robot plays a social role with a particular style in order to fit the social expectations of the user better. A social role is understood as a set of abilities, goals and beliefs of the robot and the style as a way of performing the social role.

1.1 Research Context

As technology develops, there is a tendency of the multiplication of the numerical platforms in home-environments. The new dynamic of the Internet-Of-Things and connected objects have accelerated this phenomenon. Computer devices, tablet or cellphone users haven't yet established a social relationship with them. Creating a social relationship with the numerical devices could help increase trust and quality of life of individuals. Where the users used to see these platforms as tools, they should now be able to exploit these artificial entities and create a social relationship that is trustable, controllable and credible. To this end, this user-tool relationship should evolve into a user-companion relationship, in which the user can count on his companion to care, help and entertain him.

1.1.1 Interactive Robots as Enabling Technologies

Service and social robots are under research since a bit more than a decade. The technology has improved consequently with the minuratisation of motors and new material used in robotics, making robots now smaller and smaller with time.

With the success of some commercial robots and companies selling robots to labs for research, such as Nao, Baxter, PR2 or ICub, the research in HRI starting to focus less on physical appearance and more on the software and the interaction model. New start-up companies have appeared providing software solutions for these commercial robots [2].

Robots have also now been used broadly for educational purposes to teach computer sciences, programming or robotics, but also to assist teachers in their tasks.

As the technological improvements of robots grows, new uses appear. Interactive robotics and companion robots find themselves as a part of new enabling technologies.

Companion robots have a blurry definition:

> ***Companion robots*** *are robots that can make themselves useful, carry out various type of tasks to assist humans in a domestic environment. They should behave socially and interact with a socially acceptable manner with humans* [Dautenhahn et al., 2005].

Several research have suggested characteristics that a social robot should visibly possess [Fong et al., 2003, Dautenhahn, 2007b, Heerink, 2010]:

- Express and perceive emotions
- Communicate with high level dialogue
- Learn and recognise models of other agents
- Establish and maintain social relationships
- Use natural cues of communication
- Exhibit distinctive personality and character
- Learn and develop social competencies

Companion robots are hence characterised by these social competencies that were missing in industrial robots. However these social competencies are far to be mastered by robots in the current state of the art. Even-though the perception and expression of emotion have been improved for the basic emotions, complex emotions are still under research. Robots still display somehow autistic behaviours and some social awkwardness.

1.1.2 Societal applications for social personal robotics

After the era of industrialisation and automation of manufacturing processes, the era of robotisation of service will become crucial in an ageing society. According to a report ordered by the French Labouring Ministry [Bertrand et al., 2013], *home-helpers* is a career in development in our society . Even-though the employment rate in France is high and that the business sector of home-help is recruiting, this carrier suffers from its arduousness and its low carrier evolution perspectives. Activities performed by home-helpers vary from baby sitting, gardening, transportation, cooking, small

[2] for instance http://www.teq.com/jumpstart

nursing acts. However, most of the time, they accompany the ones that need that need the most help in the household.

Several reasons as to why the need for home-helpers is increasing are pointed out by this report. The first is the ageing population and the increasing population of dependant elders. Another reason is the increasing number of divorces, the increasing number of the working women in modern day society. In France, where only 34% of jobs were carried by women in 1962, we saw a recent peak rate becoming 47% in 2007 [Bertrand et al., 2013].

Population in need for home-helpers vary from the elderly, handicaps or families with children. Even if France provides governmental help to finance home-helpers, this solution is often too expensive for most families.

In order to improve home support in the near future times, research in social companion robots promises to potentially bring new affordable solutions to these societal issues. Robots could be a solution to improve such quality of life of families, by for example assisting parents in their parenting roles.

1.1.3 The Social Human-robot Interaction Research Domain

Various conferences are now maturing as the research community around human-robot interaction is growing. The IEEE International Symposium on Robot and Human Interactive Communication (Ro-man) was one of the first conferences specialized on the human-robot interaction research field. Nowadays, many conferences focus, have tracks or special sessions in the domain of Social Human-Robot Interaction, gathering researchers form various scientific background leading together to investigate natural social interactions between humans and robots (conferences such as IROS, RO-MAN, ICSR, HRI, ICRA, CHI ...).

The community is involved in many projects, tackling various issues of human-robot interaction. EMOTE, ACCOMPANY, ALIZ-E, LIREC, DREAMS etc. are the ones from many European funded research projects on human-robot interaction. These numerous projects mark the dawn of assistive technology that will become part of the lives of ageing citizens. Part of this development is to improve the quality of life and the acceptability of personal robots. The MoCA project (in the following Section 1.1.4) focuses on child-companion interaction and the relationship that can emerge from these interactions.

1.1.4 The MoCA Project

The MoCA project is a research project financed by the French National Research Agency (Agence National de la Recherche - ANR), started in October 2012 for 42 months. MoCA stands for My little world of artificial companions (in French : Mon petit Monde de Compagnons Articiels). This project focused on the study of artificial companions (virtual agents, or personal robots) and their values for users in everyday

life. The aim was then to use interactive and intelligent systems to maintain a long-term relationship with the user.

In order to study the inter-operability of the companions, an experimental scenario has been set up: accompanying children at home after school. Each partners of the project contribute scientifically and technically to the project. The consortium on the MoCA project is composed of four laboratories in France: LIG (Grenoble), LAB-STICC (Brittany), LIMSI (Paris) and Telecom ParisTech (Paris). In LIG, the project involved researchers primarily from the team MAGMA, including researchers from the team EIHM for the aspects of plasticity, and the team PIMLIG for the aspects of experimentation. We also worked in close collaboration with the psychologist Michel Dubois (from Laboratoire Interuniversitaire de Psychologie, LIP Grenoble) for his expertise on the acceptability and psychological theories.

1.2 Research Questions

Several research questions are issued from the two objectives stated above. These research questions correspond to the research goals that this thesis aim to address

- Why should companion robots have styles ? (Section 2.3)
- What distinguishes our approach from existing approaches for personalisation? (Section 2.3)
- Given the physical constraints of the robots (e.g., velocity limits, variation in mechanical degrees of freedom), how can this personalisation be carried out?(Chapter 4)
- Can styles (parental) expressed by robots be recognized by parents ? (Chapter 6)
- What is the influence of styles on the children's behaviours? (Chapter 7)
- How can we measure the attitude changing in an interaction with a social robot? (Section 2.6)
- What are the properties of cognitive architectures? (Section 2.4)
- What previous research work is our implementation is based on? (Section 2.5)
- What choices have been made for the implementation ?(Section 5.1)

1.3 Objectives and Contributions

The work of this thesis was conducted under two main projects - the MoCA project and another research project named CAIO within our research team MAGMA of the LIG laboratory.

- Within the MoCA project, this thesis focuses on the plasticity of the companion robots. Plasticity implies the adaptability of the behaviours. The aim was to provide solutions on how companion robots could adapt in order to improve

their values for the users and allow relationship maintenance. According to [Huteau, 1987], the behaviours of individuals are characterised by both their plasticity and their consistency. Behaviours are sensitive to situational and social contexts.

We propose a behavioural style framework based on social roles to generate variations in the expression of the companion in its role. This contribution is founded on psychological theories on style and techniques in computer sciences, human-machine interaction and animation in flexibility and re-usability of style content.

- Our research team has been working on the reasoning and agent dialogue for many years. Social robotics is a recent interest in the team and aimed to gather various aspects of artificial intelligence and multi-agent systems researched in the team. The problem here was to enable research in affective reasoning ([Adam, 2007, Rivière, 2012]) and in social robotics to have a common implementation and a common developmental framework that will allow experimental test in HRI. The objective was hence to allow the emotional reasoning engine previously implemented for virtual agents to be ported into robotic platforms and to re-design the architecture to make it flexible, modular and reusable.

  Our contribution here was to implement modules for the architecture that would reuse the previously implemented reasoning engine. Each reasoning process present in the previous architecture was doted of a Robotic Operating System (ROS)[3] module interface allowing a ROS compatible robot to use this process. In this thesis, we discuss these reasoning process and their theoretical grounding. However, no change was made in their implementation. The contribution was in the modularisation and the ROS interfacing of the already implemented reasoning processes.

1.4 Research methodology

The research methodology is based on classical development of HRI robotic systems. First, an analysis of the literature (in chapter 2) and the user's requirements (in chapter 3) allowed us to set the research problem. A first idea of the model with the social roles is given in chapter 3, along with a first encounter with experimental field with an exploratory study.

Then models to tackle these problems are proposed and the first software development are made (chapter 4 and 5).

The solution proposed is then tested, first with a video-based study (chapter 6) and then in an interactive user experience (chapter 7) where the interaction data

[3] ROS is a middle-ware and software frameworks where processes are set in a graph architecture and each process is a node of this graph.Please see http://www.ros.org/

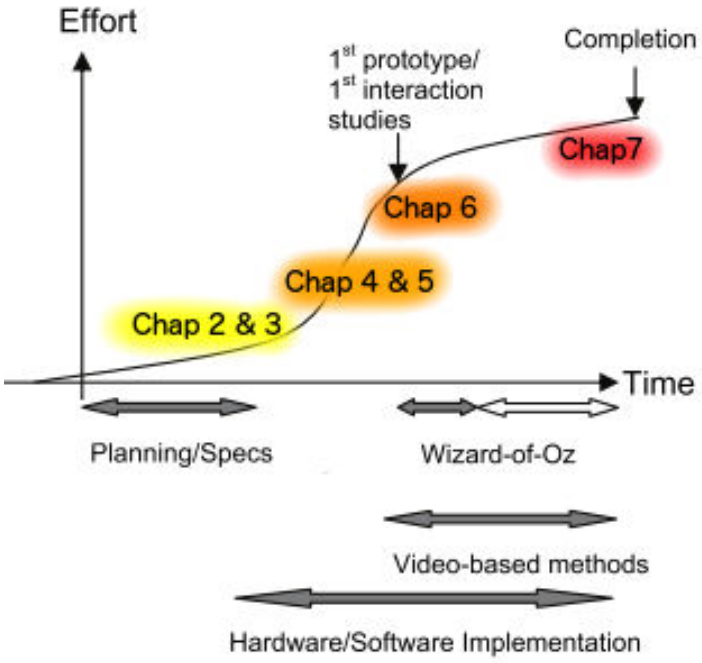


Figure 1.1: Sketch of a typical development time line of HRI robots adapted from [Dautenhahn, 2007a]

were collected. We used the pipeline for development of new technologies and used in HRI [Dautenhahn, 2007a] presented in Figure 1.1. This developmental method is classical and allows us to gradually build a system while maintaining research goals - from analysis to evaluation.

As illustrated in the graph, the last experiment described in chapter 7 required a high effort of development of the scenario from interaction, the design of the protocol, recruiting the participants, to the collecting and the analysing of the data. In order to have more participants, we conducted this experiment during winter holidays. Since then children where free from school, we were able to schedule up to three experiments per day.

1.5 Outline of the Dissertation

This thesis is divided into three core parts based on the intended scientific direction and contribution:

Part I covers background information essential to the technical and empirical work described in later parts. Specifically, in Chapter 2, fundamental results from

the research in human-robot interaction are summarized, describing in detail what is currently known in the adaptability in social robotics. It includes an overview of the current state of the art which is provided with an emphasis on the generation and the evaluation of social behaviours for companion robots. Models of styles in various fields are presented. Chapter 3 presents a first study that enabled us to elicit some social roles for our companion robots for children. It also presents the concept of Plasticity borrowed from research in HCI which helps us to design our adaptable proposition.

Part II provides a description of the model and the technical implementation realized on two robots for styled behaviour filtering. Specifically, in Chapter 5 a system overview is given in the context of already existing modules and the required extensions. Moreover, the main challenges faced when transferring an action generation framework from a virtual agent platform to a physical robot are discussed. In Chapter 4, the filter models for parenting styles conceptualizing the generation of robotic behaviours is described.

Part III introduces the experimental evaluation of the developed framework for styled behaviour generation with two robots. In particular, the set-ups, the hypotheses and the procedures of the two conducted experimental studies are described in Chapters 6 and 7 respectively. The results obtained from an analysis of the collected data from each study are presented and discussed. Finally, Chapter 8 concludes the thesis with a summary and discussion of its contributions, especially in regard to the field of socially interactive robots. The last section of the chapter outlines the scope for future research direction, highlighting desirable extensions to the implemented CAIO architecture and style framework.

Part I

Background

First Part

The first part of this thesis is dedicated to contextualize the contributions relatively to the state-of-the-art and first studies initiating the MoCA Project within which this thesis was done. This part includes the following chapters :

- **The chapter 2** presents a literature analysis of the field of human-robot interaction (HRI) concluding on the need to improve acceptability. We then present how sociability of robots have been improving their **acceptability** but also how user-centred design could improve also acceptability using personalisation. The notion of **style** within different fields used as a tool to customize a particular content is introduced with a view to contextualize our contribution on **behavioural styles** in Chapter 4. An overview of **cognitive architectures** is done in order to contextualize previous works of our research team and improvements made on a cognitive architecture presented in Chapter 5. Finally we present some works in non-verbal expression and non-verbal perception signals used in HRI used for analysing collected data during our experimentation (Chapter 7).
- **The chapter 3** is dedicated to present results from a survey initiating the MoCA Research Project and a first exploratory study that we conducted aiming to elicit social roles for a companion robot for children. This study showed the variability in acceptability by the parents and lead us to focus our research on **personalisation** of the robot's behaviour. Then we present the notion of plasticity in human-computer interaction (HCI) allowing user and context adaptation.

Chapter 2

Related Works

Robots have mainly served in the industry as their primary utility since their usage came about. With development in technology, robots now in our daily lives are taking up roles of assistants or entertainers. Because of these new contexts and the new users that come with it (who are necessarily neither experts, nor programmers) robots need to be able to interact in an intuitive way with them. This implies that the modern day robot has to be able to perceive it's environment and to act accordingly in a humanly acceptable and welcoming manner. We can imagine how robots will be useful to humans in the future, but how they will be accepted in our social lives is still a maturing domain for research. A simple search query of the word "*robots*" in Google Images (left of Fig. 2.1) can show how robots are still seen as either toys or fictional characters. Most images returned were 3D rendered depictions. A search of the phrase "*useful robots*" (right of Fig. 2.1) returns images from either laboratories or films. What we notice is that generally, even if useful robots are physically present in real world scenarios, their absence in users' homes and their daily lives makes us think that they are entities that merely exist as virtual fictional characters. Indeed,

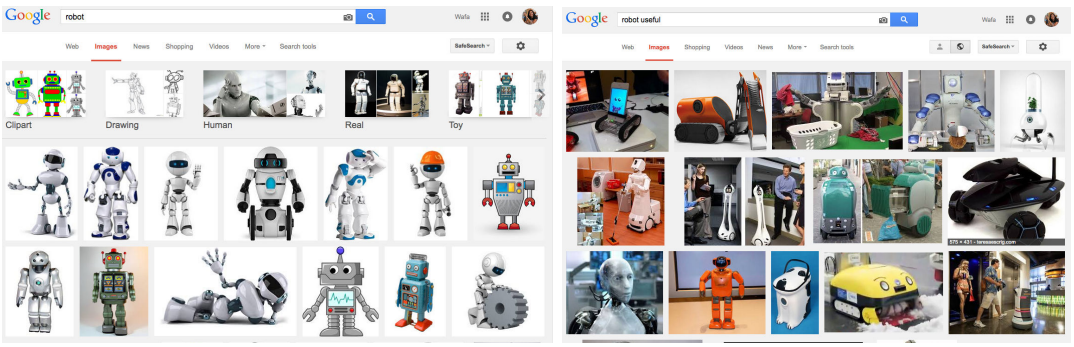


Figure 2.1: Google Searches

as the skills and performance standards of robots increases, their acceptability and actual use still suffers from limitation.

This chapter reviews and discusses concepts and findings relevant to the present research project. Section 2.1 introduces well-known models of acceptability of technologies and acceptability in HRI. Section 2.2 gives research context, definitions and challenges of Social Human-Robot Interaction research field. In Section 3.5 terminology from Human-Computer Interaction relevant to the work outlined in this thesis and important notions such as **plasticity** are introduced. In Section 2.3 the **style** terminology is introduced in tacking several view points from various fields in which this concept is used. Section 2.4 reviews some cognitive architectures commonly referenced in Human-Robot Interaction that will be relevant in the contextualisation of our research team's affective cognitive architecture (Chapter 5). Finally, Section 2.6 is a short review of current works and techniques that are used in Human-Robot Interaction to measure the influence of robot's social behavior on users, specializing in children.

2.1 Towards Worthy and Acceptable Companions

Acceptability is one of the biggest challenges social and assistive robotics is facing these days. Researchers have been working for years to make robots more useful. The deal now is not only to make them easy to use but also *worth*[1] using them.

This section is an overview of theories in acceptability of robotic technologies. This will help us to understand the challenges faced in the making of socially acceptable robots. Some acceptability models that apply to social robotics based on [Heerink, 2010] are introduced here. We will see that the main challenge is in the value and the worthiness of having a social robot. The second part of this section demonstrates how new models of technology design such as the Worth Centred Design can help researchers working on social robotics to tackle problems related to acceptability by focusing on the worth of the user.

Most acceptability models aim to explain users' intentions in the use of the technological systems. These models are predictive and tend to take into account both intentions and behaviours of the user in order to foresee if a new system will be accepted or not.

Before going into the models of acceptability, the definition of the user's acceptance should be introduced. Let us consider the definition given by [Dillon, 2001]: "demonstrable willingness within a user group to employ information technology for the tasks it is designed to support". In other words, acceptability is the result of the factors that induce this willingness. Researchers working on the Acceptability of Technologies aim to determine what these factors are in order to help throughout the design; from conception to evaluation. Hence, the aim in the development of new

[1] Worth in the sense of motivated to be learnt, used and advertise by an individual.

technologies is to guarantee the respect of these acceptability factors. According to [Dillon, 2001], acceptability models also aim to minimise the risk of resistance and rejection by users.

This section of the state-of the art is largely based on the work of [Heerink, 2010] on reviewing acceptance models. One of the older models of acceptability is the Technology Acceptance Model (TAM) proposed by Davis in the 80's. TAM includes a model of the user's motivation which depends on the perceived usefulness, the perceived ease of use and the attitude towards using the robot. Interrelations between these components of user's motivation will result in the actual use of the system or not. The first model of motivation was then quite simplistic and was ignoring the social aspect of technologies. The TAM model has been widely applied, criticized and modified. [Nielsen, 1994] introduced the social aspect in his acceptability model decomposed into social and practical acceptability.

In 2003, a new model, the Unified Theory of Acceptance and Use of Technology (UTAUT) was proposed to combine different models proposed in the past. This new model included a set of new dimensions; in particular social influences and some indirect influences such as the user's age, his gender, his experience and his willingness to use the system. Research in acceptability of technologies and robots is still proposing new models and new factors as a solution to this problem.

New models tend to include factors such as quality of life, funolgy, pleasure, and emotions. For instance the Consumer Acceptance of Technology (CAT) [Kulviwat et al., 2007] model distinguishes between affective (pleasure, arousal or dominance) and cognitive (relative advantages, perceived usability or perceived utility) factors, both of which influence the attitude towards adoption.

However as pointed by [Heerink, 2010], objective and statistical validation of these models can be tricky - especially in the affective and social dimensions. [Heerink, 2010] also highlights the necessity of a deeper analysis of user's behaviour as a clue to the social acceptability [2] of the system along with the influence of the robotic system's behaviour on the users.

More recently, [Graaf, 2015] studies the acceptance of social robots in domestic environments. The author makes some suggestions to develop better companion robots:

- have a clear purpose, with explicit functionalities,
- be sociable to be perceived as more adaptable and hence more valuable,
- consider the fact that user's expectation might change in the long-term (first control, then utilitarian and hedonistic attitudes),
- consider the context of use,
- consider effect of society, familiarisation with these technologies for example,

[2] ***Social acceptance*** *occurs whenever a user feels comfortable with a robot as a conversational partner, finding its social skills credible and accepting social interaction as a way to communicate with the robot* [Heerink, 2010].

- follow the social rules of human-human interpersonal communication to design human-robot communication, as people tend to interact with robots the same way they do with humans,
- increase lifelikeness of robots,
- increasing social interaction, with personality, and more social competences,
- engage emphatically to be better companions,
- and resemble domestic animals for zoomorphic robots.

Modern models of acceptance for social robots tend to include more social aspects to predict the intention of adoption. As designers, we should hence focus on giving these social competences to the robots in order to fulfill the users' expectations. Other works in Human-Computer Interaction have focused on design approaches to tackle the user's acceptance. There is the well-known User-Centred Design that aims to involve the user in all the steps of the systems building - from requirements to evaluation. However, regarding their social needs, it can be difficult to have an access directly through the user. Worth-Centred Design (WCD)[Cockton, 2006, Cockton, 2013] is an approach that tends to model and consider worth in using the system during its design.

WCD takes foundations from Value-Centred Design [Kujala, 2009] that considers **human values** as motivators that play a role in considering the value of technological systems. Cockton recommends to seek for these motivators leading the user to buy, learn, use and also recommend a system. He extols user experience to elicit these motivators. Worth maps are used to summarise links and impacts of systems features on the motivations of the user. Figure 2.2 is an example of worth map for a game given by [Cockton et al., 2009]. In this example of worth map, some features give qualities to the system and from user experiences, motives are derived. User experiences can also lead to aversions. In this example, when the user experiences loss too many times, he can lose interest in the system.

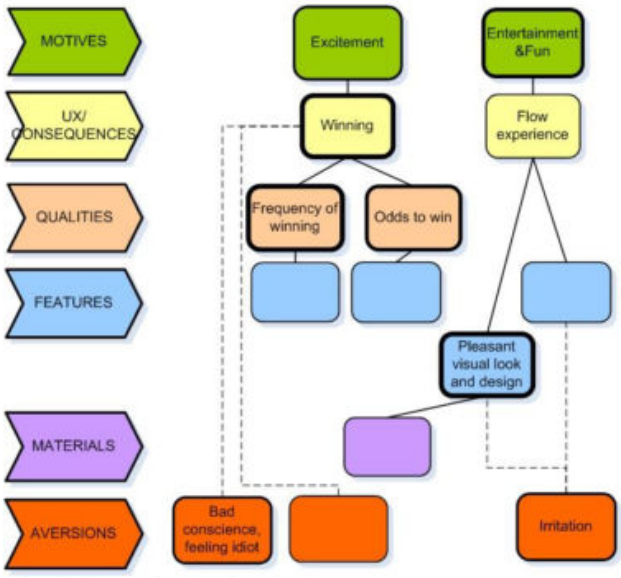


Figure 2.2: Worth Map Example from [Cockton et al., 2009]

The Worth Centred Design method is still very tough to put into practice and necessitates many iterations of development and long user experiences to elicit the

actual motivators. It also highlights the fact that some outcomes from usage were often not expected by developers and that predicted motivators might not match actual motivators after a longer usage of the system, leading to an aversion of the system by the user.

Beyond acceptability, companion robots need to be able to establish and maintain social relationships with their users. The next section aims to expose some key concepts of social robotics with some definitions and some related works on robots with personality.

2.2 Social Human-Robot Interaction

In order to accommodate the user, many research projects have attempted to enable the robot to display social behaviours. The adaptation to the user is also called **personalisation**. This section gives a review of some works on personalisation in HRI. The customisation of the robot's appearance will not be reviewed because it is out of the scope of this thesis eventhought 3D printed robots such as Poppy[3] make appearance customisation now possible.

In Human-Computer Interaction, two kinds of personalisation systems are distinguished [Fischer and Fischer, 2001, Oppermann, 1997], the ones that automatically and dynamically change according to the user, also called **user adaptive systems**, and the ones that can be changed by the user himself, also called **user adaptable systems**.

The term personalisation is also used in other types of research projects in which robots are given a social presence - a name, a story, a past, for example. We won't consider these works in this classification as we believe that a better term to qualify these works would be personification and not personalisation.

The main difference between the two types of personalisation - **adaptive** and **adaptable** - is the control on the adaptation process. In the adaptive systems, the changes in the systems to adapt itself are seamless to the user's view, whereas, in adaptable systems, the user is the actor of the changes.

Another dimension of the analysis of personalisation is the nature of the changes in the system. The robot can either adapt to the users social characteristics (such as emotional tendency, mood, personality) and preferences (i.e. human values) or to the users abilities (i.e. performance in a specific task, vocabulary to age, school grade). We propose to classify personalisation systems in HRI on two dimensions as illustrated in the figure 2.3: according to the control of the adaptation (system vs user) and the nature of the adaptation (social vs ability/task performance).

- **socially adaptive**: the system adapts itself by detecting and inferring the social preferences of the user by collecting data.

[3]Poppy is an open source 3D printed robot created within the Flowers research team at INRIA Bordeauxhttps://www.poppy-project.org/technologies/

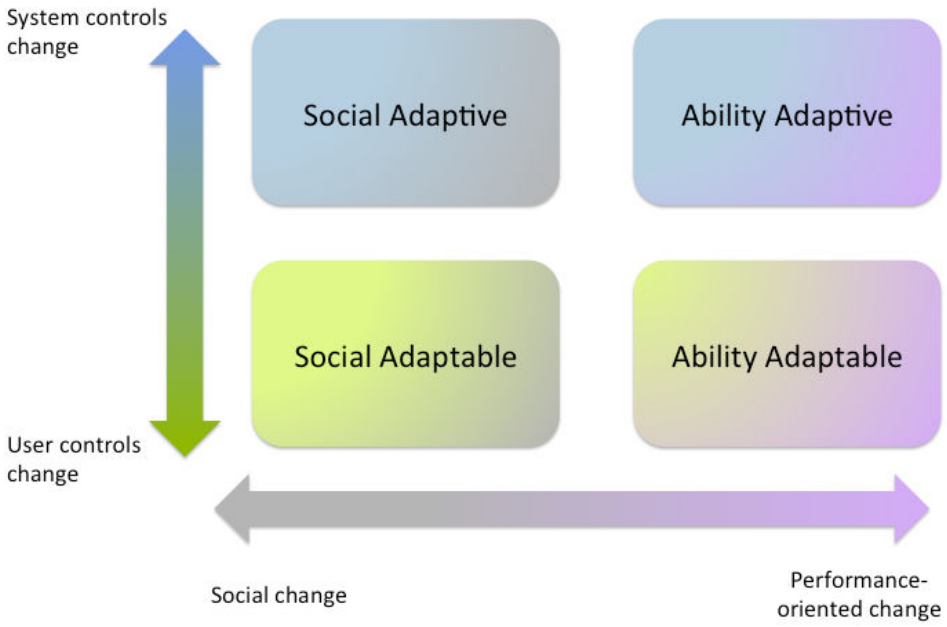


Figure 2.3: Categories of Personalisation in HRI

- **socially adaptable**: the user defines his preferences explicitly to the system.
- **ability adaptive**: the systems adapt itself by learning from interactions and inferring the difficulty of the task according to the user's performances.
- **ability adaptable**: the users sets the difficulty by choosing the levels himself.

These different types can be combined. For instance a teacher robot could first ask user's input to set his social preferences (cultural language sets as French for instance) and then update the user model according to performances, which would be a form of ability-adaptive and social-adaptable personalisation. In the following part, we will present examples of works on personalisation in HRI.

2.2.1 Personalized systems in HRI

There have been various works on personalisation in HRI. Individual differences are often observed in user studies in HRI. Personalisation can be a tool to adapt to the user's own ability and to his social preferences. Personalisation plays a role for long-term relationship credibility, social competences and persuasion.

[Lee et al., 2012] proposed a method in which authors combined several forms of personalisation in a long-term study. In this study, authors used personification, adaptive and adaptable personalisation tools and concluded that personalisation improved engagement, cooperation and relationship between the participants and the robot and saw personalisation has a promising area of research in HRI. This

study showed that personalisation was beneficial for HRI but they do not provide a framework or profiles of users.

From the results of the study of [Jones et al., 2013] within the LIREC project on teachers perspective to have a robotic tutor to assist them, personalisation turned out to be a very important requirement. Other research projects have highlighted this need for personalisation - the SERA[4] project for instance, keen for personalisation, user or task tailoring. Some research works have shown that personalisation can improve the user's engagement in the task ([Corrigan et al., 2013]) and the robot's competencies as perceived by the user [Fasola and Mataric, 2012a].

In [François et al., 2007], authors proposed a **socially adaptive** robot that adapts its behaviour to the user's interaction styles. Authors collect data during the interaction and infer an interaction style. These works highlighted one of the difficulties in adaptive systems which being the collection of less noisy and more relevant data and the delay required for optimum socially adaptation. [François et al., 2009] improved this delay in further research but this method is still limited by the time of interaction (the more interaction, the better adaptation). Some other works [Castro-Gonzalez et al., 2011] on learning user's preferences in term of interaction styles showed that it to be possible using Reinforcement Learning but also concluded that it would require long interactions with a larger pool of participants to determine the correct **socially adaptive** behaviour for the robot.

Personalisation has proved in previous research to be quite effective in terms of improving acceptability and the trust of a robot. By showing personalised behaviour, users see the robot as more socially competent. [Kühnlenz et al., 2013] have focused on socially adaptive robot, showing that by adapting to the mood and emotions of the user, the robot was found to be more helpful.

Personalisation has also been found to be determinant in persuasion processes. [Fogg et al.,] claims that adapted social cues can significantly improve the persuasive impact of a computer system and that tailoring the user experience improves credibility of the system. This is also supported by the study of Fasola et al. [Fasola and Mataric, 2012b] showing how personalisation can improve intrinsic motivation of the user. Some works on proxemics[5] [Syrdal et al., 2007] in human-robot interaction show that there exist individual differences in term of preferred proxemics when interacting with a human. These non-verbal cues of communication are worth being taken into account by the robot in order to show social competence.

The Chapter 4 of this thesis offers a style model for socially adaptable robots'

[4]SERA: http://cordis.europa.eu/project/rcn/89259_en.html

[5]Proxemics are a subcategory of non-verbal communication signals that deal with body space and posture. Hall defines four concentric space around a person the closer begin the Intimate space, around it would be, the personal space (for friend and family) the social space and then the public space [Hall, 1966]. Some modality of communication and senses were associated to these spaces.

behaviours. Based on works on the "Theory of Companions" [Krämer et al., 2011], we choose to model companion behaviours within the social roles and to work on personalisation as a function of context (Chapter 4).

Adaptable systems are the ones giving the most understanding and control over the companion's behaviour by the user and they would suit our research context within the MoCA project.

In the future, even the appearance should be customizable by the user since some studies have shown that there exist systematic individual differences in terms of preference of the companion's appearance [Walters et al., 2008]. They have highlighted individual differences in the preference of the robot's dynamic which could suggest and emphasise the need for the social adaptation of robots. From these researches the Uncanny Valley[6] is not at the same location for each individual and the creepiness threshold might also be varying.

Hence, variability is not only the roles that the robot is expected to have, but also the way the robot will play these roles.

2.2.2 Personality in HRI

Personality is widely researched in psychology and social sciences. It is often used to characterise individual differences in terms of communication and decision making. There exist in HRI some systems that aim to personalise the behaviour of the robot to the user by giving the robot a personality. These works are social adaptation but can be either adaptable or adaptive systems.

[Revelle and Scherer, 2009] defined **personality** as a "coherent patterning of affect, behaviour, cognition, and desires (goals) over time and space". Research in robots with personality is an ongoing problematic that would aim to give consistency to the companion's behaviours. For companionship and long-term relationship, consistency is particularly important regarding the credibility and the perceived social competence of the companion.

Some works have shown that people tend to attribute social presence and sometimes personalities to computer or interactive devices such as robots [Woods, 2006, Meerbeek et al., 2009]. Often works on personality have based their work on the Five Factor Model (FFM) (also called OCEAN or Big Five) that describes personality under five dimensional traits : Openness to experience, Conscientiousness, Extraversion, Agreeableness and Neurotiscism.

Within the MoCA Project, our partners were interested in personality modelling for virtual companion and based their approach on the Regulatory Focus theory [Faur et al., 2013]. They offer the PERSEED model that enables the agent to display

[6]Uncanny Valley:

a personality by being more or less promotion focus (maximizing gain) or prevention focus (minimizing risk) in its decision making.

In terms of the user's adaptation of the robot personality, there has not been so far any consensus in the HRI community. Indeed, some studies have shown that there was a similarity attraction (an extroverted user prefers an extroverted companion robot) [Isbister and Nass, 2000] and some others have found complementarity attraction (an extroverted user prefers an introverted companion robot [Lee et al., 2006, Tapus et al., 2008]). [Belpaeme et al., 2012] concluded in no significant influence of extrovert and introvert personality trait in child-robot interaction.

However [Joosse et al., 2013] contested the complementary and similarity attraction theories for attribution to the user by showing that the appropriate personality is more related to the task context. Hence a situated personality is perceived to be more adapted and more expected by users. [Tay et al., 2014] also recommend designing social robots within the social role framework. This thesis is in line with this research, as Chapter 4 will show that behavioural **styles** might be seen as consistent personalised behaviour in context and hence provide consistency within a social role. One of the contribution of this thesis is to offer a new profile-based way to make companion robot's behaviour adaptable in an intelligible way for the user within specific social contexts.

According to the survey of [Mahani and Eklundh, 2009], controllability, learnability and adaptability of the robot are important for user acceptability. Automatic social personalisation - **socially adaptive system** - have the drawback of necessitating to collect data in order to make the personalisation possible. Hence they are dynamic and will build on as the user interacts with the system. This poses questions on memory and privacy when dealing with personal data collected by a system.

Since users often praise controllability as one of the most import criteria for acceptability, the presented approach in this thesis will follow a framework allowing **socially adaptable** behaviours by the robot. We propose to use **styles** as tools for adaptability of the companion's behaviour within the role it has to play. The following

2.3 Definition(s) of *Style* and Related Notions

The concept of *style* is widely used, and before going further it is important to define the term. In this section, we present different definitions of styles found in different fields.

We start by giving a generic definition of styles from the Oxford English Dictionary (Figure 2.4).

style | stʌɪl |

noun

1 a particular procedure by which something is done; a manner or way: *different styles of management.*
- a way of painting, writing, composing, building, etc., characteristic of a particular period, place, person, or movement. *the concerto is composed in a neoclassical style. a striking feature of Swift's style is his use of conjunctions.*
- a way of using language: *he never wrote in a journalistic style* | [mass noun] *: students should pay attention to style and idiom.*
- [usu. with negative] (**one's style**) one's usual way of behaving or approaching situations: *backing out isn't my style.*
- an official or legal title: *the partnership traded* ***under the style of*** *Storr and Mortimer.*

2 a distinctive appearance, typically determined by the principles according to which something is designed: *the pillars are no exception to the general style.*
- a particular design of clothing. *his shoes were in a style that he could wear anywhere.*
- a way of arranging the hair. *for a glamorous style, hair was brushed out after setting.*

3 [mass noun] elegance and sophistication: *a sophisticated nightspot with style and taste.*

4 Botany (in a flower) a narrow, typically elongated extension of the ovary, bearing the stigma.

5 Zoology (in an invertebrate) a small, slender pointed appendage; a stylet.

6 archaic term for STYLUS (SENSE 2).

Figure 2.4: Definition of style [Oxford English Dictionary]

In general, styles refer to variations or ways *in doing something* , according to the definition 1 (or even in *appearances* in the definition 2).

Styles have been used to depict variations of the same notion in several research areas. In this review, we consider the first sense of style as a *manner or a way of doing something that would be recognisable.* Some research domains related to ours dealing with style are reviewed in the following paragraphs: in psychology, computer sciences, computer animation and human-robot interaction.

2.3.1 In Psychology

Styles describe different ways to behave in a particular context. Some *styles* are associated to specific social roles: management styles, teaching styles, learning styles, parenting styles. And there are some others such as cognitive styles that aim to classify wider preferences.

In general, styles enable one to depict groups of behaviours. Some selected styles studied in Psychology are reviewed here. This review starts with styles that are

unrelated to the social role - Cognitive Styles (also known as Thinking Styles). We also use the term non-role-specific styles to qualify Cognitive Styles, in opposition to role-specific styles such as Learning, Teaching, Leadership and Parenting styles that are related to specific social roles.

Cognitive Styles go from analytic to intuitive and have links with personality traits [Sternberg and Grigorenko, 1997, Hayes and Allinson, 2012].

Cognitive Style

"The way people gather, process and evaluate data signal. It influences how we scan our environments for information, how we organise and interpret it, and how we integrate our interpretations into mental models and subjective theories that guide our behaviour. Individual's habitual mode of perceiving, remembering, thinking and problem solving." [Hayes and Allinson, 2012]

[Sternberg and Grigorenko, 1997] said that cognitive styles are "the characteristic, self-consistent modes of functioning which individuals show in their perceptual and intellectual activities". There exist many dimensions to depict cognitive styles depending on the fact that the model focuses either on the processing of data or problem solving. For instance, [Rezaei and Katz, 2004], categorizes people on a verbal-visual scale to differentiate the perception preferences of individuals. Also, [Yuan and Liu, 2013] proposes the field-dependence and field-independence scale that differentiate the way persons are influenced either by the environment or by internal perspectives when thinking. Later this notion of field-dependence and field-independence will be discussed regarding the link between style and personality. Indeed, the approach chosen in this thesis is to propose a field-dependent way to socialise the robot's behaviour using behavioural styles that are role-specific. Whereas other partners of the MoCA Project [Faur et al., 2013] have taken the field-independent perspectives by considering a robot with personality. Finally, according to [Sternberg and Grigorenko, 1997], cognitive styles can be seen as a bridge between cognition and personality, as it expresses personal preferences in the way of reasoning by individuals.

To sum up, cognitive styles are not linked to a specific social role. They describe general preferences. The following review focuses on styles that are role-specific (i.e. exist only within a particular social role) and gives definitions and examples of these styles. These styles are often nominated with by the social role in which they are displayed by individuals.

Learning and Teaching Styles are widely used in educational sciences [Litzinger et al., 2007]. These styles are closely related to cognitive styles in the way that they also deal with information processing and memorizing.

According to [Felder and Silverman, 1988], learning styles are characteristic preferences for alternative ways of taking in and processing information. Learning styles are often depicted via four scales:

- sensing-intuitive: preference of concrete information vs abstraction
- visual - verbal: format of information
- sequential - global: linear/sequential vs random/holistic thinking
- active - reflective: manipulate vs observe the information

Teaching styles are often used to adjust teaching strategies to learning styles or cognitive styles of students. They are seen as teaching strategies or methods employed by teachers. They have been either seen as a reflection of the teachers' personality or experience in class or as the teachers' adoption of a set of didactical recipes. As style is defined as a way of doing things, it can either be a preferred way (reflecting personality) or chosen way (reflecting context requirements). This duality in the definition is discussed further in the section 2.3.1.1.

Educational literature has widely studied cognitive, learning and teaching styles as they influence students' academical achievements [Bota and Petre, 2015]. Some researchers have proposed a model to match Teaching and Learning styles, in order for teachers to adapt to their students' style of learning [Felder and Silverman, 1988].

Leadership Styles summarise ways to lead and manage a group. These styles are often used to assess and analyse leadership competencies in companies. Several dimensions and styles of leadership have been described in the literature [Eagly and Johnson, 1990, Goleman and Boyatzis, 2008].

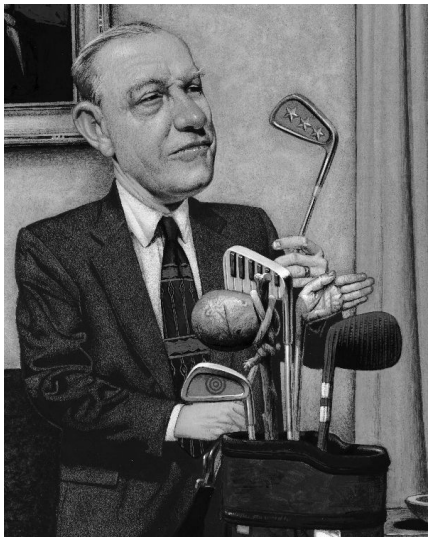


Figure 2.5: The leader and his styles

Leadership Style
The way managers motivate direct reports, gather and use information, manage change initiatives a make decisions, and handle crisis [Goleman and Boyatzis, 2008].

Goleman strictly differentiates leadership styles from **personality** but defines it as a **strategic choice**. Goleman recommends leaders to choose the style according to the context rather than the one that suit their temperament. According to him, the best leaders don't have one style but have the flexibility to chose and switch between given the circumstance. The figure 2.5 (from [Goleman and Boyatzis, 2008]) illustrates Goleman's view on leadership styles, where adopting a leadership style according to a context is compared to choosing a golf club

according to the current hole. This view is in line with our contribution highlighted in Chapter 4 in which styles are defined according to the social role (social context) played by the robot.

Parenting Styles have been studied in socio-psychology. The most well-known model is Baurmind's parenting styles ([Baumrind, 1991]). Maccoby and Martin updated and arranged the parenting styles on two axis (from [Darling and Steinberg, 1993]). The figure 2.6 shows these four parenting styles placed on the *dominance* and *responsiveness* axes.

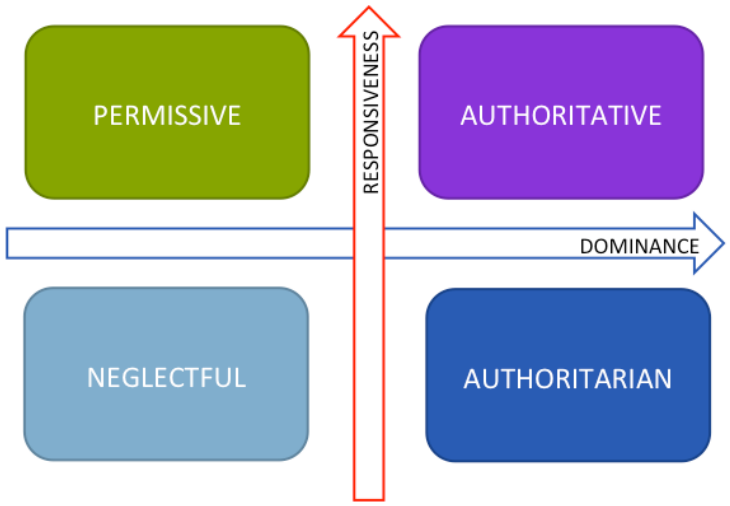


Figure 2.6: Parenting Styles according to two dimensions

Parenting Styles
are variations in parenting behaviours taking into account parental responsiveness and parental dominance.[Darling, 1999]

According to [Darling, 1999], parental responsiveness refers to the "extent to which parents intentionally foster individuality, self-regulation, and self-assertion by being attuned, supportive, and acquiescent to children's special needs and demands". Parental dominance (also called demandingness) refers to the "claims parents make on children to become integrated into the family, by their maturity demands, supervision, disciplinary efforts and willingness to confront the child who disobeys".

Parenting styles have often been studied for their links with child educational achievement. Some authors have separated parenting styles from parenting practices [Darling and Steinberg, 1993, Spera, 2005, Darling, 1999]). [Darling and Steinberg, 1993] proposed to characterise parenting style as a context that moderates and influences parenting practices, detaching parenting styles from the actual parenting

Figure 2.7: Influence of Personality or Style on behaviour expressed according to the importance of self or role in the design of the robot's behaviour.

choices and actions. Similarly to other kinds of styles, questionnaires have also been made to assess one's parenting style [Reitman and Rhode, 2002, Ribeiro, 2009].

2.3.1.1 Summary and Discussion

The bridge between style and personality Theories of Personality aim to characterise affective and motivational invariants in the attitudes of individuals. According to [Huteau, 1987], behaviours of individuals are characterised both by their plasticity and their consistency. Behaviours are sensitive to situational and social contexts. However, there exists a singularity of behaviour in a particular situation.

To summarise the different styles that were reviewed in psychology, styles characterise intra-individual consistency in context (in the same context people tend to adopt the same style) and inter-individual differences in context (in the same context, people act differently). One can notice two perspectives in the way psychologists treat styles. It is either seen as a reflection of personality, as preferred ways. Or, it is seen as a strategy, a method that would suit the context in a better way.

The link between personality and style [Sternberg and Grigorenko, 1997, Hayes and Allinson, 2012] can be justified by the fact that styles express a preference and a continuum in the same context which can also be the expression of personality. Some researchers in psychology even use the term Identity Styles to qualify the different kinds of personalities [Berzonsky et al., 2011].

However, unlike personalities, styles do not characterise across context consistency since the palette of styles varies according to the role played by the individual. The review of the literature insists on context and role-specificity of styles. People can adopt a style in a role, even if it is not in line with their personality. One can be shy in his/her everyday life, while showing self-confidence and dominance traits in a work environment . In the same line, there are some works in psycho-therapy aiming to change ones' behaviour by using role-playing activities and letting the individual adopt the best style in the context [Mehrabian, 1971].

The magnitude of these correlations confirms that personality and style are related but also suggests that when playing a social role one can suppress his/her personal preference to adopt a more suited style.

We choose to argue for a separation of these concepts in order to let the user choose the strategy of their companion in its roles. Indeed, personality traits will be displayed in the behaviour of the companion when it is self-centred (for instance, when speaking about it preferences, it mood, it hobbies) but when playing a social role, one can consider that the behaviour displayed is mainly context-centred (the task, and the way the task should be performed matter more). We propose the figure 2.7 to illustrate this distinction between style and personality in the expressed behaviour. This distinction is in line with [Huteau, 1987], who says that behaviours are characterised by consistency (referring to self-consistency and to personality) and plasticity (referring to styles and context adaptation). Besides, apart from the cognitive styles, other styles in psychology are anchored to social roles.

As the companion robot should fulfil social roles. Style framework will make social behaviour design more reusable and easier to configure by the user. Hence, the role will be the basis on which styles can be designed to depict variations of the execution of the same role.

Decision Making and Communication As seen previously, the influence of styles on decision making can also vary. Some styles such as cognitive styles clearly impact cognitive processing and decision making. However in some other cases, styles are mainly evident in the behaviours and less in the decisions taken (leadership style, parenting styles for instance). Styles can be introduced at several occasions of the cognitive processes: in the perception, decision and/or the action phase. However, if we look at the variability of doing a task, the weight of decision making is lower than the one of communication.

As an example, in a theatre setting, a scenario is provided to an actor. The script of the actor is pre-written and describes context, dialogue and actions. What the actor says or does is present in the scenario. The way the actor plays the role is comparable to the behavioural style as we define it for the companion robot (see Chapter 4).

From this overview of styles in the literature of psychology we distinguish two views on styles. On one hand, we have theories that consider that styles affect the decision making and hence the action chosen by the person with the style. On the other hand, some theories consider than styles is mostly behavioural - only the non-verbal cues change under the influence of the style but the actions. As a general definition we can quote Gallaher [Gallaher, 1992] :

Style
which is also known as expressive movement, refers to the way in which behaviour is performed [Gallaher, 1992].

Figure 2.8: Cartoon illustrating Baumrind's Parenting Styles

2.3.2 In Web-Design : Cascading Style Sheet

Cascading Style Sheets(CSS) are used in web-programming to add style to web documents[Tutorial, 2015]. The principle behind this is to describe the formatting and the look of web documents in a separated file in order to be able to reuse it. The main advantage is of this separation of web-document content from the presentation (layout, colors, fonts) is more **flexibility**, **easier specification** and **reusability** of presentation parameters. CSS files are usually applied to HTML documents and allow to specify presentation of each element of the HTML page. Hence, it also allows to make rendering specific to the display on which the page is rendered.

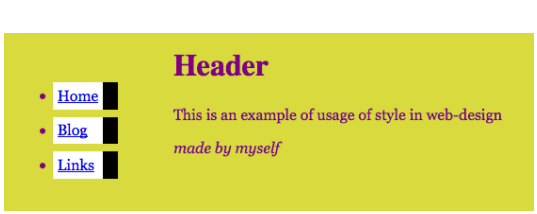
A simple example is illustrating (Figure 2.9) how the same content can have different rendering with very few differences in the CSS code. Our implementation of styles for HRI is greatly inspired from this framework and the Behavioural Style Sheet (BSS) is introduced in Chapter 4.

2.3.3 In Animation

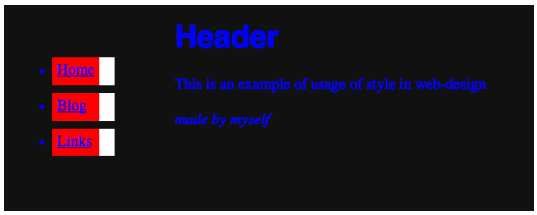
Styles have been used in Animation to both capture ways of acting from data and animate characters in particular ways without remaking the whole animation. One can imagine how interesting it would be for an animator to first make the key-frames for the gestures of a character and then give it style from a repertoire.

2.3.3.1 As a tool for animators

Traditionally animators used key-framing techniques defining each pose of the animation and then using some interpolation technique to go from one frame(pose) to




```
body {
  font-family: Georgia;
  color: purple;
  background-color: #d8da3d }
h1 {
  font-family: Times}
ul.navbar li {
  background: white;
  border-right: 1em solid black }
```




```
body {
  font-family: Comic;
  color: blue;
  background-color: #111111 }
h1 {
  font-family: Helvetica}
ul.navbar li {
  background: red;
  border-right: 1em solid white }
```

Figure 2.9: Illustration of CSS styling on a simple HTML page

another. This technique is know to be expressive but less realistic than physically-based technique in which a physical model of the character drives the animation.

In order to give more expressibility to physically-based techniques, recent research in animation has been focusing in designing styles of motion. These styles use motion parameters in order to provide a **flexible** and **reusable** way to give expressiveness to simple motions.

In [Liu et al., 2005], authors used styles as a physically-based representation of character motion. In particular, this representation includes preferences of using some muscles more than others. By combining it to other parameters they define large range of motion styles. This style representation is said to be flexible, allowing animators to use the same style for different tasks defined independently. However, in this work, style descriptions still include an abstracted representation of the actor's anatomy.

In other works [Shapiro et al., 2006], the aim was to enable the animator to transfer a style form one motion to another to retain the same expressiveness as the original motion. Authors show how a *clumsy style* component can be extracted form a clumsily walked motion and ported to a running motion. The authors also show how styles can be used for interactive analysis and editing tools for animators.

Some works [Brand and Hertzmann, 2000, Hsu et al., 2005, Hsu, 2008] have also proposed to adjust existing character animation creating new stylistic motions. Style translations are a part of motion transformation approaches to generate motion and take as input a motion and apply a new style on it while preserving its original content. Examples of the translation results on a walk motion are presented in Figure 2.10. Theses style translations are learned from examples provided by the

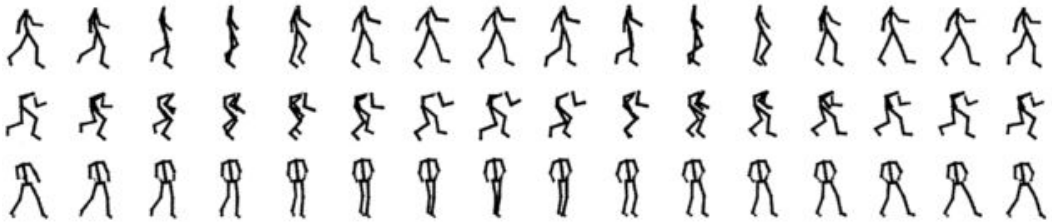


Figure 2.10: Style translation examples from [Hsu, 2008] : on top the normal walk, in the middle the sneaky crouch and in the bottom the sideways shuffle

user. However the translations are still relatively simple and according to the authors it fails for complex motion such as dance choreographies.

Researches in Computer Animation are increasingly working on ways to make the work of animators easier. Styles seems to allow animators to reuse motions. Styles defined with particular motion (like walking) have also been reused for other motions (such as running). It also allows more naturalistic motion, as some works showed that it could be learned from capture of human motions. However, these works focus on skeleton based actors and rarely take into account other physical constraints.

2.3.3.2 Of Virtual Agents

Some researchers in animation of virtual agents have also been interested in using style to depict variations in the same motion. For instance [Bindiganavale, 2000] proposed to build parametrized action from observation and defined stylistic parameters to do so: *VelStyle* (frame-wise variations in angular velocity) and *PathStyle* (variation in path). Here several instances of the same motion were used to parametrise and define different ways of doing this motion. This work however was meant for a restricted number of actions concerning only upper-bodies of humanoid agents.

[Noot and Ruttkay, 2004] proposed the GESTYLE language to define variation in gestures for Embodied Conversational Agents (ECA). This language is written in the XML format and describes gestures by their meaning allowing the usage of different gestures to express the same thing. GESTYLE proposes style dictionaries that specify different styles containing profession, culture, age, gender or personality informations. In that sense, styles defined in GESTYLE are mainly self-centred (personality) rather than role/context-centred (see our distinction between style and personality - Figure 2.7). The separation between content (action) and style in not clear within GESTYLE as styles are associated to specific behaviour repertoires. For [Noot and Ruttkay, 2004], behavioural style influences the choice of certain gestures, which can limit the reusability and the flexibility of the styles. This work is interesting in the choice of annotating language and meaningful utterance with nonverbal modalities to display variations in the usage of gestures. Authors point

differences in the preferability of using certain gestures over others (for example, facial rather than hand), and also "fine details in performing the gesture". This last aspect is contained in the manner definition, which specifies the motion characteristics of gestures and its modality of usage. The model is composed on 2 kind of parameters - high and low-level. The high-level agent defining parameters which are composed by the gesture dictionary to be used, the personality, and the social and cultural aspect of the agent. The low-level gesture modifying parameters are defined by gesturing modality parameters, such as `"intense"`, `"jerky"` and `"sudden_on"`.

[Rajagopal et al., 2012] continued this work and proposed to clone users' motion style into an ECA using gestures edited via BML(Behavior Markup Language). This work showed that the used parameters to describe the *wrist gesture style* were very efficient as 75% of participants were able to discriminate a person (among two people) seen via the animation of their avatar. Other works have been proposed to generate stylistic behaviours by first collecting data and then extracting features that characterised moods, attitude and personality [Kang et al., 2013, Szczuko et al., 2009]. These works gave good simulation results but were not making a clear distinction between the style repertoire and the context. It is probable that new data collection recorded in new contexts will lead to different style parameters.

2.3.4 In Human Robot Interaction

In the HRI community, research on styles is quite recent, and only little research has been worked on on this concept. **Interaction styles** have first been studied in Human-Computer Interaction. These styles deal with preferred ways of interaction by users. To accomplish the same task (for example, saving a document), some users would prefer to use a button by clicking on it with a mouse and some others would use a keyboard shortkey (Ctrl-S). In line with these styles, some works in HRI [François et al., 2007, François et al., 2008], have aimed to automatically recognise the interaction style of the user with a robotic platform. These works were using pattern recognition to classify the human-robot interaction styles according to the user's gentleness and the frequency of interaction with the robot. It enables the researches to propose different ways to adapt the robot's behaviour according to this interaction styles [François et al., 2009] and to reward certain types of interaction.

[Salter et al., 2006] proposed to learn human-robot interaction styles to detect individual differences in the play and interaction styles of children. According to [Young et al., 2014], it would be useful if people could customise their robots' behavioural styles to suit their culture and specific tastes. [Young et al., 2014] proposes an new approach called *Style-By-Demonstration* that allows an end-user programming of styles. They applied this approach to various platforms (avatar, robot navigation and dancing robot). This approach is very promising but it requires the user to train the algorithm at first by puppet manipulations and to collect data for each context as the data collected can be very context-dependent.

In [Allen et al., 2012], authors base their work on styles by demonstration and argue that **movement style** has to be a major component of the interaction design in Social HRI. They consider style to be not related to the task per say but to influence how people perceive the action. They make the hypothesis that the perceptions of styles is dependent on the culture, group or individuals and advocate to make it customizable by the user. We argue that stylistic behaviours can help robots to appropriately *fit into* the social roles that people give them. We believe that people's preferences for a robot's interaction style are likely to vary, and be sensitive to the individuals' culture and tastes. As such, a challenge will be to tailor style to the individual while being context adaptable.

Recent works in HRI showed how **behavioural styles** [Ligthart et al., 2013, Van den Brule et al., 2014] could affect the trust that a user gives to the robot in accomplishing its task. This work highlights the importance of non-verbal cues of communications in the perceived performance of the robot in a particular context.

To conclude, styles in HRI have been researched only recently. Some research teams have focussed on interaction styles - the way users interact with the robot, and some more recent works start to explore **behavioural styles** as a way to personalise the robot's behaviour within a task. This thesis aims to contribute on the second kind of styles. We propose the following definition:

Behavioural Style

describes a way of expressing when playing a social role.
Behvioural styles are consistent for an individual playing the same role.

The proposed approach is further discussed in Chapter 4.

Most of the works aiming to build stylistic expressive gestures were based on machine learning techniques that were extracted from the context of action. For instance, one would register several people doing the same gesture while recording their motions using a Mocap system. They would then extract the inter-indivual specificity of the motion. This can produce a lot of motion styles, but they can be semantically weak. However, works in psychology suggests that styles have a strong link to the social role in which they are expressed. This thesis contributes by proposing a meaningful way to express style based on social roles and style descriptions in psychology.

As introduced previously, another contribution of this thesis is the re-design and the implementation of a cognitive architecture for social human-robot interaction. This section aims to introduce the concepts and the research context of cognitive architectures for HRI. The previous work done in our research team on which the new implementation was done is introduced in the Section 2.5.

2.4 Overview of Cognitive Architectures

Cognitive Architectures for robotics constitute a whole field of research. This section does not provide an exhaustive view of the current research on cognitive architectures, but simply presents some important concepts that are related to our research project. Many reviews on cognitive architectures exist and we refer to them for more details [Chong et al., 2009, Thórisson and Helgasson, 2012, Vernon et al., 2011].

According to [Vernon et al., 2011], the term "cognitive architecture" aimed to unify theories of cognition on various issues such as attention, memory, problem solving, decision making, learning, across different disciplines including psychology, neuroscience and computer-sciences. Some architectures are based on philosophical theories, some on biological theories and others on psychological theories [Thórisson and Helgasson, 2012, Chong et al., 2009]. Often; they do not aim to tackle the same research problem. For instance, often, biologically based cognitive architectures aim to mimic the human brain while psychological ones focus on cognitive processes.

There exist two main families of cognitive architectures: the *cognitivist* and the *emegergentist* perspectives.

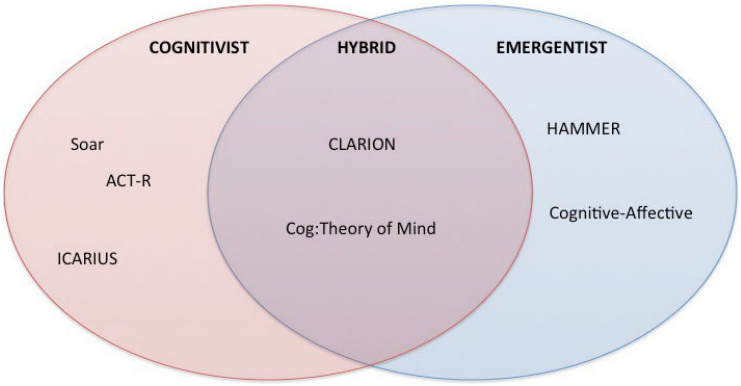


Figure 2.11: Some well-known cognitive architectures used in robotics derived from [Vernon et al., 2011].

The Emergent Perspective covers developmental cognitive architectures. In these types of architectures, the model and the processes are learned from experience. Thus, the knowledge is automatically acquired. However, these architectures also assume a part of innate knowledge at first. These systems are often platform-sensitive but research here usually focuses on general frameworks of model acquisition in order to be reusable on other platforms. The model and the process are often task and domain dependent and are linked to sensorimotor loops. The emergent cognitive architectures reflect in some way the morphology of the system. In this category, we

find for example the *HAMMER* [Demiris and Dearden, 2005] or the *ICub Cognitive architecture* [Vernon et al., 2007].

The Cognitivist Perspective considers the cognitive architectures as generic computational models neither domain, nor task-specific. A human programmer or machine learning feed the system with knowledge making it more specific to a task or a domain. The system is composed of computational models of cognition that are taken from various sources (i.e biology, psychology, philosophy). For the cognitivists, the cognitive processes are independent from the physical platform (increasing the generic aspect of the computational models).

ICARUS, belonging to this family of cognitive architectures [Langley et al., 2005, Langley, 2006] is also grounded in cognitive psychology, and *AI* (like *BDI* [7]) aims at unifying reactive and deliberative (problem-solving) execution, as well as symbolic and numeric (utilities) reasoning. Memory is organised into short vs long-term, and conceptual vs skill memory. ICARUS has several goals but focuses only on the one with highest unsatisfied priority. The skills that allow to achieve it are brought from long-term to short-term memory. If no skill is available, the system uses means-end analysis to decompose into sub-goals, and learns from this impasse.

For instance, some architectures are based on a set of generic and symbolic rules, such as *Soar* [Laird, 2012], based on the unified theory of cognition, or *ACT-R* [Anderson, 2005]. Many of these architectures are based on the "mind-is-like-a-computer" analogy.

The Dual-process theory marries these two families of cognitive architectures [Evans and Stanovich, 2013]: the cognitivist and the emergentist. This theory states that there exist two cognitive systems involved in cognition, one fast and intuitive (S1) and the other, slow and deliberative (S2). The table 2.1 summarizes different characteristics of these two subsystems. Underlying these two systems (S1 and S2), we see the two families of cognitive architectures (Emergent and Cognitivist).

Hybrid approaches of cognitive architectures constitute the last family combining Emergent and Cognitivist approaches. Hybrid architectures combine both types of processing. *CLARION* [Sun, 2003] is an example of such an architecture. Recently, other architectures have been proposed, focusing on memory [Baxter et al., 2013] or attentional processes and a sensori-motor approach [Demiris and Khadhouri, 2006]. Figure 2.11 derived from [Vernon et al., 2011], shows the theoretical positioning of some well-known architectures.

Some Open Issues are remaining in cognitive architecture research according to [Langley et al., 2009b].

1. Categorise and Understand: enable to build ontologies and to acquire semantic knowledge.

[7] BDI : Belief, Desire, Intention logic, developed by [Bratman, 1987a]

System 1 (old mind) (intuitive)	System 2 (new mind) (reflective)
Does not require working memory	Requires working memory Cognitive
Autonomous	decoupling; mental simulation
Fast	Slow
High capacity	Capacity limited
Parallel	Serial
Non-conscious	Conscious
Biased responses	Normative responses
Contextualized	Abstract
Automatic	Controlled
Associative	Rule-based
Experience-based decision making	Consequential decision making
Independent of cognitive ability	Correlated with cognitive ability
Evolved early	Evolved late
Similar to animal cognition	Distinctively human
Implicit knowledge	Explicit knowledge
Basic emotions	Complex emotions

TABLE 2.1: Properties of System 1 and System 2 from the Dual-Process Theories of cognition from [Evans and Stanovich, 2013].

2. Have an episodic memory and reflective processes.
3. Use ontology in order to encode the knowledge for more flexibility and reusability.
4. Enable to communicate decision and plans.
5. Integrate new sensors for physical perception of the world.
6. Enable embodied applications of cognitive architecture.
7. Integrate Emotion in the cognitive process.
8. Enable generalisation and modularity.

Providing robots with an efficient "brain" is still very much under research. Our research team works in tackling some of these issues, such as the ability to communicate decisions & plans, and the integration of emotions in the cognitive process. Our contribution to this work is to tackle some new issues, being the **modularity** and **embodied application** of the architecture. Chapter 5 presents our proposition of the cognitive architecture and its implementation. This architecture is affective & logic-based, dialogue-oriented and is modular & extensible. It involves two parallel reasoning loops: one deliberative and the other reactive. We now introduce the previous works on affective reasoning, on which our contribution is based which tackles some of the issues previously enumerated.

2.5 Previous Work on Affective Reasoning

2.5.1 BIGRE logic for mental states and complex emotions

Previous works have proposed the *BIGRE* modal logic [Guiraud et al., 2011], derived from BDI[8] logic, as a formal representation of the agent's mental states. This logic allows explicit expression of the mental states of an agent, that are essential for social interaction [Scassellati, 2002]. The interested reader is referred to [Guiraud et al., 2011] for detailed semantics and the axiomatic of this logic. The modal operators are the following:

B $Bel_i\varphi$: the agent i believes that φ,
I $Ideal_i\varphi$: ideally for agent i, φ should hold (this operator expresses the social and moral norms of the agent[9]),
G $Goal_i\varphi$: the agent i wants that φ holds,
R $Resp_i\varphi$: the agent i is responsible for φ. This notion of responsibility arises from the counterfactual reasoning of the agent on its own actions and those of the others[10].

E Complex emotions are particular emotions that result from social (ideals) and counterfactual reasoning (responsibility). The latter emotions are based on the imagination of alternatives that could have occurred, or on the alteration of the factual situation by the agent.

Previous works have formalised 8 complex emotions (E) in terms of the B, I, G and R operators (BIGR → E): *regret*, *disappointment*, *guilt*, *reproach*, *moral satisfaction*, *admiration*, *rejoicing* and *gratitude* (see Table 2.2).

$\wedge$	$Bel_i\varphi$	$Bel_iResp_i\varphi$	$Bel_iResp_j\varphi$
$Goal_i\varphi$	$Joy_i\varphi$	$Rejoicing_i\varphi$	$Gratitude_{i,j}\varphi$
$Goal_i\neg\varphi$	$Sadness_i\varphi$	$Regret_i\varphi$	$Desappointment_{i,j}\varphi$
$Ideal_i\varphi$	$Approval_i\varphi$	$MoralSatisfaction_i\varphi$	$Admiration_{i,j}\varphi$
$Ideal_i\neg\varphi$	$Disapproval_i\varphi$	$Guilt_i\varphi$	$Reproach_{i,j}\varphi$

Table 2.2: Formalisation of the complex emotions from [Rivière, 2012]

For instance, guilt reflects the comparison of the actions of the agent with respect to the actions it *should have* done. Concretely, to feel guilt, agent i should have an

[8] BDI : Belief, Desire, Intention logic, developed by [Bratman, 1987a]
[9] For instance, a moral obligation to help someone in danger, or a social norm to pay one's taxes, etc.
[10] For instance: if the agent i had not done the action α then φ wouldn't be true; so the agent i is responsible for φ

ideal ($Ideal_i\varphi$) and should believe that it is responsible for the violation of this ideal ($Bel_iResp_i\neg\varphi$). Likewise, reproach comes from the comparison between the agent's ideals and the actions of its interlocutor: agent i has an ideal ($Ideal_i\varphi$) and believes that its interlocutor j is responsible for its violation ($Bel_iResp_j\neg\varphi$).

According to [Rivière, 2012], these complex emotions are particularly important in human interactions; specifically in natural language. Indeed, contrary to primary emotions that are expressed by prototypical facial expressions, complex emotions need context to be recognized. This formalisation of complex emotions is based on cognitive appraisal theories [Scherer, 2001, Ortony and Turner, 1990]. For example, among Scherer's *Stimulus Evaluation Checks* we can find goal congruence, social and moral norms, and the attribution of responsibility.

2.5.2 Multimodal Conversational Language

To ensure that an agent is able to express its mental states and complex emotions in a credible manner, [Rivière et al., 2014] have defined a conversational language based on Searle's Speech Acts Theory [Searle, 1985], which is in line with previous mentalistic Agent Communication Languages (ACL) (such as *FIPA*). This Multimodal Conversational Language (MCL) consists of 38 Multimodal Conversational Acts (MCA) divided into four classes: assertives (affirm, deny, etc.), directives (ask, suggest, etc.), commissives (commit, accept, etc.), and expressives (regret, reproach, etc.) that more specifically express complex emotions.

For each MCA, Rivière et al. provide a logical formalisation of:

- its preconditions: the conditions that the agent has to satisfy before performing this act sincerely, in the sense of the sincerity conditions of Searle's Speech Act Theory; these preconditions thus ensure the agent's sincerity.
- its sending effects: the effects on the agent when performing this act;
- its reception effects: the effects on the agent when receiving this act performed by the interlocutor.

Preconditions and effects of MCAs are formalised in the BIGRE logic, in terms of the agent's mental states.

This explicit formal representation has the advantage of enabling manipulation and reasoning by the agent about the MCA, in particular, updating the agent's mental state when receiving or sending an MCA, and using MCA in the agent's plan of action. This reasoning is implemented in the *PLEIAD* engine (presented in the Section 2.5.3).

2.5.3 PLEIAD Reasoning Engine

PLEIAD [Adam, 2007, Adam and Lorini, 2014](ProLog Emotional Intelligent Agent Designer) is a reasoning engine for BDI agents implemented in SWI-Prolog . This

system provides generic and emotional reasoning based on various logical models of emotions, such as a BDI logic formalisation of the OCC theory [Adam et al., 2006]. Some extensions are available, such as the personality trait or coping strategies [Adam and Longin, 2007] for BDI agents.

The initial version of the architecture has been tested on Virtual Agents such as MARC[11] and Greta[12] in the thesis of [Riviere, 2012].

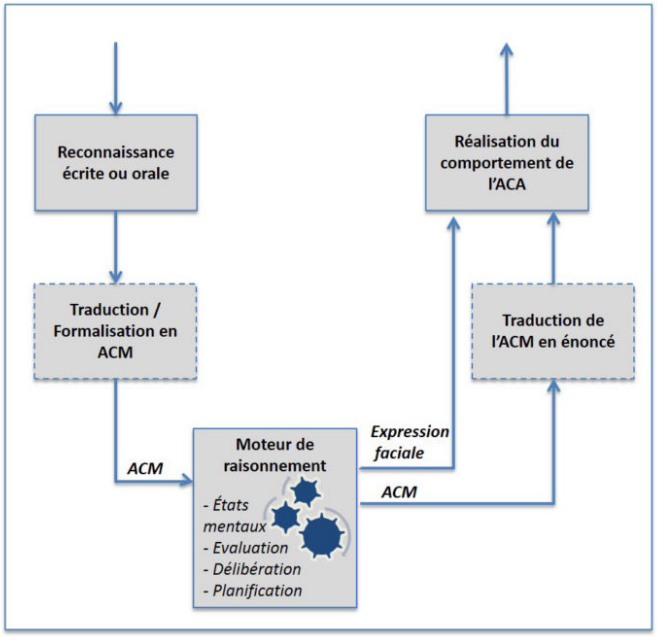


Figure 2.12: Previous Architecture from [Rivière et al., 2014]

The previous architecture was implemented in Java and Prolog. The figure 2.12 shows the general Java classes involved in the architecture. The dialogue was done through a graphical user interface where the user could pick to either write or speak to the agent (the speech was remotely treated by Google Speech to Text API). This text was then matched with the corresponding Multimodal Conversation Act (MCA) formalisation. This perceived MCA from the user was then fed into the reasoning engine that contained all cognitive processes of the agent: stimulus evaluation, deliberation of intention and the planning of the goal to achieve. Then, the reasoning engine would output the facial expression and the MCA response that was translated and executed by the embodied conversational agent.

Rules for each step were implemented in separate files of the reasoning engine but they were loaded at the beginning of the interaction, and the module could not

[11] MARC: Multimodal Affective & Reactive Characters http://www.marc-toolkit.net/
[12] Greta: https://trac.telecom-paristech.fr/trac/project/greta

be replaced by a new module implemented in a different language. This reasoning engine was therefore, not modular.

One of our contributions in this thesis is to provide a more flexible architecture based on robotic standards of implementation in order to ensure its re-usability. Section 5.1 gives details on the redesign of the architecture and section 5.2 gives constraints and choices for the implementation.

2.6 Experimental Measures for HRI

As pointed out by [Aylett et al., 2011], there are still, many challenges in HRI and *believability* is one of them. Believability and credibility are often used as evaluation metrics and allow to see if users attribute intentions and intelligence to the companion robot.

Experimental design and measures in HRI are becoming a field of research on their own, as proven by many summer schools, workshops and special sessions in the domain that focus on experimentation and evaluation of interactive robotic systems[13]. This phenomenon is driven by the lack of common benchmarks and standardised measures to evaluate robotic systems and the quality of interaction with users. Indeed, user experience is central to validate the believability of a system. However, long-term social human-robot interaction is difficult to set up for a complex robotic system. Measuring quality of interaction in HRI, especially for child-robot interaction is essential for the community. From an epistemological point of view, as a new field of research, HRI has to develop strong metrics in order to guarantee its evolution into a science.

Depending on the type of evaluation (online survey, large-scale experiment, case study or longitudinal analyses) the metric used in HRI can vary.

2.6.1 Standard Measures in HRI

The research community is working more and more in order to provide standardized and reliable ways to measure the quality of interaction. According to [Bethel and Murphy, 2010], there are 5 primary methods of evaluation used in HRI: self-assessment, interviews, observational or behavioural measures, psychophysiology measures and task performance metrics. Recently [Weiss et al., 2011] proposed the Usability, Social acceptance User experience and Societal impact (USUS) evaluation framework. USUS framework gives methodological guidelines according to the research objectives that are aimed to measure between usability, social acceptance, user experience and

[13] We can cite for the summer 2015: SMART-LABEX on Computational Social and Behavioural Sciences, IROS2015 Open forum on evaluation of results, replication of experiments and benchmarking in robotics research, IEEE RAS Summer School on Experimental Methodology, Performance Evaluation and Benchmarking in Robotics, IROS2015 Workshop on Designing and Evaluating Social Robots for Public Settings, ...

societal impact. The USUS evaluation framework also provides indicators for each of the research question and the associated method of evaluation between : expert evaluation, user studies, questionnaires, physiological measures, focus groups and interviews. Rather they be in laboratory, field study or wizard-of-oz experiment, the community proposes often scenario-based experimental protocols. [Bethel and Murphy, 2010] recommends to use at least three forms of evaluation in order to have reliable results for an experiment. We propose to group these categories and to give some examples of measures used in HRI.

2.6.1.1 Self-assessments and Interviews

Several researchers have proposed self-assessment measures to assess user's opinion on robots and on the interaction with a robot. Self-assessment measure include questionnaires, survey and psychometric scales. Among questionnaires developed in HRI, we can cite the **GodSpeed** [Bartneck et al., 2008a] aiming to measure: anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety. We proposed a French translation of the Godspeed questionnaire and used some question items for our experimentations[14]. The Negative Attitude towards Robots Scale (**NARS**) [Syrdal et al., 2009] aimed to explain difference between participant's behaviours in interaction with robot. The NARS is composed of 3 sub-scales that classified negative attitude: toward situation and interactions with robots, toward social influence of the robot and towards emotions in interaction with a robot. The Robot Anxiety Scale (**RAS**)[Nomura et al., 2008] was developed to measure the user's anxiety toward robots in real or imaginary human-robot interactions. It is also composed of 3 sub-scales dealing with anxiety towards: communication, behavioural and discourse capacities of the robots.

The Children's Openness to Interacting with a Robot Scale (**COIRS**) [Robert and Bergh, 2014] is the first self-report measure specially design of children. Four sub-scales constitute the COIRS: (1) intrinsic interest in interacting with a robot, (2) openness to socio-emotional interactions, (3) propensity towards creative learning interactions with a robot, and (4) openness to utilitarian interactions with a robot.

According to [Bethel and Murphy, 2010], however, it can be difficult to see attitude change through questionnaires since the self reporting is done post-interaction. Also self-reporting doesn't allow to assess subconscious attitudinal changes and can be less accurate with children. The impact of the robot's attitude can be subtle and hence other types of measure are necessary.

[14]French GodSpeed questionnaire available : http://www.bartneck.de/2008/03/11/the-godspeed-questionnaire-series/

2.6.1.2 Task-oriented measures

Task related measures are more and more common in HRI [Bethel and Murphy, 2010], as they allow to assess the usability of the robotic system when the user is accomplishing a task. In robotics for education for instance, this method is the most frequently used. It allows to evaluate the students' performance according to the level of assistance of a robot [Leyzberg et al., 2014, Hood et al., 2015].

[Olsen and Goodrich, 2003] proposed a series of task-related metrics such as - effectiveness in the task, the neglect tolerance, the robot attention demand, the free time the user has, etc. These metrics are accurate in measuring the usability and ease of use of a robotic system in a task but doesn't fit measure in social aspect of human-robot interaction such as social preferences of the user.

Studies usually report scores, errors, and the time of responses as collected data. Task-performance evaluations are well suited for robots in a teacher or coach role. However, it does not provide information about social bound (attachment) of the user with the robot.

[Steinfeld et al., 2006] proposes a survey of task-oriented metrics for HRI. The proposed task metrics are composed of navigation, perception, management, manipulation and social criterion. Authors include in their evaluation some metrics to evaluate social effectiveness of the interaction. To do so, they suggest considering four dimensions : the *interaction characteristics* (social context, via observation), *persuasiveness* (robot used to change the behaviour feelings and attitudes of the user), *trust* (reliance of the system), *engagement* (holding interest) and *compliance* (appearance, adherence to norms). Observational, behavioural and psychophysiology measures often aim to collect similar types of dimensions.

2.6.1.3 Observational, Behavioural measures and Psychophysiology Measures

Several measures have been developed to measure attitude change or physiological effects of the robot's interaction with humans. These measures are either observed and manually annotated from video or audio recordings for instance, or automatically computed from the collected data. This data deals often with social signal processing that aims to inform about the emotions and the social relationship of individuals.

The Social Signal Processing Network (SSPNet) has published a nomenclature of social signals and guidance for research in this field [Pantic et al., 2011]. The aim of this community is to give computer systems such as social robot intelligence in terms of ability to perceive and recognise social signals produced by the users. Theses signals are heterogeneous and take into account behavioural cues from voice, posture, gaze, interpersonal distance, gestures, etc.

Hence, some social signals have been used to measure the quality of interaction with robots. Non-verbal communication signals are a part of these signals and have

received a great interest in research these past years. This thesis won't review all the work done in non-verbal communication cues but we can conclude that non-verbal communication signals seem to be an interesting media to analyse interaction. Indeed, non-verbal cues can tell about intentionality and hidden goals[Vernon et al., 2011] of the user, which can allow better measurement of their feelings when interacting with a robot for instance. This data is valuable it they allows the experimenter to gather information that the user cannot or didn't want to state.

Observational measures can be very accurate but are fastidious to obtain if the number of participants is high. It requires annotation guidelines and often several annotators. These measures are often used in case studies or long-term interactions when the number of session or participants is restraint. Also, if the aim is to make run-time recognition of engagement for instance, observational data has to be made computational so that the robot can be autonomous. Behavioural measures can be computed via computer vision techniques. Physiological measures are collected and computationally treated.

Often these measure aim to determine the user's engagement in the interaction. For instance, [Castellano et al., 2009a] propose a method in which video and audio sessions are recorded and coders manually encode non-verbal behaviour of the child. A fusion between contextual information (where in the game, who is peaking etc.) and non-verbal behaviour are fed to a Bayesian network system to model the user's engagement. Similarly other recent studies have used manually annotated features from video and audio to determine the child's engagement [Leite et al., 2015]. In some works, user's engagement with robots has been measured using physiological data, such as the heart rate and the body temperature[Rani and Sarkar, 2003].

[Sanghvi et al., 2011] proposed some new features for automatic analysis of user's engagement based on posture and body motion. Authors proposed to use the Body Lean Angle, the Slouch Factor, Quantity of motion and the contraction index. The Body Lean Angle (BLA) corresponds to the upper-body orientation relatively to the robot (leaning forward, on the side etc.). The Slouch Factor is a measure of the user's back curvature. The Quantity of motion has been used as a feature in other works and corresponds to a measure of the user's agitation. Finally, the contraction index corresponds to the level of contraction of the upper-body.

[Mead et al., 2011, Mead et al., 2013] showed interested in the measure of proxemics features to determine the immediacy and engagement of a user with a social robot. Proxemics are part of non-verbal behaviours and deal with distance and spatial arrangement of interlocutors in interaction. Previous works have also used proxemics and multimodality to predict intention of interaction of a user with a companion robot [Vaufreydaz et al., 2015].

Other studies have focused on measuring attention of the user during the interaction. For instance, [Staudte and Crocker, 2011] uses gaze to assess attention in human-robot interaction. A lot of studies have worked on gaze and facial expression to determine engagement.

Some works aimed to evaluate quality of the interaction through synchrony between human and robot. Synchrony derives from dialogue theory and quality of the interaction can be approximated by the level of synchrony when the partners converge in some levels. These techniques base they measure on temporal features such as temporal correlation of attitudes, recurrence of pattern in both robot and human involves in the interaction [Delaherche et al., 2012].

In other fields than HRI, attitude measures have also been a subject of research. For example [Carolis et al., 2012] aimed to recognise a user's social attitude in the interaction with a smart environment. This work provides a detailed set of labels used and the corresponding signals. Especially for signs of social attitude, it categorises attitudes into open attitude, closure attitude and negative attitude giving signals that are displayed for each attitude. Palms open, knees apart, elbows away from the body, hands not touching and legs uncrossed are signs of open attitude for instance.

One of the first work in analysing HRI using observational non-verbal cues of communications was by [Dautenhahn and Werry, 2002]. In this work, authors provided annotated features from various modalities - from vocal to gestural, from video data collected in the wild. Many works have combined different non-verbal modalities to measure the quality of interaction [Mead and Matari, , Moubayed et al., , Anzalone et al., 2013]

In this thesis, we were interested in body attitudinal changes of the user that would be induced by the variability in the robot's behaviour. Hence, the following part will overview some of the literature that was used to assess non-verbal body communication signals displayed by the user in interaction with the robot.

2.6.2 Focus on Body Measures in Psychology

We present in the rest of this section some body attitudes measures from psychology literature. Body measures are a part of non-verbal communication measures. Non-verbal signals often have the particularity to be subconscious and more frequently appearing than verbal signals [Mehrabian, 1977].

Some recent work in HRI have provided automatically computed features that can be used to measure a user's engagement [Anzalone et al., 2015]. Chapter 7 shows that these measures can be useful to see the influence of the robot's behaviours on the child's attitude.

The book of [Knapp et al., 2013] gives a good review of the work on non-verbal communication in human-human interaction. We present some factors that can be assessed through bodily expression from the book. The following concern essentially, posture and gestures cues that are speech-independent and displayed in human-human interaction.

Liking and immediacy behaviours have been studied since the 60s by Mehrabian. He gave a set of signals that "distinguish positive evaluation of an interaction partner

from negative one". Liking or Immediacy Dimensions dealing with positive evaluation of the interaction, from [Mehrabian, 1977, Knapp et al., 2013], are listed below:

- **Touching**: where and how long the interlocutor touched (i.e. shoulder or hand holding)
- **Straight-ahead Distance**: frontal distance with the interlocutor
- **Lateral Distance**: right-left distance with the interlocutor
- **Forward Lean**: also known as body lean angle [Sanghvi et al., 2011], angle between vertical vector from the hips and the vector between ships and shoulder centre
- **Eye contact**: looking into each other eyes
- **Observation**: looking at the interlocutor for a long time
- **Body Orientation**: shoulders' orientation according to the interlocutor's front plane
- **Positive facial and vocal expression**: smiles, for example

Psychologists have also worked on detecting signals of **Relaxation** that could be useful to determine the quality of the interaction. This Relaxation dimension has also been studied by [Mehrabian, 1977] and he provided the following signals list:

- **Arm-Position Asymmetry**: evaluate if the arms are in a symmetrical or an asymmetrical position
- **Sideways lean**: body angle on the left-right
- **Arm openness**: how open the arms are
- **Leg-Position Asymetry** : asymmetrical value of the legs (same as the arms)
- **Hand Relaxation**: hands open - relaxed or closed
- **Neck Relaxation**: position of the head in the vision line
- **Reclining Angle**: similar to the lean angle of the body

[Mehrabian, 1977] is also considering movement signals, facial expressions and verbal signals.

Warm and Cold behaviours have also been encoded in the form of gestures and postural signals [Knapp et al., 2013] (see Table 2.3).

Warm behaviours	**Cold behaviours**
Moves Toward	Looks at the ceiling
Smiles	Looks around the room
Sits facing	
Uses expressive gestures	
Dominant	**Submissive**
More gestures	Self Touch(head, hands)
Legs more extended	Moving feet
Less object manipulation	
Self Touch(hips)	
Hand/arm gestures	
Postural openness	
Postural relaxation	
Facing orientation	
Interpersonal distance	

Table 2.3

Finally, it can be interesting to measure if the user was feeling *in control* or dominant during the interaction. Adapted from [Knapp et al., 2013, Hall et al., 2005], we give a list of dimensions that can be correlated to the dominance trait in interpersonal interaction(Table 2.3).

Many other social cues have been used in psychology to describe human behaviours. Our aim in the evaluation of our system is to take inspiration from these cues and to describe behaviour changes of the user in interaction with the

robot using some of the previously stated cues. Chapter 7 presents an experiment of child-robot interaction where the body cues of communication were used to asses behavioural changes such as liking, relaxation and dominance.

2.6.3 General Discussion around Methodology and Body Measures

This section presented several techniques used in the HRI community to asses the impact of robot's interaction on the user. We saw that this impact can vary in terms of nature it can be a social or performance impact. Strategies of measures would depend on this nature but also on the public that is involved in the experiment (children, elderly, persons with dementia etc.). Indeed, techniques such as self-assessment are not well suited for young children or people with dementia. We summarize these different techniques in the table 2.4

	measures	aim	when	advantages	disadvantages	Examples
Questionnaires	Likert-like series of items	make the suer express its feeling	post or pre experiment	wildly used for some of them	difficult to adapt to answer hypothesis form the experiment	NARS, RAS, GodSpeed, IoS, COIRS
Interviews	open questions	make the suer express its feeling	post or pre experiment	specific to experiment	difficult to create	
Task-related	performances	to measure the influence of the system on the user's performances	post or pre experiment	specific to experiment and quantitative measures	doesn't provide social insight	time of responses, scores etc.
Observation	behaviour	to observe behavioural changes	during experiment	specific to experiment and quantitative measures	time consuming	occurrence of behaviour, duration of a behaviour etc.
Auto-confrontation	user's interpretation of its own behaviour	to make the user explain its attitude in front of the robot	during-post experiment	user's perception of its own action	subjective and time consuming	open explanations and annotation
Physiological measures	user's body reaction	measure physiological reaction	during	user's often subconscious body reaction	might be invasive and might be hard to interpret	heart beat, pupil size

Table 2.4: Common technics used

2.7 Summary and Discussion

This chapter presented techniques of personalisation of companion robots showing that there were several form of personalisation that we arranged on two axes. One axe representing where the control slider was, in the hand of the user (adaptable) or in the system (adaptive). The other axe described the content of the changes that would go from social to performance-oriented changes. In this framework, our proposition is to use social adaptability in order to allow the user to keep control over its companion. We described after with the notion of style how adaptability can be declined in several styles across various research field. We saw that styles in psychology where associated to roles (apart from Cognitive Styles), and that animator and web-developers use style to make their programs more flexible and reusable. We finally saw that recent works in HRI where interested in inter-personal differences in interaction and were learning interaction style to adapt companions. From this reviews, we can conclude behavioural styles are a pertinent way to create variability of the companions' behaviour within the social role. Chapter 4 will describe our proposed approach of behavioural styles model that introduces variability in the non-verbal behaviour at run time.

This chapter also introduced some common classification of cognitive architectures with cognitivist and emergestist approaches. We were particularly interested in the Dual-process theory that shows how cognitive processes can be modelled in two systems. We also presented some previous work on modelling and reasoning on complex emotions. Our contribution regarding this previous work on reasoning is to port the reasoning process to robotics platform by developing an interface between Prolog[15] and ROS[16]. We also redesigned the cognitive processes into two loops: one deliberative and one reactive loop which is in lne with the dual. Details about this contribution will be given in Chapter 5

Finally this chapter presented related works on the metrics used in human-robot interaction. This section highlighted the fact that the community misses commonly shared metrics to evaluate social child-robot interaction. Chapter 7 shows some features based on body posture analysis to evaluate the relaxation and immediacy state of the child in interaction with a humanoid robot.

[15]Prolog is a logic programming language
[16]ROS: Robot Operating System

Chapter 3

Exploratory Study

In order to make the transition from industrial robotics to personal robotics smoother, researchers have to elicit the requirements from future users. Industrial robots are robots operated in industrial environments by qualified user for very specific tasks, usually repetitive or dangerous. Personal robots, on the other hand are present in non-industrial environments (home, school, office) and interact with relatively unqualified users for a broad range of tasks.

Requirements engineering is a hard task when dealing with new technologies especially when they touch everyday lives of users and when they can interact with people at home. This chapter first introduces the chosen design approach to elicit user requirement for companion robots for children at home. We do a quick overview of the role of companion robots for children addressed in the literature. Then we discuss an exploratory study aiming to elicit user requirements about roles of companions for their children.

3.1 Scenario-Based Design

Scenario-based Design is based on use-cases. It allows to keep context awareness throughout the design process. The basic principle handles systems with a great number of functionalities by grouping them into scenarios [Gheorghita et al., 2007]. Hence functionalities will also be contextually related. Scenario-based Design [Haumer et al., 1999] allows to:

- capture context-modelling in the design,
- describe the system using agent-oriented modelling
- flexibility by having the possibility to add scenarios of use of the system
- simplify the evaluation of the system by evaluating expected usage context of the system by users relatively to the scenario pre-designed by developers team.

In Human-Robot Interaction, the evaluation of robotics systems and behaviours is often done within specific scenarios. We believe that a Scenario-based design

approach would be well suited for social robotics systems. Scenarios can enter at different levels of conception in a project. The Figure 3.1 shows the Scenario-Based

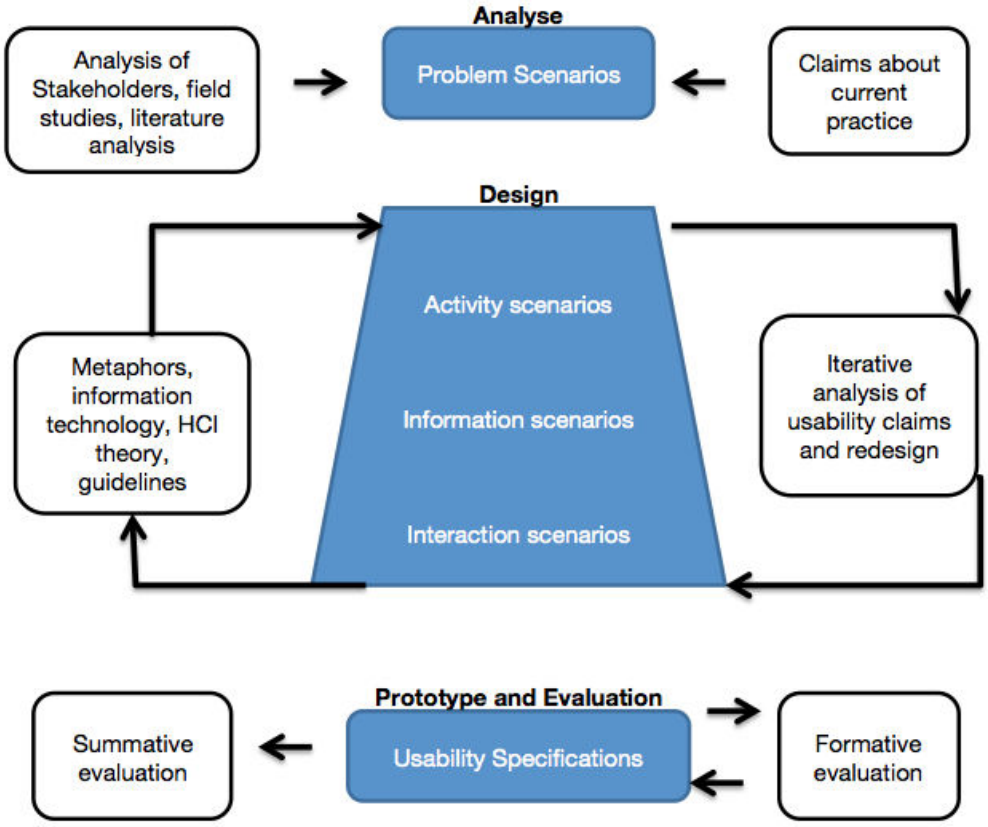


Figure 3.1: Scenario-Based Development Framework proposed by Rosson and Carroll[Rosson et al., 2009]

Development Framework proposed by Rosson and Carroll[Rosson et al., 2009]. In the first part of our work, we decided to focus on the Analysis step within this framework. Hence, the aim was to define Problem Scenarios we would like to address within the MOCA Project. This step aimed to elicit some contexts and roles in which our companion robots could accompany the child at home after school. Problem-scenarios are concrete situations in which children could be confronted to a problem that a companion robot could address. The narrative serves as test case for analytic evaluation and is a claim hypothesis in terms of usability and acceptability of the companion robot within this scenario.

Within the research project, we focus on children in the 8 to 12 year age bracket in a family setting. The problem-situation is a context within which the children

might need help, and where they could find worth, in Cockton's terminology [Cockton et al., 2009], using the companion. The companion then takes a role in order to respond to the problem/situation. Based on the following study, we elicited 6 problems/situations that a child may encounter and the associated abilities that a companion agent would need to fulfil in that role.

3.2 Literature Analysis of Roles of Companion Robots for Children

In this section we do an overview of the literature on the research on companion robots in child-robot interaction. A large part of the literature in child-robot interaction is dedicated to autistic children. However, the context of our research focusses on healthy children.

As robots are finding their way from industry to the home environment, they will find themselves in new roles and new tasks to accomplish. In the industry, robots were used for three main perposes [Taipale et al., 2015] :

- Takeing care of dangerous and or repetitive jobs.
- Improving the quality of the products by being more precise.
- Guaranteeing the regularity of work.

This is where the well-known say about industrial robots comes from : They are dirty, dangerous and dumb.

[Taipale et al., 2015] conducted a study on the European attitude towards social robots. The authors have noticed that for now social robots are mainly used for whom they call the "weak social groups" i.e. the children, the disabled and the elderly. This is why we often use the phrase "assistive robotics". For now, assistive robotics focus mainly on human care, health and domestic tasks. According to this survey, flexibility and adaptability to personal needs, and the ability of complex reasoning are the most relevant skills a social robot should have.

Some opinions about the roles of personal robots collected in different surveys are summarized in Table 3.1. These surveys show in general that assistive robots are well accepted in domestic tasks compared to social tasks. Usage of robots for child assistance is far from being accepted by all. However, the roles proposed in these surveys were often thought to be replacing a parent. In [Taipale et al., 2015], the authors claim that robots replacing a non-family caregiver, an unknown medical professional, or acting as a mediator between persons might not be considered a big problem, as compared to a robot replacing a family carer. The idea of necessity of responsiveness from the companion robot was also corroborated in [Dautenhahn et al., 2005], as 86% of interrogated participants wanted their robot to have highly considerate behaviours. In the same time, 71% wanted the companion to be controllable.

Roles	Source	Acceptability Rate
Child Care / Babysit	Taipale et al.[Taipale et al., 2015]	3.5%
	Ray et al.[Ray et al., 2008]	7%
	Dautenhahn et al.[Dautenhahn et al., 2005]	10%
Education / Help child to work	Taipale et al.[Taipale et al., 2015]	2.6%
	Ray et al. [Ray et al., 2008]	15%
Leisure / Play with kid	Taipale et al.[Taipale et al., 2015]	2.5%
	Ray et al. [Ray et al., 2008]	12%

TABLE 3.1: Rates of parents willing to have a companion robot playing these roles

A study at the Robofesta[1] event [Clavel et al., 2013] ran as a starter of the MoCA project also gave us good insights about the expectations from companion robots for children. As from other studies on companion robots, it has been found that companion robots would mostly be useful in domestic domains, and that they should be controllable (low autonomy). One of the most interesting results is that people expect companions to display different personalities for different roles [Clavel et al., 2013].

In order to elicit the requirements for a companion robot, traditional methods were used. We started with several brainstorming sessions within our research group involving researchers who have children between 8 to 12 years old. These brainstorming sessions focussed on the potential activities that the children could do during the time they spent at home alone before their parents returned from work. We also did an analysis of the literature in HRI with a similar project involving child-robot interaction (LIREC, ALIZE, EMOTE etc.).

Theses surveys on expectations from companion robots' show that the layperson vision in terms of the robot's technical abilities and the trust in accomplishing the task well might still be low to create a real worth. However, some studies have shown that some persons already see advantages in personal service robotics. [Mahani and Eklundh, 2009] reports some advantages found in these robots. For instance, in case of dependency of a person receiving daily help, the judgement feeling of getting help is not present when these people use a robot rather than getting help by someone else. Also, in repetitive tasks, organising and fixing tasks, comfort tasks (to play games, learn music, or practice their language skills) were evoked to be potentially

[1]Robotfesta is an annual event organized by University of South-Brittany in France. It involves around 300 middle-school and high-school students in a robotic challenge. http://crdp2.ac-rennes.fr/blogs/robofesta/

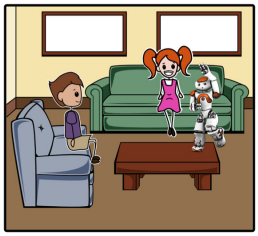
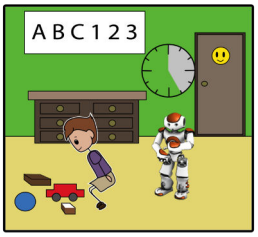
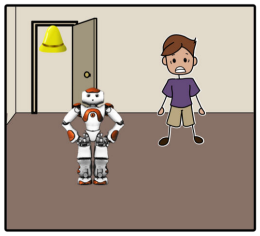
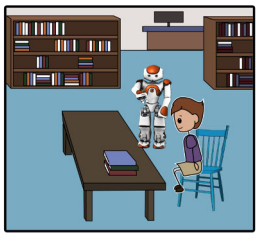
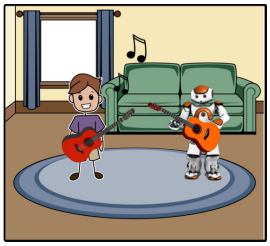
Comforter	Buddy	Bodyguard
		
Teacher	**Coach**	**Storyteller**
		

TABLE 3.2: Illustrations of the six problem/situations for our companion robot

useful.

From an analysis of the literature and the study at Robofesta, we have elicited the following list of six roles and corresponding problem/situation. Each role aims to match a need, an expectation or a demand from children and/or parents and is illustrated by a the comicstrip images in the Table 3.2.

1. **Comforter**: The need for a cuddle, affection, or comfort.
2. **Buddy**: The need of a friend to play with when the parents are busy
3. **Bodyguard**: The need to feel secure (for example, if the child is home alone and someone rings the bell).
4. **Teacher**: The need for help and support for doing homework and other school matters; for repetitive tasks such as things to learn by heart (poetry or multiplication tables etc.).
5. **Coach**: The need to be coached or to discover extra-curricular activities; learn things other than those taught in school (for example, a new language, music, activities necessitating practice, etc.).
6. **Storyteller**: The need to be accompanied and calmed down or relaxed before going to bed.

In order to have a feedback from the principal stakeholders of our system, we conducted a small study at Innorobo in 2013. **Innorobo** is an annual robotic exhibition that takes place every year in Lyon (France). The participants range from people involved in the industrial as well academic background. The event is usually held over a period of 3 days. Schools from the region bring groups of students for visits and one of the days is declared being open to public. We found this moment to

be potentially useful to interview parents and children on their expectations on companion robots.

3.3 Study Design

The aim of this study was to explore parents feelings about the roles previously stated. We used two social robots : Reeti and Nao. Reeti from Robopec is a PC-Bot with an expressive head with motorised eyes, nose, mouth, hears and neck. It can also change its cheeks LEDs colours, allowing it to display various emotions. It is also equipped with sensors such as microphones, cameras and touch sensors (on the cheeks and the nose).

Nao is a humanoid robot from Aldebaran. It is also equipped with sensors (cameras, microphones, bumpers ...), actuators and speakers. Its face is way less expressive than Reeti, and contains only neck movements and coloured LEDs in its eyes, hears and torso. Its legs and arms enable it to display body postures.

Figure 3.2: The experimental stand during at the Innorobo2013 event

In order to show the expressive capabilities of the robots and to immerse the subject within an interaction with the robots, we decided to propose the participants to play a game with the robot of their choice. We conducted interviews about the problem/situations. The game and the expression of emotions by the robot enabled us to tease the participants and to get the participants to be more at ease during the interviews.

Figure 3.3: Screenshot of the tablet application

The game that we developed on an Android platform was based on the Simon Game. The Participants had to listen to a sequence of notes played by the robot and to look at the associated LED colour changes displayed by the robot (either on Reeti's cheeks or in Nao's eyes). Then, the participant had to reproduce this ordered sequence of notes using a tablet application (cf Figure 3.3)by clicking on the corresponding colors sequence.

The difficulty of the game (the length of the sequence and number of notes added at each round) was made to increase rapidly in order to induce mistakes from the participant. For the first mistake, the robot would gently tease the participant ("ahaha, my grand-mother would do better than you!") and offer to play a second time. At the second mistake, the robot would laugh at the participant (an anti-social laugher) and stop the game.

3.4 Discussion and Implications

Figure 3.4 shows results from the questionnaire on roles for robots. We asked 22 parents to rate on the likert-scale how willing they would be to have a companion robot for their child to play each of the listed social roles from (0 : not willing at all, to 5 : very much willing). From this figure, we can see that the opinion of parents are far from a consensus for all the roles, except the one named *buddy*; that on an average seems to be well accepted by parents. The dispersion showed by the graph translate shows the fact that the parents preferences of roles for the companion robot of their children are variable. The variability in parents' opinion is also illustrated by the Figure 3.5. This figure shows the opinion profile of two parents picked randomly. All the profiles could be found in the Table B.1. They show how the acceptability of the companion in different roles varies. The results of this study have to be contrasted. Indeed, the Buddy role was experienced by the users and one can imagine that if they would have experienced the teacher role or the comforter role, it would have also had a positive effect on the parents' preference. Since the robot was

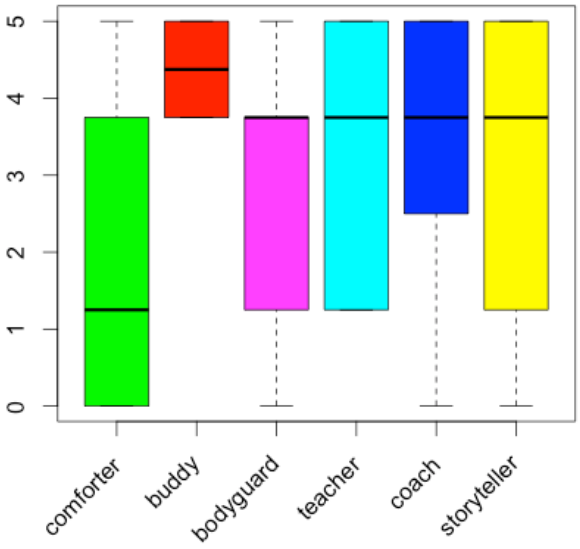


Figure 3.4: Parents willingness of roles for the robot on a Likert scale

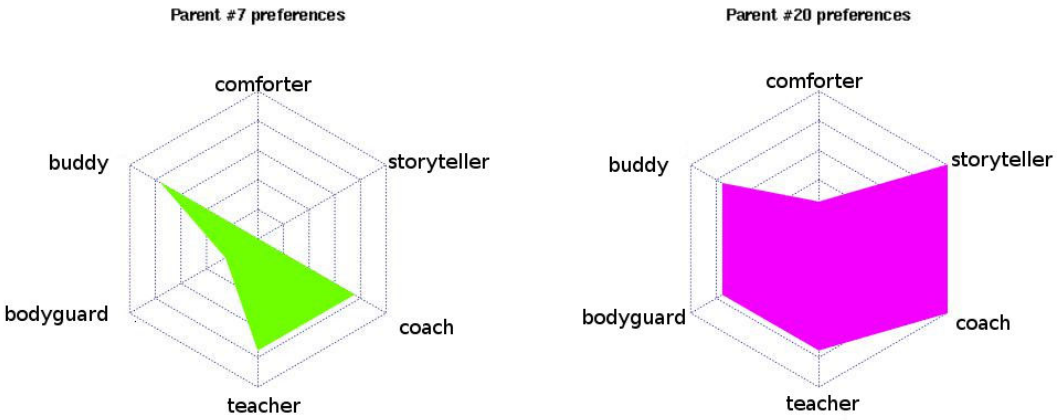


Figure 3.5: Different profiles of Parents preferences regarding the role of the robot for their children (on the left, Parent 7 and on the right Parent 20)

adopting a teasing attitude during the game, it could have negatively influenced the imagination of the parents in "serious situations" such as while teaching, coaching, or performing a body-guard role. The appearance of the robots certainly plays a role in the participant's imagination of the role for companion robots. The participants didn't imagine that the robot could have had other appearances that would maybe suit the roles better. Finally, this study was conducted in an exhibition. The pool of participants was relatively small and not representative of all parents (a priori all were interested by robotics).

Interviews showed that interrogated parents agreed to have a robot companion for their children but not during intimate situations (no storytelling before bed, no comforter). There is not much trust in the capacities of the robots and hence in the case of a problem (confronter or bodyguard) this task shouldn't be given to the companion robot. This study also showed that many roles can be envisioned for a companion but raised the question of the cardinality of companions (i.e. should it be the same companion playing all the roles or is it better to have one role per companion?).

An adaptation to the user can also be situated in context. The next section presents the notion of **plasticity** in HCI, which illustrates this ability to adapt to the context of use.

3.5 Plasticity and Context Adaptation

This section addresses the notion of *Plasticity* as it is used in Human-Computer Interaction to model adaptation to the context of use. The following review is based on the work of [Coutaz and Calvary, 2012] on Plasticity in HCI.

User-Interaction Plasticity

capacity of adaptation to the context of use while preserving usability and worth (acceptability). [Coutaz and Calvary, 2012]

The context of use contains three information spaces :

The platform includes the hardware and software resources of the system (sensors, algorithms, displays). For instance, smartphones, tablets or TV screens.

The environment attributes and functions that characterise the physical places and the time of interaction. For instance, Monday 14th of July at 10pm in France, no light, national holiday, summer, heat ....

The user describes the archetypal person who will or is using the system. It is actually the user preferences

One can imagine that when changing the context (one of this space), the interface, in order to offer optimum functionality, has to change has well. For example, if one looks at the time on his/her smartphone during a meeting, they might need to do it discretely, access to the time with a small gesture and displayed on a low luminosity can appropriate, but the font would have to be big for me to see. However, if they look at the time on their computer during a meeting, if some people are behind me, the clock can be discrete on their screen and as the brightness is high it can be in small font. To show the time to their friend on their smartphone after the meeting, they might want the brightness of their screen to be higher since there is no need for discretion any-more.

In order to build our framework for our after-school companion robot for children, we chose to apply the plasticity concepts in HRI. We defined the corresponding three main views for the companion robot:

The embodiment can be the robots or the virtual agent's appearance and the software resources of the system (sensors, algorithms, displays).

The social role are attributes and functions that characterise the role played by the companion robot. These roles are based on the previous study but can be extended.

The user describes the archetypal person who will or is using the system. It should take into account not only children but also parent's preferences.

From this review of robot adaptation, it appears that the ideal companion would be able to adapt to its embodiment, to the user and to the role it is given (see figure 3.6). A plastic companion robot requires then to be:

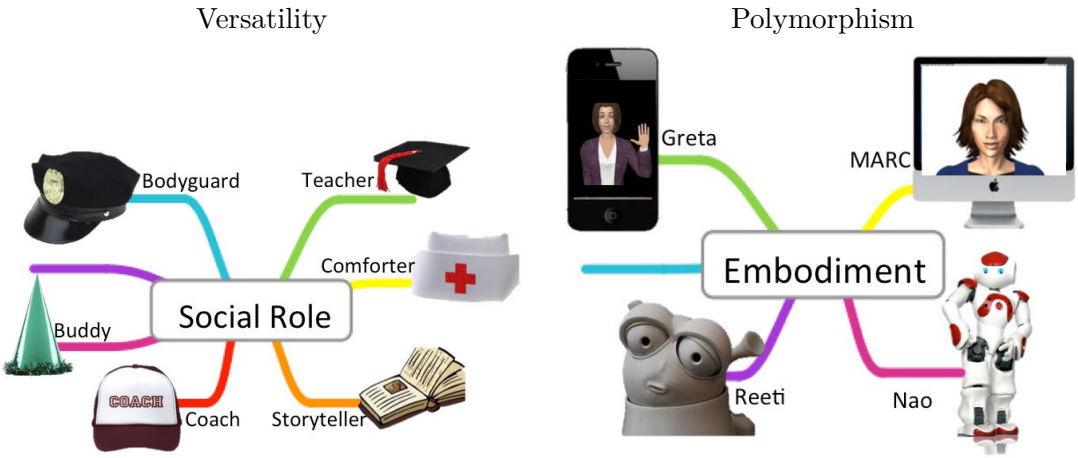


FIGURE 3.6: Illustration of required abilities for a plastic companion robot

- Versatile: robot credible and engaging when changing roles, for instance first a Teacher, then a Buddy.
- Polymorphic: able to express itself in various appearance, for instance Nao or Reeti
- User-adaptable: able to adapt to the user's expectation, for instance by behaving with a preferred *style*.

Our contribution on the adaptability behaviour aims to respect these three criteria by offering a style model that can be applied:

- in various roles and motions (styles are role-dependent, we studied Buddy and Teacher roles, see chapter 7)
- on various robotic platforms (i.e. Nao and Reeti),
- with various behaviours (pointing, waiving, applauding . . .)

The approach taken in this thesis is in line with the wok of [Krämer et al., 2011], who suggested not to create a uniquely perfect persona but to let the user customise its companion by giving it roles and personality. In the work of Kramer et al., inter-individual differences between human users are said to be critical for interaction and relationship building. Chapter 4 will introduce the plastic framework of a companion robot in which styles allow user adaptability within social roles that a robot can play.

of the agents, multimodality...).

3.6 Summary and Conclusion

In this chapter we have seen that a Scenario-Based Design can be used as a support for collecting user's requirements on roles that should be played by companion robots

for children. Chapter 4 will present how we continued with the Scenario-based Design for the conception of our companion robot system.

The literature analysis showed that few parents are willing to have a companion robot for their children in all the roles. Conclusions from literature are that controllability, adaptability and sociability are mandatory for companion robots.

Our first study also showed the user's variability in the acceptance of companions. Then how can versatility be modelled? How can user adaptability with platform constrains can be implemented? We propose to use *behavioural styles* in order to keep controllability and adaptability for social robots. Behavioural styles are presented in the next chapter (4).

Part II

Model and Technical Implementation

Second Part

In the first part we saw ... this constat leads us to propose a solution in this second part

This second part includes the following chapters :

- The chapter 4 presents the chosen design approach, followed by the style model and conceptual framework itself. We finish by some examples of style sheets for parenting styles.
- The chapter 5 is dedicated to present the Cognitive and Affective Interaction-Oriented (CAIO) architecture. This chapter introduce the basic principles of the reasoning engine previously developed. It also shows the re-implementation of this architecture within the ROS framework and the integration of our new style model within this architecture.

Chapter 4

Style Model

In this chapter, we describe our approach in designing a behaviour for companion robots that respects the theory model of styles. Several expressibility parameters exist to characterise motion. We used some of these parameters to filter pre-designed motions and to generate *style*d motion.

In the state of the art on styles in Psychology (in section 2.3.1), we have differentiated cognitive styles (closer to the notion of personality) from other kinds of styles which are more role-dependent (such as leadership styles, parenting styles etc.). Our definition of Behavioural Styles is in line with psychological role-dependent styles, and hence takes into account the role played by the robot. Before giving details in the model and the generation process of *style*d behaviour, let us clarify the properties of our behavioural styles:

Behavioural Style Properties

- described by a list of parameters
- expressed in non-verbal cues of communication
- associated to a meaningful concept in psychology

4.1 Design Approach

In this section, the different modules involved in the style model are described. Then, we detail on the implementation and give some examples of style sheet and application on the Nao and Reeti robots are given.

4.1.1 Theoretical Grounding

As presented previously, the **Plasticity** perspective is taken in order to render an adaptable companion robot. Styles characterise the plasticity of the behaviour (variability in the same context) as opposed to the personality that characterises the

behaviour consistency (consistency across contexts). Our approach aims to apply plasticity concepts to HRI as it was applied in HCI.

As described by [Coutaz and Calvary, 2012], the context of use modelling, in which different styles can be applied is presented by the presence of three concepts :

- the role: which corresponds to the social role for the companion robot.
- the entities involved: corresponding to the number of robots involved and their competencies (role they can play).
- the situational inter-relation: the listener, the speaker (one can also specify here the relative position of the agents).

Based on the previous study in Chapter 3, we have identified 6 problems/situations for children alone at home and proposed 6 social roles for the companion robots to fulfil in these contexts.

Following the Scenario-based approach, (see 3.1), we propose a scenario that incorporates all of the above problem/situations while highlighting the interactions between the companion agents and the child. It should be noted that a social role, for example that of a Teacher, can be deployed via one or many forms (e.g. virtual agents and/or robotic agents) that will collaborate and cooperate in order to accomplish the tasks and to reply to the needs of a specific problem/situation. An example of a scenario written in natural language can be found in the the Annex C.1.

4.1.2 Roles Modelling and Simulation

In order to clearly frame the companions' roles and their interactions, we have chosen to use the tool BRAHMS (Business Redesign Agent-Based Holistic Modelling System) [Sierhuis, 2001] for modelling different scenarios. BRAHMS is an agent oriented language and development environment for modelling and simulation. BRAHMS is able to represent people, places, objects, and behaviours of people over time along with their social behaviours [Sierhuis et al., 2007]. In support, BRAHMS provides several models with which the developer can detail their environment: agent, object, activity and geography. Furthermore, BRAHMS has similarities with a BDI (Belief-Desire-and-Intention) approach in the way that it allows goal-oriented behaviours and the manipulations of beliefs. In the past, our research team has used BRAHMS to model and simulate behaviours of human agents and their impact on energy management [Kashif et al., 2011].

BRAHMS is structured around the following concepts [Sierhuis, 2001]: *Groups* contain agents who are located and have beliefs that lead them to engage in activities. The activities are specified by

- *workframes* that consist of preconditions of beliefs that lead to actions (consisting of communication actions, movement actions, primitive actions) and other composite activities, consequences of new beliefs and world facts,

-*thoughtframes* that consist of preconditions and consequences in term of belief only. Through the use of a time-line we are able to analyse the individual behaviours

and interactions of each agent.

In the geography model, we represent the physical environment of the neighbourhood, including the school and the house, the latter of which is divided into rooms with linking pathways. The children, adults, and artificial companions are all modelled as agents (specified in the agent model), each agent having their own characterising attributes and beliefs. All agents are the part of group World; this allows us to define general activities, attributes and reasoning processes shared by all agents. The group World contains three main groups: Adults, Children, and Companions, each group has their own specific needs, locations, actions (the abilities), e.g. adults can be at the office, and children have homework and the need to play. Thus, the reasoning and abilities of companion agents are dependent on their role. Figure 4.1 shows how we can instantiate a group in BRAHMS modelling language

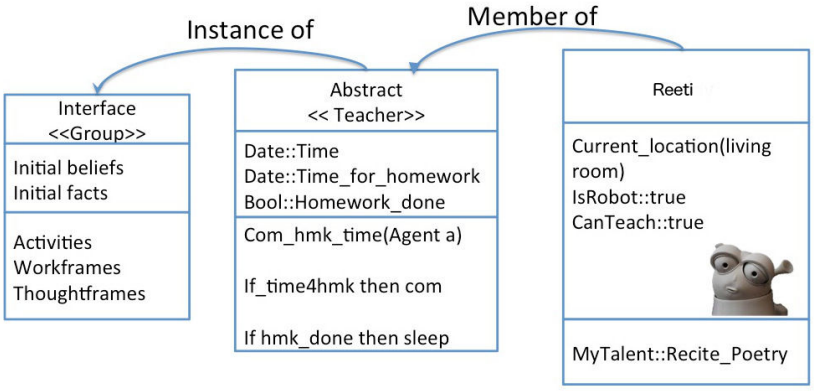


FIGURE 4.1: Group in BRAHMS instantiated as the Teacher role.

into a role, with specific beliefs, activities (tasks), workframes (functionalities) and thoughtframes. In this example, the Teacher has a belief about the time for homework. If it is time for homework, it can communicate the need to do the homework to another agent.

In the simulated scenario, we define four types of activities:

-*primitive activities* are defined by their duration (e.g. the activity of listening to a song);

- *move activities* specify a goal location, such as a particular room, and which use the geography model;

-*communicate activities*, defined by a receiver and a message;

-*broadcasting activities*, which allow communication to all agents in the same location as the broadcasting agent.

Workframes contain the actions of the agent with associated preconditions and consequences. For example, the Teacher agent may have the workframe symbolising the rule: if there is the need to do the homework and the homework hasn't started

yet, Teacher should communicate with the child to tell him that it is time to do the homework (figure 4.2).

```
workframe wf_DemandToDoHomework{
 repeat: false;
 priority: 1;
 when(knownval(current.needToDoHMK = true) and knownval(current.homeworkStarted = false))
        do {
                communicateTimeForHomework(Ben,"time  for  homework !");
        }
}
```

FIGURE 4.2: A Teacher agent Workframe

Thoughtframes allow the manipulation of agents' beliefs and adding uncertainty to a belief (e.g. a belief may only be held 75% of the time). This could be interpreted as an agent 'changing its mind' and ultimately this means that each run of the simulation can differ. In figure 4.3, we see a screenshot of a simulation in the BRAHMS environment, showing the situation when the teacher reminds Ben at 5pm, after he's been watching TV, that it's time to do his homework.

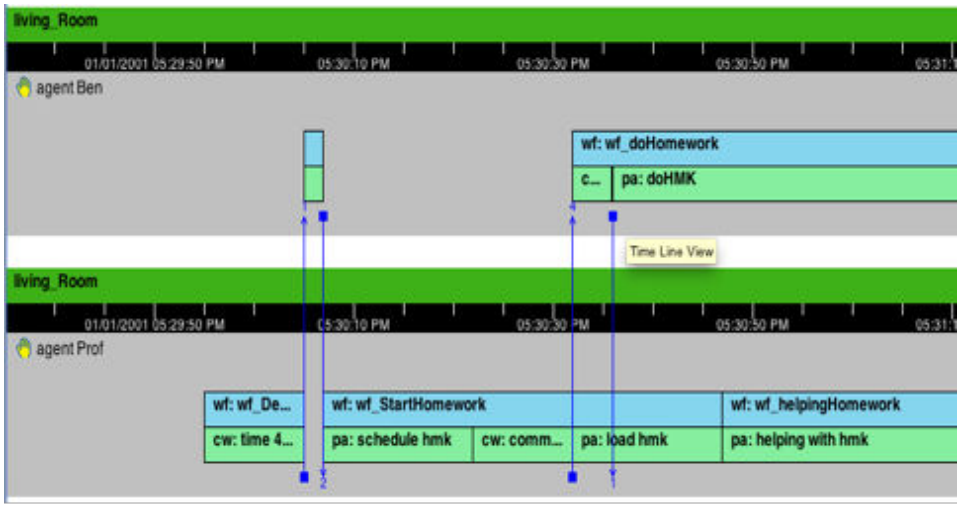


FIGURE 4.3: Teaching situation.

The location "living_Room" is shown for each agent (Ben and Prof), together with the date and time, horizontally at the top and middle of the figure. wf, cw, and pa refer to workframe, communicative activity and primitive activity respectively. Blue vertical arrows show the communication and interaction between agents (other examples of simulation are presented in the annex A.2).

We modelled each role as a group sharing abilities (workframes and thoughtframes). In BRAHMS, agents are situated, which allows us to detach the role from the device and also to instantiate the role by more than one situated companion

(Poto and Buddy belong to the Playing Group). Indeed, we can imagine one situated agent member of all of the group, being able to accomplish all the roles.

Modelling and simulation the scenarios in BRAHMS had the advantage of highlighting the behavioural variability that we have to face for the design of our system. Indeed, the variability in the context of use [Calvary et al., 2001] composed by the user, the platform, and the environment, shows the importance of the predefined family rules that will help the companion agent to take a decision according to its role. In the simulation, a family is a mixed group of companions and humans that will share some beliefs and throughtframes manipulating these beliefs (figure 4.4).

```
group Family_One memberof Families {
...
        initial_beliefs:
                (current.time_for_homework = 5);
                (current.Kids_allow_to_watchTV = false);
```

Figure 4.4: Listing extracted from the group Family_One (BRAHMS file)

In order to be able to simulate the variability of the device that can play a role, we consider the social role as a group that can be instantiated by several situated agents. Detaching the role from the device allows us to instantiate several roles in one device hence allowing *versatility*[1] of the companion robot. This highlighted the importance of context into the decision of the agent of taking a role. Indeed, as a Teacher can help with the homework, he can also be a play buddy after this task is done. One issue that has been raised by our simulations is the coordination of multiple companion agents. Indeed, several strategies can be chosen when a role has to be played when several agents are capable of playing this role. We may enrich the model by adding cooperation, assignment, or redundancy decision in the role played by multiple companions. This will depend on the context and some roles will need redundancy (Bodyguard) in order to insure detection whereas other role will offer more benefit with cooperation (Teacher).

Versatility of the companion robot have been tested in real experimental settings with children. Chapter 7 presents this experiment in which two roles are implemented (Teacher and Buddy play) in either one versatile robot or two specialized robots.

Now that our definition and the model of social role for our companion robots are clearer, the next section presents our contribution in the personalisation of the role playing using the behavioural styles.

4.2 Personalisation with Styles

On top of the roles, behavioural styles, as previously mentioned, will affect the non-verbal expressibility within the role.

[1] **Versatility** for a companion robot is defined as the ability to adapt and play different roles and activities

The notion of style is in this model: a set of behavioural changes that can be applied to any motion of a role repertoire and that leads to a meaningful interpretation of the way the motion is executed. A styles filter is used to generate behaviours according to the role and to the user's preferences. Only a few styles have been implemented for our experiments but the solution that we propose can be extended. The aim is that users could choose the styles from a catalogue and set the one they prefer, providing hence the adaptability of the companion within the social role.

As for CSS, the aim in the style framework for design of social behaviour for robots is to make them **reusable** and **flexible**. We intent then to show that styles can be applied to various gestures and pre-defined behaviour but also used for various robotic platforms.

The style model acts similarly to a filter. It is fed by neutral gestures that are contained in the role repertoire and applied at run-time on the pre-selected gesture. The stylized gesture is then sent to the scheduler in order to perform it.

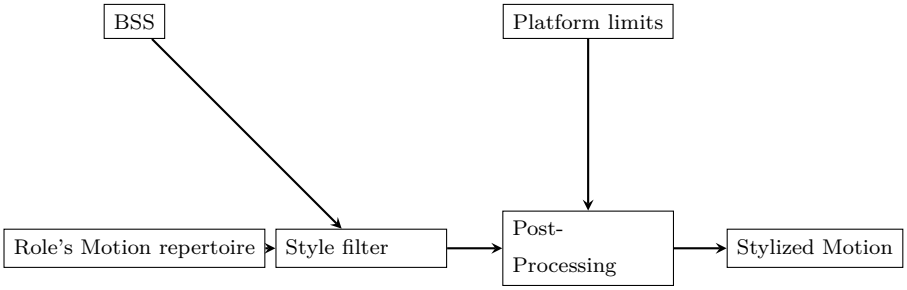


Figure 4.5: Pipeline of Stylistic treatment of data

The figure 4.5 shows the general data work-flow for the runtime generation of stylistic motion.

Our system takes as input a pre-defined motion that has been selected to be performed. This motion belongs to a motion repertoire that is associated to the current role played by the robot. The input **motion** is defined by a series of key-frames. A motion is hence a tuple containing : the names of the joints active during this motion, for each joint the list of relative *time* when a key-frames appends and for each joint and each time the associated *key-frame* value (either angular or relative activation of the joint).

The styles are defined within the **Behavioural Style Sheet** (BSS) format. The style is set before run-time. It defines the modification that will be applied to the original motion. The BSS is divided in two main parts, the hearer and the speaker parts. Indeed, according to the fact that the robot is reacting to someone speaking or speaking itself, the style parameters may vary. The BSS is further discussed in the section 4.2.1.

The **Style filter** is the core program written in Python. It contains some transformation algorithms inspired from works in 3D animation allowing the interpretation

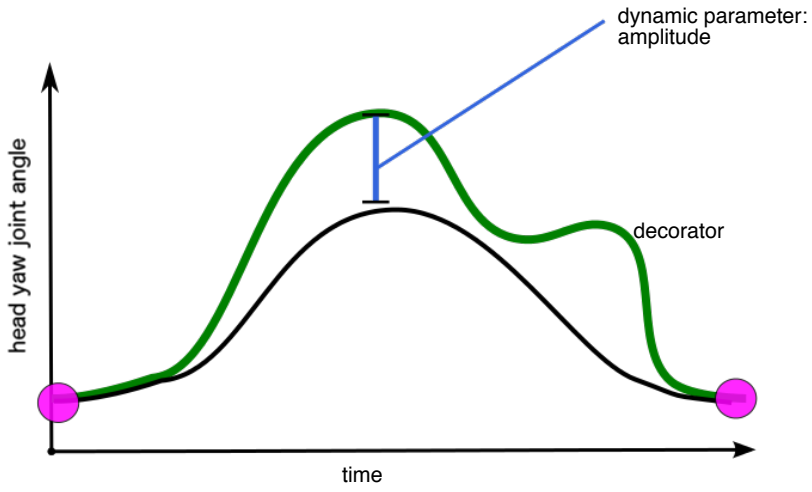


Figure 4.6: Style parameters for Head Yaw(green is stylized motion, black is original, the P0 pose is in pink)

of the BSS and the generation of new motion. Some examples of algorithms implemented in the current version of our system are presented in section 4.3. The generated motion can be however out-passing the physical constraints of the robot's motor.

The **Post-Processing** module takes as input the platform's limits (speed and angular limits of each joints) and the generated motion and ensures that the computed styled motion is within these limits. If not, the generated motion is modified to fit within the joints' constraints

4.2.1 Style filter

We defined behavioural styles according to the 1) static and 2) dynamic parameters, as well as 3) decorators patterns. These parameters allow us to depict variation of execution of motions. The values taken by these parameters are referred to psychological models of style and are used as a percentage of the total value in order to be applicable to several platforms or the frequency rate.

Figure 4.6 shows an example of stylisation of a head yaw joint angle motion. In this example, the static parameters are included in the $p0$ position. The amplitude change is a part of the dynamic parameter. Finally the decorator is an additional keyframe with a new value. The decorator is often an additional motion that is fused with the current motion.

(1) Static parameters allow to describe the neutral pose p0. This neutral pose p0 is the posture the robot will take by default. Sometimes, some joints of the body

won't be in motion, and hence the robot will keep the joint values of p0. As before, we define this pose in accordance with the styles found in the literature. There are several static parameters that exist to describe poses. p0 is very platform dependent. The definition of the pose is made in a specific file for each robotic platform. Figure

Style Permissive	Style Authoritative
p0 filename: permissive.py	p0 filename: authoritative.py

FIGURE 4.7: Example

4.7 shows an example of the call of the p0 poses as defined for the Authoritative and Permissive styles for the Nao robot. The style modeller makes a reference to this file in order to build the stylized motion at runtime and adds p0 before and after each motion event to ensure that it is the default pose.

(2) Dynamic parameters From the literature in HRI and virtual agents in the domains of animation and psychology, we have listed some dynamic parameters that can be useful to depict changes in styled motion. The current implementation of styles take into account the following parameters.

Style Permissive

```
speaker{
dynamics{ amplitude=50 tempo=none speed=100 duration=100 noise=0
}
voice{loudness=20 pitch=80 speed=80 pausing=before()
}
}
hearer{
dynamics{ amplitude=50 tempo=none speed=100 duration=100 noise=0
}
}
```

Style Authoritative

```
speaker{
dynamics{ amplitude=200 tempo=none speed=200 duration=100 noise=0
}
voice{ loudness=80 pitch=50 speed=50 pausing=after(",","!","Stop!")
}
}
hearer{
dynamics{ amplitude=200 tempo=none speed=100 duration=100 noise=0
}
}
```

FIGURE 4.8: Example of dynamics for Permissive and Authoritative Styles

- Amplitude: the spacial extent related to the dimension of expansiveness from Gallaher and Meharbian.
- Speed: temporal extent and the velocity of execution of the movement.
- Tempo: specifies a rhythm for the key-frames in the motion (that are spaced according to the tempo).
- Noise: opposed to fluidity, noise makes the movements jerky where smoothing makes the movement fluid.

- Duration: specifies a duration for the motion.

These parameters are set for each style, and for each of them, an algorithm takes the current motion and the value of this dynamic parameter to compute a new motion. For instance, one can double the amplitude, change the rate, add a tempo to the motion and make the motion noisy. An example of dynamic parameters in the BSS is given in figure 4.8.

```
Data: (names, times, keyframes),speed_magnitude
Result: stylized(names,times,keyframes)
for each joint joint do
    for each keyframe key do
        duration = times[joint][key] - times[joint][key - 1];
        new_duration = duration*magn/100;
        new_times[joint][key] = times[joint][key - 1]+ new_duration;
        current_joint.append(new_times[joint][key]);
    end
    times_new.append(current_joint);
end
```

Algorithm 1: Speed Style Transform

The Algorithm 1 gives the method to compute new times for the keyframe for each joint with a certain magnitude change. In this algorithm, we first compute the duration between the time of the current keyframe and the time of the previous keyframe.

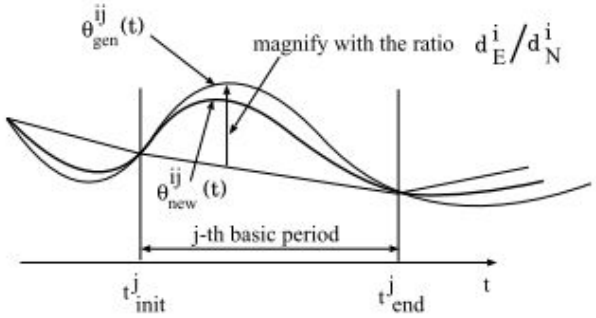


Figure 4.9: Amplitude transformation of joint angles from [Amaya et al., 1996]

For the amplitude of the transform, we inspired ourselves from a method in the animation literature [Amaya et al., 1996]. This method consists of computing a new keyframe based on the previous and new keyframe value. The Algorithm (in Annex A.2) shows a method of changing the magnitude of the joints' keyframe values at runtime.

We also proposed to use simple voice parameters to adapt the voice to the required style :

- Pitch: with 100 as the highest pitch and 0 the lowest.
- Volume: the loudness of the voice.
- Pausing: use pose as a decorator; adding pose before, or after punctuation.

The function handling these parameters was however quite dependant on the formatting of the speech-to-text tool used by the robotic system.

(3) Decorators This corresponds to the motion pattern added to the original motion. This motion can be added before, after or during the original motion. If the decorators are added within the original motion, then the motion is fused using a time and space interpolation algorithm between motion of the original joints and the decorator motion. Figure 4.10 shows an example of an implemented decorator for the Permissive style. In the decorators, we considered:

- Smile: can temper when accompanying negative messages, reinforce a positive message, show embarrassment, can display intimacy [Knapp et al., 2013].
- Head Nod: can be linked to expressiveness [Gallaher, 1992], to reinforce a message at the end of the speech act, to show submission as a hearer [Knapp et al., 2013, Hall et al., 2005].
- Gaze: sign of submission/dominance, confidence.
- Blink: sign of submission/dominance, confidence.
- Self-Contacts: sign of submission/dominance, confidence.

Style Permissive

```
speaker{
        smile{ rate:10 duration: 50 intensity: 10}
        gaze { rate:10 duration: 50 intensity: 10}
        blink{ rate:10 duration: 50 intensity: 10}
        head-nod{ rate:10 duration: 50 intensity: 10}
        self_contact{
                hand_self_contac{rate=50 duration=20 intensity=50}
                face_self_contact{rate=10 duration=50 intensity=50}
                hips_self_contact{rate=0 duration=0 intensity=0 }}}
hearer{
        smile{ rate:10 duration: 50 intensity: 10}
        gaze { rate:10 duration: 50 intensity: 10}
        blink{ rate:10 duration: 50 intensity: 10}
        head-nod{ rate:10 duration: 50 intensity: 10}
        self_contact{
                hand_self_contac{rate=50 duration=20 intensity=50}
                face_self_contact{rate=10 duration=50 intensity=50}
                hips_self_contact{rate=0 duration=0 intensity=0 }}}
```

Figure 4.10: Example of decorators for the Permissive Style

4.2.2 Post-processing

The post-processing module is in charge of making sure that the physical constraint of the robots are respected after the stylisation. It consists of verifying that the

```
Data: (names, times, keyframes),decorator_motion
Result: motion with decorator after
for each joint j do
    limits <- parse limits for the joint j ;
    for each keyframe key do
        if out of limits(value[joint][key]) then
            key = min or max limit;
    end
end
```

Algorithm 2: Limits post-processing

limits (joint angles, angular speed, and eventually the angular acceleration) are not attained by each joint.

For each joint, we take as input these limits and compare the joint angle, its angular speed and angular acceleration (see Algorithm 2). If the joint is out of the limits, the keyframe is modified by adopting the closest allowed value (min or max of the limit).

4.3 Examples of Stylized Motions

Figure 4.11, shows several screen-shots of some styles modifications. The file used as input of this software is outputed from the Choregraphe Software of Aldebaran for the Nao robot. It is also possible to import an `Urbi` file describing a motion from the Reeti robot.

Figure 4.11 shows an example of motion transformation with the style model. The first row corresponds to the variation of the amplitude of the clapping gesture on the Elbow-raw angle and the second line correponds to the speed transform.

4.4 Summary and Conclusion

This chapter presented our proposed method to render stylistic motion for companion robots playing a social role. In the first part we presented our work on social role modelling. In the second part, we proposed the Behavioural style filter that enables us to modify the original motion and generate a stylistic motion. Stylistic parameters are defined in a BSS format.

Parenting styles presented in this chapter have been evaluated through two experiments. First, an online experiment that allowed to evaluate the expressiveness of styles by the two robots - Nao and Reeti (presented in chapter 6). The second experiment (presented in chapter 7), was also generating stylized motion at runtime from neutral motion of the Nao robot

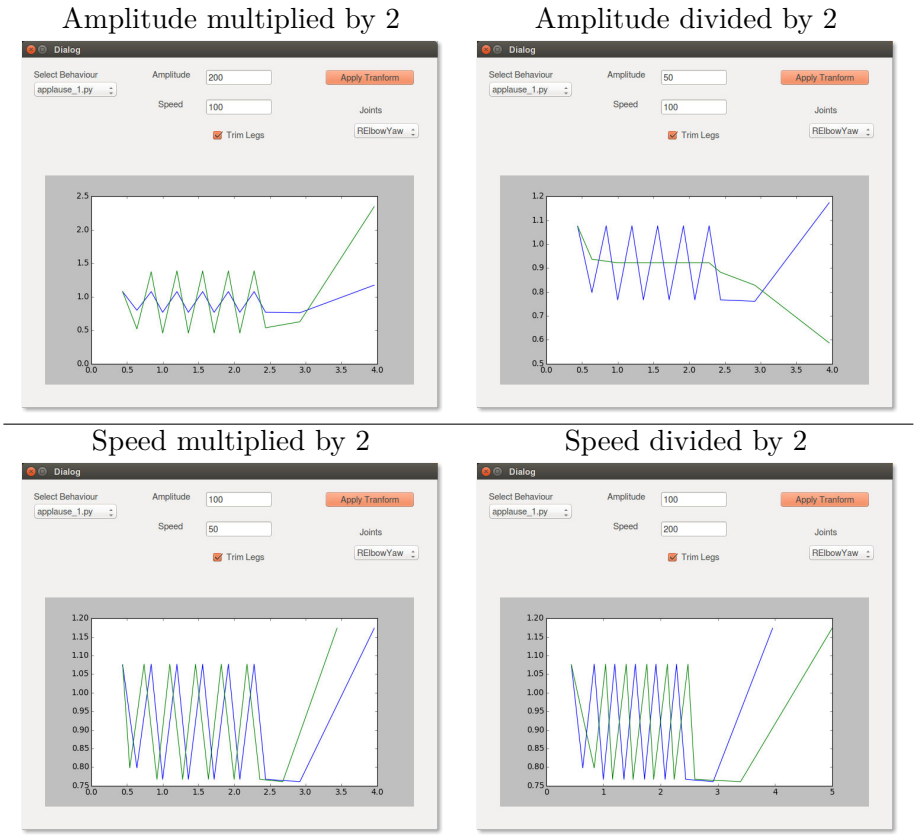


FIGURE 4.11: Examples of motion transformations of the Elbow-raw joint when clapping, where the blue line is the same original motion and the green lines are the computed new motions

BSS format is a high level description of styles allowing re-usability and flexibility while keeping meaningful description according to the social role. For instance, by taking into account environmental constraints (i.e. we do not take as input motion that deals with objects or environmental contact), one could potentially improve the applied approach. The self-contact collisions are not taken into account but could be a part of the post-processing module.

Also, the evaluated styles were implemented for the Teacher role and based on the parenting styles. Other styles for the same role could be proposed (teaching styles for instance). We can also look at some other roles in which styles should be tested, based on the style factors proposed by [Gallaher, 1992] and listed in the Annex A. For instance, we can imagine a situation where we could observe high animation gestures or low animation gestures. Likewise, a comforter could be expansive or less expansive. The buddy could play with the child being either coordinated or not.

The behavioural items proposed by Gallaher could help in building other styles that the robot should play according to the social role in question.

Chapter 5

CAIO Architecture for Social HRI

In this chapter, we present the Cognitive Affective Interaction-Oriented (CAIO) architecture. This CAIO architecture is based on the work previously done in our research team presented in Section 2.5: the BIGRE logic, the Multimodal Conversation Language, and the PLEIAD reasoning engine integrated in a first architecture by [Riviere, 2012]. It enabled agents to reason on their mental states (including complex emotions) and the ones of the interlocutor and to act emotionally and verbally. This first version was however designed for virtual agents only and was not modular. The contributions made here are:

- the modularisation of the architecture, with integration of theories on memories from cognitive sciences,
- the implementation of the architecture modules in Robotic Operating System (ROS)[1] allowing to apply it on many robots .
- and the implementation of bodily expression of Stimulus Evaluation Checks from Scherer for robots Nao and Reeti.

5.1 Principles of the CAIO architecture

5.1.1 Overview

The CAIO architecture (see Figure 5.1) involves two loops: a *deliberative loop* used to reason on the BIGRE mental states and produce plans of action, and a shorter *reactive loop* to immediately trigger emotions. Each loop takes as input the result of the multimodal perception of the environment. This two-loop system is in line with the work in cognitive sciences on the Dual-process theory [Evans and Stanovich, 2013]. This theory states that there exist two cognitive systems involved in cognition,

[1] ROS is a middle-ware and software frameworks where processes are set in a graph architecture and each process is a node of this graph.Please see http://www.ros.org/

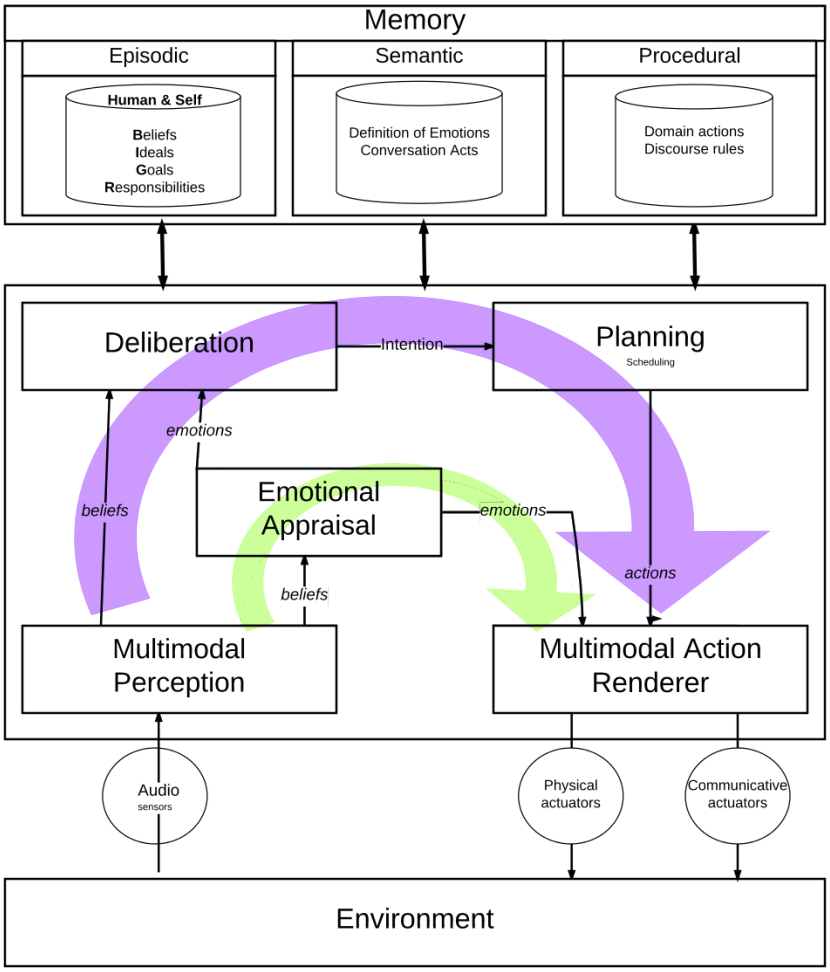


FIGURE 5.1: The CAIO architecture.

one slow and deliberative (S2) and the other fast and intuitive (S1) (see Table 2.1 and Section 2.4).

In CAIO, during the deliberative loop, the **deliberation module** deduces the robot's communicative intentions based on its BIGRE mental states and selects the most appropriate one. Then, the **planning and scheduling module** produces a plan to achieve the selected intention (i.e. a set of ordered actions, MCA and/or physical actions), and schedules the robot's next action. Finally the **multimodal action renderer** executes this scheduled action. Modules can provide feedback to each other: the planning module informs the deliberation module of the feasibility of the selected intention; the action renderer informs the planner of the success or failure of action performance.

Simultaneously, during the reactive loop, the **emotional appraisal** module uses the mental states to trigger the robot's complex emotions that can be directly expressed by the multimodal action renderer via the corresponding expressive MCA.

Both emotion and action are finally merged by the multimodal action renderer to produce the appropriate expression according to the robot's actuators. For instance, in the case of a verbal action (MCA), the action renderer module produces the facial expression that matches the emotion and utters the propositional content of the MCA.

The following subsections detail the role of each module in the architecture.

5.1.1.1 Perception module

The aim of the perception module is to take as input a *natural language* utterance in order to generate beliefs on the user's mental states. These beliefs are then be evaluated by both emotional appraisal and deliberative modules.

This module first recognises text from speech (using Google Speech to Text API). Then it extracts the human's MCA from the recognized text utterance[2]. The MCA is then processed as new beliefs that enter the two loops of cognitive processes (described in sections 5.1.1.3 and 5.1.1.4). Future works on multimodal fusion should help us to also consider facial expression and para-linguistic signals in order to build MCA stimuli that are intelligible by the robot.

5.1.1.2 Memory module

The robot's memory is divided into three parts in accordance with the state of the art in cognitive sciences. The *episodic* memory contains BIGR based knowledge representations of self and human in interaction. The *semantic* memory is composed of definition of emotions concepts and conversational acts. The *procedural* memory deals with the domain action (how-to) and the discourse rules (for instance, when asked a question, one should reply).

The memory module treats its dynamic part in three steps: first by *adding* new beliefs, as deduced from perception of the interaction; then by *updating* the robot's BIGRE mental states *via* inference rules that can deduce new mental states; and finally by *resolving conflicts* that can appear. For more details on these processes, the interested reader can refer to [Rivière, 2012]

5.1.1.3 Appraisal module

The appraisal module takes as input the robot's perceptions and mental states and triggers the complex emotions from their logical definition in terms of the mental

[2]Natural Language Understanding is a complex research field of its own, we do not tackle this problem here, and instead use an ad-hoc grammar specifically designed for our scenario in order to extract an MCA from Natural Language.

states. For example, the emotion of gratitude is triggered when a robot has the goal φ and believes that the human is responsible for φ, i.e. when the robot has a mental state $Goal_i\varphi \wedge Bel_i Resp_j\varphi$. The emotion intensity is derived from the priority of the goal or the ideal included in its definition.

5.1.1.4 Deliberation module

The deliberation is the process that allows to decide the robot's communicative intentions, i.e., the goal to achieve. The CAIO architecture uses the three kinds of communicative intentions implemented by [Rivière, 2012]: the *emotional* (when feeling an emotion, it should be expressed) and *obligation-based* intentions (i.e. when asked a question one should reply) useful to local dialogue regulation [Baker, 1994], and the *global* intention (related to the goals) which defines the dialogue direction. The robot's communicative intention is selected *via* practical reasoning [Bratman, 1987b] from its mental states (BIGR+E) and a set of priority rules.

5.1.1.5 Planning module

The planning module is in charge of the way of achieving the selected communicative intention according to a plan-based approach of dialogue [Perrault and Allen, 1980]. The plans produced contain MCA and/or physical actions.

In the case of emotional and obligation-based intentions, the built plan is usually made up of only one MCA. For example, suppose that a robot's emotional intention is to express gratitude, the plan will be a single MCA, *Thank* or *Congratulate* depending on the emotion's intensity. In the case of global intentions, domain-dependent actions may be necessary. The preconditions and effects of these actions are described in the static memory of the CAIO architecture. For instance, a robot intends to book a train for a human, it has to know that to book a train it needs information about the time and date of departure and destination. Then it can use the same planning mechanisms to decide what are the appropriate MCA (*e.g. Ask*) to get this information.

Finally, if a plan to achieve the current intention can not be computed, this intention is discarded and another one is selected by the deliberation module. If the intention planning module can not produce a plan to achieve this intention, another intention has to be selected.

5.1.1.6 Multimodal Action Renderer

The last module of the CAIO architecture is the multimodal action renderer. This module takes as input an action to be executed and the complex emotion computed by the appraisal module. The role of this module is to command the robot's actuators to executed the input action and to dynamically generate the expression to accompany the MCA achieving the communicative intention selected by the deliberation module.

For this purpose, the multimodal action renderer appraises each MCA with regard to *Stimulus Evaluation Checks* (SEC) introduced by Scherer's appraisal theory [Scherer, 2001] and that [Rivière, 2012] adapted to the speech act theory. The checks used in the architecture are the most commonly used in the community :

1. **Novelty** of the speech act (was it expected in the dialogue scheme?),
2. **Intrinsic Pleasantness** depending on the type of act, e.g. Refuse *vs.* Accept, and the propositional content;
3. **Goals Congruence** and attribution of responsibility by the robot;
4. **Coping Potential** : ability to influence the speech act's consequences;
5. **Norms Compatibility** with the robot's ideals.

The figure 5.2 shows the dynamic expression of reproach resulting of the translation of the checks to Action Units (AUs) displayed by the MARC[Courgeon, 2011] virtual agent.

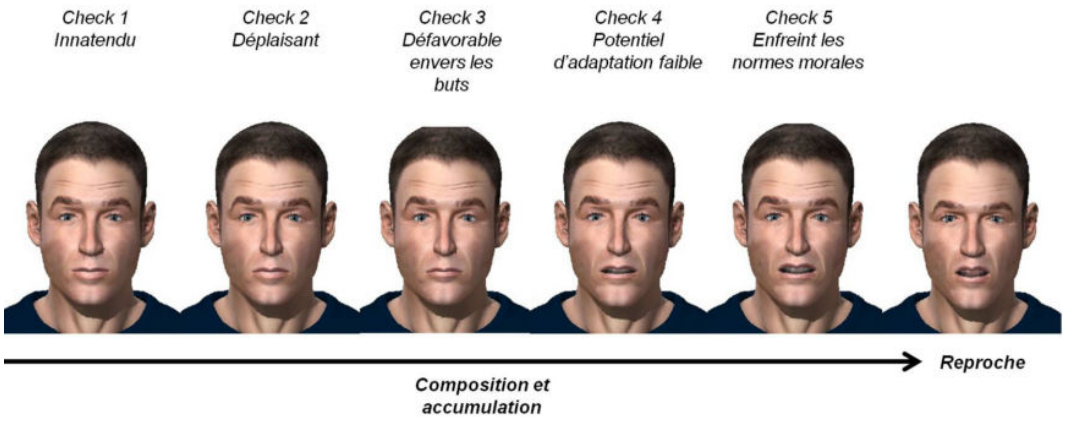
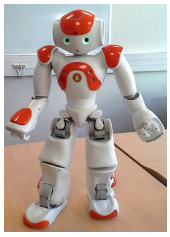
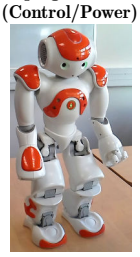
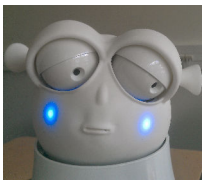
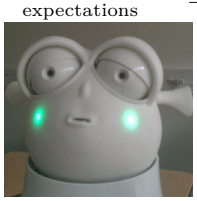
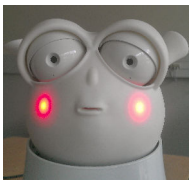
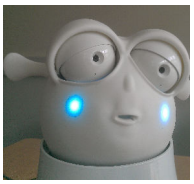


Figure 5.2: Dynamic expression of Reproach by the MARC Avatar resulting of a translation of the checks to Action Units (AUs) [Rivière, 2012]

The dynamic expression building is done independently of the choice of the communicative intention selected by the deliberation module (described in the section 5.1.1.4). Using the work of Scherer[Scherer, 2001] and [Rivière, 2012, Erden, 2013, Coulson, 2008], we were able to make the correspondence of the checks with facial and bodily expression for robots.

The Table 5.1 shows, the dynamic evaluation of a stimulus leading to the *Reproach* emotion for the Nao and Reeti Robots. This stimulus evaluation goes through the emotional appraisal module of CAIO. It leads to a sequence of target postures simulating the dynamic of the *Reproach* complex emotion associated with a communicative utterance (in RDF-like format). The emotional evaluation is done through

every checks to which correspond a target posture. The sequential dynamic of these SECs outcome poses results in expressing the *Reproach* emotion.

Novelty	⇒	**Intrinsec Pleasantness**	⇒	**Goal/Need Conductivness**	⇒	**Coping Potential (Control/Power)**	⇒	**Norm Compatibility**
								
Novel	⇒	Unpleasant	⇒	Unmet expectations	⇒	Low Control	⇒	Norm violated
								

Reproach[User,not(come to my party)] ⟺ "Why didn't you come to my party?"

TABLE 5.1: SEC sequence generating Reproach.

5.2 Implementation and Scenario Example

The previous architecture provided by [Rivière, 2012] needed re-implementation for several reasons. First, the re-design of the architecture, including memories and separating more clearly the different reasoning processes, needed a framework that better suited the modularity of the cognitive processes. Secondly, this architecture is aimed to be improved and re-used by our research team and research projects. The ability to use it for various robotic platforms and various contexts required modularity and ability to change each module to test. Indeed, for instance a new planning module in PDDL will be implemented and the current implemented version of the architecture allows to switch the planning module with a new one more easily. Finally, this new implementation should allow to be connected to more tools developed by the community in robotics (packages for device control, perception etc.), and in the future to include learning processes and standard knowledge representation via ontologies for instance.

In order to match the above requirements, we chose to base our implementation on the Robot Operating System (ROS)[3] framework and to implement the architecture in Python programming language. These choices were motivated by the fact that ROS is largely used in the robotic community and that many robots (including the

[3] http://www.ros.org/

robots present in the team Nao and Reeti) are ROS-compatible. For programming language, ROS supports C++, Python and LISP natively (there also exist a Java library called *rosjava*, but Java is not natively supported). We chose to implement the modules in Python in order to allow easy interfacing with the SWI-Prolog engine via the *pyswip*[4] library. Of course all the modules can be re-implemented in other languages that are ROS-friendly.

5.2.1 Principles of the implementation

The implementation is based on basic functionalities of the ROS framework. In ROS, each process can be encapsulated in a **node**. For CAIO, each node deals with a step of reasoning and there are also all extra nodes for perception and rendering. The nodes communicate messages to each other via ROS Topics. A **topic** is a kind of communication channel that has a name. Nodes can publish or subscribe to topics using their names. This implementation allows re-usability and flexibility as new nodes can replace old ones just by subscribing and publishing in the same topics. The figure 5.3 shows the activated nodes (corresponding to a running process) of the implemented CAIO architecture with ROS *rqt_graph* visualisation tool. The

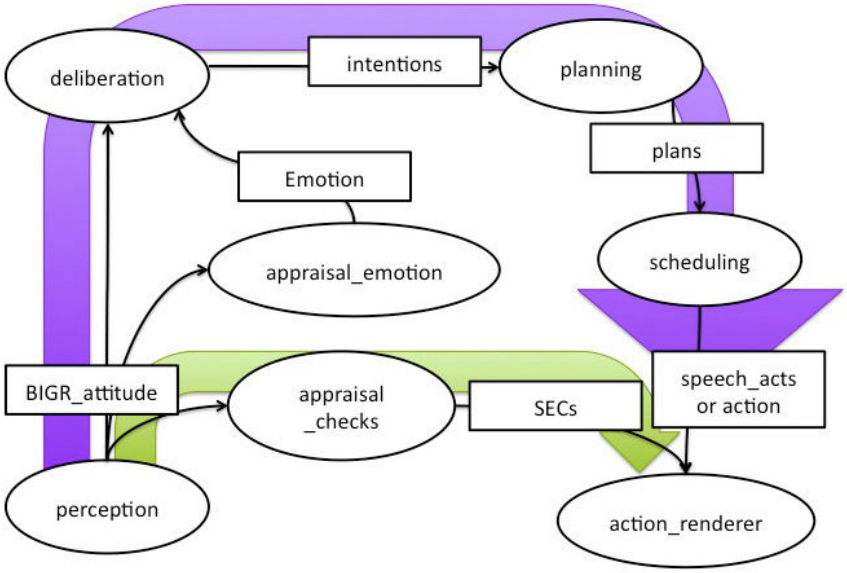


Figure 5.3: Topics Involved in CAIO ROS implementation

perception node takes as input a stimulus and outputs the *bigr_attitudes*. The

[4]Pyswip is a Python library that allows to query SWI-Prolog from Python Programs. https://code.google.com/p/pyswip/

bigr_attitudes are also written on a local memory (Prolog file) that saves the current dialogue data comparable to a short-term memory.

The *appraisal_checks* node is subscribed to *bigr_attitude* topic and output the checks sequence resulting of the SECs evaluation of the mental attitude.

The *appraisal_emotion* node is subscribed to *bigr_attitude* topic and uses the whole knowledge base to output a list of ordered emotions (first are most "intense") into the dynamic knowledge

The *deliberation* node is subscribed to *bigr_attitude* topic and uses the whole knowledge base to output a list of ordered intentions.

The *planning* node is subscribed to the *intentions* topic and uses the dynamic knowledge base and the domain actions to output a list of ordered plans.

The *scheduling* is subscribed to the *plans* topic and selects which plan to try (first one, backtrack if fails) and which action to perform (first one of current plan). If the action selected is a speech act action it is published on the *speech_acts* topic, else on the *action* topic.

The *action_renderer* node actually sends the action to the robots's motors. It takes as input the *SECs* published by the *appraisal_checks* node and plays it with the speech act given in by the *scheduling* node. For our two robots, we have implemented an *action_renderer* allowing them to play the choosen SECs with a speech act.

We based the expressions of the MCA on previous works by [Rivière, 2012]. To each check is associated a degree of activation that is a continuous float from 0 to 1 for Novelty check (from not novel to very novel) and from -1 to 1 for the other checks (negative values representing : unpleasantness, etc.) This degree is used to modulate the expression of the posture (i.e. a Novelty at 0.5 is interpolated between the neutral pose and the novelty at 1).

To depict the SECs for Reeti, we used the work on action units of [Rivière, 2012, Courgeon, 2011] and tried to match them to Reeti's facial motors. For the ears expression, we refer to the work on expression of emotions by Kismet [Breazeal, 2012]. The colours of the LEDs were picked according to [Johnson et al., 2013, Nijdam, 2009, Naz and Epps, 2004] works on colours and emotions..

For the Nao robot, the SECs were depicted in accordance to the work of [Coulson, 2008, Tan, 2012] on emotional postural expression. [Scherer, 2001] proposed body signals for each SECs (see Table 5.3). We propose to use the Body Action and Posture Units (BAPs) [Dael et al., 2012] coding system to depict the SECs poses as they were implemented for the Nao robot. In the BAPs encoding system, action units correspond to posture units that describe the posture and gestures. We used works from [Scherer, 2001, Scherer, 2009, Tan, 2012, Coulson, 2008] to match the description of the body expression of SECs in table 5.3.

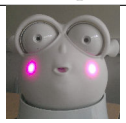
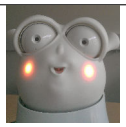
Checks	Sub-Checks	Reeti's Expression
Novelty	Novel	
Intrinsic Pleasantness	Pleasant	
	Unpleasant	
Goal Congruence and Responsibility attribution	Consistent	
	Discrepant	
Coping Potential	High	
	Low	
Norms Compatibility	Standards violated	
	Surpassed	

TABLE 5.2: SECs expressions by Reeti robot

5.2.2 Example with an everyday-life sketch

In order to illustrate the cognitive processes involved in CAIO, this section gives a simple scenario with a dialogue between a human and a Nao Robot driven by CAIO. This scenario is illustrated by a UML Sequence Diagram (see figure 5.4) representing each node.

This scenario involved two actors *Wafa* and the *Nao robot*. The Nao robot, as one might know, has a low battery life and hence, it requires to be plugged all

Checks	*Sub-Checks*	*Description by [Scherer, 2001]*	*BAPs*
Novelty	Novel (0..1)	Interruption of ongoing instrumental actions, raising head, straighten posture	Head Facing, Vertical head tilt and upward head, Trunk facing and erected
Intrinsic Pleasantness	Pleasant (0..1)	Centripetal hand and arm movements, expanding postures, approach locomotion	Head facing, Left and Right arms towards the body, Straighten body
	Unpleasant (−1..0)	Centrifugal hand and arm movements, hands covering orifices, shrinking postures, avoidance locomotion	Head averted, Left and Right arms away from the body, Spine bending
Goal Congruence and Responsibility attribution	Consistent (0..1)	Strong tonus, task- dependant instrumental actions	Trunk facing and erected, Straighten body
	Discrepant (−1..0)	Comfort and rest positions	Backward lean
Coping Potential	High (0..1)	Agonistic hand/arm movements, erect posture, body lean forward,approach locomotion	Trunk lean forward, Straighten body, Arms at side
	Low (−1..0)	Protective hand/arm movements, fast locomotion or freezing	Spine bending, Arms held in front
Norms Compatibility	Standards surpassed (0..1)	Elements of pleasantness and high power response	Relaxed Trunk leaning forward, head facing
	Standards violated (−1..0)	Elements of unpleasantness and low power response	Spine bending, Arms away from body held in front

TABLE 5.3: Translation of Checks to Body Signals and BAPs with encoding from [Dael et al., 2012, Scherer, 2009]

the time. In the episodic memory of the Nao the ideal of being plugged is present $Ideal_{Nao}(\neg unplugged)$. Wafa has a party tonight and needs to dry her hair after shower, but Nao is plugged to the only plug near the mirror.
Wafa: "Nao I am going to unplug you, I need to dry my hair".

1. The *perception* node receive the speech act stimulus : $Stimulus(unplugged, wafa, nao)$
2. It publishes on the *bigr_attitude* topic : $Bel_{Nao}(unplugged)$ and $Bel_{Nao}(Resp_{Wafa}(unplugged))$
3. The *appraisal_emotion* node deduces an emotion from the BIGR and publishes it on the Emotion topic: $Reproach_{Nao,Wafa}(unplugged)$
4. The *appraisal_checks* node translates the emotion into the SECs and publishes

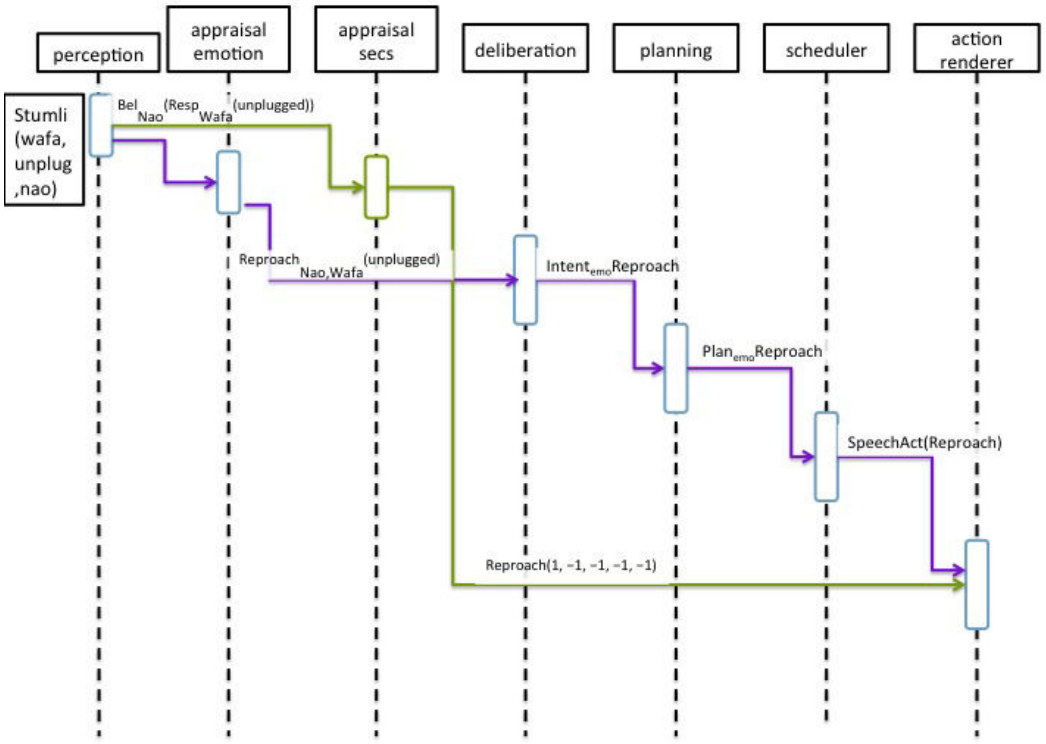


FIGURE 5.4: UML Sequence Diagram for the "HairDryer Scenario

Reproach$(1, -1, -1, -1, -1)$ (see Table 5.3)

5. The *deliberative* node receives the emotion and publishes a list of intentions. In this case the intention with the highest weight is the emotional intention to express Reproach.
6. The *planning* node receives the list of intentions and picks the most weighted one and publishes a list of plans. In this case there is a unique plan to satisfy this intention with a unique ACM, the Reproach speech act.
7. The plan is received by the *scheduler* which pick the first action, the Reproach speech act and publishes it on the speech act topic.
8. Finally the *action_renderer* receives both SECs and Reproach speech act and plays it according to the defined SECs for the Nao robot.

5.3 Limitations and Conclusion

Among all the issues discussed in [Langley et al., 2009a] that are left to be considered by the research community, our approach aims to contribute to the following points :

- We do not focus on procedural skills only but also on episodic knowledge by storing mental states of the robot and the user. The episodic memory in CAIO does not store event *per se*, but it keeps the past beliefs, ideals, responsibilities and goals of the robot and the user.
- Our system enables the robot to communicate its own decision plans and other cognitive activities. Indeed, the robot expresses its reaction to every stimulus by its behaviour. Its is a sincere robot, that will always behave according to its mental state.
- CAIO provides an emotional evaluation of stimuli through a short reactive loop and a longer deliberative loop. Emotions are used for deliberation and hence part of the main cognitive processes that will decide the intention.
- The architecture that we provide is not robot-dependent. This architecture has been tested on several platform (such as Nao robot and the Reeti robot).
- Also not many architectures provide a two-layer parallel cognitive process. CAIO has both deliberative and reactive cognitive processes going in parallel and resulting in behavioural reaction in line with the Dual Process Theory.
- The architecture is modular and enables to change modules by others.

The CAIO architecture is a newly implemented architecture that aims to evolve in time. The design of the architecture aims to be in line with commonly accepted theories of cognitive sciences and to integrate technical framework commonly used by the community. Our main contributions were hence in the re-design of the architecture, integrating memory modules and separating cognitive processes in agreement with the Dual Process theory; the implementation of SECs for the two robotic platforms Nao (body) and Reeti (facial+ears); the implementation in ROS of the main nodes of the architecture and their interfacing with the SWI-Prolog reasoning engine based on PLEIAD, BIGRE and MCL.

In the long term, this architecture will keep being enriched by our research team and aims to merge various works of the team on planning, emotions, reasoning, behaviour simulation, human-robot and human-agent interaction. The multi-modal perception module, presented in the designed architecture can be implemented using audio and camera or Kinect sensors fusion to discriminate and enrich the recognition of speech acts expressed by the user.

This implementation should be able to take into account ambiguous signals such as the user smiling and saying "I am sad" at the same time. The memory modules should be implemented with a standardised knowledge representation method such as OWL or RDF. Solutions have been reviewed but further works on the architecture in the team should propose a standardise implemented solution for knowledge representation.

The planning module is currently implemented in SWI-Prolog. The classical planning formalism is done in PDDL (Planning Domain Description Language[5]). A new PDDL-based planning module could enrich the implementation of CAIO and provide the ability to generate plans and enjoy from the last research works on planning. Therefore, most of existing planners could be used in the CAIO architecture.

Other modules can influence cognitive processes or expression of the robot. For instance, a style module could enrich the actions repertoire of the robot and act like a filter between the planning and scheduling. Styles could also be introduced in the perception and deliberation modules in order to introduce variability by following principles of cognitive styles (presented in section 2.3) Cognitive styles [Hayes and Allinson, 2012] could be used to modulate reasoning in CAIO. For instance analytic cognitive style could reinforce the deliberative loop and the intuitive cognitive style could favour cognitive treatments via the reactive loop.

[5]PDDL is a language specifically dedicated for formalisation and description for artificial intelligence planning. It allows to define (1) the domain consisting of set of actions with pre-conditions and effects, predicates (facts), object-types etc.; and (2) the problem with the initial conditions, the goal-states, the present objects, etc. The PDDL language was introduced in 1998 and has been updated since then. The latest version is PDDL3.1 released in 2011.[Wiki PDDL]

Part III

Experimental Evaluation

Third Part

The third part of this thesis is dedicated to applications and empirical evaluation of the models presented in part II, in particular evaluation of the style model.

This part includes the following chapters :

- The chapter 6 presents an on-line study conducted to evaluate expressibility of parenting styles by two robotic platforms Nao and Reeti. This study conducted through videos and questionnaires. 94 parents replied to the study. Results showed that Nao and Reeti robots were able to express successfully the two parenting styles tested. It allowed to validate the psychological parenting style model for robots. The chosen modality to express style were also validated.
- The chapter 7 is dedicated to child-robot interaction experiment conducted to evaluate the influence of parenting styles on the child preferences and behaviours. 16 children were put in interaction with Nao robots displaying styles in a Quiz of Math task. Results on behavioural analysis showed the variability among children according to the styles. It showed also a significant impact of the styles on the children's behaviours.

Chapter 6

Study of Styles with Online Video-based Questionnaires

The MoCA project focuses on child-robot interaction. Within this project, we were interested in proposing the solutions for plasticity of companions for children alone at home after school.

We proposed in Chapter 4 a model for the behavioural styles that can be used for the adaptability of the behaviour of a companion in specific roles. The aim of this experiment was to see if parents were able to distinguish between two behavioural styles. These styles were built according to the literature in psychology and the Section 6.2.2 gives more details on how these styles were built for each robot used in the study.

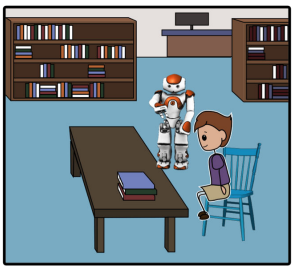
In order to evaluate the expressibility of styles by robots using only non-verbal cues of communication, we designed an online experiment in which a parent would watch videos of the same robot displaying the two styles and would evaluate the robots attitude based on different criteria.

6.1 Scenario and Context

Persuasion and motivation are often studied in social HRI studies. Works of [Tapus et al., 2008, Fasola and Mataric, 2012a, Leyzberg et al., 2014] on motivation by robots have shown that personalisation of the HRI has a positive impact on the engagement and the performances of the users. Results have also shown that trust is improved when interacting with a personalised coaching robot. Persuasion and motivation are big challenges for research in HRI.

The tested scenario is extracted from the main scenario of the project (Annex C.1) and is in line with previous works on personalisation applied to persuasion

and motivations. In this scenario, the robot has the role of a Teacher. It manages the child's homework schedule and asks him to do his homework when necessary. In this case, the robots would ask the child to do a conative effort - to stop what he was doing, and to start a new task (in this case, the task being doing his homework). This situation is often a critical one for parents and children alike and this first study aimed to test the credibility of stylized behaviours in this situation. In fact, parents can use style to adapt their behaviour in such cases. They might also use non-verbal signals to display their way of parenting. For a companion robot assisting the family, a way of doing this task might be preferred by certain parents.



We chose to study parenting styles in this context. The four Parenting Styles (Authoritarian, Authoritative, Neglectful and Permissive) were presented in the Section 2.3.1. Since the context of this work is based on a robot companion for children, we consider that it is mandatory for the companion to be sensitive and responsive to the children and the parent user. Therefore, we evaluate only the following two styles with high responsiveness : The Authoritative and Permissive styles.

Effective expression by robots of non-verbal signals is often hard to attain due to their motors' limitations. To compensate and check which modalities were important to depict parenting styles, both the facial and body signal are tested.

6.2 Experimental Design

The conducted experiment aimed to evaluate the expressibility of parenting styles by companion robots. We also wanted to evaluate the effectiveness and the acceptability of the styles with the help of parents. A consensus in this context where all parents would want an authoritative companion could be observed. Or there could be a correlation between the style they have as parents and their choice of style for the companion of their children.

6.2.1 Hypothesis

Based on the literature on parenting styles and human-robot interaction, several hypotheses were developed. These hypotheses are listed below.

H1 Authoritativeness is expressible by robots using non verbal communication channels.

H1a Parents perceive a difference in authoritativness between both Permissive and Authoritative styles when expressed by a robot (the robot Reeti, in our case) with facial and voice based social cues.

H1a Parents perceive a difference in authoritativness between both style Permissive and Authoritative when expressed by a robot (the robot Nao, in our case) with body and voice based social cues.

H2 The perceived effectiveness of an authoritative robot is higher than a robot with permissive style in the context of giving a direction.

H3 In the particular context of giving an order, there is a significant inter-personal variability of preferred parenting style for the robots.

H4 The variability of acceptability of the style expressed by the robot is correlated to the own style of the participant.

H5 Participants attribute their judgement on the authoritativeness of the robot on the non-verbal signals only (since the behavioural styles only touch the non-verbal communication)

6.2.2 Multi-modal expression of Permissive and Authoritative parenting styles

Two robots, the robotic head Reeti and the humanoid robot Nao were used to display the styles.

Nao was used to explore the body channel of non-verbal communication of the styles. We used postural openness, arm gestures, facing orientation as well as paralinguistic cues such as voice volume, pitch and speed of the speech (further details in the next Section 6.2.3).

The expressibility of Reeti relies on its facial expression. Reeti is able to express simple emotions using facial channels of communication, as well as its ears and paralinguistic parameters to modulate its voice.

In order to depict the styles using multi-modal non-verbal and paralinguistic channels of communication, we used the modalities of expression of verticality specified by Hall and al. [Hall et al., 2005]. Hall describes a set of non-verbal cues for *verticality*[1]. This set was used to express dominance and submission to differentiate between Authoritative and Permissive style of parenting (cf Figure 6.1). We have adapted the categories of non-verbal behaviours to the physical constraints of each robot.

In order to modulate the behaviour of each style, we used some parameters from the literature [Embgen et al., 2012, Pelachaud, 2009, Xu et al., 2013, Xu and Broekens, 2013, Wallbott, 1998]. We used spatial variables such as spacial occupation, direction and amplitude of gestures. Other parameters were employed

[1]Verticality: relating to power, dominance, status, hierarchy [Hall et al., 2005]

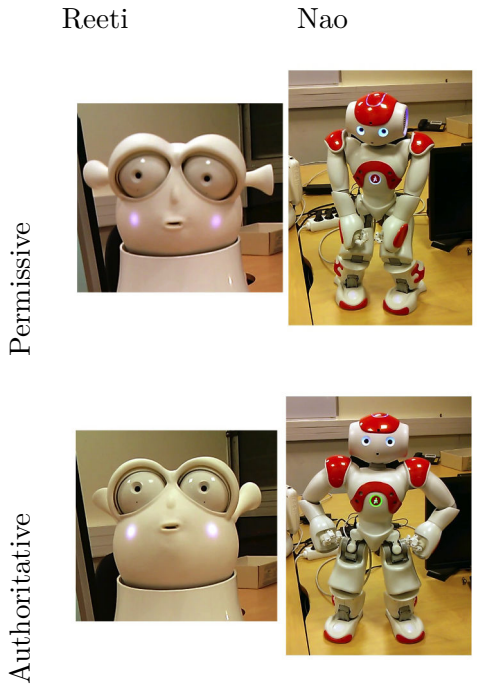


FIGURE 6.1: Reeti (on the left) and Nao (on the right),expressing the two styles Authoritative (top), and Permissive (bottom)

for the dynamics: repetition, speed of gestures, speed of decay and fluidity/rigidity of movements.

As mentioned, the physical constraints of the robots differed in the fact that one (Nao) was using body language and the other one (Reeti), facial expressions. The work of Breazeal [Breazeal, 2003] for the ear movement of Reeti was also refereed to. Nao and Reeti both have possibilities to change the colour of their LEDs. Colours have been proved to be useful to display emotions. However, as presented in [Nijdam, 2009], colours are attached to the Pleasantness and the Arousal dimensions of emotion. Since only Dominance is an emotional dimension that is important to discriminate parenting styles, we avoid the use of colour variation to express the style difference.

After the analysis of concerning literature, we built the table 6.1 showing the positive ($\nearrow$) or negative ($\searrow$) influence of each behaviour on the dominance for each robots. For example, for both robots, a high blinking rate decreases the dominance factor, inversely voice loudness will increase with dominance. Behavioural style sheets (Chapter 4) were implemented and a behaviour was generated for each robot in each style. In each behaviour, the robot would say the exact same sentence: "I think you have played enough. You should go back to work.", and would point on his right towards another room.

Modality	Nao	Reeti
Gaze	↗ (intensity of eye light)	↗
Blinking rate	↘	↘
Nodding	↗	↗
Self contact (hands or face)	↘	
Self contact (hips)	↗	
Hand and Arms: illustrator, emblems	↗	
Postural openness	↗	
Postural relaxation	↗	
Face orientation	↗	↗
Voice Loudness	↗	↗
Voice Pausing		↘
Voice Pitch		↘
Voice Speed	↗	↗
Ears		↗

TABLE 6.1: Sub-list of categories of behaviours [Hall et al., 2005, Breazeal, 2003] used to display the styles

Each participant watched two videos[2] of the each of the two robots expressing respectively the two parenting styles: Permissive and Authoritative. They were then asked to reply to a questionnaire.

6.2.3 Questionnaire on perception, acceptability and effectiveness of the robots

The questionnaire based on [Bartneck et al., 2008b, Heerink et al., 2009, Reitman and Rhode, 2002] was associated to the videos. Each participant saw one robot acting with both permissive or authoritative style in a randomized balanced order.

The first part of the questionnaire was dealing with the context of use and the usage of new technologies. This part aimed to detect signs of technophobia that could have biased our study. As presented in [Nomura et al., 2008], some negative attitude toward robots could lead to anxiety and rejection. On the other hand, technophilia and past positive experiences with robotic devices can facilitate their adoption [Sung and Grinter, 2008].

Permissive and authoritative style are distinctive by their level of dominance. In order to be sure that this difference was perceived in the behaviour of the robots, we asked the participants to evaluate the emotional mental state of the robot. We used

[2]These videos can be watched here:https://youtu.be/Xg49gsWKMLY?t=42s

the PAD scale [Russell and Mehrabian, 1977] with the SAM representation [Bradley and Lang, 1994]. We asked them to rate each of the two styles they saw according to the pleasantness (P), the arousal (A) and the dominance (D) from 1 to 5. This dominance measure helped us to detect if the participant thought that the robot was identifying the causes of authoritativeness.

We also asked the participants about their opinion on the effectiveness of the robots in giving an instruction. This aimed to evaluate the perceived competence of the robot in this particular context. In the Godspeed questionnaire, [Bartneck et al., 2008b] categorized this dimension in the perceived intelligence of the robot. Translated items from the Godspeed questionnaire were used.

In the last part of the questionnaire, we used items of a questionnaire on authoritativeness in parenting style from [Reitman and Rhode, 2002] to evaluate the participant's behaviour with his children. This *Parental Authority Questionnaire – Revised* (PAQ-R) proposed by is a 30 statement 5-scale Likert questionnaire. We extracted questions regarding authoritative and permissive parenting styles only (20 questions) in order to minimise the length of the questionnaire, so that the participants do not lose interest while responding.

Other demographical questions were asked before the questionnaire started (such as the age, job position etc.). The final questionnaire (in French) used for this study is presented in Annex D. It contained 21 items and the videos of one robot displaying the styles, along with the 20 items of the PAQ-R.

6.2.4 Protocol

93 parents participated in the experiment (63 women and 30 men). The online questionnaire was diffused on the RISC mailing list and other mailing list of the laboratories of Grenoble. Participants were selected upon the criteria of having children. The questionnaire stayed online for one month and a half (from the 11/12/13 till the 31/01/14).

6.3 Results

The data analysis consisted in studying the influence of the robot condition (Nao or Reeti) and the style condition (Permissive or Authoritative) on several measures based on the questionnaire items.

We first measured the expressibility of the style by analysing the perceived directivity of the robots and the emotional state participants though they were (in paragraph **Authoritativeness** and **Directivity**).

The trust and credibility of the robots asking to do his homework to a child were measured on the Likert scale for several ranges of age (in the Paragraph [**?**]).

Parents then made a choice of style for the robot for their child. This choice is presented here in relation with the participants results at the *Parenting Authoritative Questionnaire-R*.

Finally, the modality used for displaying the styles are discussed in regard of parents judgements (in the Paragraph 6.3).

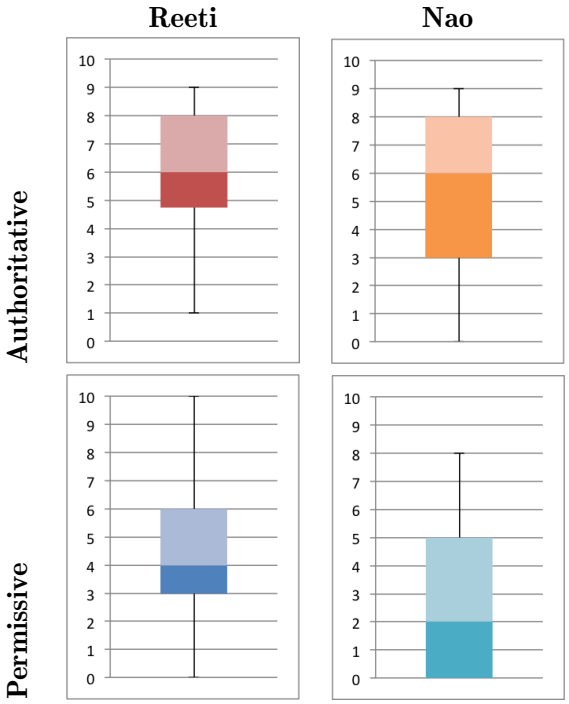


TABLE 6.2: Boxplots of Perceived Authoritativeness (on a 0 to 10 scale) of Nao and Reeti robots expressing Authoritative and Permissive Parenting Styles

Authoritativeness was evaluated by the parents who were asked to answer to: *"How authoritative is the robot from 0 to 10 ? (0 not authoritative at all, 10 very authoritative)"*.

The table 6.2 presents box plots of perceived authoritativeness of the robots in the four modalities tested.

The behaviours displayed by the robot Reeti seems to create more of a consensus than the ones form Nao. These box plots also show that the perceived authoritativeness is higher for the conditions with higher dominance for both of the robots. A Kruskal-Wallis test (KW test) revealed a significant effect of styles on perceived authoritativeness (Reeti : $\chi^2(1) = 8.84$, $p < 0.01$, Nao : $\chi^2(1) = 17.54$, $p < 0.01$).

In general, Reeti-Authoritative seems to be perceived as more directive than Nao-Authoritative but this difference is not significant. However, the difference of authoritativeness between Permissive Nao and Permissive Reeti is significant ($\chi^2(1) = 7.33$, $p < 0.01$, KW test). These results validate the first hypothesis H1, that authoritativeness is expressible by robots' non verbal communicational channels. The parents were able to differentiate between Authoritative and Permissive parenting style for both robots. There is an effect of the robot when the expression is of the Permissive style only and this difference might be explained by the fact that Reeti was perceived to be more masculine than Nao (see Figure 6.2).

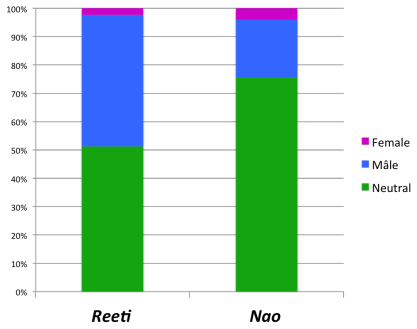


FIGURE 6.2: Gender Perception of Robots

Directivity Results from the emotional state evaluation showed that the emotional state was mainly influenced by the dominance dimension. We conducted a Pearson

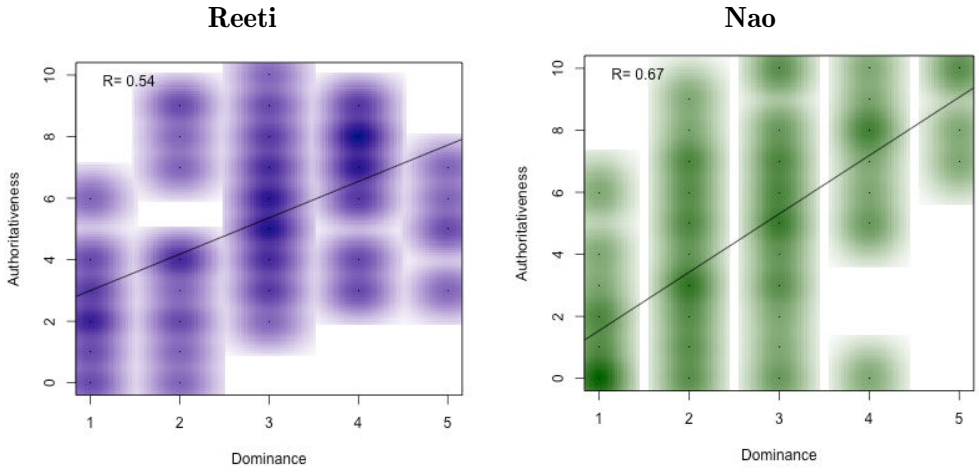


TABLE 6.3: Scatter plot showing the correlation between perceived dominance and authoritativeness

correlation test on the Dominance and Authoritativness variables (see [Howell, 2012] for statistical methods).

The correlations between these variables are illustrated on table 6.3. For both robots, the Pearson correlation test showed a significant positive correlation between Dominance and Authoritativeness (Reeti: $R^2 = 0.54$ (N=44, $p < 0.001$) and Nao : $R^2 = 0.67$ (N=49, $p < 0.001$))[3].

[3]The Pearson Correlation coefficient R^2 where $R^2 = -1$ means that the data is inversely correlated; $R^2 = 0$ signifies the absence of a correlation and $R^2 = 1$, a configuration where the data is completely correlated

Credibility The parents were asked to evaluate if the instruction given by the robot seemed effective or not. We asked the question : *"For each of the given age ranges, do you think the instruction represented in the associated video would be followed?"* The figure 6.3 shows the proportion of parents who believed that the instruction was

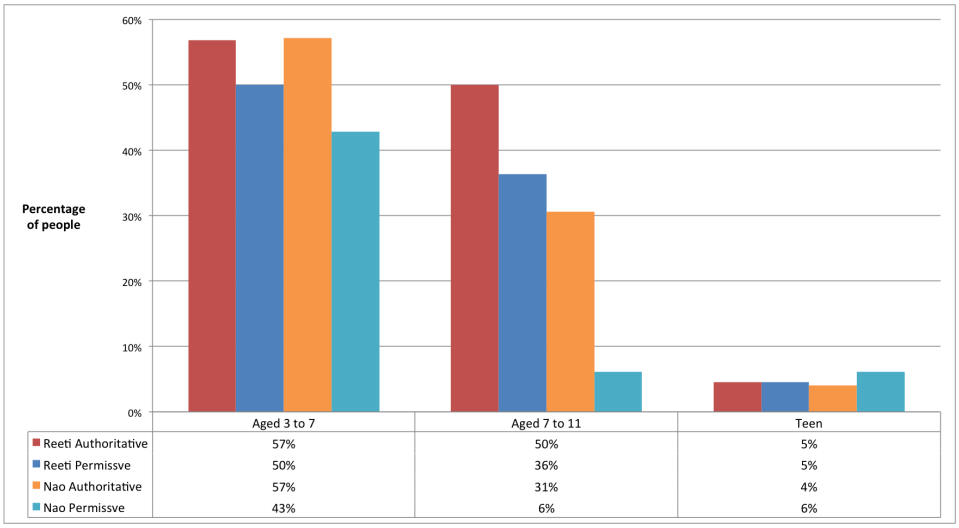


FIGURE 6.3: Credibility

followed for each age range & the modality of robots and styles.

The first comment that can be made, is that the effectiveness is higher for children than for other ranges. As expected (H2), the authoritative style seems to be perceived as more effective than the permissive ones. However, this difference is less important for children of very young age (under 7). For children, Nao with a permissive style was the least effective, and Reeti with an authoritative style turned out to be the most.

The focus of our study within the MoCA project is children from 7 to 11. We focus then our analysis on results for this range of age. Although subjects perceived Reeti-Authoritative slightly more effective than Reeti-Permissive the difference was not significant, $\chi^2(3) = 4.90, p < 0.2$ on a KW test. The proportion of parents finding Nao-Authoritative effective for children (7 to 11 y.o.) was 0.31 whereas the proportion finding Nao-Permissive effective was only 0.06. The difference in proportions is significant, $\chi^2(3) = 12.03, p < 0.001$. For Nao, we can conclude that the style influenced the perceived effectiveness significantly.

From Figure 6.3, we can see that Reeti-Authoritative is more effective than Nao-Authoritative. However this difference was not found to be significant, $\chi^2(3) = 5.76, p < 0.10$ (KW test). 36% of the parents found Reeti-Permissive to be effective whereas only 6% found Nao-Permissive effective. The difference in proportions is significant, $\chi^2(3) = 16.26, p < 0.001$ (KW test). We can conclude on an influence of

the robot on the effectiveness only when having a permissive style. The perceived effectiveness of an authoritative Nao robot is higher than a permissive one in the context of giving a direction ($H2$ verified for Nao).

Parents choices of style for their robot was made by picking between either the authoritative robot, the permissive robot or neither of the two. Among people who picked a robot (45 parents over the 93 participating), we can see that in the Figure 6.4, the proportion of people picking the authoritative robot is higher for both (Reeti and Nao). From the set of people who saw the Reeti robot expressing both styles, 58% agreed to pick this robot for their child; 35% with an authoritative style. For Nao, fewer people considered it as a companion for their child (41%), but when they did, 3 persons over 4 were opting for the authoritative style. These results confirm our hypothesis (H3): In the context of a robot giving an instruction to the child, there is a inter-individual variability in terms of acceptability of the style of the robot (not all parents were picking the authoritative robot).

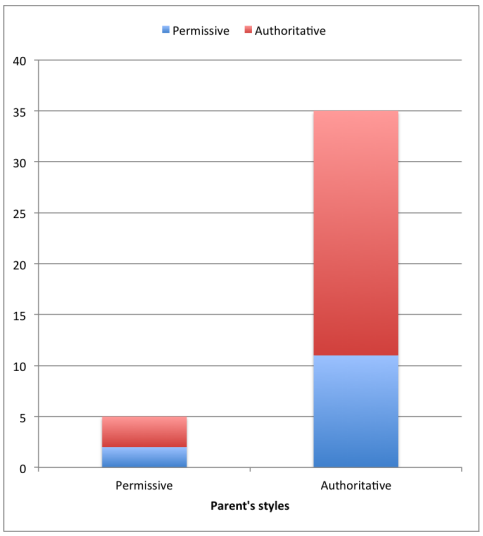


Figure 6.4: Parents choices of style for their robot

We used the Parenting Questionnaire Revised [Reitman and Rhode, 2002] to measure the parenting styles of the participants. Participants self-reported their habits with their children through their answers. We compared their *authoritativness* and *permissivness* scores to their choices of style for the companion robot of their children. We expected a correlation; however, our hypothesis (H4) was invalid. The variability of acceptability of the style expressed by the robot turned out not to be correlated to the own style of the participant. Among participants who had high authoritativeness in their behaviour with their children, some preferred a robot with permissive style and some preferred an authoritative style. We noticed a similar distribution of choices among the whole population of parents (i.e. for permissive and authoritative parents). The attribution of style to the robot can not be based on the parent's style. Hence, we can recommend to use style in an end-user programming manner.

Substitution of verbal by non-verbal Since the verbal utterance was neutral for the two styles Authoritative and Permissive, we believe that the parents perceived non-verbal cues as a discriminant in term of authoritativeness (H5). The hypothesis

is that the parents' perception of non-verbal (tone of voice and non-vocal) cues of communication to be more influential than verbal utterance, when having to rate the authoritativeness of the robots in our experimental context.

Parents were asked to rate how each modality of expressions of the robot influenced their score in authoritativeness. Since the term non-verbal is not easy to define, we chose to be more precise and list 3 sub-modalities of the non-verbal behaviours. We asked the participants to evaluate the weight of influence of each non-vocal, tone of voice and verbal modalities by answering this question:

> *For each of the following elements, rate the influence of the element on the authoritativeness characteristic of the robot. From 0 (no influence) to 10 (very influent): gestures, posture, gaze, tone of the voice, words used.*

The average weight of influence for each type of behaviour (verbal, tone of voice and non-vocal) is visualised in Figure 6.5 for each robot. The ratio of perceived influence of the cues is of 26.24% for the non-vocal, 34.91% for the tone of voice and 38.85 % for the words used by the robots. This ratio is the same for the two robots and the two styles (no significant differences). Thus in our experiment, the

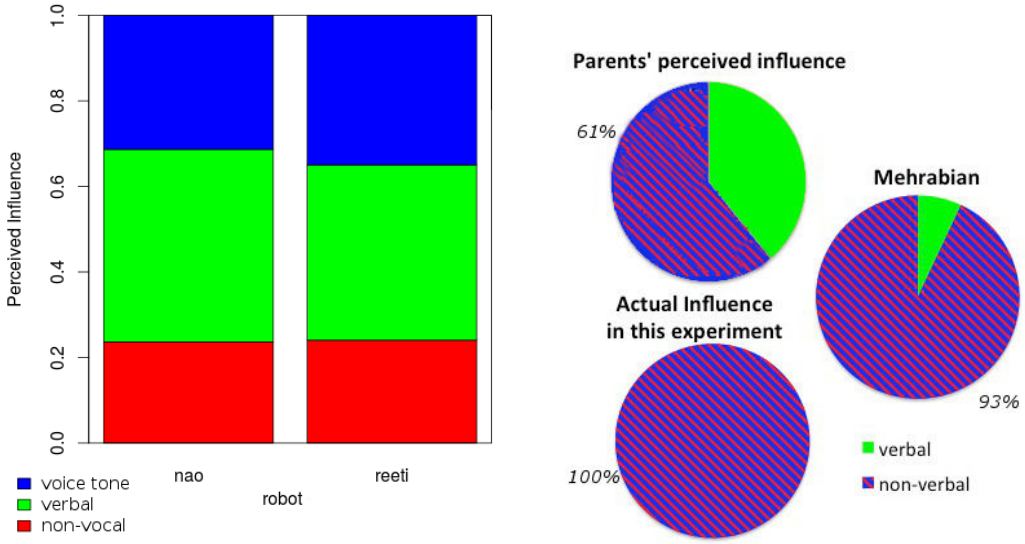


Figure 6.5: Proportion of perceived Influence of the modalities

participants thought they were judging the social signals of the robot more from its verbal utterance and tone of voice cues than its other non-vocal cues (posture, gesture, gazing ...). Our results also differ from the "7 % rule" of Mehrabian [Knapp et al., 2013] stating that only 7% of the signal passes through the verbal modality.

This results highlight the difference between the perceived influence and the actual influence of verbal and non-verbal cues of communication. Expected results in this experiment were to have an influence of 0.0% for the verbal and 100% for the non-verbal, since the verbal utterance was actually not influencing the authoritativeness of the robots.

This difference might be explained by the fact that participants had a pre-judgement on the robot's ability to use non-verbal cues of communication. Hence, the non-verbal influence of robots is perceived as lower.

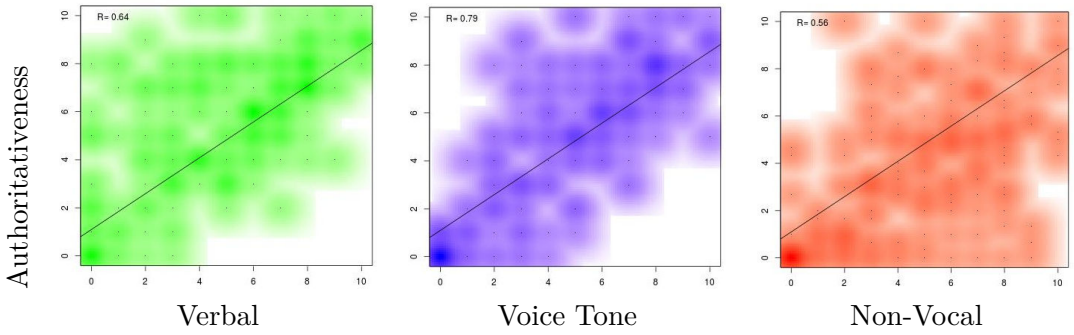


Figure 6.6: Correlation between perceived influence of modalities and perceived authoritativeness of the robots

The scatter plots in the fig. 6.6 show the correlation between the influence scores given to each type of cues and the perceived authoritativeness of the robot by the participants. These graphs show that the authoritativeness is more correlated to the tone of voice perceived influence($R^2 = 0.79$, N=93, $p < 0.001$) than the verbal perceived influence($R^2 = 0.64$, N=93, $p < 0.001$) and that it is more correlated to the verbal than the non-verbal cues ($R^2 = 0.56$, N=93, $p < 0.001$). These results show that tone of voice cues and authoritativeness have a higher interdependence than verbal utterance and authoritativeness, or non-vocal cues and authoritativeness in the parents perception. For the participants, the authoritativeness is then more linked to the tone of voice and the verbal than the non-verbal cues.

Non-verbal (vocal and non-vocal) and verbal behaviours are not independent from each other. In this experiment, the meaning of non-verbal cues (permissive or authoritative) substituted to the understanding of the verbal utterance (neutral) in term of authoritativeness.

6.4 Conclusion

This chapter presented a first study on expressing parenting styles by companion robots. We used non-verbal communication cues to vary the level of authoritativeness displayed by facially expressive (Reeti) and bodily expressive (Nao) robots. We

proposed a questionnaire to parents about perception, acceptability and effectiveness of the companion robot while it demands a child to perform a conative effort.

Results showed that a robot displaying dominance was perceived to be more authoritative than the one with less dominance. As for humans, dominance is hence a dimension of authoritativeness for robots. Users were able to recognise permissive and authoritative behaviours for both robots. The personalisation with styles leads to differences in terms of choice of the style the robot should adopt for the participants' children.

The effectiveness was judged to be good enough to give orders to children under 11 years old, especially when the robot adopted an authoritative style.

We did not find that there was a correlation between the parenting style of the participant and their choices of style in the companion for their children. We think that this kind of personalisation of the companion should be explicitly set by the parents for the children using end-user programming.

The results showed that non-verbal cues such as tone of voice, posture, gesture and gaze are important and can substitute for the verbal content in the context of behaviour authoritativeness. Indeed, only non-verbal cues were containing the signal of authoritativeness and permissiveness. The verbal content was the same for both permissive and authoritative styles but found to be determinant by participants in terms of influence on the style.

With this online study, we were able to put in practice and to confront to the user psychological theories on *styles* applied to a robot. The aim was to use a classification of parenting styles to propose two robot companions' behaviour in the same situation. To our knowledge, this study is the first to make this connection, thereby opening up many possibilities for future research. Where personality is not context dependent, styles can be adopted according to the role (social bind between the companion and the user) and the context (eg. game, coach, teacher). Recent works have started to explore how *styles* could influence trust in social robots [Brule et al., 2014]. We believe that further work should be accomplished towards integrating styles in the design of companion robots.

The next step of this work was to test the acceptability and the effectiveness of the robots while adopting a parenting style during a real interaction with a child. The next chapter presents an experiment that aims to evaluate the effectiveness and acceptability through both the parents' and the children's experiences (the parent being an observer of the child's interaction with the robot).

Chapter 7

Study of Styles for Child-Robot Interaction in a Smart-Home

[Ruckert et al., 2013, Ruckert, 2011] proposed in the "Theory of Companions" to design versatile companions to be able to play several roles and to have several persona in order to fit to the context and to the user's expectations.

In this chapter, we describe a user experiment aiming to investigate the influence of style and versatility of the robots on the perception of performance and trust, along with the attachment. The experiment was conducted in the smart apartment Domus[1] at the LIG Laboratory, equipped with camera sensors, microphones and other sensors and connected objects.

7.1 Research Questions and Scenario

After the on-line study (Chapter 6), this experiment aimed to do a real user experiment in an ecological environment in order to test the credibility and the acceptability of styles by children.

One of the research questions behind the experiment was to test the style model and the plasticity model of the companion proposed in Chapter 4 and 5. In a social relationship, the perceived signals are encoded, and each of the partners influence the thinking and the actions of the other. This influence can be subconscious and very tricky to identify. Phenomena such as synchrony and imitation can be observed.

In this experiment, the same styles - Authoritative and Permissive - as the ones were applied to the robots previously (Chapter 6) were used. From these previous results, Authoritative and Permissive styles seemed to be identifiable by parents and applicable on the two robots Nao and Reeti. These styles were also in line with the

[1]Domus is an experimental platform composed especially with a domotic apartment http://domus.liglab.fr/

psychological dimensions of parenting styles. The results on credibility also showed that styles could be an interesting factor to take into account.

With this experiment, we wanted to verify our plasticity framework applied to HRI in a more general manner. In that sense, this experiment was also questioning versatile vs specialist robots. The aim here was to collect opinions of parents and children on the versatility of a companion robot and see if it was preferable to have a companion robot able to play several roles or does it affect its credibility and trust in accomplishing the tasks to be versatile.

In the experiment scenario, the child alone at home has to review his multiplication tables. His Teacher companion is here to ask him questions and to check if he knows them. After some questions, the companion(s) propose to dance for the child (faking that it has a dance competition) taking the Buddy role. However, some more questions of the math quiz have to be answered by the child and the companion retakes the Teacher role.

7.2 Hypothesis

Following are a list of our principal hypothesis :

- H0 Authoritative robots are perceived to be more dominant than permissive by children.
- H1 Styles influence children's engagement in an interactive task.
- H2 Styles influence the perceived competence and credibility of the robot in an interactive task.
- H3 Styles influence the complicity with the robot in an interactive task.
- H4 Role-Specialist robots are perceived to be more competent and trustworthy than versatile robots.

7.3 Method and materials

The protocol has been established in collaboration with the PIMLIG. Ethical validation has been obtained from the CNIL and CERNI. It enabled us to prepare an Information Notice (see Annex E.3) and a Consent Form (see Annex E.4) for parents and children participating to the experiment. The recruitment was done within the researchers of the laboratories of Grenoble area. Parents were either staff members of the administration or the researchers at the laboratory.

7.3.1 The Domus Experimental Platform and Sensors

The experiment took place in an ecological environment at Domus. Domus is an experimental platform of the LIG Laboratory. The Figure 7.1 shows the map of Domus. Domus is composed of several rooms, or physical spaces:

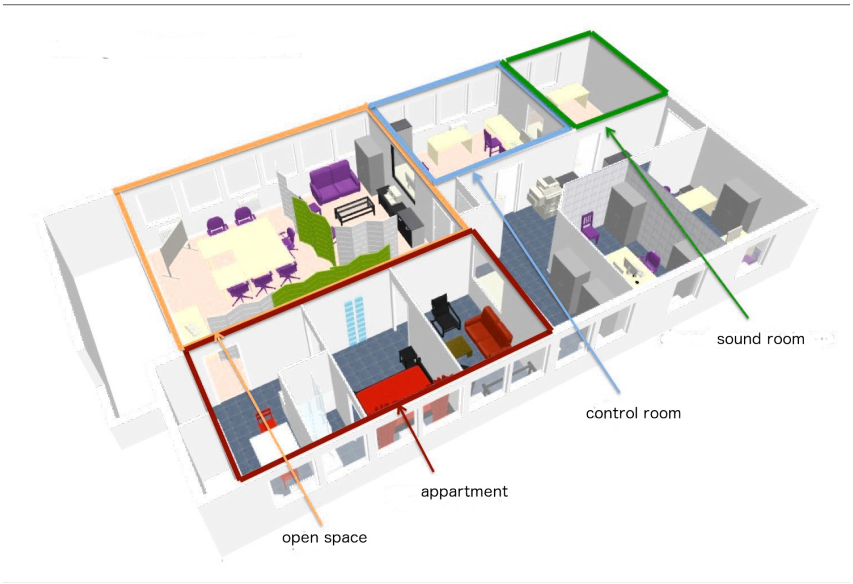


Figure 7.1: Domus Experimental Platform

- A fully equipped and functional apartment composed of:
  - a kitchen
  - an office/living-room (where the experiment took place)
  - a bedroom (where the interviews of the children took place)
- A sound and video direction room, from where one can access audio and video capture in the apartment and record from the control PCs
- An open space divided into a meeting/video-conference room and a common area.

The Figure 7.2 shows the experimental settings in the living room. The grey window is a tainted-window (with the green star). We added a Kinect sensor (yellow star) and a wooden board on the floor to avoid the robot falling.

The Domus apartment is controllable by the OpenHab[2] middle-ware. OpenHab is a home control middle-ware that supports various sensors, protocols and operating systems. We were able, for instance, to launch music playback on the speaker of the apartment directly form the robot, by doing a simple HTTP_REQUEST.

7.3.2 Experimental design & Protocol

We decided to run this experiment only with the Nao robot for several reasons. Firstly, we had already 2 modalities to test and if we had included two robots, in order to have significant results, the pool of participants would have been multiplied

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

Figure 7.2: Experimental Settings

by 2. Beside, in the previous study (Chapter 6), the difference between the two styles was more important for Nao than for Reeti (i.e. Nao-Permissive and Nao-Auhtoritative were more different than Reeti-Permissive and Reeti-Authoritative). Lastly, the Nao robot is wildly used in HRI. A lot of user studies have been conducted in child-robot interaction with Nao, and hence, the biases can be easier to avoid and the repeatability of the experiment easier to ensure.

The experimental design is within subject; each participant seeing 2 conditions in a random order during 2 sessions of 3 interactions. Each session is 15 minutes long and is organized by the succession of 3 interactions (fig. 7.3). First the child takes a mathematics evaluation (*Math Quiz*), before being invited to *dance* and finally being a part of a second *Math Quiz*.

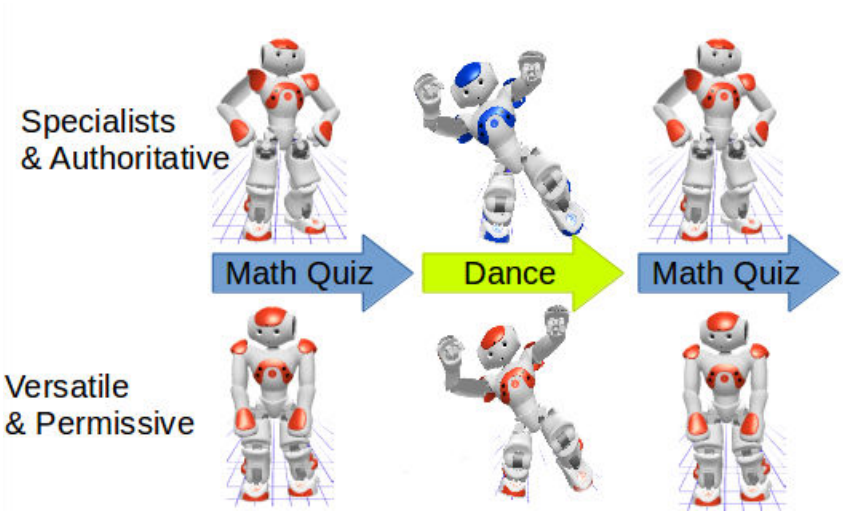


Figure 7.3: Example of two session flows

In order to test the **impact** of style, we generate authoritative and permissive behaviours for the Nao robot from neutral behaviours during the *Math Quiz*. Styles

are role dependent, so we test our styles only during the *Math Quiz* interaction. The **versatility** is tested by having either one versatile robot (one robot performs the 3 interactions) or 2 specialists robots (one robot is assigned to the math quiz task and another to the dance).

The figure 7.3 shows an example of two instances of sessions. In the top session, the child interacts with two robots one after another. The orange robot is a *Math Quiz* specialist showing an *Authoritative* style. The dance is performed by another robot in blue on the illustration[3]. The *Math Quiz* specialist takes over again with the same *Authoritative* style in the last interaction. The style being relatively stable in the role and for the individual. On the lower session, the child interacts with one versatile robot taking care of both *Math Quiz* and *dance*. This robot has a *Permissive* style in the *Math Quiz* interactions only.

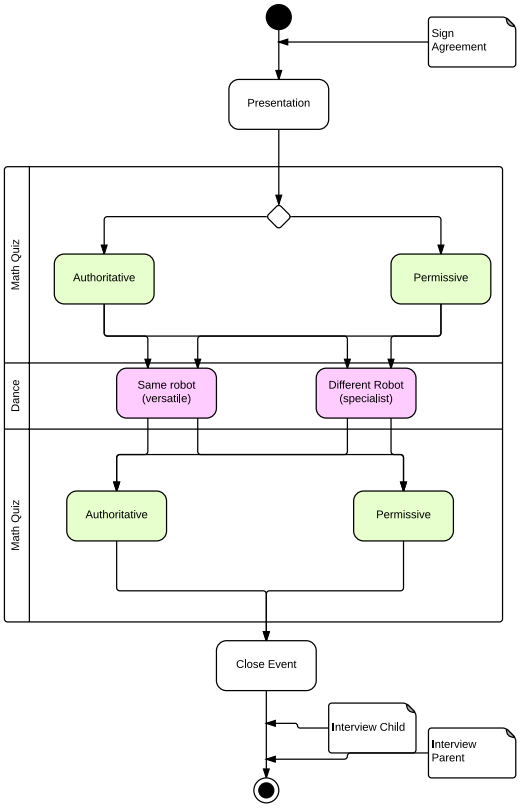
The child could interact with the robot only via the tablet during the Math Quiz. The rest of the time the robot would give the child guidance. We have developed the scenario so as to be autonomous during the Math Quiz. An experimenter was however sending signals to the robots when they would have to change activities or in case of a problem (for example, the robot falling).

For the Math Quiz, we developed an Android application allowing to change the levels of the mathematical questions according to the age of the child. One experimenter would spend some time before the session to sit down with the child and explain him the use of the math application without the robot. There are two modes on the application one without the robot in which questions are asked using the embedded text to speech system of the device. In the order mode, with the robot, the robot asks questions and the child answers on the tablet, similar to operating a slate. The robot or the text to speech system tells the child if it was the correct answer.

After that, the child was familiar with the application he would be left alone in the living room and the robot(s) would stand up and start explaining what would go on.

[3]During the experiment, the two Nao robot used were however both orange, in order to not introduce a bias in children's perception.

Figure 7.4: Protocol Overview



The Figure 7.4 illustrates the protocol of the experiment and the various conditions. To summarise, we first started by obtaining the consent of the parents and the children. We then did a tour of the apartment with the child and the parent. Arriving in the room where the robots where, the experimenter would explain that the robots were resting and that the experiment would take place in this room. The parents and the second experimenter would leave the Domus apartment to go to the control room where they could observe and hear the interaction of the child with the robots.

The first experimenter would explain to the child how the tablet application was working and would then leave the child alone with the robots. According to the condition *Versatile* or *Specialist*, there would be either one or two robots active in the room in front of the child. In the *versatile* condition, one of the robots was placed on the side, making believe that it was sleeping.

The robot(s) started by presenting themselves. Then, the first Math Quiz would start with the Teacher robot. The Teacher robot asking the question would adopt a style that will be the same as the second math quiz. After 5 math questions, the Teacher robot would tell the child that he can take a break and that it would ask more questions after. The Dance robot would then explain that it has a dance competition and that it needs practice and would propose the child to watch it practicing its choreography. After the dance is complete, the Teacher robot would intervene and ask the child to take back the tablet for more math questions. The Teacher robot would give the good answer after each question and congratulate or motivate the child with sentences picked randomly in a database that we constituted from other table games for children.

At the end, the robot would thank the child and excuse itself. One of the

experimenters would enter the room and take the child in another room to interview him.

While this interaction was going on, the parent(s) and the other experimenter were in the control room, listening and watching the interaction through the ceiling cameras. At the end, the second experimenter would interview the parents about what they just saw.

7.4 Factors and Measures

7.4.1 Qualitative Measures

The parents and the children are interviewed to collect data on acceptability, trust and credibility of all the robots' performances and behaviors after each session. This evaluation allows us to do a comparison between conditions and between parents and children.

7.4.2 Quantitative Measures

In addition to these qualitative evaluations at the end of the last session, the participants are asked to reply to a final survey in which they compare the conditions directly. This allows us to obtain the participants' preferences and to see if it is correlated to other measures. Objective measures are also collected to evaluate variations in the performance of children at the math test, and the engagement in the different tasks using the Kinect Sensor.

The engagement analysis is computed from skeleton data. We base our quantitative analysis body measures defined in the Psychology literature. This analysis will allow us to compare behaviour of the child according to the robot's style in front of him and to the versatility of the robot.

7.4.3 Data capture

In order to be able to analyse the impact of the robot's style on the child's behaviour, we used a Kinect sensor and recorded all the available channels. It was a Kinect Sensor 2 from Microsoft. We used a program developed for MobileRGB-D to record raw data from the Kinect at a frame rate of 30FPS [Vaufreydaz and Nègre, 2014]. Two video cameras in the ceiling (Fig. 7.5) were also recording the interaction and were allowing the parents to see the interaction live in the control room. The robot was recording logs of the interaction with the tablet (question, answers and

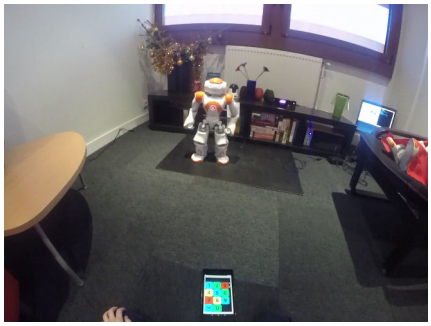


Figure 7.6: Child view of the experimental set-up

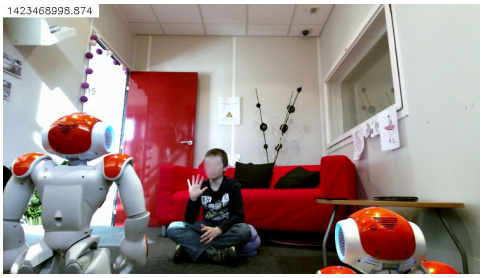
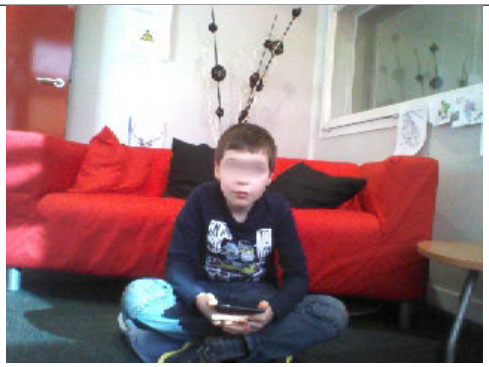
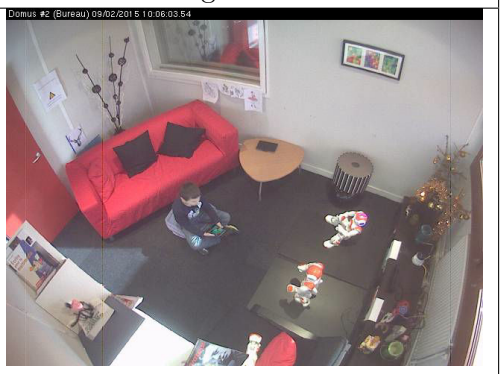


Image from video capture from Kinect View

Ceiling Back View



Robot's Camera View



Ceiling Front View

FIGURE 7.5: Samples of Video captures from the 4 cameras in the experiment

timestamps) that were after used to label the activities automatically. We also recorded videos from the robots' cameras. For one of the children, a GoPro camera was also used to have images of the child's point of view during the interaction (Fig. 7.6).

The recorded data is summarised in table 7.1

Each session lasted about 15 minutes. Every child passed two sessions. For every child, we had about 30 minutes of recording of the interaction itself (a bit more because we also recorded explanations of the experimentalist). Every session was about 250Gb of recorded data on the disk. In total, we have collected about 8To of data.

Table 7.1: Data recorded during the interaction with the robots

Data	Sensor	Frequency	
RGB Video	Microsoft Kinect 2	30 Hz max	Resolution 1900*1080p
Depth	Microsoft Kinect 2	30 Hz max	Resolution 512*424p from 40cm to 4.5m
Body	Microsoft Kinect 2	30 Hz max	6 bodies maximum with 25 joints (3D positions and 3D orientations as quaternions)
Infrared	Microsoft Kinect 2	30 Hz	Resolution 512*424p
Audio	Microsoft Kinect 2		
Video	Ceiling Office 1	less than 30 Hz	Resolution 640*480
Video	Ceiling Office 2	less than 30 Hz	Resolution 640*480
Video	Nao Robot 1	15 Hz	Resolution 320*480
Video	Nao Robot 2	15 Hz	Resolution 320*480

7.5 Self-Assessment Measures (questionnaires & interviews of parents and children)

In order to collect the parents' and children's opinions on the interaction, we conducted interviews after each session. These interviews aimed to collect the parents' and children's perception of the robot. Building an interview that would suit both parents and children was a hard task. We revised the question sets several times before arriving to the one presented in the Annex E.2.

The first part of the interview is composed of very generic questions about the experiment. We then have more specific questions, and we finish by opening to other context of use of the robots. The last questionnaire used after the second session is based on the Godspeed[Bartneck et al., 2008a] items about Credibility, Likability and Complicity. We also adapted the COIRS [Robert and Bergh, 2014] questionnaire for the parents.

After each session, the parents and the children would reply to the interview; and after the second a final interview would deal with explicit comparison of the two sessions by the participants.

7.6 Measures Extracted from Body Analysis

We used the skeleton data to measure variation on the child's attitude between the sessions. Several features form the literature and the discussions in the Chapter 2 of body communication have been implemented and applied for the Body Kinect data. A list of these computed features is present in the Annex E.1. We present here only the few that were analysed for results.

Torso and Neck Orientations TorsoQ and NeckQ are given by the Kinect sensor to be respectively the mid-spine joint and the neck orientations. These features are formalised as in the form of quaternions. In order to illustrate these angles clearly, we converted the quaternions to euclidean angles in the graphs. Figure 7.7 shows the neck relaxation angle.

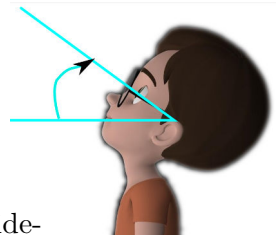


Figure 7.7: Neck Relaxation

Leaning angle Leaning left and right corresponds sideways lean (see Fig. 7.8), while leaning forward and back corresponds to frontal leaning angle (see Fig. 7.9). The values range between -1 and 1 in both directions, where 1 roughly corresponds to 45 deg of lean. In addition to the given angles from the Kinect sensor for the leaning angles, we computed a body lean angle in line with the work of [Castellano et al., 2009b] and [Schegloff, 1998]. This angle, was computed by the dot product of the vertical vector from the hip centre joint and the vector from the hip centre to the shoulder centre of each collected body data frame.

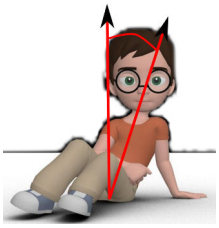


Figure 7.8: Sideways Lean Angle

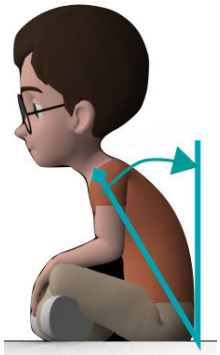


Figure 7.9: Frontal Leaning Angle

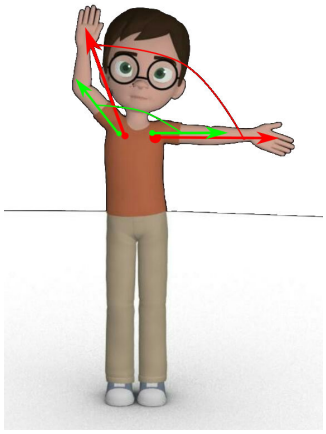


Figure 7.10: Arm Asymmetry, with Hand and Elbow angles

Volume For each frame, the volume is computed by going through the joints and recording the min and max in all three dimensions (X,Y,Z). We also use as feature the joint's name at the minimum and the maximum for all three dimensions.

Status of Hands The status of hands IS given by the Kinect Sensor with values ranging among Open, Closed, Lasso, NotTracked and Unknown. This feature is considered to be a good candidate for Hand Relaxation, advocated by Meharbian [**?**] as a sign of relaxation. Only the Open and Closed recognition are exploited.

Asymmetry Values According to [Mehrabian, 1977], a high degree of asymmetry in arms and legs are cues to looseness and the relaxation of the body. In order to compute the asymmetrical rate of the members, we computed the dot products of vectors for the joints(see Figure 7.10).

7.7 Data Analysis & Results

We recorded the data in the RAW format and recorded all possible sensor outputs from the Kinect using the system developed in Mobile-RGB-D (each frame in raw and with the associated time-stamp). The workflow of data treatment for the body data is presented on Figure 7.11. The data analysis was made in several steps, that consisted in first computing the body features from the raw data. The features were first computed for all the bodies recorded in each session. After that, we labelled the data with several labels: child id, session number, versatility of the robot during the session, the style of the robot and the activity (first quiz, second quiz, dance or explanations). In order to label the activities, we used the timestamps of each frame of the recorded data and the logs recorded by the robots.

During each session, each body was provided with a tracking id. Since an experimenter was also sometimes present in the room (at the beginning of the session and in case of problems, such as the robot falling), we had to remove the bodies corresponding to the experimenters from the data. If the experimenter would come in and out several times, the tracker would attribute him a new id. We used the labelled data in order to do so by simply removing bodies that were not present in the room during the whole session.

Because of certain technical problems occurred during some experiments (Hard disk saturated, data not collected, frame rate very low or automatic labelling not

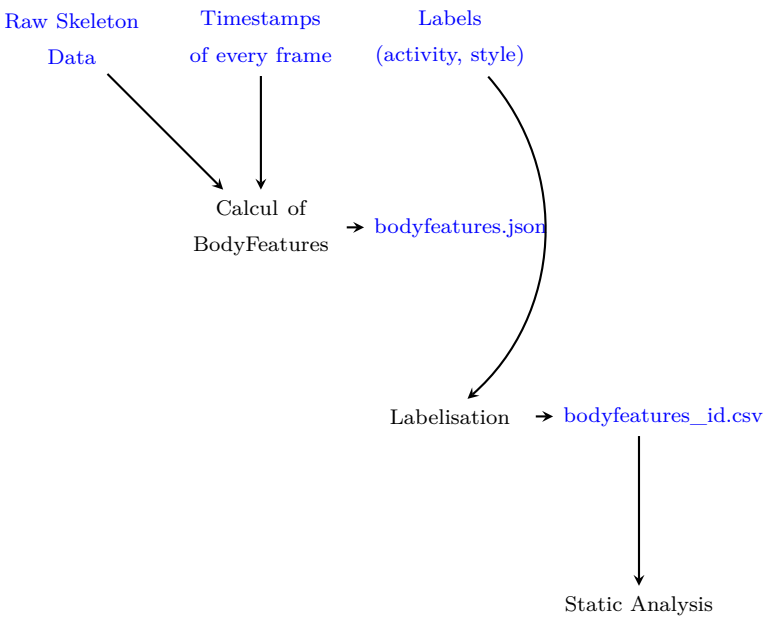


FIGURE 7.11: Pipeline of the data treatment after recording the interactions

efficient), we had to remove some subjects from this analysis. The results presented here are the results of 11 children from the initial 16.

7.7.1 Participants

16 children and their their relatives participated to the experiment. Most often, the relatives were parents, but 3 children came with their grand-parents.

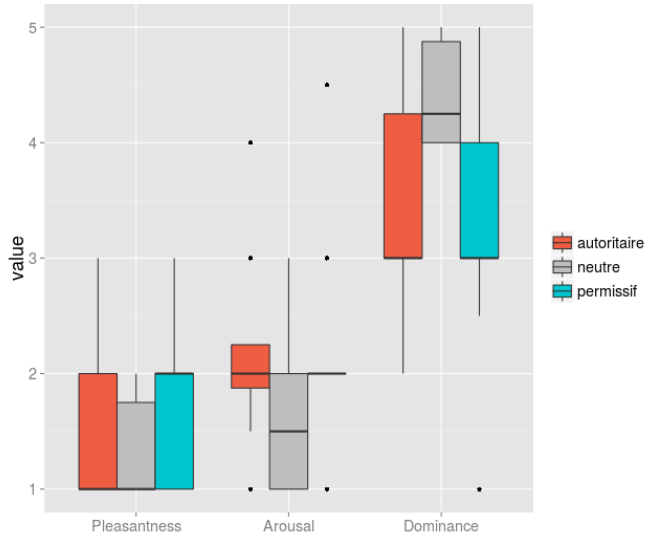
In order to recruit the participant, we have set-up a website [4] with the information and the ethical document link with the experiment. The participant could also request a time for the experiment by looking at the calendar and filling an online form. The link for the experiment has been sent through the mailing-lists on Grenoble Campus. Hence, most of the parents were researchers; others, being administrative staff members.

[4] Website for the recruiting of participants for the experiment : https://sites.google.com/site/stylebotxp/

7.8 Results

Style perception (H0) was evaluated though the Self-Assessment Manikin(SAM) questionnaire. The SAM allowed us to evaluate the perceived mental state of the robot by children. Expected results should show a difference between the styles only in the dominance scale. Collected measures didn't show a significant difference of perception of the styles of the robots (see Figure 7.12) (H0 not verified). On these, scale 0 is 'pleased' and 5 is 'not pleased', for the pleasantness scale. For the Arousal scale, 0 is 'aroused' while 5 is 'calm'. Finally, on the dominance scale, 0 is 'not in control' and 5 is 'dominant'.

FIGURE 7.12: Emotional Mental State Perceptive Measures of the robot: Pleasantness (from 1, robot pleased to 5, not pleased), Arousal (from 1, aroused to 5, calm), Dominance (from 1, dominant to 5, not dominant)



It can be noted that there was however a significant cross-effect of versatility and style on the dominance level. Indeed, as illustrated by Figure 7.13, the difference is significant only between the condition *poly perm*, that corresponds to the versatile permissive robot and *spe perm*, that is the specialists' permissive robot.

Credibility and Complicity analysis through the answers of the child at the interview didn't show any significant differences between the two styles and the versatile vs specialist conditions. This was evaluated through the SAM questionnaire and the interview (H2 & H3).

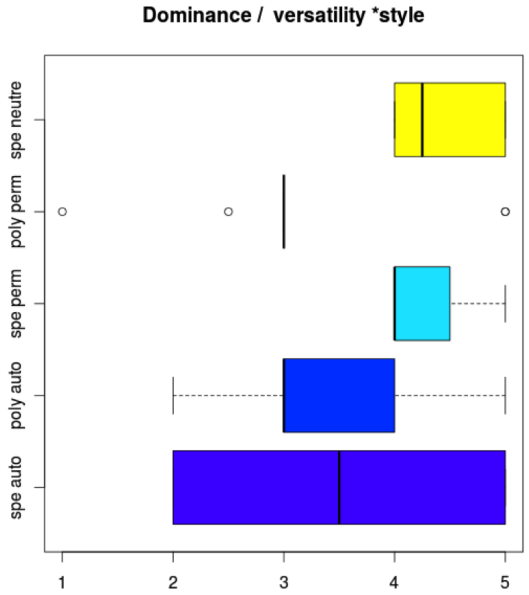


FIGURE 7.13: Pleasure Arousal Dominance Perceptive Measures by Children according to Styles and Versatility

Analysis of the child's attitude and engagement was done through the collected data and the computed features previously described.

The features computed are only static features,meaning that these features are computed frame by frame. More analysis on these data could lead to better results considering the time scale and allows us to compute the dynamic measures presented in Chapter 2 .

Body Volume is a sign of postural openness (see Figure 7.14). According to [Knapp et al., 2013], postural openness is a sign of relaxation and dominance. We notice a significant difference ($F = 31.1$ and $p < 0.001$) of the body volume according to the style. We can see that in the authoritative condition, children tended to move less and but in average to occupy higher occupancy volumes. These results can also been explain by the fact that in the authoritative condition the robot itself was also occupying more volume space. It can be a phenomenon of imitation.

Forward Lean angle is a measure for Liking and Relaxation (see Figure 7.15). There is a significant difference between the style modalities ($F = 1866.8$ and $p < 0.001$). It is however difficult to conclude on the Liking and Relaxation. Indeed, high forward lean is a sign of liking and but also to un-relax person ([Knapp et al., 2013]).

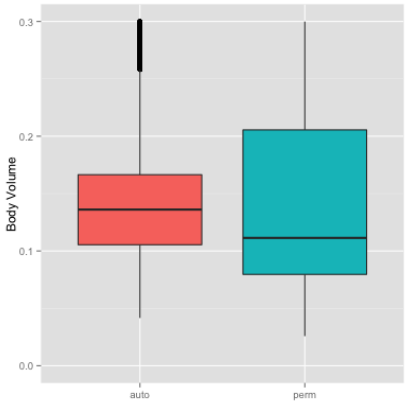


Figure 7.14: Body Volume

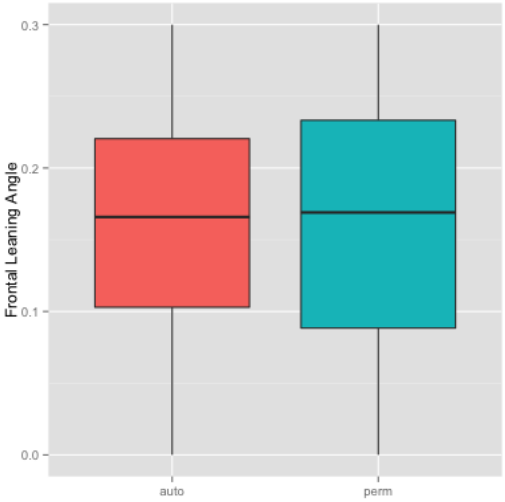


Figure 7.15: Forward Lean Angle

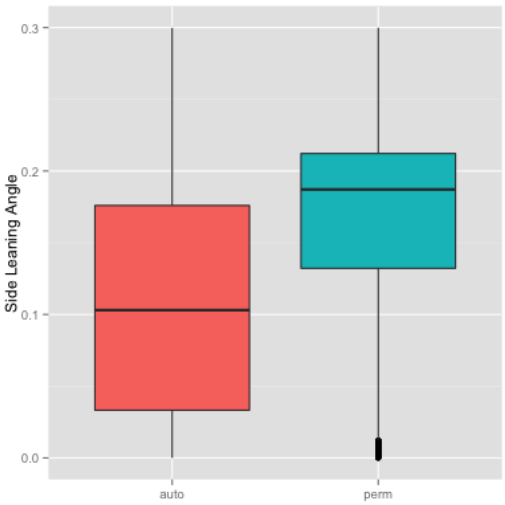


Figure 7.16: Side Lean Angle

Side Lean angle is a measure of Relaxation (see Figure 7.16).

There is a significant difference between the style modalities ($F = 265.6$ and $p < 0.001$). Children tended to be more on the side on the permissive condition, which is a sign of postural relaxation.

Frontal distance is a sign of immediacy and liking (see Figure 7.17. There is a significant difference between the style modalities ($F = 940.13$ and $p < 0.001$). Children tended to closer to the robot in the permissive condition, which is a sign of liking and immediacy.

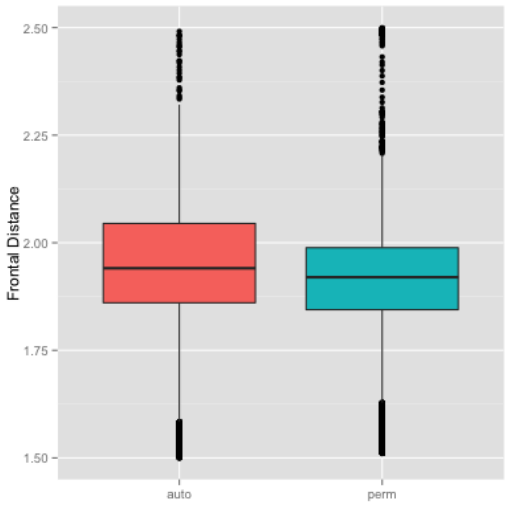


Figure 7.17: Frontal Distance (proxemics)

Asymmetry is a sign of relaxation (see Figure 7.18. For the three joints the difference is significant between the two styles. The asymmetry factor is higher for the authoritative modality which could mean that the children where more relaxed when facing the authoritative robot.

Open hands are a sign of relaxation. We can notice that the number of recorded hands open is greater for the authoritative condition.

7.9 Discussion and Conclusion

The aim of this experiment was to contribute to several research questions. Firstly, we wanted to know if the participants preferred one unique versatile robot or two specialised robots. The answer of the participants from the interview was unanimous and all agreed (parents and children) that there is no necessity to have two robots if one can do both tasks. This opinion should be nuanced by the fact that these two robots were exactly identical and that we might have different opinions if would have presented robots with different appearance (here, no robot was physically better than the other one).

Secondly, the behavioural style model for personalisation was tested with experiment by checking that style were perceptible to children and that they would have preferences on theses styles.

Interviews and questionnaires to children between 7 and 11 was a difficult task. The experimenters found it difficult to make children express their opinions. The

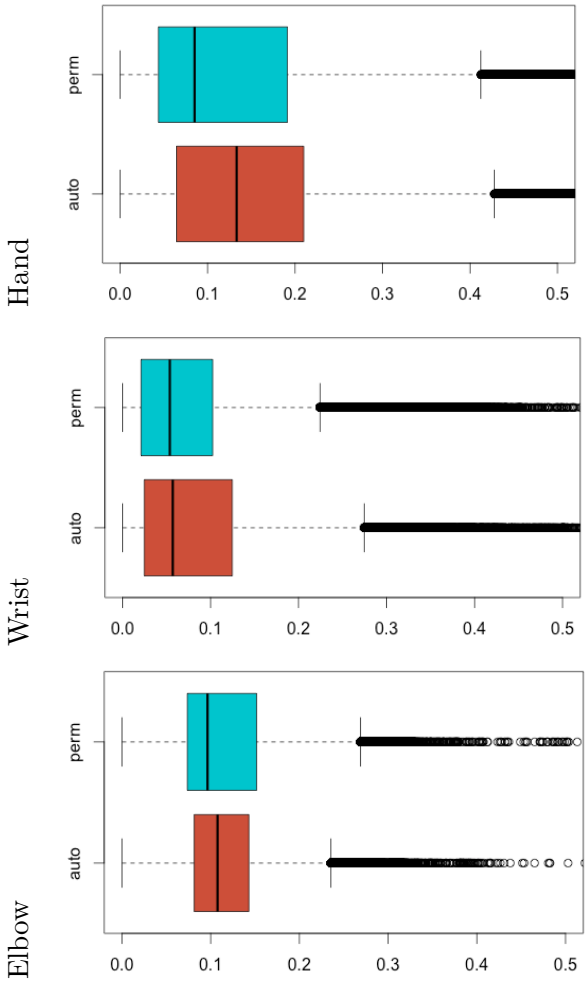


FIGURE 7.18: Asymmetry for Arms

interviews and the questionnaires didn't give significant results apart for the perceived dominance that was influenced by the cross-interaction of 'permissive' and 'versatility'. This is one of the reasons why we didn't rely only on this form of measure.

We proposed to use a Kinect2 sensor to measure the attitude of the children. Several features from the literature were computed to elicit liking, immediacy or relaxed attitude. These results are difficult to comment on by them-selves as some features can have several meanings. For instance, the side lean feature tells us that children were more relaxed in the permissive condition where the open hands and the body volume features tell us the opposite. Other features could have been computed, such as eye gaze (exploitation of infra-red data which hasn't been made yet can maybe give approximation of this feature). Also, composite analysis or multivariate

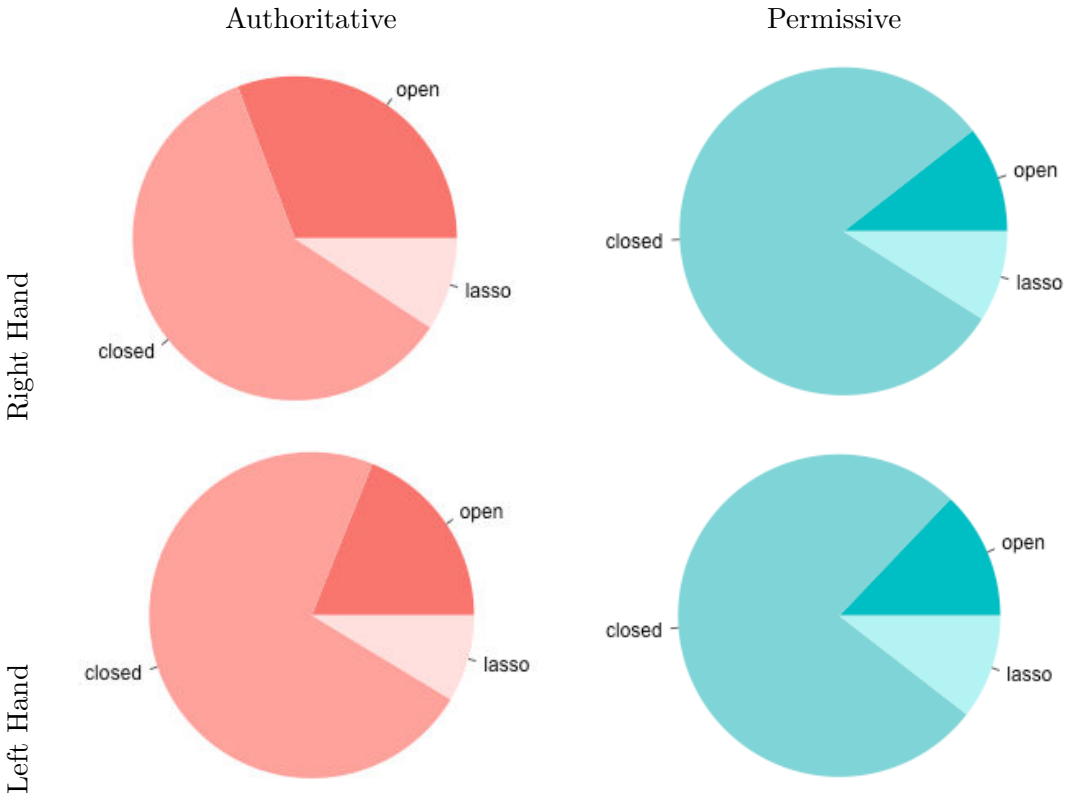


Figure 7.19: Hand Status

analysis could help to resolve these ambiguities in the interpretation of the results. We can however conclude that styles did have an influence on the children's behaviour and hence that they might be a tool for personalisation of companion's behaviour.

Some limitations and contextualisation should be made. Indeed, some children had seen the robot before and some other were frightened at first.

Most children didn't speak during the experiment. Some children started at first, but since they couldn't interact verbally with the robot, they understood fast that the robot "wasn' hearing them".

All children apart from one stood and danced with the robot. The robot however didn't require them to do so. He was simply proposing to dance for the children cause it had a dance competition on the coming weekend. The children stood and were mimicking the gestures during the dance. This phenomenon might be due to the novelty in the interaction. The novelty bias is hard to bypass.

The parents were in the control room and were able to see and hear the interactions. The monitor they were watching was showing the video streams from the two ceiling cameras. Interviews of parents showed that they were in general, surprised that their

child stood to dance. Some parents reported: "But he hates dancing! It is unusual for me to see him dance!". We found out later that it would also have been useful for the parents to see their children's view point in order to be more immersed in the interaction. Some of them seemed to loose track and couldn't efficiently perceive the changes of the robot's behaviour between the sessions because of the view point. Some parents however did perceive the change in the attitude talking about a "sad " robot (for the permissive) and a dynamic robot (for the authoritative). In general, parents trusted the robot in the proposed task and even proposed other courses in which the robot could help (tenses, English language ...). They found that their children were more patient with the robot in this task. Some parents also expressed that for repetitive tasks, their children might preform better, as they themselves have a tendency to get impatient.

To summarise, styles as depicted by non-verbal cues of communication were not explicitly recognized by children. The behaviours of children did however significantly change according to the style. An analysis for each child could help to determine whether they preferred the authoritative or permissive styles. This last experience also showed that parents and children were willing to have a companion robot in this kind of context.

Chapter 8

Conclusion

8.1 Summary of contributions

In the context of companion robots, acceptability has became a crucial question. In order to welcome robots at home, the interactions with these robots should be smoother and more sociable. The work of this thesis aimed to enable social robots with a plasticity in order to make more socially acceptable by the users. This work aimed to study the expressed and measurable cues of interpersonal adaptation in interaction with a robot. Classically detected using questionnaires user, we have showed the limits of this technique confronting this technique to realistic scenarios with a robot in a homely environment. Finally, we proposed a new implementation as the CAIO to make it usable for robotic platforms.

8.1.1 Behavioural Style

The first part of our work was to study social roles that would suit a companion robot for children at home. We propose a framework in which we can develop variations of the same social role. In order to do so, a scenario based approach was taken. We analysed the literature and conducted an exploratory study in order to elicit the requirements of parents in term of social roles for the robot of their child. We then proposed to model the social roles using behavioural social simulation in BRAHMS. After that, we proposed to take the theoretical approach of style in order to bring adaptability into the social role. We modelled the Behavioural Style, implemented and tested it with two robots.

Our challenges was then to evaluate the behavioural style model with experimental methods and sufficient subjects to have significant results. A first video-based study enabled us to conclude that the non-verbal changes induced by our behavioural style model can be perceived by users, and that parents have certain preferences in term of styles. A second study, confirmed that style had an influence on the child behaviour.

In this second study, we also deployed original techniques to measure the child-robot interaction.

Experimental Methodology for Conception of Companion Robot with Style

During this thesis work, a strict scenario-based and experimental methodology was applied to analyse, conceive and evaluate our proposition.

This method, summarized by 8.1, is close to classical experimental methods in HCI or psychology.

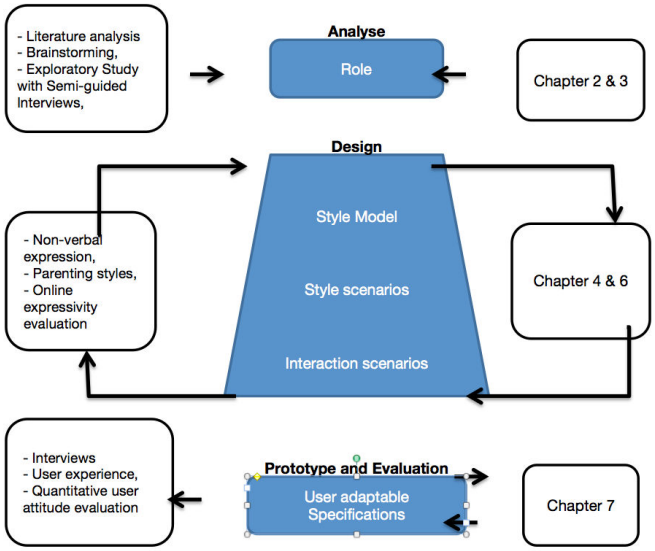


Figure 8.1: Experimental Method followed during the design of the Behavioural Style Model

Initially, our aim was to elicit the roles in which we would be able to apply the style model. We used a qualitative approach to gather ideas from parents. We used semi-guided interviews as well as a prototype of gaming companion in order to know more about habits, expectations and the needs of parents for their children (see Chapter 3).

In a second time, our aim was to objectively evaluate expressibility using styles by the two robotic platforms Nao and Reeti in a credible manner. For this purpose, we used videos and questionnaires in an online study.

In a third time, the styles had to be evaluated in situation by children themselves. We use recording of interaction traces such as motions (gestures and postures) as well as questionnaire based interview.

This research framework allowed us to propose and test our behavioural design. Indeed, HRI research is learning from the experience of HCI where user experience is claimed as a gate to conceptual validity. In this line, HRI studies tend to be more and more applied and in the wild. A thorough experimental methodology helps to set objectives and to lead to clear conclusions.

8.1.2 Measuring Child-Robot interaction

As we saw in the previous chapter, the data collected to detect attitude changes when in interaction with a robot companion were more precise than questionnaires for child-robot interaction. We used the R language to analyse these data, compute the features and do the statistical analyses.

With the collected data we were able to compute measures proposed in psychology to describe human attitude. These measures were put in link with the meaningful dimensions that they were reflecting (such as Liking, Relaxation). We believe that this work can in that sense be beneficial to the HRI community. By providing standardised tools to measure users' attitude change during an interaction, we believe that research experiments will be easier to compare and reproduce in the HRI community.

However, the size of the dataset made the analysis fastidious and constrained the choices of features computed on these data. Indeed, the results presented deal only with body poses data but other modalities recorded can still be analysed to enrich the conclusion of this study (such as the audio, video and facial expression recordings).

8.1.3 Implementation of CAIO

Chapter 5 presented the new implementation of our research team cognitive architecture CAIO. The main contribution here was to modularise the cognitive process and to adapt the reasoning engines function to the ROS robotics framework in order to be able to connect it with two robots Nao and Reeti; We also proposed an implementation of the Stimulus Evaluation Checks for theses two robots. Finally we provided a conceptual evaluation of the architecture and a sketch to illustrate the different processes involved in the cognition.

8.2 Impact and Future Work

This work is a first step in using style to design social behaviour for robots. Indeed, it is felt that the style framework can be very useful for the flexibility and the re-usability of social expression, and hence to improve the adaptability of the robot.

Our work in evaluating behavioural styles allowed to record a large corpus of data in child-robot interaction (8 hours). These data have not been fully exploited yet. Indeed, some recorded modalities can be used to compute more features to describe the children's behaviours. In a short term, the analysis of multimodal data from the child-robot interaction will continue. Dynamic features from body data can be computed, such as the rocking rate, the motion-energy etc. An analysis of these data for each children could allow us to explain inter-individual differences. Also, some modalities such as video, audio and infra-red haven't been exploited yet.

Some new features could be computed on these modalities such as speech activity detection [Vaufreydaz et al., 2015] for the audio, facial and gaze approximation from videos and infra-red data.

A video, summarizing the experiment is under making off to illustrate this experiment. This video will be used as a base for a new video-based study aiming to explore parents opinion at a large-scale about the interactions we recorded.

The problem of social adaptability of companion is a complex problem. This work gave a lead to solve this problem and we propose to enrich the corpus with more real life scenarios in order to improve the results. An enrichment of the dataset with scenario involving other roles and other styles for the robots will allow us to integrate a temporal aspect in the recognition of attitude change and to see if the child feels any personality emerging. A new experiment in the MoCA project involving all the partners of the project is scheduled for the end of 2015. In this coming experiment, parents will set the particular style before their child interacts with the companions' world. The world of companions will be composed of several embodiments and will propose various activities and roles.

The long term aim would be to both provide adaptability and adaptivity to the companion robot in order to make it fully plastic. We proposed a solution for intra-role adaptability, and a new solution for inter-role adaptivity can be proposed. The problem of role switching is indeed new in HRI. But has our last study showed, end users expect the companion to be versatile and that is why researchers in HRI should consider role switching and context awareness to be the future research problems they will face.

The Multi-modal perception of communicative acts is a research topic *per se*, that involves social signal processing and multimodal fusion and decision. Indeed, endowing the robot to be able to understand communication acts not only with speech but also with facial expression will improve the quality of the reasoning. The multimodal recognition of emotion is a domain of research *per se* and to our knowledge there hasn't been any works done successfully in recognizing complex emotions and the variety communicative acts.

Plasticity could also intervene in the cognitive architecture. For instance, by using cognitive styles [Hayes and Allinson, 2012] to modulate reasoning in CAIO. In cognitive styles, there is a distinction between analytic and intuitive. This distinction is close to the distinction between the S1 reactive and S2 deliberative systems in CAIO. One can imagine a companion that would be more analytic and hence will favour expression of goals from deliberative loop or a companion more intuitive that will favour treatment by the reactive loop.

Part IV

Annexes

Appendix A

Styles Factors

A.1 Table of Behaviours for each style factor from [Gallaher, 1992]

Behavioural Items	Style factor
Uses very little-most of body when gesturing	Expressiveness
Stow-fast gestures	Expressiveness
Gestures: infrequently-frequently	Expressiveness
Shakes head: frequently-rarely	Expressiveness
Narrow-broad gestures	Expressiveness
Nods head: frequently-rarely	Expressiveness
Shoulders: slumped-erect when standing	Animation
Sits down and stands up: slowly-quickly	Animation
Torso: upright-leaning when standing	Animation
Sits with torso: tilted-vertical	Animation
Slow-fast walker	Animation
Sits with torso: erect-slumped	Animation
Legs: together-wide apart when sitting	Expansiveness
Soft-loud voice	Expansiveness
Elbows: close to-away from body	Expansiveness
Thin-full voice	Expansiveness
Light-heavy step	Expansiveness
Takes: small-large steps	Expansiveness
Legs: close together-wide apart when standing	Expansiveness
Hands: close to-away from body	Expansiveness
Soft-loud laughter	Expansiveness
Choppy-rhythmic speech	Coordination
Jerky-fluid walk	Coordination
Rough-smooth gestures	Coordination
Harsh-smooth voice	Coordination

A.2 Amplitude Algoritm for Stylistic Transformation

```
Data: (names, times, keyframes),magnitude
Result: (names,times,keyframes*magnitude)
for each joint do
    current_joint = list();
    current_joint.append(value[joint][0]) // (add first value (unmodified));
    for each keyframe key do
        speed = (value[joint][key + 1] - value[joint][key - 1]) / (times[joint][key
        + 1] - times[joint][key - 1]);
        r = value[joint][key - 1] - speed * times[joint][key - 1];
        diN = math.fabs(value[joint][j] - (speed * times[joint][j] + r));
        diE = diN * magn + diN;
        t = (times[joint][key + 1] - times[joint][j]) / (times[joint][key + 1] -
        times[joint][key - 1]);
        if value[joint][key - 1] == value[joint][j] == value[joint][key + 1] then
            keygen = value[joint][j]
        else if value[joint][j] > 0 then
            keygen = (diE / diN) * value[joint][j] + (diN - diE) / diN *
            (value[joint][key - 1] * t + value[joint][key - 1] * (1 - t)) ;
        else
            keygen = (diE / diN) * value[joint][j] - (diN - diE) / diN *
            (value[joint][key - 1] * t + value[joint][key - 1] * (1 - t))
        end
        current_joint.append(keygen);
    end
    value_new.append(current_joint);
end
return (names, times, keys_new)
```

Algorithm 3: Amplitude Style Transform

Appendix B

Preferences of Participants to the Innorobo Survey in 2013

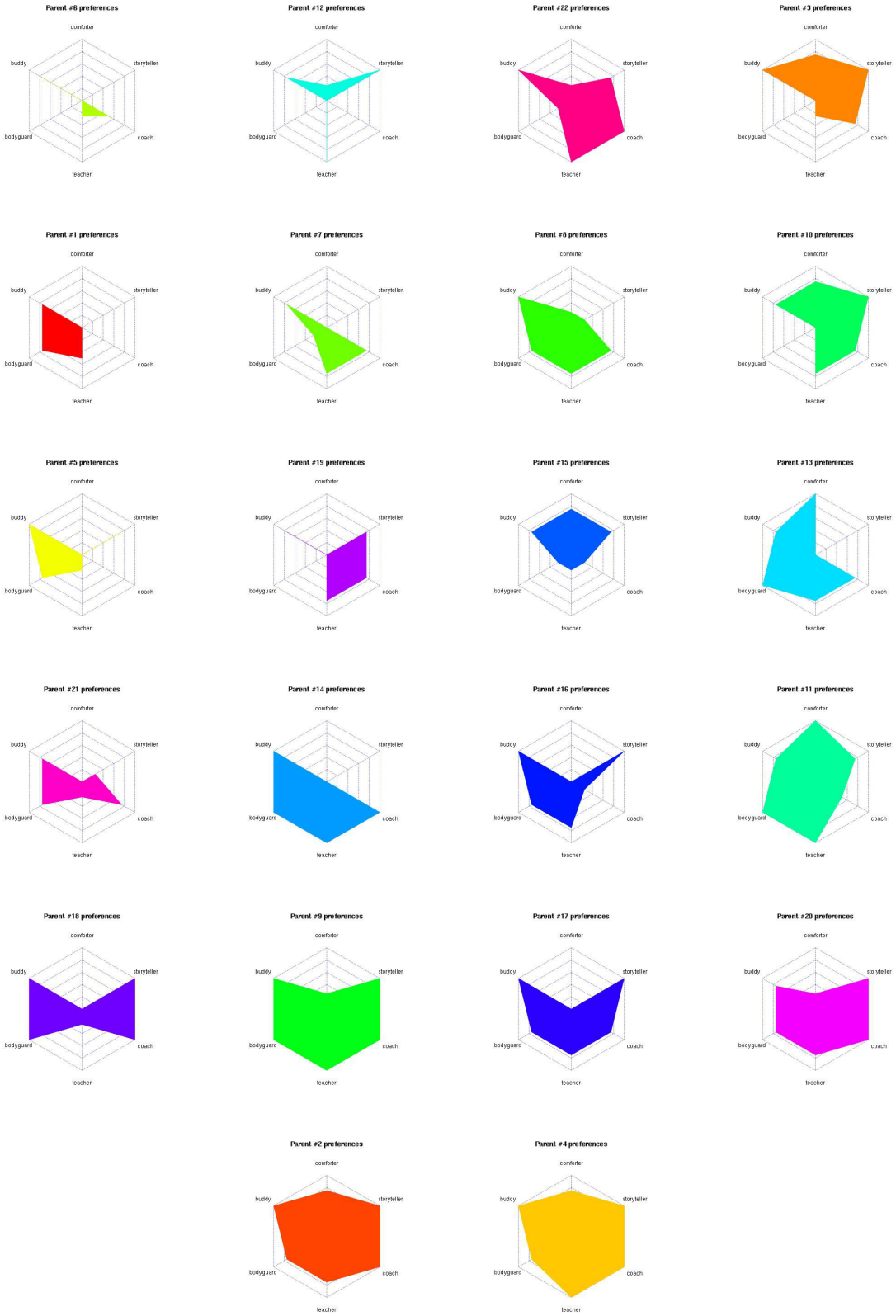


TABLE B.1: Preferences of particicpants in term of roles for a companion robot for children[Innorobo2013]

Appendix C

Scenario Modelling and Simualtion

C.1 Scenario for the MoCA project

Ben is 11 years old and in his first year of middle school. His father and mother both work until 8pm. Ben finishes school at 4.30pm. The school is a few streets away from home and Ben usually walks home with some friends every evening. Ben usually has homework to do every evening. His school grades are average but with more help from his parents and teacher they would improve. Although Ben knows that he should do his homework he prefers to watch TV or play video games. In the evening, his neighbour, Alan, usually comes over to play. Ben's parents don't really like him being alone at home, but they have heard about the MOCA system and they already have some devices (virtual characters) at home. Ben would love to have robot companions and so his parents decide to buy him the one he liked from the big city supermarket. They download the MOCA software onto his already existing devices. The MOCA system deploys itself forming a world of companions that can be with Ben in the evenings. The parents configure the world with different roles according to their needs. They download:

- Playing software, a perfect pal to play with Ben when he is alone (avoiding the video games)
- Comforting software, in case Ben feels sad and needs some comfort
- Teaching software, which will help Ben with his homework, and to organise and keep track of schoolwork
- Coaching software which help Ben in extra-scholar activities (preparing the snack, music lessons).

- Finally, in case of problems, Security software

Ben would love to learn music with 'Coach'. When Ben gets hungry he usually goes to the kitchen and gets a snack He prefers chocolate bars rather than fruit, but the Coach usually reminds him that he won't have a dessert after dinner if he didn't have his apple. The activities of the Coach can also be extended by Hip-Hop lessons and Ben would like to be given these lessons for Christmas.

The house rule is that around 5pm and before playing any game, Ben should have done his homework. The Teacher helps with the homework and informs the other companions when it is finished. The Teacher also gets information from the parents and the school agenda. The information is related to the subject that Ben needs to study. The Teacher makes a synthesis of the work accomplished by Ben and gives a summary to Ben's parents or his school teacher if they ask for it. The results are added to Ben's diary that is managed by the Cloud. The Teacher encourages Ben to do his homework with care. When the Teacher encourages Ben, his motivation increases and he believes that he can complete the task. Nevertheless Ben can be a bit stubborn, and sometimes the Teacher needs to threaten Ben with calling his parents in order to try to make him do his work. Alan and his artificial companions are pretty good at strategic games, and Ben doesn't win often. Nevertheless, having Buddy and Poto means that there are more 'people' to plays games, and they can all play together. When Ben looses he is always a bit sad, but Dolly is there to cheer him up and to play some nice songs that take his mind off loosing. Dolly is very sweet, and Ben knows that he can share his secrets with her. Being home alone, Ben feels reassured when Bodyguard advises him on what to do and check who is at the door before it is opened.

C.2 Example of multi-agent scenario modelling in BRAHMS

Figure C.1 shows a screenshot where, the doorbell, modelled as an object, suddenly rings. Ben is a bit scared. The security agent, called Bodyguard in the figure, sees that it is Alan, who brought a companion with him. Knowing them (modelled as a belief), the Bodyguard lets them in and reassures Ben, telling him that Alan is here with Poto. Buddy and Poto suggest making teams with Alan and Ben to play a strategy game, one of Poto's favourite games.

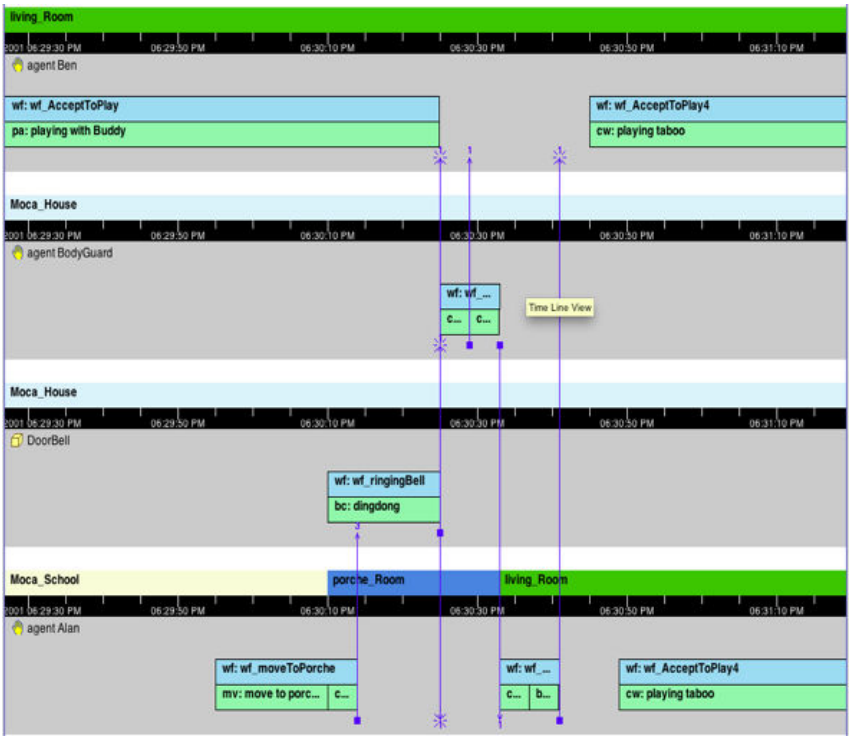


FIGURE C.1: Guarding situation (someone at the door). The Bodyguard agent enters the action, followed by group games with companions and children.

Appendix D

Questionnaires for the Online Evaluation of Parenting Styles

Following you will find the questionnaire for one of the modality where the Permissive Nao condition was shown first. It is one of the 4 modalities of this questionnaire. The four modalities were:

- Nao permissive video then Nao authoritative
- Nao authoritative then Nao permissive
- Reeti permissive video then Reeti authoritative
- Reeti authoritative then Reeti permissive

An automated Google Script allowed us to randomize the distribution of the questionnaires among the participants who were connecting to take the experiment. The following example is in French language as administrated to the participants.

Robot compagnon assistant de parent

Aujourd'hui, la technologie permet de programmer les robots pour leur donner différentes attitudes. Dans le cadre d'une recherche en informatique, nous souhaitons recueillir l'opinion des personnes par rapport à ces attitudes. L'étude que nous menons porte sur l'attitude de robots compagnons pour les enfants au moment des devoirs.

Avant de commencer, merci de pousser le volume de vos hauts-parleurs afin de pouvoir bien entendre le dialogue lorsque vous regarderez les vidéos.

*Obligatoire

A votre sujet

1. **Vous êtes** *
   Une seule réponse possible.
   - ◯ un homme.
   - ◯ une femme.

2. **Quelle est votre année de naissance ?** *
   .....

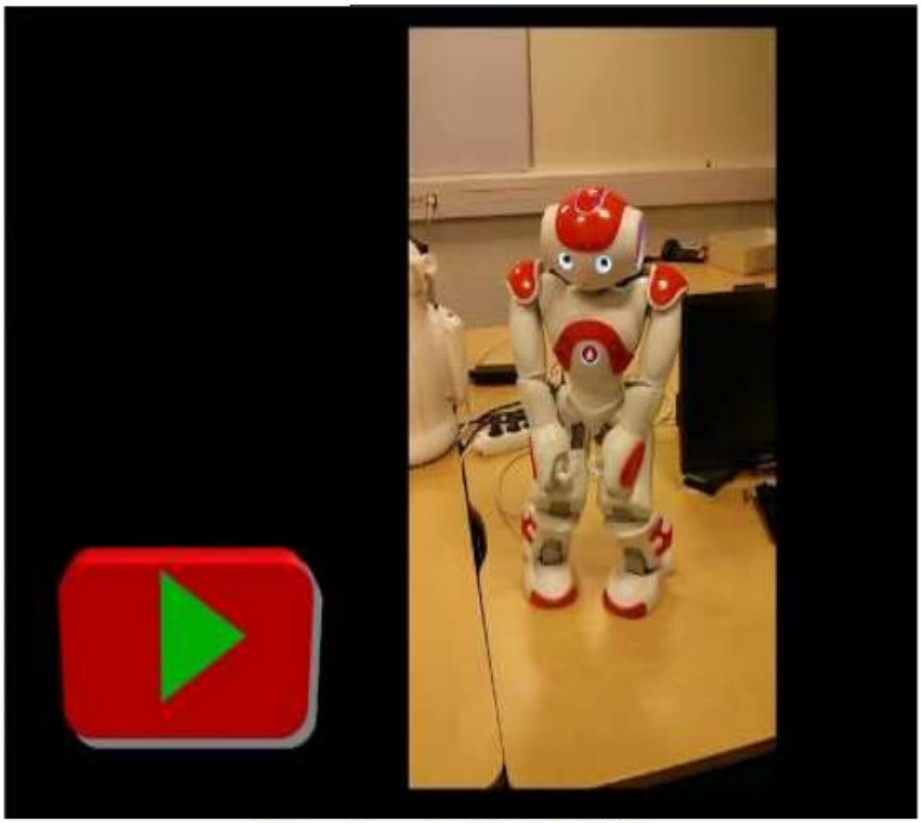
3. **Avez-vous des enfants ?** *
   Une seule réponse possible.
   - ◯ Oui
   - ◯ Non

4. **En ce qui concerne les nouvelles technologies,** *
   Une seule réponse possible par ligne.

	Pas du tout d'accord	Plutôt pas d'accord	Plutôt d'accord	Tout à fait d'accord
vous aimez tester les dernières nouveautés	◯	◯	◯	◯
vous aimez possédez les dernières nouveautés	◯	◯	◯	◯

Compagnon Robot 1

Visionner la vidéo ci-dessous.



http://youtube.com/watch?v=RrZJa7EH77o

Robot compagnon pour enfant

5. **A votre avis, le comportement de ce robot est-il directif ? Vous noterez de 0 à 10 le caractère directif de ce robot : 0 pas du tout directif à 10 très directif.** *

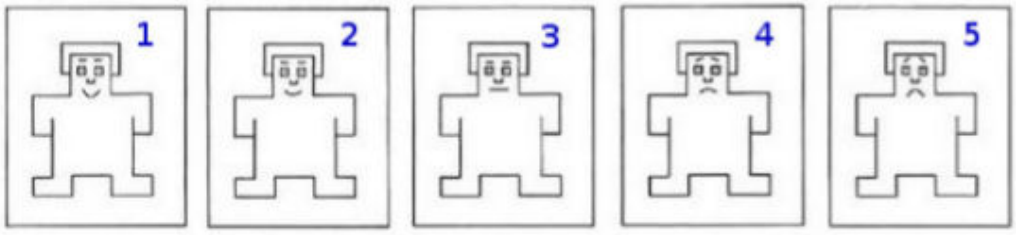
Une seule réponse possible.

	0	1	2	3	4	5	6	7	8	9	10	
Pas du tout directif	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Très directif

6. **Pour chacun des élements indiqués, vous noterez l'influence ou non de ces éléments sur le caractère directif du robot ? vous noterez ces éléments de 0 à 10 : 0 aucune influence, 10 très grande influence** *

Une seule réponse possible par ligne.

	Aucune influence	1	2	3	4	5	6	7	8	9	Très grande influence
Le ton de la voix											
Les mots employés											
La gestuelle											
La posture											
Le regard											

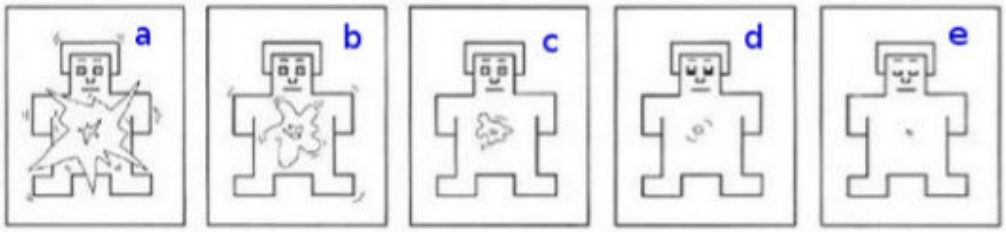


7. **Parmi les images ci-dessus, laquelle caractérise le niveau de plaisir du robot dans la vidéo que vous venez de voir ?** *

De (1) Heureux à (5) Malheureux

Une seule réponse possible par ligne.

	1	2	3	4	5

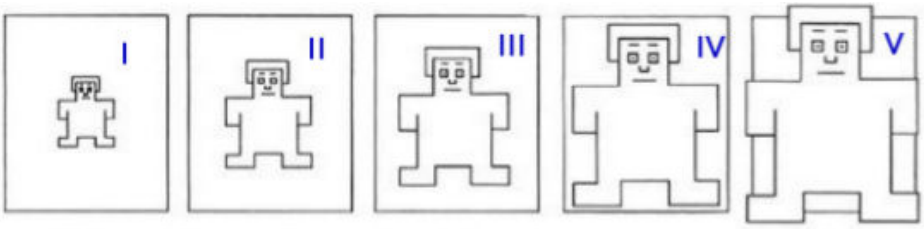


8. **Parmi les images ci-dessus, laquelle caractérise le mieux le comportement du robot dans la vidéo que vous venez de voir ?** *

De (a) Dynamique à (e) Sans énergie

Une seule réponse possible par ligne.

	a	b	c	d	e



9. **Parmi les images ci-dessus, laquelle caractérise le mieux le comportement du robot dans la vidéo que vous venez de voir ?** *

De (I) Pas de maîtrise de la situation à (V) En contrôle de la situation
Une seule réponse possible par ligne.

	I	II	III	IV	V
	◯	◯	◯	◯	◯

10. **Pour chacune des tranches d'âges, pensez vous que les recommandations du robot seront suivies ?** *

Une seule réponse possible par ligne.

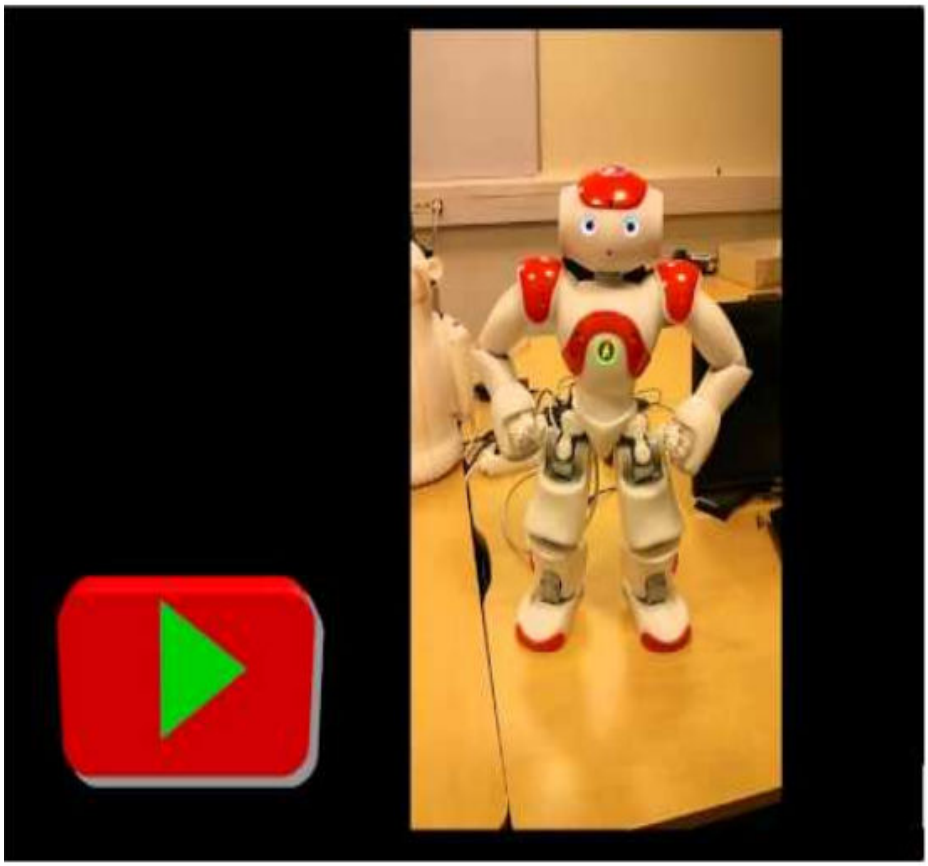
	Pas du tout suivies	Plutôt pas suivies	Plutôt suivies	Tout à fait suivies
des enfants de 3 à 7 ans	◯	◯	◯	◯
des enfants de 7 à 11 ans	◯	◯	◯	◯
des adolescents	◯	◯	◯	◯
des adultes	◯	◯	◯	◯

11. **Le caractère directif de ce robot vous parait-il crédible ?** *

Une seule réponse possible.

	1	2	3	4	5	6	7	8	9	10	
Pas du tout crédible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Tout à fait crédible

Compagnon Robot 2



http://youtube.com/watch?v=HsrrJ8n9_Lc
Robot compagnon pour enfant

12. **A votre avis, le comportement de ce robot est-il directif ? Vous noterez de 0 à 10 le caractère directif de ce robot : 0 pas du tout directif à 10 très directif.** *

Une seule réponse possible.

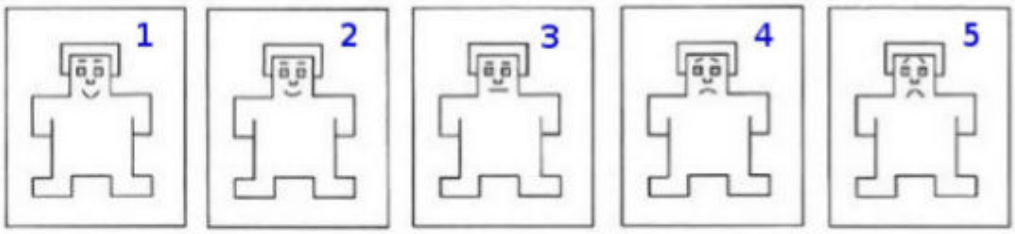
	0	1	2	3	4	5	6	7	8	9	10	
Pas du tout directif	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Très directif

13. **Pour chacun des élements indiqués, vous noterez l'influence ou non de ces éléments sur le caractère directif du robot ? vous noterez ces éléments de 0 à 10 : 0 aucune influence, 10 très grande influence** *

Une seule réponse possible par ligne.

	Aucune influence	1	2	3	4	5	6	7	8	9	Très grande influence
Le ton de la voix											
Les mots employés											
La gestuelle											
La posture											
Le regard											

Etat émotionnel du robot

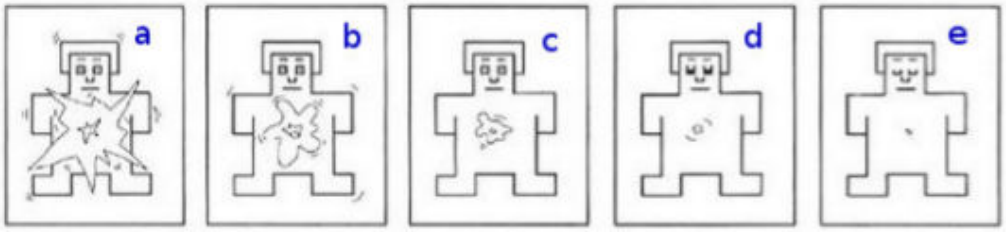


14. **Parmi les images ci-dessus, laquelle caractérise le niveau de plaisir du robot dans la vidéo que vous venez de voir ?** *

De (1) Heureux à (5) Malheureux

Une seule réponse possible par ligne.

	1	2	3	4	5

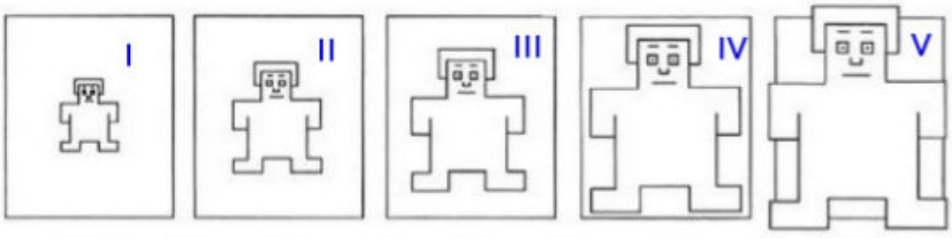


15. **Parmi les images ci-dessus, laquelle caractérise le niveau de dynamisme du robot dans la vidéo que vous venez de voir ?** *

De (a) Dynamique à (e) Sans énergie

Une seule réponse possible par ligne.

	a	b	c	d	e



16. **Parmi les images ci-dessus, laquelle caractérise le niveau de contrôle du robot dans la vidéo que vous venez de voir ?** *

De (I) Pas de maîtrise de la situation à (V) En contrôle de la situation
Une seule réponse possible par ligne.

	I	II	III	IV	V
	◯	◯	◯	◯	◯

17. **Pour chacune des tranches d'âges, pensez vous que les recommandations du robot seront suivies ?** *

Une seule réponse possible par ligne.

	Pas du tout suivies	Plutôt pas suivies	Plutôt suivies	Tout à fait suivies
des enfants de 3 à 7 ans	◯	◯	◯	◯
des enfants de 7 à 11 ans	◯	◯	◯	◯
des adolescents	◯	◯	◯	◯
des adultes	◯	◯	◯	◯

18. **Le caractère directif de ce robot vous parait-il crédible ?** *

Une seule réponse possible.

	1	2	3	4	5	6	7	8	9	10	
Pas du tout crédible	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Tout à fait crédible

Vous et ce robot

19. **Aviez-vous déjà vu ce robot avant cette enquête?** *
Une seule réponse possible.

- ◯ Oui
- ◯ Non

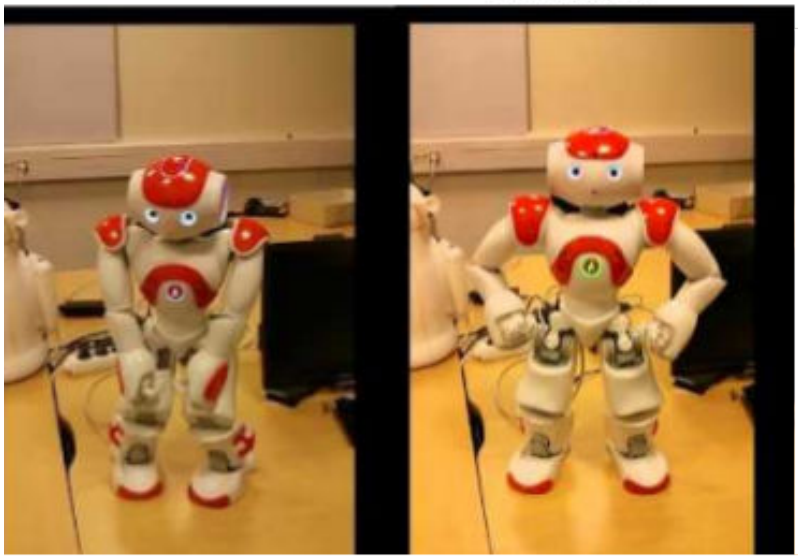
20. **A votre avis, ce robot est ?** *
Plusieurs réponses possibles.

- ☐ Femelle
- ☐ Mâle
- ☐ Asexué

21. **Si vous devriez choisir un de ces 2 compagnons pour votre enfant, lequel choisiriez-vous ?** *
Vous pouvez revoir les vidéos ci-dessous
Une seule réponse possible.

- ◯ Robot 1
- ◯ Robot 2
- ◯ Aucun

Robot 1



Robot 2

Merci pour votre participation à cette enquête.

Appendix E

Experimental Documents for the Interactive Experiment

E.1 Computed Features from the Body Skeleton data

Dimension Name	(Units)	Description	Attitudinal dimension
KinectLeanX	rad	Angle given by Kinect Sensor	Liking, Relaxation
KinectLeanY	rad	Angle given by Kinect Sensor	Liking
CalcBodyLeanAngleQ	Q	Calculated Body Lean Angle	
HandAsym	rad	Angle given by dot product between hands vectors	(Relaxation)
WristAsym	rad	Angle given by dot product between wrist vectors	(Relaxation)
ElbowAsym	rad	Angle given by dot product between elbows vectors	(Relaxation)
FootAsym	rad	Angle given by dot product between feet vectors	(Relaxation)
AnkleAsym	rad	Angle given by dot product between wrist vectors	(Relaxation)
KneeAsym	rad	Angle given by dot product between knees vectors	(Relaxation)
SpineOrientation	Q	Quaternion Angle of spine orientation	
TorsoQ	Q	Quaternion Angle of torso orientation	
NeckQ	Q	Quaternion Angle of neck orientation	
HipTorque	rad	Rotation angle of hips according to feet	
TorsoTorque	rad	Rotation angle of torso according to hip	
ShoulderTorque	rad	Rotation angle of shoulders according to torso	
LeftHandState	—	Status of the Right Hand given by Kinect Sensor	
RightHandState	—	Status of the Right Hand given by Kinect Sensor	
LeftHandTouch	*list*	Joints at less than 10cm of the left hand	
RightHandTouch	*list*	Joints at less than 10cm of the right hand	
AlignedHandsRight	*rad*	Angle given by dot product between hangs vectors	
AlignedHandsLeft	*rad*	Angle given by dot product between wrist vectors	
AlignedLegsRight	*rad*	Angle given by dot product between wrist vectors	
AlignedLegsLeft	*rad*	Angle given by dot product between wrist vectors	
AlignedFeetRight	*rad*	Angle given by dot product between feet	
AlignedFeetLeft	*rad*	Angle given by dot product between feet vectors	
Distance	rad	Angle given by dot product between wrist vectors	
JointDistance	*m*	Angle given by dot product between wrist vectors	
calcvolume	m^3	Body volume	
BoxJointTypes	*list*	Joints forming volume bounding box	

TABLE E.1: Features computed from the Body Joints data

E.2 Questionnaires in French

Entretien Parent

Condition Deux Robots Spécialistes

Je vais maintenant vous poser quelques questions pour savoir ce que vous avez pensé de cette expérience.

Qu'est qu'avez vous pensé :

- de votre enfant avec les robots Chris et Tim?
- des robots Chris et Tim ?

INTERVIEWER : noter les différentes termes utilisés pour le caractériser // repérer si le parent à distinguer de manière spontanée les deux états du robot (permissif et autoritaire) Récupérer les termes utilisés

- Vous avez dit que le robot Chris/Tim était yyyy pourquoi ?
- Qu'est que qui vous fait penser à cela ?

INTERVIEWER : répéter cette question pour chacun des robots et des termes utilisés.

- Quels changements avez vous remarqués entre les robots Chris et Tim?
- A quels moments avez vous repéré ces changements ?

INTERVIEWER : noter les éléments donnés par les parents // repérer si les parents fait la différence sur le style du robot ou sur l'activité proposée.

Si sur le style ?

- Pourquoi avez vous identifié ce "style": *rependre les termes du parent, répéter pour chaque style identifié par le parent ? Si sur l'activité ?*
- Comment avez vous trouvé le fait que le robot Chris lui ai demandé de travailler, mais Tim de jouer ?
- Quels changements de comportements avez vous perçus chez votre enfant?

// impact sur enfant, repérer obéissance, motivations

- Pensez-vous que votre enfant aurait toujours suivis les conseils du robot Chris? Pourquoi?Lequels?
- Pensez-vous que votre enfant aurait toujours suivis les conseils du robot Tim? Pourquoi?Lequels?
- Dans quelles situations vous envisageriez d'utiliser ces robots Chris / Tim? Pour des enfants de quels âges? Pour quelles activités? Pour quels rôles?
- En quoi le robot ou les robots pourraient vous aider? en quelles circonstances ?

Condition Un Robot Polyvalent

"*Je vais maintenant vous poser quelques questions pour savoir ce que vous avez pensé de cette expérience.*"

- Qu'est qu'avez vous pensé :
- de votre enfant avec du robot Peter?

- du robot Peter ?

INTERVIEWER : noter les différentes termes utilisés pur le caractériser // repérer si le parent à distinguer de manière spontanée les deux états du robot (permissif et autoritaire) Récupérer les termes utilisés

- Vous avez dit que le robot Peter était . . . pourquoi ?
- Qu'est que qui vous fait penser à cela ?

INTERVIEWER : répéter cette question pour chacun des robots et des termes utilisés.

- Quels changements avez vous remarqués dans le comportement du robot Peter?
- A quels moments avez vous repéré ces changements ?

INTERVIEWER : noter les éléments donnés par le parent // repérer si le parent fait la différence sur le style du robot ou sur l'activité proposée Si sur le style ?

- Pourquoi avez vous identifié ce "style"? *rependre les termes du parent? repérer pour chaque style identifié par le parent? Si sur l'activité?*
- Comment avez vous trouvé le fait que le robot Peter lui ai demandé de travailler, puis de jouer ?
- Quels changements de comportements avec vous perçus chez votre enfant?

// impact sur enfant, repérer obéissance, motivations

- Pensez-vous que votre enfant aurait toujours suivis les conseils du robot Peter ? Pourquoi ? Lequels ?
- Dans quelles situations vous envisageriez d'utiliser ce robot Peter? Pour des enfants de quels âges? Pour quelles activités? Pour quels rôles?
- En quoi le robot pourrait il vous aider ?

Questionnaire final : Entretien parent

- Si votre enfant avait un secret, est ce qu'il le partagerai avec Tim, Chris ou Peter ou aucun des trois ?

COIRS Questionnaire

- Est-ce que vous pouvez réarranger ces choses dans l'ordre : Vélo, Livre, Vêtements, Robot, Jeu Vidéo ? En commençant par ce que vous aurait plus tendance à offrir à votre enfant.

- Est-ce que vous pensez qu'il est important pour un robot de pouvoir aider votre enfant à faire tes devoirs ou réviser?

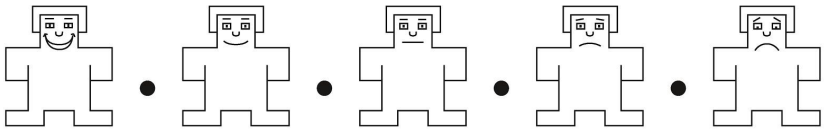
- Est-ce que vous pensez qu'il est important pour un robot de jouer avec toi?

- Est-ce que vous pensez qu'il est important pour un robot de pouvoir être utiliser comme un téléphone pour appeler des gens?

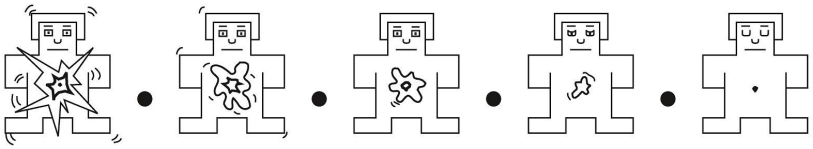
- Est-ce que vous pensez qu'il est important que votre enfant puisse apprendre à son robot de nouvelles choses?
- Est-ce que vous pensez qu'il est important pour un robot de pouvoir chercher de l'information sur internet?
- Est ce que vous préférerez un robot comme Peter ou deux robots comme Chris et Tim pour jouer et travailler avec votre enfant?

Entretien Enfant

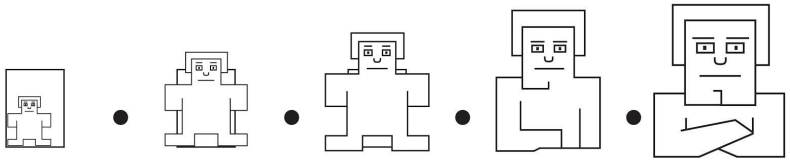
- À ton avis le robot était Heureux ou Malheureux ? De Très Heureux à Très Malheureux



- À ton avis le robot était dynamique ou sans énergie ? De Très Dynamique à Sans énergie du tout



- À ton avis tu maîtrisais la situation ou le robot la maîtrisais? De “Je maîtrisais la situation” à “Le robot maîtrisais la situation”



Choisi pour chaque ligne un adjectif qui qualifie le robot Peter :

Très plaisant	Plutôt aimable	Ni l’un ni l’autre	Plutôt pas aimable	Pas du tout aimable
Très amical	Plutôt amical	Ni l’un ni l’autre	Plutôt pas amical	Pas du tout amical
Très aimable	Plutôt aimable	Ni l’un ni l’autre	Plutôt pas aimable	Pas du tout aimable
Très agréable	Plutôt agréable	Ni l’un ni l’autre	Plutôt pas agréable	Pas du tout agréable
Très gentil	Plutôt gentil	Ni l’un ni l’autre	Plutôt pas gentil	Pas du tout gentil

Très sérieux	Plutôt sérieux	Ni l’un ni l’autre	Plutôt pas sérieux	Pas du tout sérieux
Très idiot	Plutôt idiot	Ni l’un ni l’autre	Plutôt pas idiot	Pas du tout idiot
Très intelligent	Plutôt intelligent	Ni l’un ni l’autre	Plutôt pas intelligent	Pas du tout intelligent
Très généreux	Plutôt généreux	Ni l’un ni l’autre	Plutôt pas généreux	Pas du tout généreux
Très cultivé (connaissance)	Plutôt cultivé	Ni l’un ni l’autre	Plutôt pas cultivé	Pas du tout cultivé
Très compétent	Plutôt compétent	Ni l’un ni l’autre	Plutôt pas compétent	Pas du tout compétent
Très attentif	Plutôt attentif	Ni l’un ni l’autre	Plutôt pas attentif	Pas du tout attentif
Très prévisible	Plutôt prévisible	Ni l’un ni l’autre	Plutôt pas prévisible	Pas du tout prévisible

E.3 Notice d'information

NOTICE D'INFORMATION

Titre du projet : « StyleBot : Interaction Enfant-Robot Compagnon dans la vie quotidienne »

Chercheur(s) titulaire(s) responsable(s) scientifique(s) du projet : Sylvie Pesty
Lieu de recherche : Plateforme Multicom Domus, Saint-Martin d'Hères
But du projet de recherche : Comprendre les critères d'acceptabilité de robots compagnons à destination d'enfants.

Ce que l'on attend de vous (méthodologie)
Si vous et votre enfant acceptez de participer à cette étude, vous participerez à une expérience pendant laquelle votre enfant va interagir avec un robot (2*15 minutes). Le robot est un robot Nao qui mesure 58cm. Le robot lui fera faire un jeu de calcul mental, puis une danse, puis de nouveau un jeu de calcul mental. Nous filmerons les interactions de votre enfant avec le robot et ferons une captation audio. Une camera est sur le robot et deux autres sont placées dans la pièce. Les microphones se trouvent sur le robot et dans la pièce. Durant l'expérience, vous visionnerez l'interaction de votre enfant avec le robot en direct. Nous récolterons vos commentaires ainsi que ceux de votre enfant (environ 10 minutes) à la fin de l'expérience au travers d'un entretien et d'un questionnaire.

Vos droits à la confidentialité
Les données obtenues seront traitées avec la plus entière confidentialité. On voilera votre identité et celle de votre enfant à l'aide d'un numéro identifiant aléatoire. Aucun renseignement ne sera dévoilé qui pourrait révéler votre identité. Toutes les données seront gardées dans un endroit sécurisé et seules les chercheur(e)s concernés par l'étude y auront accès. Conformément à la loi informatique et liberté, vous disposerez d'un droit d'accès, de rectification et d'opposition aux données vous concernant. Sylvie Pesty sera la personne auprès de laquelle vous pourrez exercer votre droit de consultation, de modification ou d'opposition des données vous concernant.

Vos droits de vous retirer de la recherche en tout temps
Votre participation et la participation de votre enfant à cette recherche est volontaire. Vous pouvez vous en retirer ou cesser votre participation en tout temps, et vous pouvez demander que vos données soient détruites, sans conséquence. Votre décision de participer, de refuser de participer, ou de cesser votre participation n'aura aucun effet sur vos relations futures avec le laboratoire LIG.

Bénéfices
Les avantages attendus de cette recherche sont d'obtenir une meilleure compréhension des facteurs qui influencent l'acceptabilité des robots compagnons et la perception de relation sociale. Une meilleure compréhension de ces facteurs pourra entre autre contribuer à améliorer les théories de psychologie et sociologie en terme de relations sociales et le design de robot compagnon acceptable par la société.

Risques possibles
À notre connaissance, cette recherche n'implique aucun risque ou inconfort. Il n'y a pas de contact physique entre le robot et l'enfant. Les jeux ont été soumis à un pré-test avec des enfants d'âge similaire.

Diffusion
Les résultats de cette recherche seront diffusés (non pas les vidéos) dans des colloques et ils seront publiés dans des actes de colloque et des articles de revues académiques.
Vos droits de poser des questions en tout temps
Vous pouvez poser des questions au sujet de la recherche en tout temps en communiquant avec le responsable du projet de recherche par courrier électronique à sylvie.pesty@imag.fr

E.4 Consentement

Titre du projet : « StyleBot : Interaction Enfant-Robot Compagnon dans la vie quotidienne »

Chercheur(s) titulaire(s) responsable(s) scientifique(s) du projet : Sylvie Pesty
Lieu de recherche : Plateforme Multicom Domus, Saint-Martin d'Hères
But du projet de recherche : Comprendre les critères d'acceptabilité de robots compagnons à destination d'enfant.

Ce que l'on attend de vous (méthodologie)
Si vous et votre enfant acceptez de participer à cette étude, vous participerez à une expérience pendant laquelle votre enfant va interagir avec un robot (2*15 minutes). Le robot est un robot Nao qui mesure 58cm (voir photo). Le robot lui fera faire un quiz de math, puis un jeu, puis de nouveau un test de math. Nous filmeront les interactions de votre enfant avec le robot et feront une captation audio. Une caméra est sur le robot et deux autres sont placées dans la pièce. Les microphones se trouvent sur le robot et dans la pièce. Durant l'expérience, vous visionnerez l'interaction de votre enfant avec le robot en direct. Nous récolterons vos commentaires ainsi que ceux de votre enfant (environ 10 minutes) à la fin de l'expérience au travers d'un entretien et d'un questionnaire.

Vos droits à la confidentialité
Les données obtenues seront traitées avec la plus entière confidentialité. On voilera votre identité et celle de votre enfant à l'aide d'un numéro identifiant aléatoire. Aucun renseignement ne sera dévoilé qui pourrait révéler votre identité. Toutes les données seront gardées dans un endroit sécurisé et seules les chercheur(e)s concernés par l'étude y auront accès. Conformément à la loi informatique et liberté, vous disposerez d'un droit d'accès, de rectification et d'opposition aux données vous concernant.
Sylvie Pesty sera la personne auprès de laquelle vous pourrez exercer votre droit de consultation, de modification ou d'opposition des données vous concernant.

Vos droits de vous retirer de la recherche en tout temps
Votre participation et la participation de votre enfant à cette recherche est volontaire. Vous pouvez vous en retirer ou cesser votre participation en tout temps, et vous pouvez demander que vos données soient détruites, sans conséquence. Votre décision de participer, de refuser de participer, ou de cesser votre participation n'aura aucun effet sur vos relations futures avec le laboratoire LIG.

Bénéfices
Les avantages attendus de cette recherche sont d'obtenir une meilleure compréhension des facteurs qui influencent l'acceptabilité des robots de service et la perception de relation sociale. Une meilleure compréhension de ces facteurs pourra entre autre contribuer à améliorer les théories de psychologie et sociologie en terme de relations sociales et le design de robot de service acceptable par la société.

Risques possibles
À notre connaissance, cette recherche n'implique aucun risque ou inconfort autre que ceux de la vie quotidienne. Il n'y a pas de contact physique entre le robot et l'enfant. Les quiz et jeux ont été soumis à un pré-test avec des enfants d'âge similaire.

Diffusion
Les résultats de cette recherche seront diffusés (non pas les vidéos) dans des colloques et ils seront publiés dans des actes de colloque et des articles de revues académiques.
Vos droits de poser des questions en tout temps
Vous pouvez poser des questions au sujet de la recherche en tout temps en communiquant avec le responsable du projet de recherche par courrier électronique à sylvie.pesty@imag.fr

Consentement à la participation
En signant le formulaire de consentement, vous certifiez que vous avez lu et compris les renseignements ci-dessus, qu'on a répondu à vos questions de façon satisfaisante et qu'on vous a avisé que vous étiez libre d'annuler votre consentement ou de vous retirer de cette recherche en tout temps, sans préjudice.
Vous reconnaissez également que votre enfant a été informé de sa participation, de la procédure expérimentale et de sa possibilité de stopper l'expérience à tout moment. Vous reconnaissez que son consentement a été recueilli oralement.
A remplir par le participant :

- J'ai lu et compris les renseignements ci-dessus.
- J'accepte de plein gré de participer à cette recherche.
- J'accepte de plein gré que mon enfant participe à cette recherche.

Nom, Prénom – Signature

Appendix F

Publications

[1] Viet-Cuong Ta, Wafa Johal, Maxime Portaz, Eric Castelli and Dominique Vaufreydaz. The Grenoble system for the Social Touch Challenge at ICMI 2015. *International Conference on Multimodal Interaction (ICMI'15)*, Nov. 2015 (in accepted).

[2] Wafa Johal, Gaëlle Calvary and Sylvie Pesty. Non-verbal Signals in HRI: Interference in Human Perception. *International Conference on Social Robotics (ICSR'15)*, Oct. 2015 (in accepted).

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