Human-Agent Teamwork in Collaborative Virtual Environments

By

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A thesis submitted in fulfilment
of the requirements for the degree of
Doctor of Philosophy

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Faculty of Science and Engineering
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2016

Statement of Candidate

I certify that the work in this thesis entitled "Human-Agent Teamwork in Collaborative Virtual Environments" has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

I also certify that the thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged.

In addition, I certify that all information sources and literature used are indicated in the thesis.

Nader Hanna Abdel-massieh Hanna

7th of January 2016

Dedication

To my parents and my brother

Hanna Abdelmassieh, Souhir Shehata and Tamer Hanna

for dedicating their entire lives to me.

To my wife *Mary Rizk* and my son *Abraam (Biro)*

for filling my life with joy

Acknowledgments

I am truly blessed and honoured to be supported by many wonderful people throughout my PhD journey, and through my entire life. First and foremost, I would like to thank my supervisor, *Professor Deborah Richards*, for accepting me as her student, and for guiding me throughout the PhD study. Working with you was a wonderful experience and I enjoyed every day of it. Your confidence in my abilities was and is something for which I am especially thankful. I thank *A/prof. Michael Hitchens* for his supervision and valuable advice to tune this dissertation. In addition, I am thankful to *Prof. Michael Jacobson* from Sydney University for providing the opportunity to have this PhD scholarship.

I would like to thank John Porte and Meredith Tylor for their contributions in Virtual Reality Lab at Macquarie University. I am grateful to their continuous help in developing the virtual scenarios in this PhD study.

In Macquarie University, I would like to thank Higher Degree Research (HDR) for granting my a Postgraduate Research Fund (PGRF) to cover the expenses to travel to the 13th International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS 2015) in Paris, France. In addition, I thank *Vivienne Burridge*, *Penelope Huisman* for their support.

In Computing Department, I am grateful to *Dr. Peter Busch* for his sincere help and support along my candidature. I thank *Dr. Yan Wang* and *Prof. Mike Johnson* for their helpful advice. I would like to express my deep appreciation to the staff for their administrative help. I would like to thank Melina Chan, Sylvian Chow, Camille Hoffman, Donna Hua, Jackie Walsh and Fiona Yang for their warm support and sincere help. Also, I am thankful to Computing Department for organising Macquarie Computing Doctoral Conference (MCDC). This mini-conference was a good chance to present yearly my research findings.

Back to Menoufia University-Egypt, I would like to thank prof. Mohiy M. Hadhoud who laid the foundation of my interest in research. Also, I would like to thank all my teachers and colleagues there.

Away from the academic life, I would like to thank the people who help me during my PhD journey, I would like to thank *Prof. Scott Dunkley, Dr. Hany Ebid, Amy Ko, Dr. Medhat Melik, Dr. Magy Nada, Delphine Schwartzmann and Prof. Amany Zekry.*

I am grateful to the Coptic community in Sydney who supported me during my PhD study; I would like to give special thanks to *Abouna Bishoy, Abouna Matthew, Mr. Sameh Shawky* and *Mr. Trivo*. I want to thank those whose friendship and support helped me to have a social life away from my family, I mean *Eng. Adeeb Mikhail,* his wife *Jacko* and his family. I want to thank *Janet* who made me feel the care of a mom.

Most important of all, I would like to thank my family. My father, *Hanna Abdel-massieh*, who has been dedicating his life just for my brother and myself. My mother, *Souhir Shehata*, for being a symbol of a wise and a compassionate mom. My brother, *Tamer Hanna*, who has been always my 'Big brother'.

Last but not least, I would like to thank my soulmate, my precious pearl and my wife, *Mary Rizk 'Marmar'*, who is kind to accept me as I am, not complaining from being busy all the time and overwhelmed me with care and love. If I were a laptop, *Marmar* would be the charger. I would not do anything without you. Finally, I would like to thank my son, *Abraam 'Biro'* for filling my life with joy and happiness.

Abstract

There is a growing interest in the use of heterogeneous teams comprised of humans and Intelligent Virtual Agents (IVAs). Human teamwork studies have provided cumulative knowledge about team features and performance. How well this knowledge transfers to human-IVA teams requires further investigation. The development of a Shared Mental Model (SMM) between team members and effective communication of the shared knowledge have been found to improve human teamwork performance. In human-IVA heterogeneous teams, the communication required to develop a SMM is further complicated as each party belongs to different worlds (i.e. real and virtual). Communication is a vital factor in the collaboration between team members. Creating IVAs that are able to communicate with humans in Virtual Environments (VEs) is a challenging research area. When both the IVA and the human user should communicate together while performing a collaborative activity, communication becomes more critical and the challenge becomes more difficult. Moreover, humans may differ in how they produce and perceive communication acts according to their personality traits. The main aim of my PhD is to study the factors that tend to improve team performance and foster collaboration between humans and IVAs in VEs.

To understand the requirements of human-IVA collaboration in VEs, we present the design of a framework based on Activity Theory called Multi-Agent Collaborative VirtuaL Learning Environment (MACVILLE), which is a framework to understand the nature of collaboration in human teams. The MACVILLE framework indicated the importance of communication for collaboration in the VE. In addition, the proposed framework demonstrates the need to extend the design of an IVA to include collaborative and social abilities. To address this essential extension we propose an agent architecture that handles two-way human-agent collaboration. To support human-IVA communication in VEs, we present Human-Agent Teamwork Communication Model (HAT-CoM). HAT-CoM was designed based on Speech Act Theory (SAT), which is a methodology to understand the structure of human speech. HAT-CoM was implemented and integrated into our agent architecture.

To evaluate the impact of HAT-CoM on developing/breaking a SMM between a human and an agent, a study was conducted with 66 undergraduate students. The evaluation was conducted by analytical and inductive means. The analytical evaluation aims at investigating the impact of HAT-CoM components, i.e. verbal and non-verbal, on the development of SMM features, i.e. knowledge about the task and the team. The inductive evaluation aims at verifying the development of a SMM via HAT-CoM through tracking the changes in the designated outcomes of the SMM. The outcomes of the SMM are anticipating a teammate's decisions, reduced explicit communication, match in cognitive perspective, competence in decision-making (ease of flow of decisions) and involvement in the shared task. Another aim of the study was to investigate the impact of an implausible or unreasonable request on the SMM. The results show that HAT-CoM is effective in assisting the human and agent teammates to develop a SMM. In addition, the results show that an implausible request breaks the developed SMM.

A second study was carried out to investigate the impact of the IVA's multimodal communication on the development of a SMM between humans and IVAs. Moreover, this study aimed to explore the impact of the developed SMM on the human's trust in the IVA's decisions and the human's commitment to honour his promises to an IVA. The result showed that there is a significant positive correlation between the developed SMM and the human's trust in the IVA's decision and the human's commitment to honour his/her promises (the establishment of the social aspect of teamwork). Additionally, the results showed a collective effect of all of these aspects on human-agent team performance.

The two conducted studies showed that IVA multimodal communication plays a crucial role in the development of a SMM between humans and IVA; nevertheless, humans may differ in how they produce and perceive communication acts according to their personality traits. To investigate how different IVA personalities affect multimodal communication and development of a SMM, a third study was carried out. In this study, we seek to understand how people trust an IVA teammate. The study considers two facets of trust: personality and cognition. Results indicated that cognitive-based facets played a more dominant role in establishing trust than personality-based facets. Additionally, the results showed that human trust in the IVA had a significantly positive influence on human-IVA team performance.

The results of the three conducted studies stressed the importance of IVA multimodal communication on the development of trust and commitment in human-IVA teamwork. Trust and commitment were found to contribute positively to the development of a SMM and hence team performance. Additionally, personality traits were found to influence human perception of IVA multimodal communication.

Publications

Results of the research work leading to this PhD thesis have been published in various conferences and book chapters. Presentations have been given at national and international conferences:

1. Nader Hanna and Deborah Richards (2016): "*Do Birds of a Feather Work Better Together? The Impact of a Match in Personality between Humans and Virtual Agents on a Shared Mental Model during Collaboration*". (Accepted on the 7th of January 2016 to be published at the International Journal of Computational Intelligent Studies (IJCIS)).
2. Nader Hanna and Deborah Richards (2015): "*The Influence of Users' Personality on the Perception of Intelligent Virtual Agents' Personality and the Trust within a Collaborative Context*". Advances in Social Computing and Multi-agent Systems, F. Koch et al. (Eds.) CARE-MFSC 2015, CCIS 541, pp. 1–17.
3. Nader Hanna and Deborah Richards (2015): "*Towards a 'Smart' Collaborative Virtual Environment and Multi-Agent Approach to Designing an Intelligent Virtual Agent*", Environments for Multi-Agent Systems IV, Weyns, Danny, Fabien, Michel (Eds.) E4MAS 2014 – 10 years later, LNAI 9068, pp. 1–17.
4. Nader Hanna and Deborah Richards (2015): "*The Impact of Virtual Agent Personality on a Shared Mental Model with Humans during Collaboration (Extended Abstract)*", the 14th International Conference on Autonomous Agents and Multi-agent Systems (AAMAS '15), pp. 1777-1778, Istanbul, Turkey.
5. Deborah Richards, Cedric Roxas, Ayse Aysin Bilgin, Nader Hanna: "*A Dancing Virtual Agent to Evoke Human Emotion (Extended Abstract)*", the 14th International Conference on Autonomous Agents and Multi-agent Systems (AAMAS'15), pp. 1701-1702, Istanbul, Turkey.

6. Nader Hanna and Deborah Richards (2015): "*The Influence of Users' Personality on the Perception of Intelligent Virtual Agents' Personality within a Collaborative Context*", the 6th International Workshop on Collaborative Agents Research & Development (CARE2015) In conjunction with the 14th International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS '15), Istanbul, Turkey. 4th-8th May 2015.

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Pacific Asia Conference on Information Systems: Ubiquitous IT and Collaborative Innovation (PACIS'14), Chengdu, China, 24-28 June 2014.

12. Nader Hanna and Deborah Richards (2014): "*The Impact of Human-Agent Communication in a Collaborative Environment on Shared Mental Model and Team Performance*". In Proceedings of the 2nd International Workshop on Collaborative Online Organizations (COOS'14) in conjunction with the 13th International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS'14), Paris, France. 5th-9th May 2014.

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Glossary of Terms

Abbreviation		Term
VE	…	Virtual Environment
VW	…	Virtual World
RQ	…	Research Question
EQ	…	Evaluation Question
1PP	…	First Person Perspective
3PP	…	Third Person Perspective
AT	…	Activity Theory
FFM	…	Five-Factor Model
SMM	…	Shared Mental Model
IVA	…	Intelligent Virtual Agent
ACL	…	Agent Communication Language
SAT	…	Speech Act Theory
CVE	…	Collaborative Virtual Environment
SAL	…	Sensitive Artificial Listener
BDI	…	Believe-Desire-Intention
MBTI	…	Myers Briggs Type Indicator
HMM	…	Hidden Markov Model
ACL	…	Agent Communication Language
GDL	…	Game Description Language
BFI	…	Big Five Inventory
IPI	…	Ten-Item Personality Inventory

CHAPTER 1

Introduction

Collaboration between humans and autonomous software agents (hereafter referred to as "agents") offers potential in a wide range of fields. For instance, for educational purposes, collaborative agents may have properties and behaviours appropriate to a range of roles to support the learner. These roles include agents acting as a simulated student (Virvou and Manos, 2003, Vizcaíno, 2004), computational learner (Dillenbourg and Self, 1992), learning companion (Kim and Baylor, 2006) and teachable agent (Blair et al., 2007). For medical purposes, there is growing interest in using agent-based applications to solve problems in medical domains (Nealon and Moreno, 2003). The collaboration between an agent and a human in a medical context could be to coordinate problem solving (Wei et al., 2009), provide the human with medical knowledge (Bickmore et al., 2010) or provide social support (ZWAAN et al., 2012).

Agents in a collaborative environment may have to play multiple roles. Zhang and Li (Zhang and Li, 2009) mention a number of general aims to be achieved by an agent in a collaborative environment including facilitating the teamwork between humans. In some human-agent teams, agents will be allocated tasks that are dangerous or difficult for humans (Williams-Bell et al., 2015), training military personnel to cope with stress (Bouchard et al., 2011), in the battlefield (Herrero and Antonio, 2005), safety analysis (Stüring and Trasi, 2004) and risk prevention (Camus et al., 2012).

A less explored type of human-agent team involves having human and agent teammates working together to performing a certain task. This combination imposes additional intelligent behaviours such as monitoring human and agent performance and checking if individual and overall goals are achieved. This is the sort of human-agent collaboration considered in this thesis.

1

1.1 Motivation

It is obvious that a significant ratio of human daily activity includes people collaborating. Examples of collaboration include playing in a sport team, working on a school assignment, working in a business team, working in a team to provide medical or an administrative services, even the atoms of any society, i.e. family, is built on the collaboration between family members. Humans cannot live without providing/receiving services from others. Nowadays, we live in the era of technology. Every day we depend on technology in most aspects of our lives. Computers, smart phones and tablets, all their variations, have come into the hands of many.

The revolution in advances in computing hardware has seen a parallel revolution in the software field. Social media and communication applications provide just one of innumerable examples. A software agent is one outstanding example of innovative software. An agent as an autonomous reasoning entity designed with many cognitive and personal/affective skills has drawn increasing interest. In the collaborative context, an agent should be able to collaborate with people in a mature and reasonable way to achieve a shared goal. Agent-based technology opens a new horizon to create an agent that is able to collaborate with people when it is more feasible and safer to have an agent as a collaborator. A number of aims to be achieved by an agent in a collaborative environment including facilitating the team work between humans (Zhang and Li, 2009). In human teams, Cohen et al. (Cohen et al., 1997) stressed the importance of having shared knowledge and understanding between team members or what is called Shared Mental Model (SMM). Similarly, when it comes to a heterogeneous team that combines a human and an agent, Sycara and Sukthankar (Sycara and Sukthankar, 2006) stated that the biggest challenge in human-agent team work is to establish a shared understanding.

Previous research has studied the collaboration that may exist between humans and agents (Gerbaud et al., 2007). With the increasing interest in creating agents that can collaborate with humans (i.e., (Zhao et al., 2014) (Schmeil and Eppler, 2010)), agents are more and more seen as partners for humans rather than tools (Dignum et al., 2014).

1.2 Research Objectives

The main aim of this research is to investigate the factors that are likely to influence the collaboration between humans and embodied agents in virtual environments when they work together in a team towards achieving a shared goal. An embodied agent that resides in a virtual environment is known as an Intelligent Virtual Agent (hereafter referred to as "IVA"). Identifying these influential factors will give us a clear insight into how these heterogeneous teams work. As an initial goal of this research, we wanted to explore if these factors would be merely cognitive aspects that are internal to the IVAs and can be managed by the agent's reasoning processes or whether social aspects are of prime importance requiring more focus on the social context.

The initial findings of our research work suggested an interdependency between the cognitive aspects such as decision-making and SMMs and the personal/social aspects such as trust and communication were found to influence the collaboration activity. Hence, the main objective of this research was further refined to focus on how to tune an existing IVA architecture or to create a new architecture that fulfils this incorporation of both aspects. Creating IVA architecture is not the research objective in itself. Rather the objective is to include these aspects in an IVA and study the influence of the cognitive-social combination on the output of the collaboration. With the findings of this research, we wish to bridge the current research gap where studies on human-IVA collaboration tend to focus on either one of these aspects, but not both.

1.3 Research Challenges

Due to the potential benefits of human-IVA teams, researchers have investigated various aspects of human-agent teamwork. For example, the work by Dignum et al (Dignum et al., 2014) focused on specific aspects of the collaboration, namely cognitive aspects and how they can tune the output of the teamwork. Other work focuses on the social aspects and how they can empower the individual to achieve their target (Chen and Chiu, 2007). What is needed is an integrated approach that considers both cognitive and social aspects.

A challenge in building Human-IVA teams is the lack of supporting technology. (Dignum et al., 2014) reported that agent technology is not geared towards implementing truly realistic social and collaborative behaviour. While there are a number of proposed agent architectures (e.g. (Anderson et al., 2004) (Langley and Choi, 2006) (Gratch, 2000) (Yen et al., 2006)), these architectures either seek to be general to allow usage in different situations (e.g. (Brito et al., 2000) (Laird et al., 1987)) or are specific to a cognitive aspect of the agent ((Yen et al., 2006) (Yorke-Smith et al., 2009)). General IVA architectures focus on creating a general-purpose decision making agent rather than an agent for a particular situation; while other architectures designed to support a task-based agent tend to focus on one skill or characteristic, such as emotional, social, and/or administrative behaviour, to be included in the architecture without providing an integrated view of the agent. An integrated or holistic view is necessary in order to handle collaborative situations with a human.

Another challenge raised by Human-IVA collaboration is handling communication between the two parties. Communication has been found to be the main tool of interaction in collaborative activity (Smith-Jentsch et al., 1998). While a standard agent communication language (ACL) has been specified, a sufficiently rich human-agent language is lacking. To handle communication, many of agent architectures either include a communication module inside the architecture or include two separate modules, one to act to as sensor and the other one as an effector.

Multimodal communication has been found to influence the collaborative activity and the output of teams (Smith-Jentsch et al., 1998). IVA researchers often focus on either verbal or non-verbal communication, though increasingly architectures are seeking to include both. However, consideration of the role that personality plays in multimodal communication has been underexplored. Humans are likely to produce and perceive communication acts in a different way as a matter of our personality. Additionally, humans tend to perceive the verbal and non-verbal communication acts differently according to our own personality traits. Therefore, it is necessary when we study the possible collaboration between humans and IVAs to consider the effect of their personalities on the interaction. A number of IVA's architectures (e.g. (Lim et al., 2012) (Saberi et al., 2014)) paid attention to the importance of creating an IVA with a personality like humans. The aim of these architectures was to create a believable IVA. To the best of our knowledge, none of these architectures included personality as a factor that may improve the collaboration with humans.

Research has been done on the topic of human-IVA teamwork; however, most research concerns interactions between agents (Prada and Paiva, 2005) or interaction between humans and IVAs but not with a goal-driven interaction.

1.4 Research Question

Based on the research objectives in Section 1.2 and the challenges in prior research identified in section 1.3, we propose the following research questions to understand the nature of human-IVA teams and identify the factors that are likely to improve the performance of these teams.

> ***Research Question 1:*** *What are the factors that influence human-IVA collaboration?*

To answer the main research question, we used Activity Theory (AT) as a framework to understand the nature of the interactions in a collaborative context. AT was selected, as it is a framework that studies the collaboration as a matter of individual as well as group acts. Because of using AT, the importance of collaborative tools or artefacts as a means of exchanging knowledge between team members was identified. According to the literature on collaboration, this tool is the IVAs' multimodal communication to express their beliefs, desires and intentions. Nevertheless, humans may differ in how they produce and perceive communication acts according to their personality traits.

Personality is communicated verbally as our personality is likely to influence how we speak (Scherer, 1979). Speaking style can reveal certain personality traits; some traits are easier to detect than others (Scherer, 1978). A number of studies have used verbal capabilities to represent different IVA personalities (Krishnan et al., 2012). Hence, studying the influence of multimodal communication itself without exploring the impact of IVA's and humans' personalities on the production and the perception of the communication would not give the complete picture. Therefore, the main research question was split into the following sub-questions:

> ***Research Question 1.1:*** *What is the influence of IVA's multimodal communication on the collaboration with the humans?*

> ***Research Question 1.2:*** *"What is the influence of the IVA's personality and the match/mismatch in personality with the humans on the collaboration?"*

Research Question 1.1 inquiries about the role of an IVA's multimodal communication in the collaboration with humans. However, we firstly need to evaluate the human's perception of the IVA's communication. In Chapter 6, Research Question 1.1 will be further elaborated to sub-questions in order to understand the effect of IVA's multimodal communication on human-IVA team dynamics.

Research Question 1.2 aims to investigate the effect of the IVA's personality as well as the match/mismatch with humans' personality on the human-IVA collaboration. Firstly, the research question will investigate the influence of each factor (i.e. IVA personality, human-IVA personality (mis)match) individually and then investigate their combined influence to explore which factor has a stronger effect. In Chapter 7, this question will be broken into sub-questions to study the content of IVA's communication (the cognitive-based interaction) versus how this content is presented (personality-based interaction) on the collaboration with a human.

1.5 Research Scope

In this section, we will delineate the scope of this research. The scope describes the notion of an IVA, nature of the Human-IVA collaborative scenario, extent of their multimodal communication and the personality-traits chosen for inclusion in the collaborative context.

1.5.1 The notion of IVA

The notion of an IVA has been widely used in research. IVA is a term used to define an autonomous entity in a virtual environment (Herrero and de Antonio, 2004). This entity should not only look like, but also behave as a living organism (e.g., human, animal, imaginary creature) (Vosinakis and Panayiotopoulos, 2001). Some, if not most, IVAs are created as virtual humans and designed to mimic the behaviour of real humans. Several studies aimed to create believable IVAs and include sophisticated characteristics similar to humans such as remembering/forgetting (Bransky and Richards, 2011), mood (Burkitt and Romano, 2008), personality (Sandercock et al., 2006), planning capabilities (Vosinakis and Panayiotopoulos, 2001), awareness (Ranathunga and Cranefield, 2013), human-like senses (Herrero and de Antonio, 2004). In this thesis, we will concentrate on the collaborative and social aspects of IVAs. We aimed to create an IVA that mimics the behaviour of the humans while collaborating as a part of a team to carry out a shared task.

1.5.2 The Nature of Collaborative Scenario

A number of studies have been interested in exploring collaboration between humans and IVAs (Sycara and Sukthankar, 2006) (Barange et al., 2014); nevertheless, the nature of this collaboration can vary. Collaboration could be viewed simply as Human-IVA interaction that is social or task-oriented, or a combination. In our use of the term collaboration, we focus on interaction towards achieving a task. The collaborative situation between the humans and the IVAs may include different tasks and roles for the IVA. This role could be a helper to the human while he/she does the task. Some scenarios may not involve tasks but be socially focused. Another role for an agent is as a responsive partner that executes humans' requests. Another possible role for the agent while collaborating with humans is as an independent partner without real-time synchronization. In the case of an independent partner, the agent can follow his own plan and at the end, his achievement is combined with what the human did. Alternatively, scenarios may require the human and the IVA to coordinate their efforts in real-time toward achieving a shared task. In this thesis, we study scenarios that are task-based and involve a joint task that necessitates real-time coordination between the humans and the IVAs.

1.5.3 Multimodal communication

An autonomous agent needs to be able to coordinate dynamically its behaviour according to the changing environment. Furthermore, the associated communication behaviour of the agent has to be dynamic to respond to the unexpected changes and these behaviours need to exhibit a level of believability that does not interrupt flow or impede communication. Several studies focused on creating an IVA with one or more aspects of multimodal communication (Oijen and Dignum, 2012). Multimodal communication includes verbal and non-verbal clues (Massaro, 1998). Non-verbal clues include the meanings that could be expressed using body language. Non-verbal cues include head-related animations such as eye gaze, smile, head pose or body-related animations such as hand gesture, body pose and distance with interlocutor.

The variety in verbal cues in humans-agent interactions is much less. While the verbal cues of the agent tends to be organized from a pool of messages, the studies on human-side of the interaction range between either selecting an appropriate message from a pool to do a sort of natural language processing on the humans' uttered speech. Although the later method of processing humans' verbal speech seems more believable in the interaction with agents, it tends to negatively effect on the success of the interaction if the agent fails to understand the human's speech. Additionally, agents that can understand human speech is its own branch of study and it is not the scope of ours. In this study, the verbal communication between the humans and the IVAs is via selecting the messages from a message pool. While the human is free to select the message that is suitable to the situation, the agent architecture is responsible for reasoning to identify a suitable message and the combined communication model is responsible to select and coordinate with the non-verbal cue.

In cases where the IVA has a full-body, resulting in a small face, and needs to move around a VE to achieve its own tasks, probably its face will not be visible to the humans all the time, and thus IVA facial expressions will be hard to detect and interpret. Given this limitation, we believe face-related animations are less useful in such situations where IVAs need to move around and do not stand facing the humans. The two scenarios designed in this study required the IVA to move around the VE. In this study, the implemented non-verbal cues are head pose, hand gesture and body distance to the human' view. While the verbal cues are exchanging messages from a message pool.

1.5.4 Human View

In 3D VEs, user's experience relies to a great extent on the user's point of view or perspective of the VE (Kallinen et al., 2007). Among different users' point of view, there are two main perspective in 3D games, namely a First Person Perspective (1PP) or a Third Person Perspective (3PP). It was found that the perspective of VE users influences their emotional experience (Riva et al., 2007). Moreover, perspective may also impact on the perception of objects (Hayes et al., 2006).

In the 1PP, the human cannot see a body for himself in the VE; instead, he/she sees the VE through the eyes of his avatar. The 1PP is commonly found in VE applications that require the humans to focus on a task or a target without paying too much attention to the surroundings objects. The 3PP is similar to the view of a puppeteer. The users see the VE objects including their own avatar from the top. The 3PP provides the users with a much wider field of vision than the 1PP. The 3PP lets them be aware of the situation surrounding their avatar. In this study, to avoid humans' confusion with too much information from 3PP and to focus the attention to the collaborative task with does not need a wide field of view; we implemented the two collaborative scenarios with 1PP.

1.5.5 Collaboration-Related Personality Traits

Personality is a personal aspect that makes it possible to distinguish between different people (Kasap and Magnenat-Thalmann, 2008). Because our personality affects our internal perception and actual behaviour (von der Pütten et al., 2010), personality has been included in multiple aspects of IVAs including their expressive aspect, i.e. non-verbal communication and verbal communication , and their internal aspect, such as planning (Doce et al., 2010). However, personality has multiple factors. Studying all of these factors would make the experimental design very complex, so the research focusses on those personality traits that have been found to be most relevant for collaboration.

Studies that have explored personality traits and teamwork stress the role of both extroversion and agreeableness to foster inter-relationships between team members. Extraversion and agreeableness were selected in our study because they have been shown to be predominant traits in collaboration and teamwork (Bosch et al., 2012). The extraversion trait influences interpersonal relationships through the quality of social settings (Barry and Stewart, 1997) (McCrae and John, 1992). Extraverts are usually active members in teams and often popular among their mates (Mann, 1959). In this thesis, the agent was created with the personality traits that were found to impact teamwork. These personality traits are extraversion and agreeableness.

1.6 Research Steps

In order to answer the research questions, the following steps were followed:

1. **Review related research**: Research was surveyed and discussed to give an insight into the current research and identify the gap/s in the research on human-IVA teamwork (presented in Chapter 3).

2. **Propose a conceptual framework:** After reviewing the literature, a conceptual framework based on AT was proposed, namely MACVILLE. This framework used an analogous human-human framework in the physical world (i.e. AT) but modified it to match the nature of the collaboration between humans and IVAs (presented in Section 4.2).

3. **Propose an IVA's architecture:** Based on the literature review conducted in step 1 and the MACVILLE framework developed in step 2, an IVA architecture was proposed to fill the gap in existing agent architectures. This new collaboration focused architecture takes into consideration the importance of multimodal communication, a SMM between agents and humans and the personality of each teammate (subject) (presented in Section 4.3).

4. **Propose an IVA's communication model:** Because multimodal communication was found to critically influence the collaborative behaviour in teams, a specific Human- AgenT Communication Model (HAT-CoM) that manages verbal and non-verbal clues of agents was developed (presented in 4.4.1).

5. **Evaluate the plausibility of the agent architecture and the communication model:** Before answering the research question, the plausibility of the proposed architecture and communication model were tested through the implementation of two virtual scenarios (presented in Chapter 5).

6. **Evaluate the IVA's multimodal communication and development of a SMM with humans:** To answer the research questions (Research Question 1.1); an experiment was conducted to investigate the impact of IVA's multimodal communication of the development of a SMM with humans (presented in Chapter 6).

7. **Evaluate the IVA's personality and development of a SMM with humans:** to answer the research questions (Research Question 1.2); an experiment was conducted to investigate the impact of IVA's personality on the development of a SMM with humans (presented in Chapter 7).

1.7 Contributions

In answering the research questions, a number of contributions have been made. In summary, the main contributions are:

1. Presented a framework for a huMan-Agent Collaborative in VIrtuaL Learning Environments (MACVILLE) built on Activity Theory. Activity Theory has been used to understand the requirements of collaboration in human teamwork and confined to collaboration in the physical world. MACVILLE extends the requirements in physical world collaboration to physical and virtual world collaboration between humans and virtual agents.

2. Proposed a novel agent architecture that combines a social and a collaborative core in addition to the reasoning core. The social and collaborative core enables the collaborative agent to be aware of the human's activities while achieving a goal, and to give appropriate feedback such as encouraging the user when collaboration is occurring or urging the user to collaborate when insufficient collaborative activity is taking place. A number of agent architectures have been proposed (e.g., (Maldonado and Hayes-Roth, 2004), (Prada and Paiva, 2005), (Rehm et al., 2007), (Mascarenhas et al., 2011), (Dias and Paiva, 2005)). Either these architectures focused on the reasoning role of the agent without paying attention to the social and collaborative aspects of the agent's behaviour, or the collaboration is directed by goals without a consideration of the performance of individual peers in the team (one-way human-agent collaboration).

3. Proposed a human-agent communication model in a collaborative virtual environment (HAT-CoM). This communication model goes beyond the common belief, desires, intention (BDI)-agent or the use of middleware to facilitate agent communication (Oijen and Dignum, 2012). Closest to this work, (Traum et al., 2003) sketched a spoken negotiation model for a peacemaker scenario to handle communication involving tasks in hybrid human-agents teams designed for training purposes.

4. Used Speech Act Theory (SAT) as a designing tool to the flow of messaging between human and agent. Speech Act Theory is known as a theory to understand how the humans convey their intention via verbal messaging.

5. Studied the impact of the agent architecture and HAT-CoM components, i.e. the verbal and non-verbal communication, on the development of a shared understanding and a grounding knowledge, i.e. Shared Mental Model (SMM), between the human and the agent. This impact was represented in the team members' knowledge about the teammate and their knowledge about the shared task.
6. Verified the development of the SMM between the human and the agent as represented in the outcomes of the SMM, namely anticipating a teammate's decisions, reduced explicit communication, match in cognitive perspective and competence in decision-making (easiness in flow of decisions). SMM outcomes were studied in human teamwork and never verified in human-agent teamwork.
7. Studied the impact of implausible requests between the humans and the agent teammates on the development of a SMM as represented in the outcomes of the SMM (described in the previous point). Implausible requests are those that humans will consider as unachievable or unreasonable such as requesting the human to select something which has been already selected (will be discussed in 5.5.1). The few studies that investigated the factors that foster the development of a SMM between humans and IVAs never explored the opposite situation of breaking the developed SMM.
8. Exposed whether the development of the taskwork and the teamwork SMMs influence human-IVA team performance? Moreover, discovered which SMM aspect has a greater effect.
9. Revealed the influence of taskwork and teamwork SMMs between humans and IVAs on human trust in the IVA's decision. Additionally, studied which of taskwork or teamwork SMM contributes more toward human's trust.
10. Explored whether human trust in the IVA's decision impacts on human commitment to honour their promises towards achieving the shared task.
11. Investigated whether human commitment to honour their promises impacts on the human-IVA team performance.

12. Revealed whether the IVA's personality influence human trust in the IVA's decision. Moreover, explore if the match in personality between the human and IVA influence human trust in the IVA.
13. Investigated either personality and/or cognitive behaviour of the IVA contribute more towards human trust.

1.8 Dissertation Outline

Below the outline of this thesis is described. In addition, the relation between separate chapters, research objectives and published articles is explained:

Chapter 2: Background. This chapter provides a background to the main terms used in the dissertation.

Chapter 3: Related Work. This chapter presents the previous work related to this research. This study intersects with different branch of research including agent studies, agent communication study and human-IVA interaction. It was not easy to find previous studies that investigate the intersection of these variables. Firstly, this chapter report the important research work in each branch. Then, the most related work that intersects these variables will be presented.

Chapter 4: The approach…Agent Architecture. This chapter presents the proposed framework and models that are required to conducted the study. Firstly, the chapter presents the proposed framework based on Activity Theory used to understand the factors that control the collaborative activity. Secondly, based on the potential factors discovered in AT-based framework, an agent architecture is proposed. Finally, a human-IVA communication model is presented.

Chapter 5: Evaluating IVA's multimodal communication. This chapter presents an evaluation of the proposed agent architecture and communication model. Speech Act Theory (SAT) is used as a tool to evaluate the agent's verbal communication. Through two experiments, this chapter couples the data from participants' survey and logging their behaviour during the collaborative context. These experiments were conducted to gather participants' perception of the IVA's multimodal communication. This chapter aims to investigate the plausibility of the communication between the humans and the IVAs to be used later to investigate the influence on other research variables.

Chapter 6: IVA’s multimodal Communication and Human-IVA Collaboration. Built upon the results of Chapter 5, this chapter investigates the impact of IVA’ multimodal communication on the human-IVA collaboration. This chapter goes beyond finding the direct relationship between the two study variables and explores a set of some minor variables. These variables show the cause and effect between communication and the performance of collaboration. The Research Question addressed is RQ 1.1.

Chapter 7: IVA’s Personality and Human-IVA Collaboration. This chapter covers the second aspect of team members’ collaboration that is personality traits. It presents the results of investigating the impact of IVA’s personality on human-IVA collaboration. This chapter followed the sequence of relationships that was explored in the previous chapter but including IVA’s personality. The research question addressed is RQ 1.2.

Chapter 8: Discussion. Chapters 5 to 7 include a discussion of the results of each experiment in line with the sub-questions investigated. In this chapter, we discuss the main findings in the 3 experiments in line with the RQ 1 and sub questions RQ 1.1 and RQ 1.2.

Chapter 9: Conclusion. In this chapter, we summarize our research contributions, limitations and discuss future research directions.

CHAPTER 2

Background

This chapter provides an overview of the concepts and terms related to the thesis. Section 2.1 presents an overview of Virtual Environments (VEs) and the main applications of VEs. An overview of collaborative virtual environment (Section 2.2), IVAs (Section 2.3) and IVAs in a collaborative context (Section 2.4) are presented. Multimodal communication which is a main study variable is presented in Section 2.5. Background about the factors that could foster the collaboration with IVAs is presented in Section 2.6.

2.1 Virtual Environments

In this section, definition, categories and applications of VEs are to be proposed.

2.1.1 Definition of VEs

There is a debate over using the terms 'virtual reality' or 'virtual environment' (Champion, 2011). A number of studies have examined virtual worlds, and many of them have presented their own definition of the term (Bryson, 1995). These definitions focus on different aspects of VEs. 3D VEs are not just a medium of communication, but also the simulated "world" where we shop, socialize, are entertained and get educated (Kalay and Marx, 2001). VR definitions could be classified according to two different viewpoints of VR: VR as a simulation tool and VR as an interaction tool (Claudio and Maddalena, 2014). To lay the foundation of proposing a definition, (Chesebro, 1985) argued that a definition should include the outstanding and structural ingredients of a situation. The definitions that describe VEs could be classified into two dimensions: the first dimension includes definitions that stress the technical aspects, while the other dimension demonstrates the psychological aspects of VEs.

2.1.1.1 Technological Dimension

Researchers are inclined to define VE from the viewpoint of which technological tools are being used. Most popular definitions of VE refer to one or more technological aspects of VEs (Heim, 1998).

"Three-dimensional realities implemented with stereo viewing goggles and reality gloves" (p. xiii) (Krueger, 1991). "A computer-generated simulation of the real or imagined environment or world." (Gaddis, 1998)

2

Another VE definition was:

"Electronic simulations of environments experienced via head mounted eye goggles and wired clothing enabling the end user to interact in realistic three-dimensional situations." (Coaets, 1992)

(Greenbaum, 1992) presented a more detailed definition:

*"An alternate world filled with computer-generated images that respond to human movements. These simulated environments are usually visited with the aid of an expensive data suit which features stereophonic video goggles and fibre-optic data gloves" (*P.60)

The technological perspective definitions consider the input and output tools as the factors that differentiate between different VEs.

2.1.1.2 Psychological Dimension

While the first perspective of VEs focused on the technological aspect, virtual realities embody much more than just the technology that enables us to enter virtual worlds that are separate from our everyday lives. Other researchers defined VR from a psychological perspective as a state produced in the users' minds that can reside in their awareness like that of physical environments (Riva, 1999).

(Schuurink and Toet, 2010) defined VWs as *"networked, computer-simulated 3D VEs resembling the real world, with real-world rules, such as distance, gravity, and the ability to explore the world."* (p.725). this view of VEs stressed the fact that VEs are meant to imitate the physical world and give a user a natural experience while navigating exterior landscape or inside buildings. Moreover, the definition aimed to give users the experience of picking objects with different properties and dropping these objects. While (Schuurink and Toet, 2010) stressed the experience of users with the objects and the places in VEs, another definition considered the representation of a user and interaction with other users *"A 3D computer environment in which users are represented on screen as themselves or as made-up characters and interact in real time with other users."* (PCMagazine, 2015). Psychological perspectives of VEs share a common perspective including shared space, real time interactivity, immediacy, applying physics rules, and the use of graphical user interfaces (Shore and Zhou, 2009).

2.1.2 Categories of VEs

(Cronin, 1997) divides VEs according to the following principles of immersion: non-immersive, semi-immersive and fully immersive. (Kalawsky, 1996) categorises the various VR implementations:

1. **Non-immersive (desktop)**

   VE that is the most common and the least expensive form of VR. Non-immersive VE are usually presented on a standard desktop computer. This method is the easiest to use for research that needs a large number of users.

2. **Semi-immersive (projected)**

   In this category, the sense of immersion is given by projecting the images. A Semi-immersive system consists of high performance graphics system that projects the virtual objects on either a large and wide screen or on a large screen projector system.,

3. **Fully Immersive VE**

   This is the most expensive and sophisticated VE; it requires special interface devices such as data gloves and head mounted displays. It typically consists of 3D glasses or other form of head mounted display units that let users feel isolated from the physical world outside.

2.1.3 Applications of VEs

VEs have been created for many different types of applications. To provide a brief overview, this section provides examples of application areas and research conducted in these areas.

One of the common reasons to create VEs is for entertainment (Zhang et al., 2013) (Huang et al., 2011), particularly for gaming. Over the past decades, the games industry accompanied designing games with more advanced virtual technologies. Another example of using VEs for entertainment is the 3D animated movies to create imaginary scenes for movie audiences. A growing genre of VEs are known as serious games, so named because they involve the use of VEs that have a purpose, such as education, rather than simply entertainment.

VEs have been widely used for educational purposes (Novak-Marcincin et al., 2014) (Brocato et al., 2015). VEs have been used in many projects to improve trainees' learning motivation and achievement. The importance of using VEs in training emerges from the fact that VEs can simulate situations which are not safe or easy to train in (Aggarwal et al., 2011). Many studies indicated the importance of using VEs as a training tool in military field (Koźlak et al., 2013) (Li et al., 2014) (Lele, 2013). Other training usages for VEs include simulating a transmission electron microscope laboratory (Tarng et al., 2015) and motherboard assembly (Westerfield et al., 2015).

VEs have been used in the healthcare field in medical education and teaching of anatomy through the visualization of body organs and enabling the educators to navigate through body volumes (Dobson et al., 2003). VEs have been used, or proposed for use, in diagnostics, preoperative planning education and training (Adamovich et al., 2009), cooperative surgeries, therapies such as flying phobia (da Costa et al., 2008) or public speaking anxiety (Wallach et al., 2009), facilitating clinical decision (Levac and Galvin, 2011), nursing practices (Davis, 2009) and Orthopaedics (Mabrey et al., 2010).

VEs have been used in a number of business applications including virtual tours of business environments (e.g., the impact of VE on distance fashion shopping (Lau et al., 2011)), training of employees on using business tools (Grabowski and Jankowski, 2015), and 360 degree view to products (Sanna and Montrucchio, 2001).

2.2 Collaborative Virtual Environment

A Collaborative Virtual Environment (CVE) has been defined as "a computer-based, distributed, virtual space or set of places. In such places, people can meet and interact with others, with agents or with virtual objects." P.5 (Snowdon et al., 2001). CVEs have been used as a mediation tool to facilitate the human-human collaboration across disparate spaces. Moreover, the concept of CVE includes the collaboration between human participant and virtual entities such as Intelligent Virtual Agents (IVAs).

The past two decades have witnessed increasing interest in using CVEs to facilitate virtual teamwork (Greenberg and Buxton, 2008). CVEs have been used in multiple of fields depending on their purpose of use, such as, business (Bishop and Stock, 2010), entertainment, learning (Giraldo et al., 2007) (Lorenzo et al., 2012), training (Holmberg et al., 2006), medicine (Chee and Hooi, 2002) and dancing (Zhenyu et al., 2006). CVE has gained a lot of interest due to the evolving growth in networking and telecommunication technologies. Following increasing interest in CVEs, a vast body of literature work has been published to report the advantages and disadvantages of different CVE designs.

Collaborative virtual environments have been used in many applications, such as e-learning, training and military simulations. For example, in learning applications Virtual Environment technology offers a potential group-learning environment particularly suited to exploration of problems that are hazardous or difficult to deal with in reality. Collaborative learning in virtual environment includes collaboration between learners. Research has found that a CVE may support collaboration in ways which go beyond what is possible using some other technology such as video conferencing (Benford et al., 1994). A number of technologies could be used to build a CVE. A survey conducted by (Wright and Madey, 2009) identified FreeVR, Java3D, OGRE, OpenGL, OpenVRML. These technologies are used to create VEs that allow humans to collaborate with each other and do not support human-agent collaboration. The applications that require collaboration between humans and agents need a number of additional features to support the creation of IVAs that are able to interact rationally with humans. Most commonly, researchers have used game engine technology to create CVEs for human-agent collaboration (Ricci et al., 2003, Gifford and Enyedy, 1999).

2.3 Intelligent Virtual Agent

An Intelligent virtual agent (IVA) is a term used to define an autonomous entity in a virtual environment. This entity should not only look like, but also behave as a living organism (e.g., human, animal, imaginary creature) (Vosinakis and Panayiotopoulos, 2001). Several studies aimed to create believable IVAs and include sophisticated characteristics similar to humans. Among these characteristics, researchers have sought to create unique IVAs with distinct personalities.

There are a variety of terms used to describe IVAs including anthropomorphic agents, avatars, synthetic actors, non-player characters or embodied conversational agents are among commonly used terms. (Prendinger and Ishizuka, 2004) described these agents as life-like characters that were graphically represented or animated, not robotic agents.

(Gratch et al., 2002) identified 10 research areas needed for building an IVA. These research areas are human figure animation, facial expression, perception, cognitive modelling, emotions and personality, natural language processing, speech recognition and synthesis, non-verbal communication, distributed simulation and computer games. These research areas could be classified into three main classes. The first research class is communication related area that includes multimodal communications. The second area is personality and affective related area that includes personality and emotions. The third class of research is the cognition related area that includes perception and cognitive models.

2.3.1 The Roles of IVAs

IVAs have different roles in VEs. The roles could be classified in many different ways. In line with the focus of this thesis on collaboration, we can identify a number of examples of collaborative roles as follows:

1. **Sensitive Artificial Listener (SAL)…** SALs are designed to listen to human users while talking and provide reactions to what is said. SALs requires realistic interaction with human users, despite having limited verbal skills. This interaction could be verbally and/or non-verbally.

2. **Interactive Demonstrator…**The role of the agent is to explain a topic or demonstrate procedures. Steve (Rickel and Johnson, 1999) is an example of an interactive demonstrator agent. Steve inhabits a 3D scene of a US Navy ship with students, and can demonstrate procedures while providing spoken commentary describing his objectives and actions. Another example was an IVA that provides instruction for a large service-oriented travel agency (Yueh et al., 2007).

3. **Navigation Guidance…**The role of the agent is to help the users to explore a VE. Navigation guidance aims to teach the user where things are and how to get around.

4. **Collaboration partner…**where the IVA should work as a team either with another IVA or with a human to achieve a shared task.

2.3.2 BDI model

Several approaches have been proposed to incorporate mental model or reasoning modules in IVAs. Perhaps the most adopted is the belief-desire-intention (BDI) model which was originally proposed by (Bratman, 1987). BDI has been adopted, and extended, by numerous agent researcher (e.g. (Rao and Georgeff, 1995) (Torres et al., 2003)). The assumption of the BDI model is that the agent has a set of desires (D) that is selected to be achieved, according to the current situation of the agent's beliefs (B). Then, determination of how these goals or desires produced in the previous step can be achieved by means of the available options for the agent.

The three cognitive attitudes that are part of a BDI model are the following:

- **Beliefs.** Represent environment characteristics or the information about the surrounding world. Beliefs are updated accordingly after the perception of each action. They can be seen as the knowledge base of the agent.

- **Desires.** Store the information of the goals to be achieved, as well as properties associated with each goal, and represent the motivations of the agent.

- **Intentions.** Represent the current action plan chosen and capture the deliberative component of the system.

The main idea behind the BDI agent approach is that it allows agent developers to describe agent behaviour in terms of beliefs (what is known of the world), goals (what is to be achieved), and plans (how the goals can be achieved). Decision making in goal-driven BDI agent is called practical reasoning (Morreale et al., 2006). Practical reasoning consists of two processes: deliberation and means-ends reasoning (Pokahr and Braubach, 2012). The outcome of deliberation process results in the agent adopting intentions. While the outcome of means-ends reasoning process helps in deciding how to reach the intentions the agent has adopted. Means-ends reasoning resembles the concept of planning in the Artificial Intelligence research area (Bordini et al., 2007).

2.4 IVAs in Collaborative Contexts

To understand the interaction between humans and IVAs we need to consider approaches that allow us to analyse the actions of humans within the system. To this end, in Section 2.4.1 we introduce Activity Theory, which is commonly used to model human collaboration, and consider its application to human-IVA collaboration, followed by agent-agent collaboration and human-agent collaboration in Sections 2.4.2 to 2.4.3.

2.4.1 Activity Theory

Activity Theory (AT) is a theoretical framework for analysing human practices in a given context. According to AT, people are embedded actors (not processors or system components) with both individual and social levels interlaced at the same time. The origin of activity theory can be found in the early writings of Vygotsky (1896-1934), who suggests that social activity, the basic unit of analysis, may serve as an explanatory principle concerning human consciousness.

(K.Kuutti, 1996) considers three levels in an activity: activity, action, operation. Figure 2-1 depicts the Hierarchical Levels of an Activity that describe the short-term processes that take place during the course of that activity. The activity level consists of actions or chains of actions. The first condition for any activity is the presence of a need. Needs stimulate but do not direct the activity.

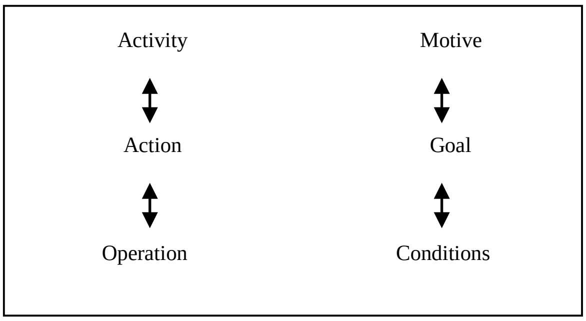

Figure 2-1: Hierarchical Levels of an Activity

In his general model, (Engeström, 2005) asserts that human activity is "*object-oriented, collective, and culturally mediated human activity*" (Engeström and Miettinen, 1999), composed of subject, object, actions, and operation, as shown in Figure 2-2. The subject, object, and community interact through tools, rules, and a division of labour (Engeström,

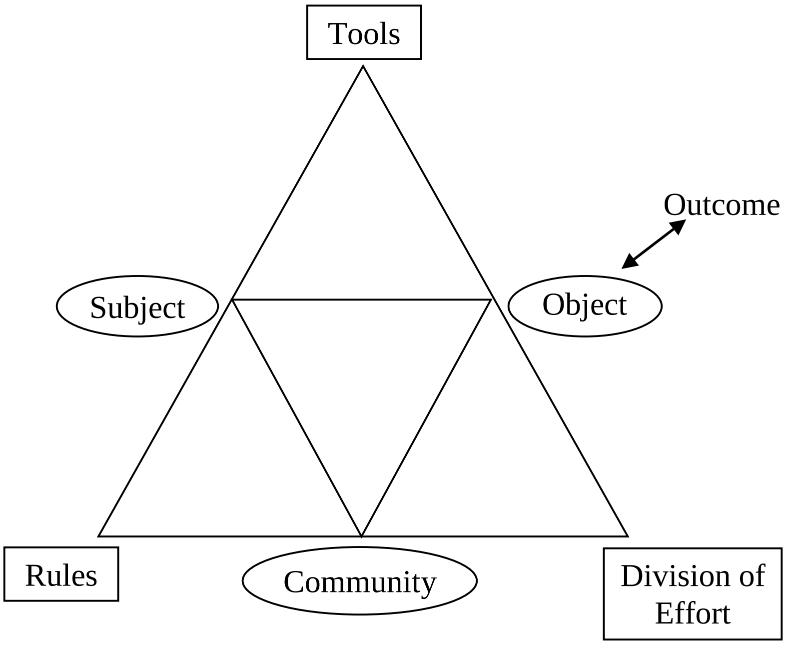

Figure 2-2: Structure of Activity theory (Engeström, 1987)

1987). A subject is an individual or a group involved in an activity. An object aids the subject and motivates activity (Kaptelinin et al., 1995). The Subjects use Tools to interact with the Objects. Tools are used to mediate the activity. In the same way, Community uses Division of Effort to interact with Object, and uses Rules to interact with Subject. Internalization is a key concept where the subject uses tools seamlessly and automatically to execute actions which require conscious thought or planning. The Subject will make a plan according to his mental model of the real world and then s/he will use actions to achieve this plan. If actions are not performed according to the subject's plan, s/he will adjust them and retry to execute actions (K.Kuutti, 1996). In summary, key AT concepts include object-orientedness; hierarchical structure of activity; internalization/externalization; mediation and development.

According to AT, the subject or the actors/individuals who are involved in the activity are directed to their object by the tools that are available for use. These tools or artefacts that are used by the subjects involved in the activity to reach their objects/outcome. These tools or artefacts are used for the accumulation and transmission of social knowledge and change accordingly with accumulating experience. These tools will direct to a great extent the activity of the actors towards their goal. In human-IVA collaboration in virtual environments, the predominant tool of interaction is IVA's multimodal communication from the IVA side and human verbal communication from the human side. Communication from both human and IVA is the tool that will direct the progress of activity. Back to AT, the subjects need a community to belong to for directing the achievement of goals. The community or externalization is the context in which the actors will interact using the available tools to plan for fulfilling their activity. Community component relates more to how the actors will socially and culturally interact towards their activity. Community will include factors such as social appeal, trusting other actors and committing toward achieve the objective.

Towards answering the first research question, AT provides some answers to the factors that influence human-IVA collaboration. These factors could be classified into two classes:

First: the factor that is related to the tool or artefacts of interaction. These tools are meant to be the shared ground that the actors will use to exchange their intention, thoughts, and ideas. Using the tools should contribute to the shared cognitive state of the actors. The shared knowledge is conveyed via goal-directed communication.

Second: the factor that is related to community or external effectors on the ongoing activity. Community relates more with the social rule of each actor in the collaborative situation and the impression the actor gets from the other actors.

2.4.2 Agent-agent Collaboration

There are a number of approaches to manage the mental attitudes in agent-agent coordination, (Pokahr and Braubach, 2012) differentiate some of these approaches. Agent-agent coordination approaches range between sharing some of their beliefs such as Hive BDI agents (Barbieri and Mascardi, 2011). In the Hive coordination approach, communication between agents is crucial in exchanging the shared beliefs. Another approach of agent coordination is goal delegation (Bergenti et al., 2003) where one agent is committed to achieve an agreed on goal; however, the agent can control how to achieve the agreed on goal. While the goal delegation approach depends on sharing goals between agents, the Coordinating SaPa approach (Hashmi and Seghrouchni, 2010), an extension to the well-known planner SaPa, is a more rigid approach where an agent send plans to other agents to select their nominated actions in a way to avoid conflict. While the three examples of coordination approaches consider sharing one cognitive attitude, approaches such as joint intention necessitate sharing knowledge about the state of the situation as well as the goals. Another approach, joint responsibility (Jennings and Mamdani, 1999), takes a further step and considers coordinating the three cognitive attitudes. A different approach of agent coordination is organisation-centred multi-agent systems (OCMAS) (Ferber et al., 2004), where an agent interacts with other agents as a black box entity that does not need to share any cognitive attitudes. Table 2.1 provides a comparative summary of the approaches.

Table 2-1: Different approaches to sharing in agent-agent coordination

Example Approach	Beliefs	Goals	Plans
Hive BDI	X	-	-
Goal Delegation	-	X	-
Coordinating SaPa	-	-	X
Joint Intentions	X	X	-
Joint Responsibility	X	X	X
organization-centred multi-agent systems (OCMAS)	-	-	-

2.4.3 Human-IVA Collaboration

Human-IVA collaboration has been considered in a number of different domains, such as education. In this domain, there is a range of research that presents collaborative agents with properties that are appropriate to a range of roles. For example, to support learners. These roles include agents acting as a simulated student (Virvou and Manos, 2003, Vizcaíno, 2004), learner agent (Dillenbourg and Self, 1992), learning companion that accompanies the user during his learning (Kim and Baylor, 2006) and teachable agent (Blair et al., 2006).

Agents in a collaborative environment may have to play multiple roles. Zhang and Li (Zhang and Li, 2009) mention a number of general aims to be achieved by an agent in a collaborative environment including facilitating the team work between humans. A less explored combination involves making the human and agent one team in performing a certain task. This combination adds other aims such as monitoring human performance and checking if the goal is achieved. As a result of a number of studies, (Grosz et al., 2004) stressed on the importance of building cooperative agents when designing and building agents that will be engaged in group activities with humans.

However, collaboration is difficult and humans often need assistance to learn how to collaborate effectively. Autonomous agents and Multi-Agent Systems (MAS) can play an important role in providing this assistance. Autonomous agents are able to control the environment they are embedded in as well as their internal state and behaviour; perform a specific role or achieve determined goals; and due to their proactive and reactive ability, they are ideally suitable entities for problem-solving situations (Jennings, 2001). Agent-based systems are used in different areas, including team analysis (Raines et al., 2000), workflow systems (Tony et al., 2004) and affective tutoring systems (Mao and Li, 2010). In addition to these studies, there are other studies that explored the context in which decision are made by individuals or agents in collaborative settings. (Gal et al., 2007). The study investigated the influence of different settings on the negotiation and decision-making. They explored two settings. The first setting was a task context in which the relationships among goals are explicitly stated. The second one was an abstract context where only the payoffs of the taken decisions were known. The results showed people tend to be more helpful and less selfish when they are involved in a task context.

2.5 Multimodal Communication

In recent research there is an increasing interest in agent communication in multi-agent virtual systems (Nijholt and Heylen, 2002) (Oijen and Dignum, 2012) (Oijen et al., 2011) (Chopra et al., 2013) (Wei et al., 2014). Research in the area of intelligent virtual agents (IVAs), such as embodied conversational agents, focuses on agents that are able to interface with human users. In multi-agent systems, it is widely known that communication between agents is a challenging research area (Chaib-draa and Dignum, 2002). Research on human-agent interaction is still in its infancy and faces many challenges. Horvitz (Horvitz, 1999) identifies a number of challenges in human-machine interaction, including seeking mutual understanding or grounding of shared activity, combining solutions found by humans and machines, and maintaining natural communication and coordination during these processes. Ferguson and Allen (Ferguson and Allen, 2007) state that true human-agent collaborative behaviour requires an agent to possess a number of capabilities, including reasoning, communication, planning, execution, and learning.

In the following subsections, we consider the nature of communication in teamwork (2.5.1). Taxonomy of human-agent communication is presented in Section 2.5.2. Section 2.5.3 introduces a well-known communication theory, i.e. SAT, to that we will draw on later in the design and evaluation of our agent communication.

2.5.1 The Role of Communication in Teamwork

The term teamwork has been discussed in the psychological and social sciences literature. Among the variant definitions of teamwork, Larson and LaFasto (Larson and LaFasto, 1989) define a team as two or more people with a specific objective or recognizable goal and activity among members that is coordinated to reach this common goal. Other definitions of teamwork exists (Miller et al., 2000, Cohen and Levesque, 1991). (Maddux and Wingfield, 1986) mentioned 3 factors to encourage collaboration between team members: 1) recognize areas of interdependence; 2) create communication possibilities; and 3) make team members know that teamwork will positively influence their individual recognition. Larson and LaFasto (Larson and LaFasto, 1989) assert the importance of communication between collaborative team members.

Communication is considered a vital element in successful teamwork. (Smith-Jentsch et al., 1998) defined four factors that are crucial to effective teamwork: Information Exchange, Communication, Supporting Behaviour and Initiative/Leadership. (Lenox et al., 1998) used agents to support the team as a whole, this support includes facilitating communication, allocation of tasks, coordination among the human agents, and improving attention focus. Sycara and Lenox (Lenox et al., 1998) (Sycara and Lewis, 2002) acknowledged three roles for agents in interacting with human teams: agents aiding individual team members to complete their tasks, agents support the team as a whole and agents assume the role of an equal team member; communication is needed to perform the three roles of agents.

2.5.2 Taxonomy of Human-Agent Communication

There are different methods to establish a communication channel between virtual agents and humans. These methods could involve verbal or non-verbal communication. Verbal communication involves the use of words and may be oral or spoken communication or textual communication. Non-verbal communication may include eye gaze and head gesture and behavioural communication. In this section, we will provide a taxonomy of the various forms of communication.

2.5.2.1 Verbal Communication

Verbal communication relies on exchanging opinions, expressions, ideas or/and language statements between the human and agent in order to express their internal state and intentions. Exchanged verbal statements could be one-way, produced by the human or agent and received by the other, or two-way in a conversation-like manner.

1. Oral Communication

In oral communication, the agent has to be able to either: produce an understandable utterance to the human user; to understand what the human user says; or do both in a conversation-like manner. (Watters et al., 2005) designed and implemented an agent architecture in which the agent's sensation of the environment was used to guide the recognition of spoken and gestural directives given by a human user using a probabilistic language model. Based on observations of human behaviours, (Yuasa et al., 2010) proposed an utterance attitude model and applied the model to a conversational agent. The authors categorize utterance behaviours into four subtle implicit expressive behaviours and four direct explicit behaviours. (Luin et al., 2001a) presented a natural language accessible navigation agent for a VE where the user can navigate into the environment and the agents inside the system can answer the user's questions. The virtual system is for a theatre with multiple agents, the main agent is Karin. Visitors can ask Karin questions in natural language. The agent answers the question by accessing a database about the theatre and trying to extract and formulate answers. In another paper (Jeroen et al., 2001) the authors extend their work by adding 3 databases for the navigation agent to use to answer visitors' questions. (Bouzouba et al., 2005) proposed a computational model for human-agent conversational communication along with an implementation of the model in a multi-agent system called POSTAGE.

2. Textual Communication

In textual communication, the agent has to be able to either produce understandable text that conveys meaning to the human; understand what the user types; or do both in a chatroom-like manner. (van Wissen et al., 2012) investigated empirically whether human users treat an agent differently than human members when they form a team to carry out a joint task. They also studied the effects of trust and fairness on people's behaviour towards humans and agents in a collaborative environment. A specially created test bed was used in which human users decide whether to create a team with other human users and/or agents. The results showed that, when negotiating to create teams, people offered less incentive to agents to join their team than they did to people. The results also showed that people were as loyal to agent-led teams as they were to human-led teams. In addition, people preferred to create teams with those they trust and have had positive interactions before (humans and agents alike).

(Sharpanskykh and Treur, 2008) proposed an agent model to read minds though monitoring a person while interacting with his/her environment. They stated that monitoring humans while making decisions in their environment leads to determining their cognitive state, in this way it is as if the agent is reading their mind.

2.5.2.2 Non-Verbal Communication

There is a lot of research work concerned with non-verbal communication in humans such as eye gaze, head gesture, body gestures, and facial expression. We will call this bodily communication. A good overview of research focused on bodily communication between virtual agents and human users can be found in (Allwood, 2002). We identify another type on non-verbal communication that involves actions and responses that we call behavioural communication. Both are reviewed below.

1. Bodily Communication

Emotional and empathic agents are currently of high interest in the embodied conversational agent and IVA research space. Non-verbal methods of communication are seen as particularly relevant for conveying emotional content. In particular, we see considerable interest in agent-human communication involving eye gaze and head gesture. Concerning non-verbal cues that an agent may transfer in order to create a favourable environment for following interactions, (Bee et al., 2009) presented an eye-gaze model of interaction to study whether flirting strategies help improve first encounters between a human and an agent. In the study of (Nakano and Ishii:, 2010) the user's gaze behaviours are analysed and a method for estimating whether the user is engaged in the conversation is proposed based on gaze patterns. (Kipp and Gebhard, 2008) presented a semi-immersive human-avatar interaction system where an avatar produced responsive gaze behaviour that is based on the user’s current state of his head in an interview situation. Ishii and Nakano (Ishii and Nakano, 2008, Ishii and Nakano, 2010) analysed the user's gaze behaviours and proposed a method for predicting whether the user is engaged in the conversation with an agent. The authors propose an engagement estimation algorithm that estimates the user's degree of engagement from gaze transition patterns. (Zhang et al., 2010) presented a platform for the virtual agent to track the user's gaze and hand movements in real time and adjusted the agent's behaviours accordingly. Data was collected from both the human user and the virtual agent that recorded speech, eye gaze, and hand and head movements.

These works try to mimic human-like behaviours in the agent in order to generate appropriate agent and human reactions at the right times. (Yu et al., 2012) investigated eye gaze patterns of both human-human and human-agent interactions and discovered various behavioural patterns by asking participants to interact with either another human or embodied agent in a shared task. Some works focused on other ways to estimate the level of communication involving between human, (Ooko et al., 2011) proposed a method of judging a user's engagement in a conversation based on head pose records. The author stated that when the system can monitor the user's attitude toward the conversation and detect whether the user is engaged in the conversation, the system could then adapt its behaviour and communication strategy according to the user's attitude.

2. Behavioural Communication

In behavioural communication, both the human and agent may not interchange text, oral, eye gaze or gesture, but both of them can observe the actions of each other in the virtual environment and deduce what is the internal state or the intentions of the other one. In behavioural communication, the agent should have the ability to monitor human performance and recognize the plan of the human from human's behaviour in the virtual environment. To monitor human performance in achieving their individual goal, (Payne et al., 2000) presented an interface agent, MokSAF, that facilitates time-critical team-planning tasks in mixed human/agent teams. When the human commander fails to achieve his/her individual goal, the agent autonomously performs team subtasks to automate parts of the goal to assist the commander. (Bui, 2003) presented a framework for online probabilistic plan recognition called the Abstract Hidden Markov Memory Model (AHMEM). (Goldman et al., 1999) presented a general model of plan recognition based on probabilistic abductive logic.

As an agent may often have to guess the needs of his human teammate, (Horvitz, 1999) presented methods for managing the uncertainties that agents may have about users' goals and foci of attention. (Sukthankar and Sycara, 2005) presented a methodology for recording, representing, and recognizing team behaviours performed by human players. The system records the location and orientation of the user while using an environment developed by Unreal. Behaviour recognition is performed offline using a set of hidden Markov models on short movement sequences. To explicitly create a shared understanding of the task between a human and an agent, (Zimmerman et al., 2009) made the human user communicate with the agent by creating a structured form. The form-construction communication method allowed users to declare the outcome they wanted while implicitly demonstrating how the agent should perform the task. Miao et al. (Miao et al., 2006a, Miao et al., 2006b) presented a multi-agent multi-user system to train participants to handle abnormal situations while driving cars. Multiple agents were created to produce a few highly abnormal and dangerous situations. The problem creator agent does not communicate directly with users however; it interacts with learners through the simulation environment.

2.5.3 Speech Act Theory (SAT)

The meaning of utterance has been defined by many disciplines such as philosophy, linguistics, social sciences and artificial intelligence. Theories that study the meaning of utterance are called the theories of meaning. (Lemaître and Fallah-Seghrouchni, 2000) present three categories of theories of meaning that influence Multi-agent communication formalisms. The first one is the *classical formal semantics* which studies the conditions used to estimate the truth/false of the proposition uttered. The focus of this theory is on the linguistic expression and not the relationship between the sender and the receiver or the communication situation. The second theory is *intentionalistic semantics* which focuses on what the speaker meant to say in his/her speech. The meaning is conveyed by the speaker's intention. The third theory is the *use-theory of meaning* which defines the meaning of language as based on how it is used in the communicative situation.

Using the foundation of use-theory of meaning, Austin presented Speech Act Theory (SAT). According to (Austin, 1975), SAT is a theory of performative language, in which to say something is to do something and all speech acts should exist in a context in order to be meaningful. To define a speech act, it must be associated with appropriate social situations and changes in mental states of both the speaker and listener. According to speech act theory, what the speaker is doing is creating social realities within certain social contexts. We find SAT to be superior to other theories of meaning because it seeks to interpret actions that relate to human communication and understand the effectiveness of the communication.

The main idea of SAT is that during communication people do not just utter propositions to be answered with acceptance or rejection, instead every exchanged sentence in a communication situation includes the intention of the speaker to accomplish something such as requesting, advising, and so on. SAT considers how words (utterances) could be used not only to present information, but also to perform actions. Austin described three characteristics, or acts, of statements that begin with the building blocks of words and end with the effects those words have on an audience.

- Locutionary acts: the physical act of uttering the sentence.
- Illocutionary acts: the action of conveying the speaker's intention, such as informing, ordering, warning, and undertaking.
- Perlocutionary acts: what we achieve by saying something, such as persuading, convincing, requesting. Perlocutionary effect of an utterance is what is actually achieved by the locution. The perlocutionary effect could be informing of possible next step, informing of accomplishing a task, persuading of my point of view, etc.

There are different speech act taxonomies for classifying the literal and pragmatic meaning of utterances such as Verbal Response Modes (VRM) (Chien and Soo, 2012) and Searle's taxonomy. Searle's taxonomy is more commonly used as his classification covers a wider variety of intentions of utterances.

(Searle, 1969) has set up the following classification of illocutionary speech acts:

- Commissives - speech acts that commit a speaker to perform an action, e.g. promises.
- Declarations - speech acts that bring something about in the world, e.g. pronouncing something.
- Directives - speech acts that influence the listener to take a particular action, e.g. requests, commands and advice.

- Expressive - speech acts that express the speaker's psychological state, attitudes towards a proposition which has an impact on the listener, e.g. congratulations, excuses and thanking.
- Representatives - speech acts that express the state of the speaker.

There cannot be any utterance in a given context without intention from the speaker, i.e. the illocutionary force (Eppler and Mengis, 2004). Moreover, the same utterances may have various illocutionary forces. For example, '*The requested region is far to go to*' can either be a statement, rejection, a promise, or excuse, depending on the context of use. The illocutionary force is different from the meaning of the utterance. For instance, both "*I would like to know your next step*" and "*do you have any hint for me?*" have the same illocutionary force in that they are intentions to obtain information from the partner, while both sentences have different propositional content. The first sentence talks about the possible next step, while the second one asks for any hint.

An important assumption of speech act theory is that effective communication requires accurate recognition of speech acts that are exchanged between players (Eppler and Mengis, 2004). The proposed model of human-agent collaborative communication (HAT-CoM), will rely on speech act theory as a guide to design effective communication, and also as an evaluation reference to measure the effectiveness of communication, specially on the agent's side of communication.

2.6 Factors that Foster Collaboration

In designing IVAs that can collaborate with humans, we need to understand what factors that tend to hinder or foster collaboration. In this section, we draw on the literature on teamwork to understand the factors that affect human teams and seek to apply that body of knowledge to human-IVA teams. This body of knowledge is separated into cognitive factors (section 2.6.1) and personal factors (Section 2.6.2).

2.6.1 Cognitive Factors of Collaboration

2.6.1.1 Shared Mental Modal (SMM)

In his definition of agent teamwork, (Cohen et al., 1997) stressed the importance of having shared objectives and mental state or mental model between team members. A Shared

Mental Model (SMM) is the state among team members where the members have intersecting knowledge and beliefs. SMM was introduced by (Cannon-Bowers et al., 1993) in the context of human-human teams. Later, it became clear that SMM is not only important in human teams, but also in human-agent teams (Kieft et al., 2011). Hence, it has gained the attention of many researchers in psychology, social sciences and artificial intelligence. SMM was used to study the relationship between team members in different situations, for example crew performance in highly critical situations (Waller et al., 2004). Many researchers who have been studying SMM classified the shared knowledge into two classes: knowledge about the team and knowledge about the task (Cannon-Bowers et al., 1993). Taskwork SMM refers to the shared knowledge of task strategies, procedures to achieve the task, and the environment in which the task to be performed. Teamwork SMM refers to an understanding of team interactions and communications, teammates' knowledge, skills, abilities, preferences and beliefs (Mathieu et al., 2000).

The impact of SMM on teamwork has been identified in many research studies (Salas et al., 2005). Many researchers claimed that team performance in achieving a shared goal will be effectively improved if team members have sufficient shared understanding of the shared task, situation and other team members (Mohammed and Dumville, 2001). Many studies found that there is a positive correlation between team-based knowledge of SMM and overall team performance (Lim and Klein, 2006), other studies found the positive correlation between task-based knowledge of SMM and team performance (Mathieu et al., 2005). Moreover, researchers found that SMM plays a crucial role in collaborative activity (Tweedale and Jain, 2011). Many studies have argued that the development of SMM among interacting team members has a significant positive effect on task performance (Lim and Klein, 2006) as well as team effectiveness (Smith-Jentsch et al., 2005).

Communication is considered as a catalyst in successful teamwork (Smith-Jentsch et al., 1998). Many researchers have agreed that SMM could be created by the experience of team members who work together (Tsuchiya and Tsuchiya, 1999) and/or communication between them. (Stout et al., 1999) assumed that SMM among team members enabled them to utilise communication approaches efficiently during high-workload situations. On the other hand, effective communication positively affects the degree of coordinated performance attained by teammates which in turn fosters the development of SMM (Espevik et al., 2006).

As many researchers have been interested in the development of SMM in the human team, (Sycara and Sukthankar, 2006) stated that the biggest challenge in human-agent team work is to establish SMM. In recent studies, many researchers have been interested in extending the concept of SMM to include the teamwork of agents or situations that combine the human and the agent in one team (Fan and Yen, 2011) (Hodhod et al., 2012). Nevertheless, creating agents to behave like a human teammate is a challenging task (Lewis, 1998).

2.6.2 Personal Factors of Collaboration

2.6.2.1 Personality Traits

In psychology, different theories exist that explain the behaviour of humans along with personality traits or types. These theories are similar in considering each trait/type as a characteristic feature of a human, which can be used to explain the human behaviour and its motives along patterns of behaviour. Currently, there are two major theories about human personality (Furnham, 1996). These theories are Five Factor Model of personality or sometimes called Five-Factor Model (FFM) or (Big5) (McCrae and John, 1992) which is a widely-accepted theories is Big Five Model of personality (John and Srivastava, 1999). The second theory is Myers Briggs Type Indicator (MBTI) (Myers and Byers, 1995). It is note-worthy to mention the early work of H.J Eysenck (Eysenck, 1950, Eysenck, 1970, Eysenck, 1991) who developed a very influential model of personality. Based on the analysis of responses on personality questionnaires, he identified three dimensions of personality: extraversion, neuroticism and psychoticism. Two of these, i.e. extraversion and neuroticism, also form part of FFM. Moreover, extraversion is part of MBTI.

Personality is a personal aspect that makes it possible to distinguish between different people (Kasap and Magnenat-Thalmann, 2008). Because our personality affects our internal perception and actual behaviour (von der Pütten et al., 2010), personality has been included in multiple aspects of IVAs including their expressive aspect, i.e. non-verbal communication and verbal communication , and their internal aspect, such as planning (Doce et al., 2010).

A number of psychological theories proposed foundations to understand personality, yet one of the most well-known and FFM is comprised of five-personality dimensions openness to experience, conscientiousness, extraversion (antonym-introversion), agreeableness (antonym antagonism), and neuroticism. After its wide success in understanding humans' personalities, numerous studies used the foundations of FFM to personalize the behaviour of IVAs (Neto and Silva, 2012). IVA with personality according to FFM was studied in different contexts including interviews, medical treatment, and interactive narrative (Bahamón and Young, 2012).

- **Extraversion**: The degree to which one is outgoing, unreserved, talkative, and sociable versus cautious, reclusive, and shy.
- **Agreeableness**: The degree to which people are friendly, cooperative, and trusting versus resentful, cranky, and hostile.
- **Conscientiousness**: The extent to which people are responsible, dutiful, and dependable versus unreliable and careless.
- **Neuroticism**: The degree to which people are impulsive and prone to worry, anxiety, and anger.
- **Openness to experience**: The degree to which people are imaginative, unconventional, and artistic versus conforming, uncreative, and stodgy.

Extravert characters use more direct and powerful speech (Furnham, 1990), tend to speak louder and faster (Scherer, 1979) and use more spread-out space to do gestures (Gallaher, 1992).

Table 2-2 shows a few aspects that represent high and low values of each dimension. Some of the five personality traits and its associated aspects are not commonly visible such as neuroticism and its aspects such as worrying and insecurity. On the other hand, other traits and its associated aspects are common among humans and are more visible (Miller et al., 2011).

2.6.2.2 Trust

Trust is widely recognized as an important facilitator of successful relationships. Trust has been defined as individual belief in another person's capabilities and honesty based on his/her own direct experiences (Wang and Vassileva, 2003). A commonly used classic definition of trust is "*the willingness of a party to be vulnerable to the actions of another* *party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party*" (p.712) (Mayer et al., 1995). Another definition is "*a psychological state comprising the intention to accept vulnerability based upon the positive expectations of the intentions or behaviour of another*" (p.395) (Rousseau et al., 1998). This definition

Table 2-2: The components of the FFM model and high/low value traits for each dimension

Dimensions	**High Value Traits**	**Low Value Traits**
Extraversion	Sociable, Friendly, Talkative, Fun-loving	Introverted, Reserved, Inhibited, Quiet
Agreeableness	Courteous, Forgiving, Sympathetic	Critical, Rude, Harsh, Callous
Conscientiousness	Reliable, Careful, Well-organized, Self-disciplined	Negligent, Disorganized, Un-dependable
Neuroticism	Nervous, Insecure, Worrying, High-strung	Calm, Relaxed, Secure, Hardy
Openness	Creative, Curious, Complex	Conventional, Narrow interests, Uncreative

considers trust as a transient state in any particular situation. Many other definitions of trust exist that offer alternative perspectives (see (Mitchell and Zigurs, 2009)); nevertheless, the majority of these definitions share the concept of expectation and confidence in the other actors' reliability, fairness and integrity.

Trust has been the subject of study across many different disciplines and domains including psychology, sociology, business and e-commerce (Lumsden and MacKay, 2006) and computer science. The study of trust in psychology and other human science branches focused on building/breaking the trust between humans in different situations. In addition to a considerable body of knowledge that has studied human-human trust, interest has moved to understand human-machine trust (Barber, 1983) and later to understand human-agent trust (e.g. in the use of in-vehicle agents to drive cars safely (Cramer et al., 2008)).

It is widely accepted that trust is an important factor in the digital world including web-services (Noor and Sheng, 2014), e-commerce (Lumsden and MacKay, 2006), (Morid and Shajari, 2012), social media (Quijano et al., 2010), (Huang et al., 2013), (Mei et al., 2014) and virtual teams (El-Kassrawy, 2014). In e-commerce trust has been coupled with reputation and much literature focuses on how established reputation influences trust (Zhao et al., 2012). Studies on trust in software agents tend to explore how the agent reasons in a way that gains the trust of the other agent or interacting humans. Studies looking at trust in virtual teams are more concerned with understanding the features of online teams that tend to foster trust between dispersed members.

Researchers have revealed that trust among members of virtual team is a major critical success factor (Nilles, 1998). Based on a survey of the literature on virtual teams, Mitchell and Zigurs (Mitchell and Zigurs, 2009) identified several dimensions of trust. The socio-emotional dimension was identified as crucial for teamwork in virtual worlds. Trust based socio-emotional processes included affect, calculated, cognitive, commitment, companion, dispositional, fragile, and inter-personal and personality. (van Wissen et al., 2012) investigated if a human participant treats an agent differently to human members when they have to work in a team. They also studied the impact of trust and fairness on people's behaviour towards humans and agents in a collaborative environment.

One line of research has indicated that the nature of trust may be cognitive and depend on rational reasoning. While another stream of research has emphasized the affective nature of trust and the possible dependence on the trustee's personal merits. Hence, it is reasonable to distinguish between affective or personality-based trust and strategic or cognitive-based trust. The drift in classifying trust has moved from human research to agent and MAS (Castelfranchi and Falcone, 1998), (Atkinson and Clark, 2013). Based on these two drivers of trust, studies have identified several factors that foster trust among team members. Among these factors the personality of team members and sharing mutually valuable information with others were identified (Piccoli and Ives, 2000). Building on these factors, (Sarker et al., 2003) presented a three-faceted conception of trust including personality-based, cognitive-based and institutional-based trust. Personality-based trust evolves because of a person's tendency to trust. Cognitive-based trust develops from exchanged knowledge and impressions during an interactive task. Institutional-based trust due to an individual's belief in institutional procedures, and of less relevance to our focus on trust within human-IVA teams.

2.6.2.3 Commitment

The notion of commitment expresses a mental state of obligation to behave in a specific manner. A commitment is a promise to do or abstain from doing something (Humphrey, 2005). According to (Moreland and Levine, 1992), commitment is an emotional bond between the team members. Commitment is formed through the process of negotiation, agreement, involvement and participation and performance. There are different levels of commitment from personal to collective commitment (Zhang et al., 2004). Collective commitment is the most effective motivation to be considered in teamwork (Dunin-Keplicz and Verbrugge., 1999) as this level of commitment stimulates individual social behaviour toward the welfare of a group they belong to. Commitment in the context of teamwork could be classified at three levels: task-based commitment, individual team-based and collective team-based commitment. Task-based commitment refers to self-pledge to complete a shared mission regardless of the involved participants; while individual team-based commitment denotes the long-term desire to maintain a valued partnership with one or more members from the whole team; this desire goes beyond the designated task. Collective team-based commitment indicates the social willingness to belong to a team. Perhaps one of the earliest work that studied the relationship between trust and commitment was commitment-trust theory of relationships in business teamwork (Morgan and Hunt, 1994). Later the interest in the principles of trust and commitment reached other types of teamwork.

Communication was found to play a crucial role in teamwork (Conigliaro, 2014). Weinger and Blike (Weinger and Blike, 2003) has proposed that effective teamwork in the healthcare setting requires the presence of the “5 Cs” as outlined Common Goal, Commitment, Competence, Communication and Coordination. According to (Walther, 1997) (p. 67) “*computer-mediated communication does not differ from face-to-face communication in terms of the capability of social-information exchange*”.

There has been minimal research studying the development of human-IVA trust and commitment. Moreover, to the best of our knowledge, there is no study that has investigated the impact of IVA multimodal communication, i.e. verbal and non-verbal communication, on human trust in IVA and their commitment to accomplish the task.

2.7 Summary

In this chapter, we presented a brief introduction to the terms and concepts that are used in the rest of the dissertation. In the beginning of the chapter, we discussed the meaning of virtual environments. After talking about virtual environment, we discussed collaborative virtual environment that is the focus of this study. In the context of collaborative virtual environment, different roles of virtual agent were summarised. More attention will be paid to virtual agents in collaboration with humans; therefore, the main concepts of activity theory were introduced which will be used later as a foundation to understand the nature of the collaboration between a human and an IVA. A main element in Activity theory, i.e. multimodal communication, was introduced and classified. Speech act theory, a theory to evaluate the plausibility of the verbal communication of an IVA was introduced. As this dissertation aims to study the factors that foster human-IVA collaborations, these factors were classified into cognitive and personal factors. The cognitive factor, i.e. SMM, relates to the knowledge and reasoning, while personal factors such as personality traits, trust and commitment relate to individual preferences.

CHAPTER 3

Related Work

3.1 Background

The research objective of this thesis is to study the relevant features for designing IVAs that collaborate with humans. Additionally, this PhD study aimed to analyse the factors that influence human-IVA team performance. Collaboration is a complex activity and many factors will affect performance. While not claiming to provide an exhaustive review all possible aspects and influences, this chapter reviews those factors that have been identified and studied in this thesis. Each factor is reviewed in a separate section because, with some exceptions, existing research does not integrate the factors together.

This PhD study utilised AT as a framework to explore human-IVA teamwork. According to AT (see section 2.4.1), a collaborative activity includes three basic elements, i.e. subject(s), tools and motive(s). In addition, an activity includes three elements that are considered as a social base for the collaborative activity, i.e. rules, community and division of labour. We aimed to study human-IVA collaboration from the IVA's point of view. Therefore, the subject was the agent itself. As the decision and the plans of any IVA are created through agent architecture, agent architecture was the first branch to study. In addition to agent architecture, IVA is studied as a character with an individual entity; hence, personality was studied as a part of the subject. In line with using AT, tools were promoted as a means to achieve team motives. In Section 3.2 we review related agent architectures, particularly architectures that include personality.

Communication and using a language were noted as effective artefacts that a team could use. Multimodal communication and its two channels of communication, i.e. verbal and non-verbal communication, was found to leave a stronger impression than just one channel. Additionally, in the VE context, tools are limited to what activity contributors can use. Humans belong to the physical world, while IVAs belong to a virtual world. As a result, in the current study multimodal communication was adopted as an artefact that an IVA can use. As a conclusion, agent architecture and agent personality are to be studied as a representation of a subject. Multimodal communication is to be explored as a tool subjects can use to achieve their goal.

In addition to the basic elements of AT, (Engeström, 1999) proposed the importance of three elements of the collaboration activity. These three elements, i.e. rules, community and division of labour, form a social base to an activity. In Section 4.2.3, we demonstrate the rule that we need to study. These rules expressed the human's commitment to fulfil his/her promises and human's trust in IVA's decisions. In addition, in Section 4.2.3, we note that the dynamics of subjects' interactions need a study to better understand the community comprising humans and IVAs. These dynamics should include how team members during a collaborative activity share knowledge and common understanding that help to establish a community that work toward a shared goal. We found that the concept SMM best expresses the dynamics between team members (subjects) who work in a team (a community). A few research works have studied the rules that deploy human-IVA teams such as commitment and trust, and a few studies explored human-IVA team dynamics such as SMM. To conclude, we aimed to study subject (IVA), its architecture and personality. The tools, such as multimodal communication, can be used by a subject to foster a team dynamics of a community such as SMM. The rules that manage human-IVA team (community) were studied. These rules were found to be human's commitment and human's trust in IVA.

Section 3.3 presents AT as a base to understand the requirements of collaboration in VEs. In Section 3.4, research work that investigated human-IVA collaboration has been classified. Section 3.5 reviews research using SAT. The research work that studied the development of SMM between humans and IVAs is presented in section 3.6. Section 3.7 considers the use of personality traits in IVA research. Section 3.8 introduces the research work that studies trust and commitment between humans and IVAs.

Figure 3.1 depicts the four main research areas that are most relevant to our study; here we present a survey of those areas. The first area related to the studies about the agent architecture and the integrated personality traits. The second stream of study is about the tools the agent can use which is multimodal communication. The third branch of study relates to the rules the deploy human-IVA collaboration. While the fourth research area is about the rules that may manage human-IVA working in a team. As discussed in

Section 4.2.3, the selected rules are humans' commitment to honour their promises that are related to the shared goal. Another rule to study is human's trust in IVA's decision.

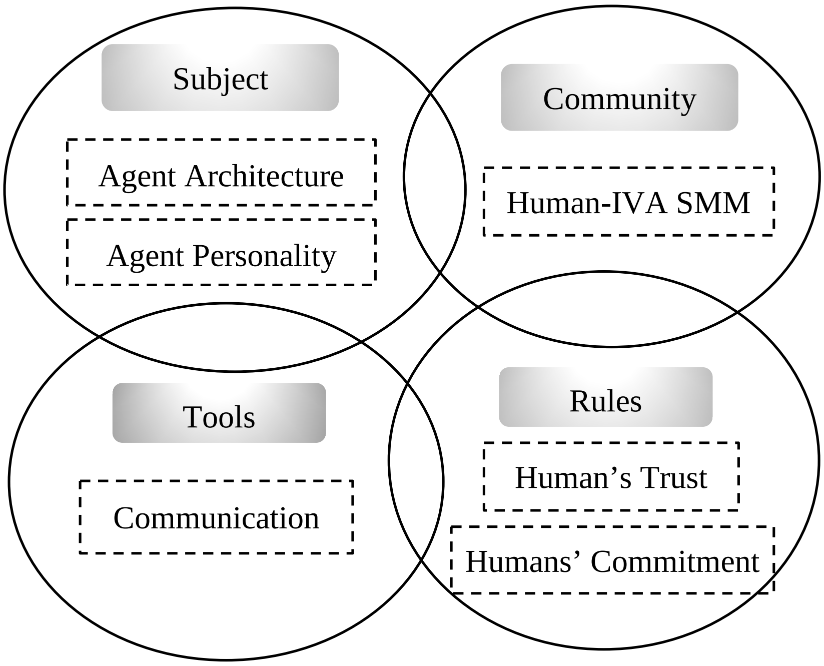

Figure 3-1: The intersection between related research areas

3.2 Agent Architecture

The agent architectures can be classified into architectures that model the agent's cognitive abilities and architectures that model non-cognitive abilities.

3.2.1 Cognitive-based Architecture

A number of agent cognitive architectures were surveyed by (Langley et al., 2009). These architectures include one or more of the cognitive capabilities including perception and situation awareness, memory processes, recognition, decision-making and prediction and monitoring.

3.2.1.1 Perception and Situation Awareness

Perception is the cognitive process through which the agent becomes aware of the surrounding environment and the changes that could happen. (Weyns et al., 2004) decomposed agent perception into three parts: sensing, interpreting, and filtering.

(Anderson et al., 2004) presented Adaptive Control of Thought-Rational (ACT-R). ACT-R consisted of multiple modules that are integrated to produce coherent cognition. ACT-R focused on higher-level cognition and perception and not perception or action, and so it needs modifications to be used as an architecture for agent design.

(Hayes-Roth et al., 1995) presented adaptive intelligent system (AIS) architecture procedural knowledge as a set of behaviours. Each behaviour has associated conditions that trigger that behaviour. The architecture currently has two layers/levels to control concurrent physical and cognitive behaviours. Behaviours at the physical level implement perception and action in the external environment. While behaviours at the cognitive level implement more abstract reasoning activities such as situation assessment, planning, problem-solving, etc. The results of cognitive behaviors can influence behaviors of the physical layers and vice versa.

3.2.1.2 Memory Processes

(Langley and Choi, 2006) presented ICARUS, a cognitive architecture for physical agents. In addition to including the cognitive structure which is similar to other architectures, i.e. (Laird et al., 1987) (Anderson, 1993), ICARUS included multiple memory structures and the related processes. Memory structures included dynamic short-term memories and long-term memories, which store more stable content. Additionally, ICARUS had *a goal memory* that contains the agent's top-level objectives; Conceptual *memory*, which contains long-term structures that describe classes of environmental situations; and a *Belief memory* that contains higher-level inferences about the agent's situation. ICARUS claimed to simulate the memory structure in human cognition.

3.2.1.3 Recognition

(Gratch, 2000) proposed Émile, a model of emotional reasoning. Émile is a plan-based approach to model how cognition influences one’s emotional state. This model had five separate stages of processing, each of which is informed by plan representations. First, Émile must represent plans and manipulate this representation to determine which actions will promote its goals. Second, the model must qualitatively appraise how events relate to its plans and goals. Third, the model must assign a quantity to the appraisal. Fourth, it must integrate a variety of appraisals into an overall emotional state. Finally, it must use appraisals to guide action selection and planning. Emile provided an architectural consideration to emotions and their effect on cognitive behaviour.

3.2.1.4 Decision Making

While all agent architectures include decision making, some architectures focus on decision making as one of their major design aims.. (Sycara and Zeng, 1996) presented a Multi-agent architecture that contains three types of agents: interface agent, task agent and information agent. Focusing on decision making, the role of the task agent is to formulate problem solving. Interface agent is resposible for receiving stimuli and express the results of task agent to agent's environment. The information agent is responsible for fetching and integating information that task agent requires to do its work.

3.2.1.5 Prediction and monitoring

(Yen et al., 2006) presented an agent architecture called Collaborative Agents for Simulating Teamwork (CAST) for agents working in teams. CAST seeks to permit agents that are working in teamwork to predict the information needs of teammates and proactively provide the required information. A CAST agent consists of six components: reasoning engine (RE), shared mental model (SMM), individual mental model (IMM), team process tracking (TPT), proactive behavior (PB), and goal management (GM). In a later extension, (Fan et al., 2005) presented the architecture of R-CAST which is the CAST architecture with Recognition-Primed Decision framework (RPD), a human-like decision-making model,for supporting distributed team decision making.

3.2.2 Non-cognitive-based Architecture

In addition to the cognitive-based architectures, some architectures focused on behavioural and personal aspects. These proposals attempted to envisage human-like properties to create not only an agent that can behave cognitively in a reasonable way, but also an agent that can behave in a believable human-like way. Among the non-cognitive aspects studied were emotion, personality, social relationships.

3.2.2.1 Emotion

FAtiMA (Fearnot AffecTIve Mind Architecture) (Dias and Paiva, 2005) (Dias et al., 2011) is an Agent Architecture that follows the OCC (Ortony, Clore and Collins) model of emotions (Ortony et al., 1988) for creating believable IVAs. FAtiMA includes planning abilities that use emotions and personality to impact on the agent's behaviour. FAtiMA consists of a core layer (named FAtiMA Core) comprised of the following components:

- Reactive Component: to determine the value of the OCC appraisal variables, it uses existing emotional response rules.

- Deliberative Component: handles behaviour directed by goals and includes planning capabilities to the agent.
- OCC Affect Derivation Component: produces emotions from the appraisal variables according to the OCC.
- Motivational Component: models basic human motivations and uses them to select between opposing goals in the deliberative component.
- Theory of Mind Component: models the internal states of other agents. This component identifies the attractiveness of an event for others.
- Cultural Component: integrates agents' cultural-driven behaviour of using rituals and cultural dimensions.

This architecture and all of the modules and extensions to add more emotional and cultural capabilities have made FAtiMA a noteworthy approach to design affective and cultural agents. Although emotions and cultural background may be among other factors that contribute to teamwork performance, these factors are out of the scope of this study.

3.2.2.2 Personality

(Maldonado and Hayes-Roth, 2004) presented a synthetic character, named Kyra, with autonomous behaviour and a personality traits model. Their framework includes ten key qualities: identity, backstory, appearance, content of speech, manner of speaking, manner of gesturing, emotional dynamics, social interaction patterns, role, and role dynamics. They presented the general framework to be modified to fit different situations; however, this framework focused more on the personality traits that would be used in cultural interaction rather than in achieving a task.

3.2.2.3 Social Relationship

One work that addresses the cognitive-social balance was the Synthetic Group Dynamics (SGD) model (Prada and Paiva, 2005) (Prada and Paiva, 2009). SGD is a model designed to manage group interactions in social groups of autonomous agents. The model focuses on small groups, without a strong organizational structure, that are committed to the resolution of collaborative tasks. This model divided to four levels: individual, group, interactions and context levels.

a) The individual level that defines the individual characteristics of each group member, such as their personality.

b) The group level that defines the group and its underlying structure.

c) The interactions level that defines the different classes of interactions and their dynamics.

d) The context level that defines the environment and the tasks that the agents can perform.

Although these four levels cover wide perspectives in collaboration context, a continuous monitoring to whether a shared understanding is developed was not considered.

3.2.2.4 Cultural Awareness

Rehm et al. (Rehm et al., 2007) presented a computational model called CUBE-G (CUlture-adaptive BEhavior Generation for interactions with embodied conversational agents). CUBE-G could be used to design an agent that has cultural awareness. CUBE-G consists of a sequence of processes: “Behaviour observation” to detect the user’s non-verbal behaviour, “Appraisal” using the observed behaviour to estimate the user’s culture, “Mode” is the matching between the user’s cultural background and the agent’s culture, “Simulation” is the process of calculating the agent’s cultural and non-verbal behaviour, “Behaviour display” is the process to show the agent’s non-verbal behaviour. This model is meant to create an agent that is able to perceive the non-verbal behaviour of the user and adapt the agent’s behaviour to match the user’s behaviour; nevertheless, the interaction between the agent and the user is not considered in this model.

Another proposed agent architecture was Culturally Affected Behaviour (CAB) (Solomon et al., 2009) that represented socio-cultural knowledge and reasoning. The aim of the model is to be able to encode data about people and cultures on cultural norms and stereotypes. The encoded data can be used to drive the behaviour of IVAs. (Mascarenhas et al., 2010) (Mascarenhas et al., 2011) (Mascarenhas and Paiva, 2010) proposed an agent architecture that integrates cultural aspects to communication cues such as gestures as well as to more high level behaviours, such as decision-making and emotional appraisal processes. The presented architecture integrates cultural aspects in the way the agent feels and chooses its goals and actions, based on anthropological studies. The proposed architecture was integrated with the FAtiMA agent architecture.

3.3 Activity Theory

3D VEs have been used for collaborative learning. An early example is the project of Virtual European Schools (VES) (Bouras et al., 1999) that simulates a classroom where several students are allowed to explore simultaneously the environment; students communicate with each other using a text-chat facility. More recently, C-VISions (Chee and Hooi, 2002) is a multi-user collaborative science education environment, where users interact with the environment to make scientific experiments. (Monahan et al., 2008) presented a collaborative multi-user virtual reality web-based system called CLEV-R which provides communication tools to support collaboration among students. (Zhi et al., 2006) presented an agent-based approach to design and implement virtual e-learning system. The system includes a student agent, teacher agent and instructor agent. The learner can log into the system, select learning material, and discuss it with other learners or teacher.

Gifford and Enyedy (Gifford and Enyedy, 1999) presented a framework using AT called Activity Cantered Design (ACD). Their proposed framework is based on three main concepts of AT: a) that activity is mediated by cultural artefacts; b) that activity must be analysed at various levels; and c) that internal activity (thinking) first occurs in the social plane (contextualized activity). In ACD, learners progress through activities as partial participants to full participants. (Lim and Hang, 2003, Jonassen and Rohrer-Murphy, 1999) argue that AT provides a powerful framework for analysing needs, tasks, and outcomes for designing constructivist learning environment and provide six steps for determining the components of the activity system of any constructivist learning environment. (Zurita and Nussbaum, 2007) identified six steps to propose a conceptual framework for mobile Computer Supported Collaborative Learning (MCSCL) activities. Liang et al. (Liang et al., 2009) further build on the six steps to define components and their relationships for collaborative network learning as follows. Norris and Wong (Norris and Wong, 2000) use AT to identify any difficulties that users may have when navigating through QuickTime Virtual Reality Environments (QTVR). The authors use a technique called the Critical Decision Method (CDM) that relies on the user recalling memorable incidents while doing a certain task. CDM is used to provide data to Activity Theory. (Miao, 2000) presents a conceptual framework for the design of virtual problem-based learning environments in the light of activity theory. We build upon this framework.

3.4 Human-Agent Collaboration

There are several approaches related to agent collaboration (Cabri et al., 2004), including Tuple-Spaces, Group Computation, Activity Theory and Roles. Tuple space is an unordered container of tuples. A "space" is a shared persistent memory in which clients may read, write, and take objects; a "tuple" can be thought of as a data structure or a set of attributes to be used as a template for matching. Tuple space provides a multi-agent like architecture, where agents can collaborate through writing, reading or removing tuples in the space (Xing et al., 2010). Tuple space mechanism could be centralized or decentralized. There are various implementations for centralized tuple space; the most well-known are Sun Java Space and IBM TSpaces (Lehman et al., 1999). LIME as an example of the decentralized tuple space which was implemented and extended by Murphy and Picco (Murphy and Picco, 2004).

Group Computation is another approach to address programming the reasoning ability of an agent's activities in a group (Hirsch et al., 2003). Activity Theory is used as a framework to design the mediated interaction that may happen between the user and computer system or between agents. There are a few projects (Ricci et al., 2003, Gifford and Enyedy, 1999) that present frameworks for collaborative activity in virtual environments. Some frameworks analyse needs, tasks, and outcomes for designing constructivist learning (Lim and Hang, 2003), others identify any difficulties that users may have when navigating through Virtual Reality Environments (Norris and Wong, 2000) and others design a virtual problem-based learning environments (Miao, 2000).

Roles are used to define common interactions between agents in virtual environment. Roles include all information and capabilities needed in a particular execution environment for agent to communicate and collaborate with other agents. One of the characteristics of a role-based collaborative agent is the separation in implementation between the agent and the roles that are going to be used (Cabri et al., 2004, Naoyasu, 2000).

While these approaches may be used in contexts involving humans, we see them as agent-agent approaches due to the use of shared spaces/processes that does not seem appropriate for human-agent collaboration. We admit that there may be shared understandings, even a set of common beliefs, desires and intentions, however, it is an oversimplification to bundle them together as one.

3.4.1 One-way Human-agent Collaboration

Other research work considers one-way interaction between the user and agent, such as making the agent a team leader. (Aguilar et al., 2006) presented a system that makes use of an Intelligent Collaborative Virtual Environment (ICVE) that incorporates a Pedagogical Virtual Agent (PVA) to assist the group during the execution stage of a Team Training Strategy (TTS). The system has four stages: the first Integration stage aims to integrate the human team. The next stage is Execution, where the team uses an ICVE for training to perform the target activities. In the Execution stage, a PVA plays the role of a team leader to help the trainees. In the third stage (Evaluation), the team members have to evaluate the execution from the previous stage. Additionally, they must find both individual and group errors. Finally, in the last stage (Improvement) the team members in a virtual setting cooperatively create a new strategy. Another feature of one way interaction is to make the agent answer the user's questions while navigating in a virtual world (Luin et al., 2001a).

Other research works limit the role of the agent in the collaboration environment to be a mediator while human users interact with the system. Yacine and Tahar (Yacine and Tahar, 2006) presented an architecture of a collaborative learning system which is composed of a set of artificial agents. The collaboration occurs between users using technical tools such as chat rooms, electronic mail and forums; the agents' role is to facilitate the collaboration between users and giving feedback.

Zhang et al. (Zhang and Li, 2009, Zhang et al., 2008) presented an approach to support collaborative design by providing intelligent multi-agent technology. The multi-agent system includes a User Interface Agent (IA), Assisting Agent (AA), Collaboration Agent (CA), and Mediate Agent. The role of the mediator agent is to facilitate the communication of each user with other users, while the collaborative agent's role concerns the collaboration process between users as the project progresses from the beginning of project design through to the end, as well as managing the other associated collaboration problems.

3.4.2 Two-way Human-agent Collaboration

There are few research works about human-agent teamwork. Miller et al. (Miller et al., 2000) presented, as introduced in Section 3.2.1.5, an approach called Collaborative Agent architecture for Simulating Teamwork (CAST). It is an agent-based approach to designing intelligent team training systems. Intelligent agents can play two different roles in the system as virtual team members or as coach.

A COLLaboration manager for software interface AGENts called COLLAGEN presented by Lesh et al. (Lesh et al., 1999) uses a plan recognition algorithm to reduce communication during human-agent collaboration. Attention, partial plans, and clarification were used to enable COLLAGEN-based agents to interact with humans in an intelligent manner. In a later work COLLAGEN was given a physical body (Mel) and gesture ability using BEAT framework (Patel and Hexmoor, 2009). Miao et al. (Miao et al., 2006a) adopted a multi-agent multi-user system to train learners to deal with abnormal circumstances while driving cars. Multiple users can drive cars in a shared virtual environment. The authors employ multiple pedagogical agents. The *coach* agent warns, directs, or comments on the user’s driving performance. The *situation creator*, a kind of pedagogical agent represented as a car that drives according to traffic rules and can deliberately create normal situations within a collaborative 3D car driving simulation environment. The *problem creator* agent that is represented as a pedestrian, a vehicle, a motorbike, or an animal to create abnormal and dangerous situations for drivers. Problem creator agent does not communicate directly with users however; it interacts with learners through the simulation environment. In Miao et al.’s work, both the trainee and the agent do not collaborate to achieve any task, but the user may be affected by the agent’s actions/responses. Another example of limited collaboration of an agent and a human was presented by (Hedfi et al., 2010) who developed a negotiation architecture for product design. When the user designs the product using a 3D interface, the agent will negotiate over the possible optimal design of the product. The system is an online negotiation framework.

(Babaian et al., 2002) presented writer's assistant system that works collaboratively with a human user. The collaboration in the system is represented in the system's commitment to shared goals of producing accurate, well-shaped citations. The system included communication between an agent and a human in both directions where the user provides query information and bibliographic choices to the system, the system provides query status and gathered information to the user. Although this work included two-way human-agent collaboration and communication, the agent was not embodied and so the social aspect of collaboration was not studied.

3.5 Speech Act Theory (SAT)

When it was first introduced, speech act theory was meant to be a tool to interpret the verbal communication that takes place between human beings. SAT has been used to analyse different forms of communication including questionnaires (Rose, 1992), written messages in forum posts (Chien and Soo, 2012) and email messages (Finin, 1994). Originally, SAT was introduced as an interpretation tool to analyse communication between humans. In the 1990s, artificial intelligence (AI) researchers adopted SAT as a design tool to work in the field of AI and inter-agent communication (Shoham, 1993, Sidner, 1994, Cohen and Levesque, 1997, Cohen and Perrault, 1979). SAT has been used as an integration approach to aid the design and interpretation of communication between humans and agents. In the majority of research work that combines SAT and agent communication, SAT has been used as a reference to design the agent's communication language, understand the human-agent exchange of messages or for analysis of mutual understanding.

(Finin, 1994) defined a well-known Agent Communication Language (ACL) called Knowledge Query Manipulation Language (KQML) that was based on speech act theory for intelligent agents. FIPA-ACL (FIPA, 2015) extended KQML and defined 22 performatives for agents to communicate. (Moreira et al., 2004), (2012) used SAT as a foundation for giving semantics to messages received by an AgentSpeak(L) agent in order to fill the gap concerning neglected aspects in agent programming languages such as communication primitives. Using speech-act based communication to enable the agent to communicate arguments between the agents to share its internal state with other agents and influence other agents' states, (Bedi and Vashisth, 2011) extended the operational semantics to speech-act based communication messages by an AgentSpeak(L) BDI agent in order to enable argumentation in cognitive agents.

(Jiang and Zhou, 2008) provide a general agent automated negotiation protocol based on speech act theory in MAS. (Chien and Soo, 2012) designed a speech act model using a dynamic Bayesian Network (DBN) that provided a communication bridge to help virtual agents to reason about different dialogue contexts that include norms, social relations, emotion, personality, intention or goals among agents in a dialogue scene. (Dragone et al., 2005) make use of the accurate and expressive communication mechanism of SAT in agent-agent communication in a multi-agent system. The agents send messages (such as requesting, ordering, informing or promising) of socially capable acquaintances in order to affect their mental states. The interacting agents used an ACL that was designed using SAT. (Cohen and Perrault, 2003) used SAT as a model to understand human-agent exchange of speech acts in a plan-based situation. (Traum and Allen, 1992) used SAT to analyse the achievement of a mutual understanding between participants in a conversation, i.e. grounding.

3.6 Shared Mental Model (SMM)

A limited amount of research has focused on human-agent communication during collaboration to help development of a SMM. Amongst this research work, Landman et al. (Landman et al., 2009) confirmed the importance of communication in creating a functioning SMM between teammates. Waller et al. (Waller et al., 2004) proposed various hypotheses about the performance of two different types of teamwork; the higher-performing crew versus lower-performing crew in non-routine, monitoring and routine tasks. The hypotheses included the effect of different teams on information collection, defining priorities, task distribution and developing the SMM. The study investigated the impact of different teams on the level of communication and attention to time.

Extending their agent architecture, called CAST (Yin et al., 2000), which enables a team of agents to establish a computational shared mental model, Yen et al. (Yen et al., 2006) studied the impact of SMM-supported decision-making on an agent's communication of required information with another teammate and the overall performance of a team of agents or humans. In addition, the authors assumed that designing agents with an understanding of the behaviour of individuals in a team of agents and humans could be used to address the challenges that face teams.

In order to design an agent's cognitive structure especially for human-agent teamwork, Fan and Yen (Fan and Yen, 2011) developed a system called Shared Mental Models for all - SMMall. SMMall is built using a hidden Markov model (HMM) to help the agent to estimate the status of its human partner's cognitive load, that is, the load a particular task imposes on the performer. In addition, it includes a user interface that proposes a representation of the team members' information space and enables them to share their beliefs. Based on how human improvisers construct SMMs in an improvised scene, Hodhod et al. (Hodhod et al., 2012) developed a computational SMM for interactive narrative agents and/or a human. The model consists of three components beliefs, commitments, and reasoning and decision making modules.

Many researchers present SSM for multi-agent systems. However these often are agent-only systems, for example the model of Xu and Volz (2003) (Xu et al., 2003) ignored the human in agents' teamwork. Having a SMM is common in multi-agent systems with agent-to-agent collaboration without a human component (Jones et al., 1999). In their study, Sycara and Lewis (Sycara and Lewis, 2004) investigated the importance of the agent in assisting human partners in their activities via communication. They claimed that the collaboration becomes more effective when the agent is designed from a human's need perspective and not agent's capabilities.

3.7 Personality Traits

Many researchers have been working on human-IVA relationships (Zhao et al., 2014, Stanković et al., 2014, Bevacqua et al., 2014). Numerous studies have considered whether human participants are able to perceive an IVA's personality through communication with the IVA. Personality in synthetic agents is present in several research fields such as entertainment, education and learning (Rickel et al., 2000) and multi-agent systems (Rizzo et al., 1997). (Doce et al., 2010) presented a model to create an IVA with distinguishable FFM personality traits. In their model, four cognitive/behavioural processes were identified that were strongly affected by personality traits. These processes were emotions, coping behaviour, planning and bodily expression. Personality traits were incorporated into the IVA to influence each of these processes. Users were asked to identify the different personalities of the IVA. Although users' classification was correlated with the original values for extraversion, neuroticism, and agreeableness, the results of the proposed model was only partially successful, since users failed to identify conscientiousness. Moreover, the model did not introduce personality in IVA's verbal communication.

Rushforth et al. (Rushforth et al., 2009) presented an initial attempt to build a personality framework for virtual characters that allows the domain designer to author different personalities for the same character. The results of two experiments showed that the presented framework had an impact on user perception of several aspects of the personality of the virtual character. Neff et al. exploited the extraversion (Neff et al., 2010) and neuroticism (Neff et al., 2011) traits of the FFM in multimodal characters evaluating the effects of verbal and non-verbal behaviour in personality perception studies. Cafaro et al. (Cafaro et al., 2012) conducted a study to investigate how IVA's non-verbal communication influenced the first encounters between humans and virtual agents. Each agent exclusively exhibited non-verbal cues (smile, gaze and proximity), and then participants judged IVA's personality (extraversion) and interpersonal attitude (hostility/friendliness) based on the non-verbal cues. The results showed that participants could form an impression about the IVA's personality from the observed non-verbal behaviour.

Despite the extensive body of research in human perception of IVAs' personality, little research has considered personality in a collaborative context. Among these few studies, Aguilar et al. (Aguilar et al., 2007) proposed a Team Training Strategy whose purpose was to promote social skills. In this training strategy, personality traits were assigned to appropriate team tasks. However, their study did not investigate the interaction between the personalities of both humans and IVAs.

3.8 Trust and Commitment in human-IVA teamwork

A number of studies investigated the factors that make a human trust an IVA. These studies in human-IVA trust could be classified into two classes. The first class investigated the influence of IVA personal features on human trust. While the second class explored the impact of the IVA exchanging knowledge or information with humans on building human trust.

The first class of studies focused on visible factors in IVAs to convey trust to humans. These visible IVA's characteristics, such as facial expressions (Oosterhof and Todorov, 2008) and verbal information (Bickmore and Cassell, 2001), play important roles in building levels of trust by a human trustor. Studies in this class include how the IVA is displayed to a human, i.e. spherical or flat (Pan et al., 2014) or if the agent matches the humans in their body shape, i.e. over-weight or skinny (Vugt et al., 2006). Normoyle et al. (Normoyle et al., 2013) explored the impact of the IVA's eye gaze on the humans' feeling of trust toward the IVA. The study investigated only one property that is related to the IVA, which is eye gaze. Although many studies showed a significant impact of IVA's physical characteristics on human trust, these characteristics were animation-related and affective and personality aspects were not explored.

The second class of research includes studies that explored cognitive-based human-IVA trust. This class of research inquired about the influence of cognitive-based activities such as exchange of information, negotiation, and small-talk on human trust in an agent. In studying agent-agent trust, Castelfranchi and Falcone (Castelfranchi and Falcone, 1998), (Falcone and Castelfranchi, 2001) presented a cognitive-based model of trust. This model emphasized the rational nature of trusting in an agent. Martínez-Miranda (Martínez-Miranda et al., 2008) created a model of the level of trust that an agent had in a human collaborator using verbal replies to mirror the cognitive state of the agent. Colburn et al. (Colburn et al., 2000) built a predictive model of trust build on voice for the purposes of guiding user interface interactions according to the user's mental state. In a study to discover the influence of an agent's use of small-talk on human trust, Bickmore and Cassell (Bickmore and Cassell, 2001) found there was a significant effect. Moreover, the study explored the impact of agent small-talk on different human personalities. The results showed that small-talk affected trust in the case of extravert users but not for introverts.

Although a few papers studied building trust between humans and IVAs, none of these studies explored the influence of the personalities of both the human and the IVA on building trust. Moreover, there is no study that compared between the cognitive-based and personality-based trust and explored which dimension is more dominant in building human trust in an IVA. The absence of studies was the motivation for the current study.

Studying the factors that impact on teams is not new to human teamwork (Hinds et al., 2000). Research work investigated how to foster trust in human teams (Hinckley, 1981) and strengthen commitment between teammates (Bratman, 1992). A number of studies have investigated commitment between a team of agents (Chopra and Singh, 2009) (Traum, 2008) or in multi-agent systems (El-Menshawy et al., 2013). These studies have taken advantage of being able to design agents that have shared understanding of the common goal as agents share the same world. However, when it comes to heterogeneous teams that include humans and IVAs, the mission becomes difficult as humans and IVAs have different beliefs and different intentions that drive them while participating in teamwork.

Very few studies have considered commitment to fulfil a joint task executed by a team of humans and IVAs. In one of these few studies, van Wissen et al. (Wissen et al., 2012) found that humans tend to be unfair and less committed to agent teammates. In their study, there was a simplified means of communication between humans and agents via exchanging text messages with requests/replies. The human's commitment was evaluated by calculating the ratio of fulfilled promises to give an agent a reward agreed on beforehand. Given the importance of commitment in human teams, commitment between agents and humans in heterogeneous teams has been understudied. The relationship between humans and IVAs has drawn researchers' interest (Sycara and Sukthankar, 2006) (Barange et al., 2014). There has been particular interest in the development of human friendship with emotionally-intelligent IVAs that can intentionally establish and strengthen social relations with other agents and humans (Dias and Paiva, 2013).

3.9 Summary

In this chapter, we presented a brief review of the research work that is related to this PhD study. Because we used AT as a framework to understand the nature of human-IVA collaboration, four areas emerged under the focus of our study. The first research area relates to the subject or the IVA and its architecture. Several agent architectures were classified and briefly presented to show that previous studies have been interested in designing an architecture to target different contexts that an agent may exist in. This classification showed the importance of having an architecture that comprises reasoning and planning, manipulating communication (tools) and monitoring the development of a SMM with human teammate (creating a community). Additionally, the first area of related work introduced the studies that investigated an IVA with personality. The second area of related work was agent communication. The related work was classified into two classes of studies: verbal and non-verbal communication. The third research area introduced was about the development of a SMM between human and IVAs while working in a team. A few studies investigated human-IVA SMM. These studies explored different aspects in this relationship; however, no of them investigated designing an IVA to foster the development of a SMM with humans. Hence, we tried to introduce the most related work to our study. The fourth research area presented in this chapter was the factors, i.e. commitment and trust that form rules in human-IVA interaction. Although, to the best of our knowledge, there is no similar study to ours, we needed to draw briefly the attention to the different research areas that are related to the current study.

CHAPTER 4

Approach

This chapter presents the approach used to achieve the stated research objectives (section 4.1). We propose that collaboration can be facilitated via the inclusion of agent technology where the agents become team partners. As a first step, we aimed to understand the nature of a collaborative situation. This understanding needs to include the elements that control the collaboration. From among the theories that aim to understand the nature of collaboration, we selected Activity Theory (AT) (Engeström, 2005), one of the most well-known and accepted collaboration theories, as a framework to understand the dominant elements that exist in human-IVA collaboration in VE. AT was initially presented to study the context of human collaboration. Later AT found its way into the field of human-computer interaction. Using AT as a foundation, we designed the Multi-Agent Collaborative VIrtuaL Learning Environment (MACVILLE) (section 4.2). AT provides a number of useful concepts that can be used to analyse collaborative activities and to create a conceptual framework for collaboration between humans and agents. Drawing on the MACVILLE framework, a number of factors relevant to collaboration between humans and agents were identified. Building upon the findings of MACVILLE, that will be described in this chapter, factors that could elaborate the collaboration between human and agents were identified. These factors were included in our agent architecture (section 4.3), agent behaviour (section 4.4) and communication model (section 4.4.1). In order to verify the proposed agent architecture and communication model, the essential features of collaborative scenarios have been identified and two virtual collaboration scenarios have been designed (section 4.5).

4.1 Thesis Research Approach

In this section, we outline the research approaches, each from a different stance, that were followed to investigate the potential role of an IVA’s multimodal communication on the development of a SMM with a human teammate and answer the research questions that were identified in section 1.4. Figure 4-1 shows a graphical representation of this approach, which is explained in the remainder of this section.

4.1.1 Research Stances

4.1.1.1 Conceptual Stance

From a conceptual stance, we addressed the gap by designing a framework that aims to understand the requirements of collaboration between IVAs and humans. In the literature, there are a number of frameworks proposed to understand the collaboration requirements between humans in the physical world (Prada and Paiva, 2005) (Prada and Paiva, 2009). In addition, while other researchers have presented agent architectures that support collaboration, they do no present a framework that studies human-IVA collaboration or employ a human collaboration theory to discover the features to be included in a collaborative agent architecture (Aguilar et al., 2006). To address this gap, we have used the human collaboration theory of Activity Theory to design a collaboration framework that aims to capture the requirements of human-IVA collaboration in the virtual world.

4.1.1.2 Architectural Stance

From an architectural stance, we designed an IVA that is able to do the following:

- Plan autonomously for a dynamic situation.
- Monitor the development of a shared understanding (SMM) with the human teammate while in collaboration context.
- Utilize multimodal communication to facilitate/direct the development of the SMM.
- Possess personality traits that influence both the agent's reasoning and communication.

4.1.1.3 Experimental Stance

At the experimental stance, we investigated the outcomes of the IVA architecture on human-IVA collaboration through studying the impact of related variables, including cognitive and personal factors. This study not only explored the effect of both cognitive and personal factors of IVAs, but also showed which one has the greater effect on the outcomes of collaboration.

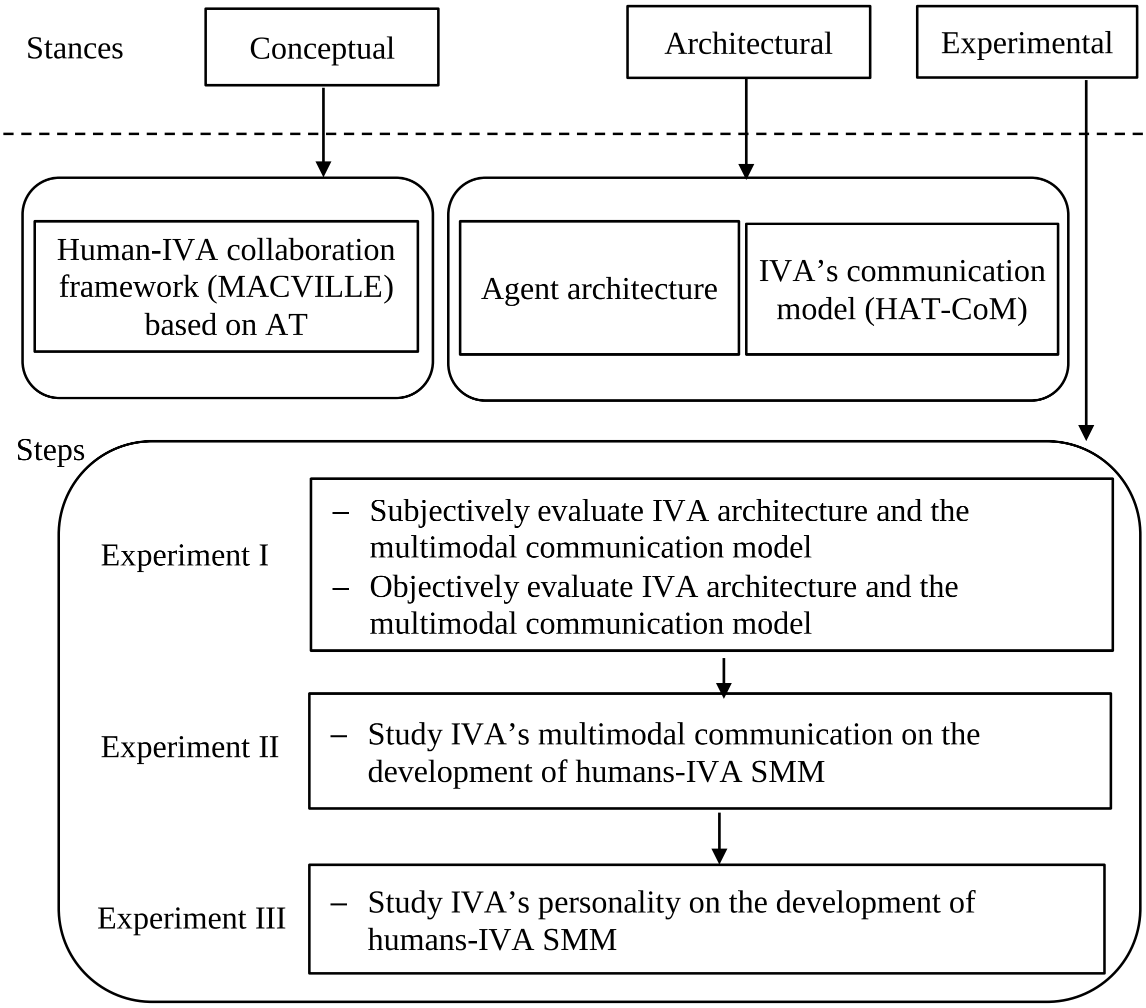

Figure 4-1: Research stances and the purpose of each experiment

4.2 MACVILLE Framework based on Activity Theory

This thesis proposes a framework for human-agent collaboration, known as MACVILLE. The proposed framework uses AT to analyse the elements of activities that may take place in a collaborative environment. Three important goals of activity theory to be utilized include:

1. Elaborating aspects of a collaboration activity to better understand its nature.
2. Analysing how the elements of a collaboration activity work together to better anticipate participants' needs and goals.
3. Identifying problems that may emerge during an activity to develop solutions.

Figure 4-2 shows that MACVILLE framework is divided into two cores, each core is meant to address activities conducted in VEs. These activities were divided into activities between humans collaborating in a VE and activities between a human and an IVA. Each of these activities were analysed using AT, as shown in. In this PhD study, we concentrate on the activities between a human and an IVA. In MACVILLE, each core has a part in the real world and another part in a collaborative virtual world. Besides AT, there are other theories such as situated action models (Lave, 1988) and distributed cognition theory (Flor and Hutchins, 1991) that aim to understand the collaborative context. A key characteristic of AT is the focus on argumentative analysis on the interaction between people and their mediated tools or artefacts which have been shaped by human activity. The widespread use of AT in the context of human-computer interaction demonstrates that the concepts in AT are easily applied for that purpose. We also found that in comparison to the other theories, the AT elements (i.e. subject, object, tools, community, rules, division of labour) were easier to extend to virtual worlds. For example, the subject

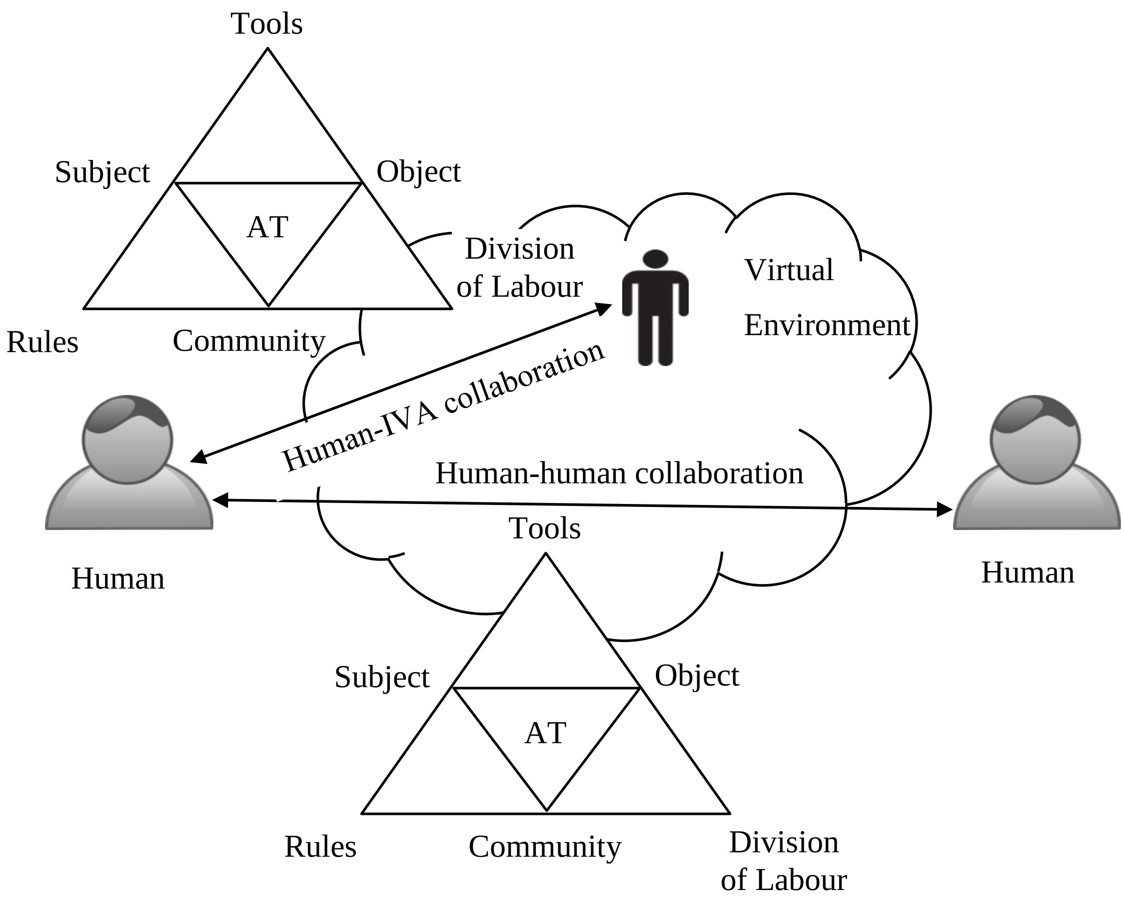

Figure 4-2: MACVILLE used to analyse human-human and human-IVA collaboration in a VE

represents the individual or groups of members engaged in the activities. The subject could be a human or a virtual human (agent). The object represents the motive or problem space and the goal of the activity to achieve the object. The tools represent the artefacts used in the human activity, including physical objects and other resources such as technological tools. In this thesis, the tools included the tools in the virtual world that both the human and the virtual agent could use to achieve the shared goal. Another reason to choose AT as a base to our framework is that it is a more matured and well-developed theory. We note that in Human-IVA collaboration, activities occur in the virtual and physical world, resulting in virtual and physical activities.

At the start of this thesis project, the focus was on human-agent collaboration. Thus, AT was used to design a Multi-Agent Collaborative VIrtuaL Learning Environment (MACVILLE). We later widened our focus to encompass human-IVA collaboration more broadly beyond the application area of education. This section presents MACVILLE that identifies and separates activities that can occur between humans or between a human and an IVA. Inside the dashed line in Figure 4-3, we find the activities that occur in the collaborative virtual world between human users and IVAs, discussed further in section 4.2.2. Outside the dashed line are the activities that occur in the physical world. While beyond the scope and further study of this thesis, section 4.2.1 provides some discussion of the activities that might occur in the physical world between humans.

4.2.1 The Elements of the Human-Human Activity over a VE

In considering the activities that may happen between human collaborators while working in a team using a VE, following (Engeström, 1987) (Engeström, 1999) the elements of AT may be represented as follows:

Subjects- the subjects in the physical world are the human teammate who collaborate to work in a VE. The collaboration could include collecting and/or sharing data, finding evidence, collaborating to design, or writing a document.

Tools- communication is a main tool that may be used by human teammates to organise their effort towards the shared goal. Communication could be either verbal-based or text-based. Recent technologies in VR enable participants to use various technologies to communicate while they reside in different places. Database and Internet protocols are technical tools used to connect different teammates who are working in a team. There are

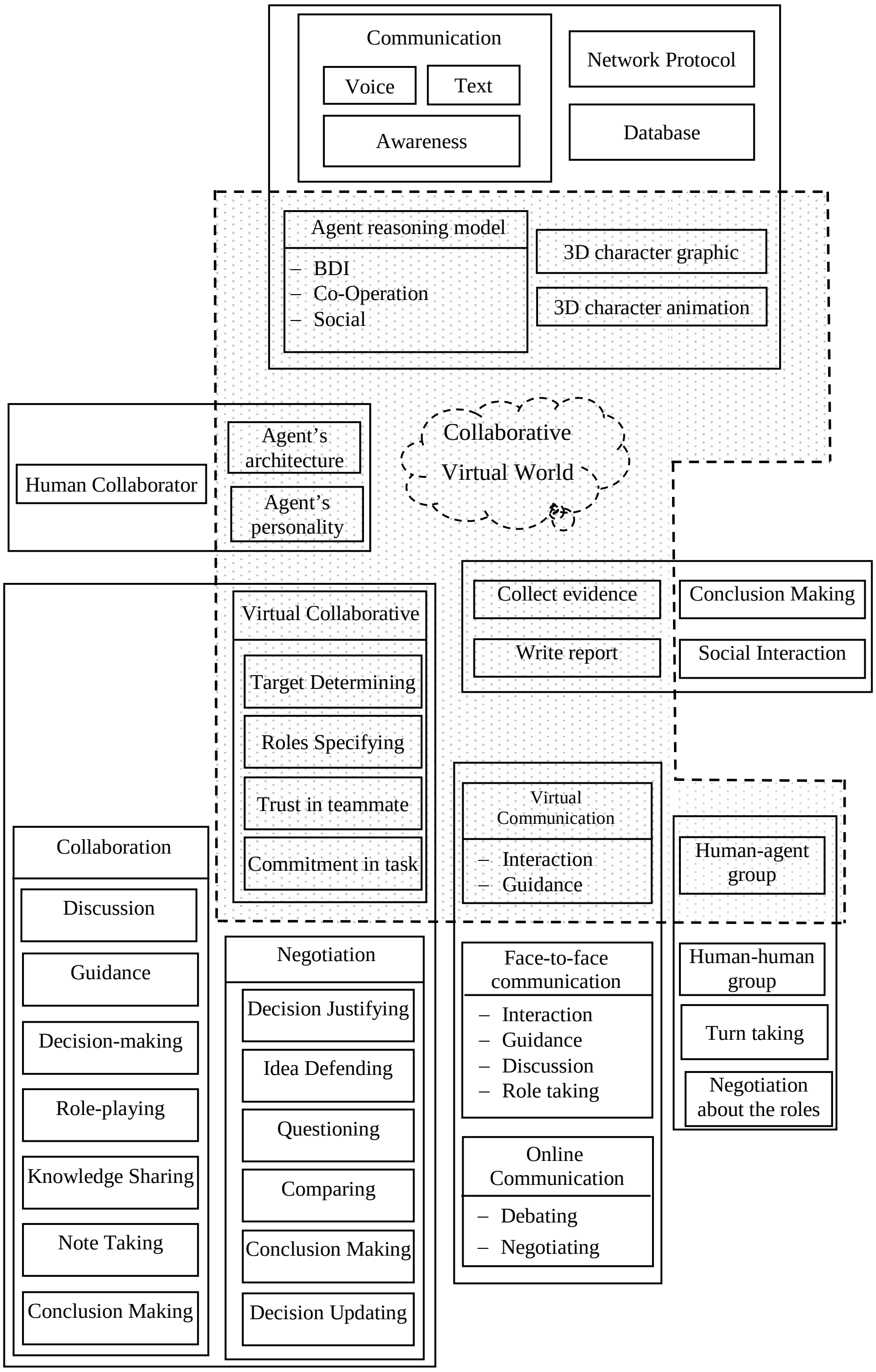

Figure 4-3: MACVILLE framework for virtual collaborative learning based on *Engestrom*'s expanded Activity Theory model

many differences between human-human communication and human-IVA communication. Perhaps one main difference is that the communication between a human and an agent is typically synchronous, that is to say a human and an agent in a VE communicate in real-time. Synchronous communication is possible because agents can reside in VEs and be available all the time. On the other hand, due to physical limitation human-human communication could be either synchronous or asynchronous.

Community-The group of subjects (actors) who work together in a VE in which collaborations takes place. This group may include a collaboration between individuals who know each other and so have prior knowledge about the capabilities other teammates have. This prior knowledge will help to foster the shared understanding of the task they work on. Collaboration may include individuals who do not know each other. Hence, they have to rely more on activity artefacts to get a better understanding of the knowledge they need to share and the capabilities of each team member.

Rules – The conventions and the codes that influence the work in a community. Concerning the conventions that manage human-human teams, the codes that influence any team may apply to work in a VE. These conventions include trust between members and individual commitment to work within a team. In addition to general conventions, there are rules that control the communication between participants.

These rules may be divided into two sections: the first section is the rules that control the synchronous communication between the two human collaborators who use the same virtual environment at the same time. These rules include discussions that may take place between the two partners, guidance concerning the shared activity, decision making, knowledge sharing between the partners, note taking and making conclusions. The second section is the rules that manage the asynchronous communication that may take place at a different time. These rules may include each group justifying his/her own decision, defending his/her idea if the other group comments on his/her contribution, or questioning the reasons of others' options.

Division of Effort –When it comes to human-human collaboration in a VE, the division of effort needs more regulation than human-IVA collaboration. The need of regulation emerges because human-human collaborative activity could be either synchronous or asynchronous activity. Synchronous collaboration requires some arrangements to guarantee that partners are using the VE at the same time. Asynchronous collaboration means each participant in the activity should be able to access a VE in their own time and see the contribution of other teammates, read their comments and feedback, make his/her own contribution and add comments and feedback to other teammates to read when they access the VE.

Object– Achieving the goal maybe similar in human-human and human-IVA collaboration. Nevertheless, the requirement of the activity itself may need careful consideration. There is ongoing research to make IVAs more believable, intelligent and comprise social and personal skills. However, there are still some limitations on the level of complexity and creativity that can be proposed or achieved in the activity goal.

4.2.2 The Elements of the Human-Agent Virtual Activity

Using the elements of Activity Theory, we can analyse the virtual activities that may happen between different agents and the human as follows:

Subject – subjects in the human-IVA activity are human(s) and IVA(s). A human in VEs could be represented from 1PP where s/he cannot see her/his embodiment in the VE. Another option is to make the human participant to see his 3D embodiment in the VE. Either the 1PP or 3PP perspective may also affect the perception of the surrounding objects in VEs (Hayes et al., 2006). Different perspectives tend to influence variant types of collaborative activities.

Tools – include the 3D graphic character, 3D character animation and agent-reasoning model. The 3D graphic of the agent should be interesting and believable so the human would be encouraged to collaborate with these agents (characters). 3D character animation is related to the reasoning model of the agent. The motion or animation is a reflection of what the agent reasons or decides to do. The reasoning model of the agent will follow the model of BDI that helps the agent in realising the environment around him and carrying out the required activity; the agent should realise the role of the human teammate in performing the activity and the intersection with his role. As the agent is going to collaborate with a human and work in a team, the agent architecture should integrate both the reasoning skills as well as the social and collaborative skills. Another tool that could be used in the VE is communication. Communication includes cues that happen between a human participant and an agent while performing the activity. An agent can express its intentions and decision via both verbal and non-verbal communication. On the other hand, a human can only express himself through verbal communication if the human interacts in a VE as a 1PP. If the human is embodied in a 3PP, then the human can express himself through multimodal communication.

Community - is the group or the context that includes the subjects. This context relies on the nature of the collaboration between the subjects. For example, if a human and an IVA need to work equally on an activity, the team form a community with members with equal roles. In another example, a human could achieve a task in a VE while an IVA could collaborate through monitoring and giving feedback. In this context, a human-IVA community is formed between a team member and a coach.

Rules - are those controlling the performance of the activity in the virtual world. The initial rule is to determine the target of each activity the human will participate in each location in the environment. Participants and agents should specify their roles in the activity, their roles should integrate together to fulfil the target determined in the first rule. The agent should be able to check the human teammate's behaviour and progress in achieving the activity. Additionally, the rules related to the reasoning model decide the optimal decision the agent should take.

Division of Effort- is the division of roles in the virtual world. Human-agent group will be responsible for doing the virtual activity.

Object- the object in the virtual world would be to achieve the shared tasks between a human and an agent; combining the objects of the virtual and physical activities will lead to reaching the outcome of real world activity.

4.2.3 AT Utilization in the Current Study

To elaborate human-IVA collaboration aspects, understand how the elements of a collaboration activity work together and identify problems that may emerge, we extended AT to include the elements of human-IVA collaboration Figure 4-4.

Recall that in section 2.4.1, the following elements of AT were introduced. The Subject(s) of an activity is the person or people who are directly collaborating in the activity. The subject provides a point of view for studying the collaborative activity. The Motives direct the subject's activities towards achieving the motives. Motives may include the Object of the activity, which is a short-term result, and the Outcome, which is a long-term result. The Subject(s) use Tools to get their object(ives) done and achieve their target Outcomes. The subjects are stirred to use these tools because they will help the subjects to achieve

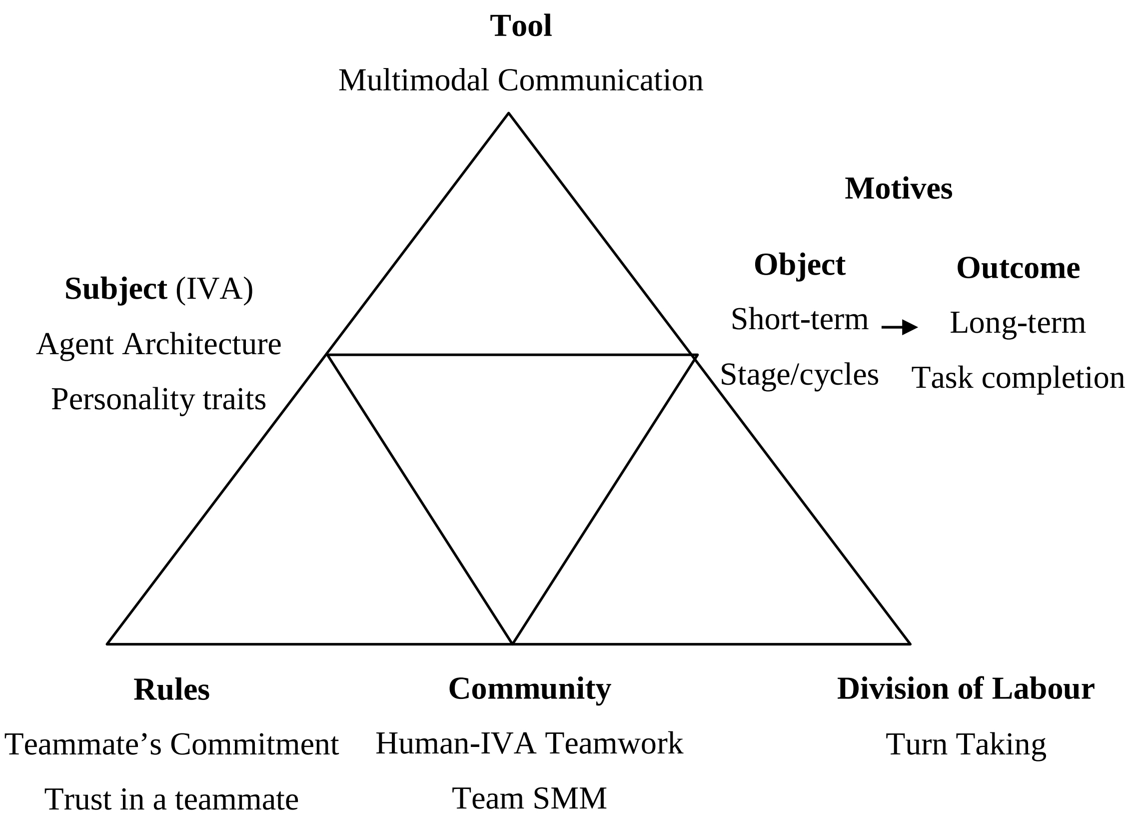

Figure 4-4: Using Activity Theory (AT) to study human-IVA collaboration

their motives. The Tools may include both physical tools such as computers and other artefacts, as well as non-physical tools such as multimodal communication and skills.

The more the subjects use a tool in their collaboration, the more they use the tool subconsciously. Tool usage only moves back to conscious use if there is a new challenge and a new required action with that tool.

(Engeström, 1999) refers to the three elements at the base of AT triangle, i.e. Rules, Community, and Division of Labour, as the "social basis" of the activity. These three elements provide a social context for the collaborative activity. Rules may include codes and conventions such as mutual respect, trust and agreements that team member follow to achieve their goal. Community is a group of subjects that have something in common that makes them a distinguishable group that have a shared goal.

In this PhD study, AT with its elements were applied to the human-IVA collaboration context. As AT is an analysis of the activity from one of the subjects' point of view, Human-IVA collaboration will be analysed from IVA point of view. The tools used will be the tools an IVA can use. The rules will be studied or observed as the conventions that an IVA tends to foster such as human's commitment to honour her/his promises or human's trust in an IVA. The third element is division of labour that describes how the work in the activity is divided between the subjects of one activity. In our study, the division of labour was kept to be simple so it would not interfere with the other element. As the human-IVA teamwork (di) consists of just two members, turn taking is adopted as a simple division of labour. Based on AT, we aimed to understand human-IVA collaboration. This situation includes the following three basic elements.

The first basic element is an **agent** where a subject is represented as an agent. This agent is an instantiation of an agent architecture that gives the agent the planning and decision-making ability. In this study, we needed to design and implement an agent that uses a tool to support creation of a community with the human teammate. Additionally, the subject (IVA) includes the aspects that may influence subject decisions and tool selection. Personality trait is considered a major factor that influences subject (IVA) decision making as well as the IVA's selection of appropriate multimodal cues during the collaboration activity. In this PhD study, we selected two personality traits according to FFM, i.e. extraversion and agreeableness. These two personality traits were found to affect working in a team. It is note-worthy to mention that agent personality traits influence not only the planning and agent's decision-making, but also the selection of the artefacts such as communication. The agent's personality should influence both the selection of verbal cues and the expression of the non-verbal cues.

The second basic element is the **tool**. In this PhD study, the tool that we studied is multimodal communication from the agent point of view. Multimodal communication will include the verbal messages and the non-verbal cues that an IVA can produce to express its thoughts, recommend a step to be taken or give feedback to a teammate.

The third basic element is **motive**. The motive is the purpose or the reason for the activity and it could be short-term (object) or long-term (outcome). In the current study, we designed two virtual scenarios that required a collaboration between a human and an IVA in real-time, see Sections 4.5.1 and 4.5.2. Each virtual scenario is divided into stages or cycles. Each stage or cycle is considered as an object (short-term motive) and the completion of all the stages should form the outcome of the activity (long-term motive).

In addition to the three basic elements, the activity triangle, according to (Engeström, 1999), has three elements that provide a social base for collaboration. In this study, the following three social base elements were used.

The first socially based element is **rules**. Among several social codes and conventions that influence collaborative activity, we investigated the role of two rules: commitment to fulfil promises that are related to achieving objects (Smith, 1996) and trust in the teammate's abilities and decisions (Critchley and Case, 1986). These social rules were studied from the IVA point of view, or in other words, the IVA's view of the human's commitment to achieve his/her promises to complete actions to complete objects and human's trust in IVA's abilities and decisions. Regarding team members interpersonal relationships , trust is considered a very important factor (Costa, 2003), as working in a team would influence members' trust in others. Trust can even be treated as representative of all interpersonal relationships (Bligh et al., 2006).

The second socially based element is **community.** In our study, the community is the human-IVA team. This heterogeneous team is needed to study what are the dynamics that may exist between human-IVA teams (community). These dynamics include the skills team members have, shared knowledge about the motives and the knowledge about the other team members (Cannon-Bowers et al., 1993).

The third socially based element is **division of labour**. In our study, the work of activity is divided as turn taking. The stages or objects of the activity are organised so that a human and an IVA will take turns to negotiate with the other teammate and make a decision on how to complete that stage.

4.3 Agent Architecture

While a number of agent-based architectures for collaboration have been proposed (Chuan et al., 2008, Liu and Chee, 2004, Marin et al., 2004, Liu et al., 2010, Jakobson et al., 2008, Zhang et al., 2008), these architectures either focus on the reasoning module (core) of the agent neglecting to address the social and collaborative aspects of the agent's behaviour e.g. (Zhang et al., 2008), or the collaboration is directed by goals without consideration of the performance of individual peers in the team (one-way human-agent collaboration, e.g. (Jakobson et al., 2008)). In this section, we propose our architecture for agents in a collaborative environment. We also briefly present how we intend to implement and evaluate the architecture.

To manage agent reasoning and human-IVA collaboration and communication we have designed and implemented an agent architecture and supporting communication module. Figure 4-5 shows a high-level integration of key components of our agent architecture, including reasoning, memory and social processes (will be presented in details in Figure 4-6), and the communication model (will be presented in details in Figure 4-10). We used a pipes-and-filters architecture to design our agent's cognitive and social capabilities. This architecture is suitable in a situation where a human and an IVA take turns to achieve a target where the agent has to take known steps but the input and the output of each step is non-deterministic and unpredictable. Additionally, the pipes-and-filters approach supports our communication model that requires as input the output of agent cognition. This output was shared on a blackboard with the communication model to express verbally and non-verbally the intention of the agent. A blackboard is suitable for sharing memory between the agent architecture and the communication module because it is feasible for the agent to have access to the stored states and knowledge. Using blackboard technique, an agent is able to transfer its decisions and recommendation to humans and hence build a SMM. However, we note that use of a blackboard is not suitable for sharing knowledge and state between the human and the IVA, as it is not possible to directly access the human's mind. It is for this reason that our work focuses on development and maintenance of a shared mental model for determining what the human may be thinking and if it is consistent with the agent's reasoning.

Among the different collaboration features, we target human-agent two-way collaboration. Agents should combine both reasoning and social elements, and they

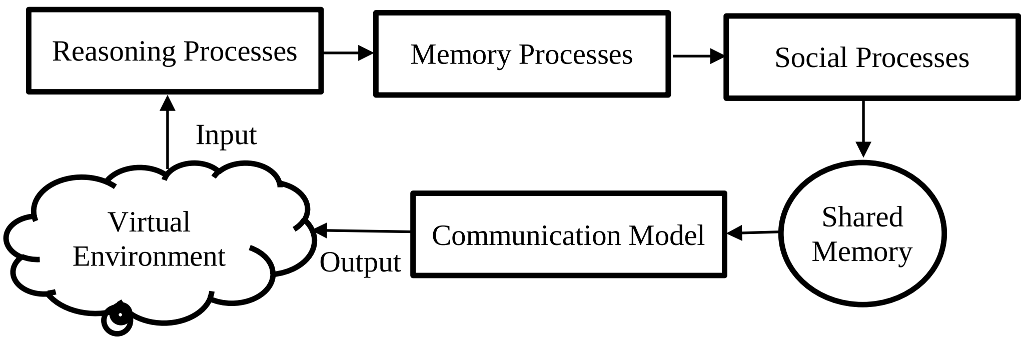

Figure 4-5: High-level agent architecture with pipe and filter design and blackboarded with communication model

should be aware of the human’s activity and adapt its own performance to the changes in the human’s actions. Furthermore, the collaborative agent should be aware of the partner’s attitude and their objectives to be achieved. The collaborative agent should contain components to handle their cognitive processes including memory and its related processes as well as the social and collaborative processes.

In the literature, the previously presented intelligent agent architectures were designed to be used in situations that did not involve two-way agent-human collaboration, and the embedded processes in the reasoning core of their agent architectures were designed to be general purpose. The proposed novel agent architecture will combine a social and collaborative core in addition to the reasoning core. The social and collaborative core will enable the collaborative agent to be aware of the human’s activities while achieving a task, and to give appropriate feedback such as encouraging the user when collaboration is occurring or urging the user to collaborate when insufficient collaborative activity is taking place. Besides the novel collaborative core, the proposed agent architecture will adjust the processes included in the reasoning core of agent to be suitable for collaboration with a partner. Our presented agent architecture is a conceptual model, not a physical/implementation model. The architecture components are abstractions that may be realised and made concrete through a wide range of possible implementations. As shown in Figure 4-6 the agent architecture is comprised of a number of modules. These modules are responsible for receiving the details about the current collaborative situation from the virtual environment and managing the decisions required.

The Intelligent and Cognitive Processes this component includes two processes: Memory and Cognitive. The memory or the knowledge base is where the agents store information, knowledge and experience. There are two processes related to the memory: *Knowledge Integration* to add new experience to the stored knowledge, and *Information Retrieval* to get the appropriate piece of information to the current situation. Retrieving information from the memory could be done during any process.

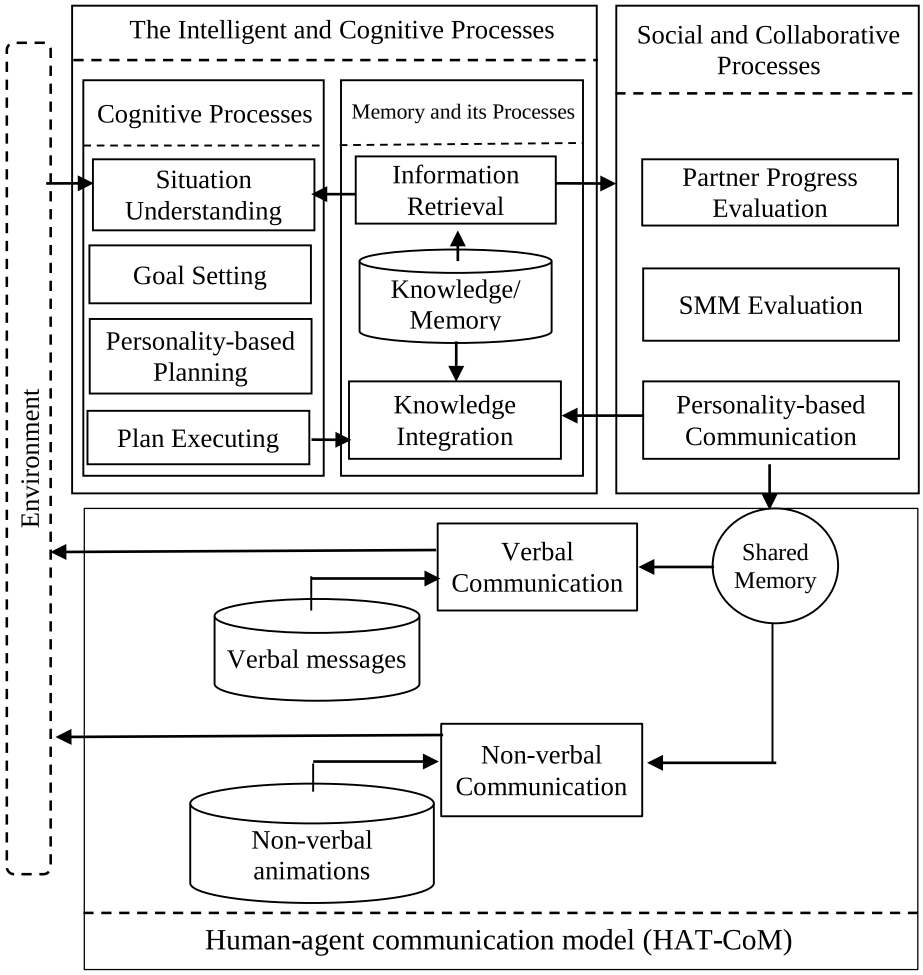

Figure 4-6: A proposed architecture for a collaborative agent

Cognitive Processes include the reasoning model that the agent has to perform in the situations s/he faces. The Cognitive Processes begin with understanding the situation and determining if this situation has appropriate knowledge in the memory or it is a new situation and the agent will have to do inference on the situation. As the proposed framework of collaboration between a human and an agent includes a role to be played by the agent, the agent should have the ability to plan what activity to do and what is his share in this activity and what is human's role. After specifying the role the agent is going to play, s/he needs to plan how this share in the activity should be done. By knowing his share in the activity, the agent should have solutions for possible problems s/he may encounter. At the end of the reasoning processes, the agent may add a piece of knowledge that is not in his memory for later use; this process is similar to learning.

Social and Collaborative Process One of the most important elements of working in a team is social interaction with other teammates. The agent in a collaborative environment should have the ability to socially interact with a human and encourage collaboration together. The agent has a mechanism to identify the social properties of human teammate. *Partner Progress Evaluation* process is a continuous process that the agent should do during execution of the collaborative activity with a human; the agent should make sure that humans are participating with it. The agent is going to evaluate the progress of the task relying on another two processes: planning process to determine the share of the agent and the human and a process to acquire the properties of human that may lead the virtual agent to adopt different evaluation criteria. At the end of the social and collaborative process, the agent will need to take a social action such as encouraging the human to do more effort, or congratulate the human for his hard work.

A sequence diagram is presented in Figure 4-7 to demonstrate the interactions between these modules and the tasks they perform. Each module is represented by a class/object. Virtual environment parameters are perceived by the *situation-understanding* module where these parameters will be collected and stored in a data structure. These data structures will be passed to the *goal-setting* module. The goal-setting module contains the main goal of the task to be achieved in the virtual environment; and the sub-goals to be achieved to reach the main goal. However, as the virtual environment is dynamic, the sub-goals need to be dynamically planned each time there is a change in the environment. The task of the continuous planning is achieved by the planning module. *Planning* receives the updated sub-goals along with the current parameters of the virtual situation and calculates the best way to achieve the sub-goals. The generated plan is stored in the knowledge repository of the agent in knowledge/memory class. The results of calculating the best way to tackle the sub-goals are stored in knowledge/memory repository.

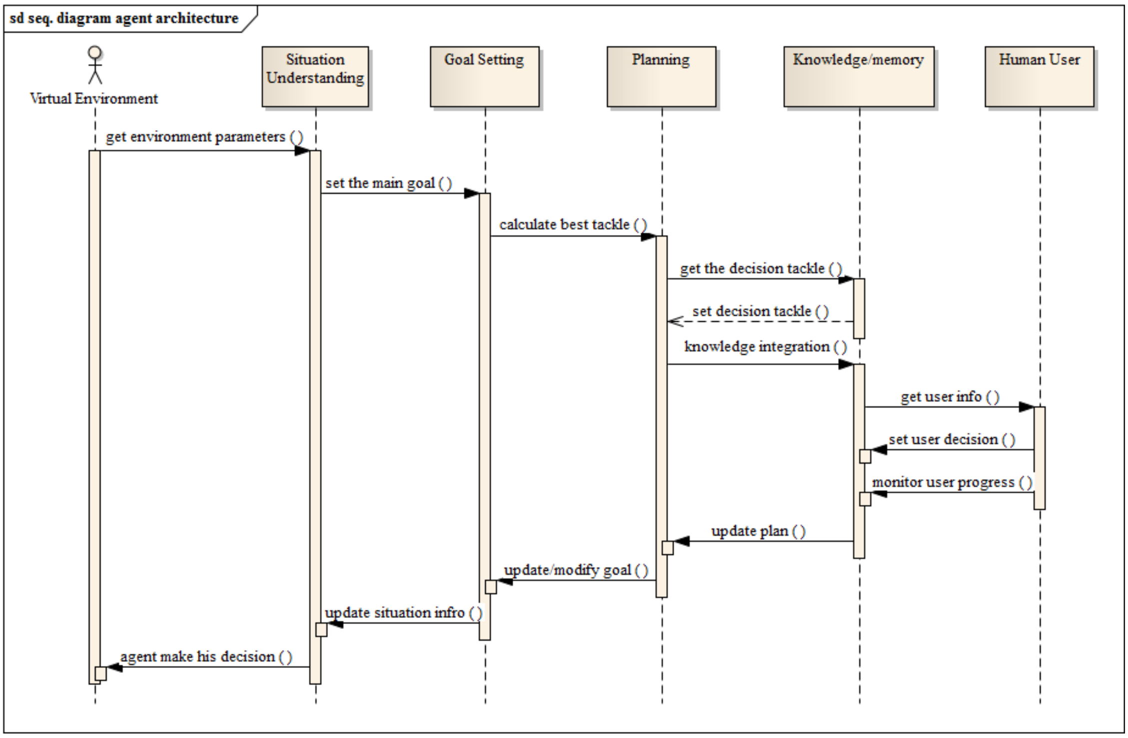

Figure 4-7: Sequence diagram to show the interaction between the modules of the agent architecture

4.4 Agent Behaviour

The integration of the inner reasoning and multimodal communication is represented in Figure 4-8. The initial state of the agent is to wait for the user's decision/selection. The initial state is followed by continuous verbal and non-verbal prompting to the user to take his/her decision. When the human user takes his/her decision, the agent will update its knowledge about the current environment and will make/select a plan to take its own decision. To investigate whether the human user shares the same understanding of the collaborative situation, the agent will ask the user to optionally give some recommendations for the agent to help it to take the decision. The match between the agent's plan and human teammate's recommendation is calculated by the agent. When the human offers/selects a recommendation to the agent, the agent selects and modifies an appropriate response, e.g. supportive/confirming statement or statement of disappointment, depending on the match with the agent's plan. Additionally, the agent will give a reason for the response it has provided. Later, the agent will achieve its turn and begin a new round of achieving sub-goals.

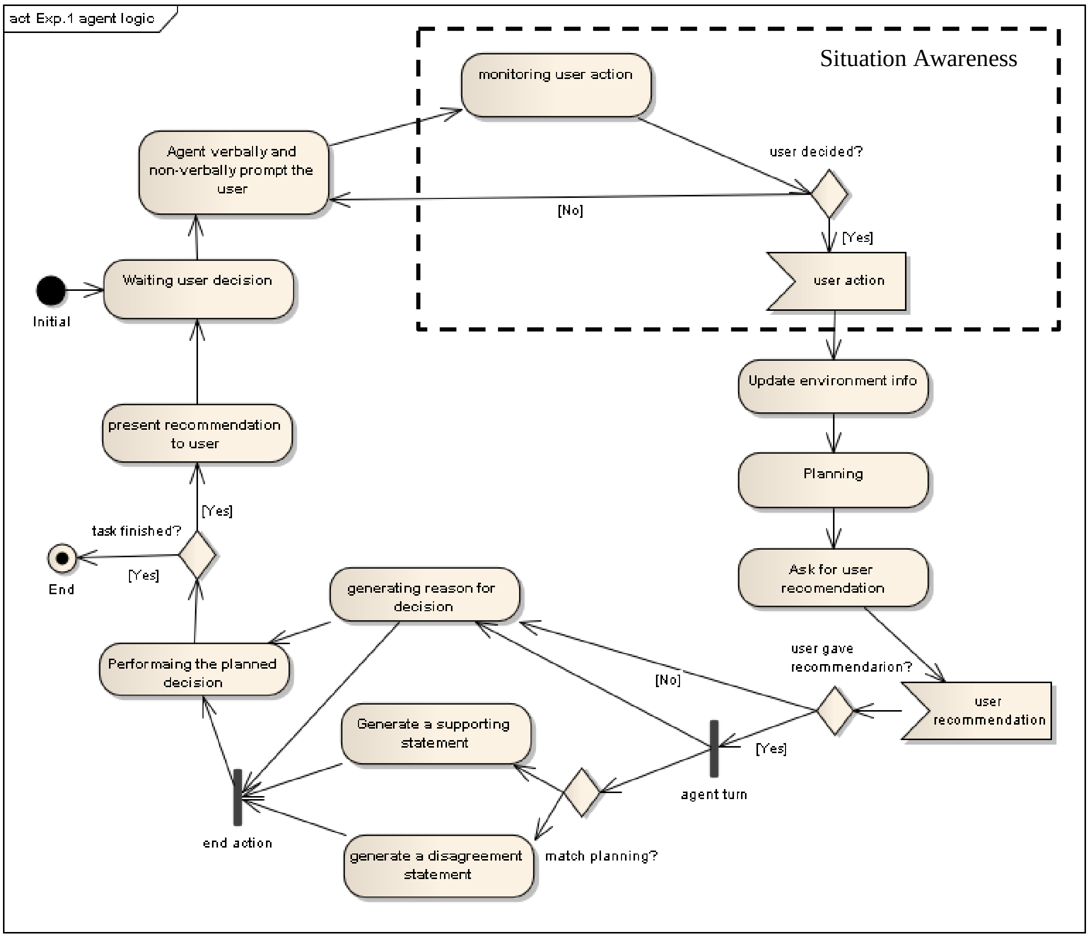

Figure 4-8: Activity diagram of the proposed agent architecture

Some research has focused on extending a BDI-agent to communicate with other agents and humans in the MAS in a human-like manner. Using middleware to facilitate agent communication, (Oijen and Dignum, 2012) present a model for realising believable human-like interaction between virtual agents in a MAS, but their work handles the communication between agents in the same virtual environment, where agents share the same resources. (Traum et al., 2003) sketch a spoken negotiation model for a peacemaker scenario to handle communication involving tasks in hybrid human-agents teams designed for training purposes.

We proposed a human-agent communication model in a human-agent collaborative environment; see Figure 4-10. This communication model extends an agent planner, and so every response made or perceived by the agent depends on agent planning. The communication model includes both verbal communication (i.e. textual communication) and non-verbal communication (i.e. behavioural communication).

4.4.1 HAT-CoM

HAT-CoM is a communication model, see Figure 4-10, which translates the agent's plans into multimodal communication acts. HAT-CoM receives information about the current collaboration situation from the agent architecture via the *Situation Awareness* module. The situation awareness module is modelled as an interface/boundary/view/presentation layer class. As shown in the sequence diagram in, Figure 4-9, the information passed includes the tasks achieved (array tasks), whether the human user accepts or rejects agent recommendation and the possible planned tasks (array tasks). As shown in Figure 4-9, the *Situation Awareness* class is modelled as an interface class that takes both verbal and non-verbal input in parallel (modelled by the *par* fragment notation) from the virtual environment which it passes to *message selector* or *animation selector*, respectively.

To manage verbal communication, *Message Selector*, modelled as a control class, uses the information received from the *Situation Awareness* module. The information received includes the state of the current situation such as the coordinates of the agent and the number of sub-tasks left, the recommended choice/decision to achieve the task and the unhelpful decisions toward task completion. The *Message Selector* will retrieve the suitable message template from the *Message Pool*, which is modelled as an entity class

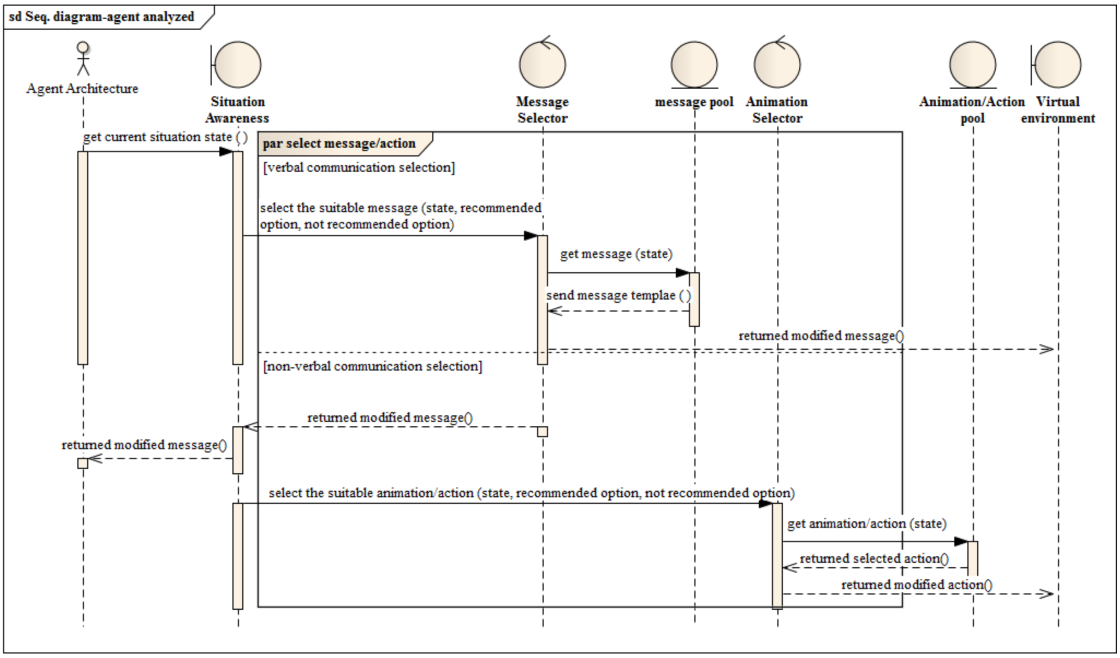

Figure 4-9: Verbal and non-verbal human-IVA communication in HAT-CoM

in Figure 4-9. After the process of message retrieval, the *Message Selector* will modify the selected message to be suitable to the current situation and send it to the virtual environment interface.

Regarding non-verbal communication, the *Situation Awareness* process will pass information to the *Animation Selector*. The same parameters are passed as for verbal communication. The *Animation Selector* will retrieve the suitable animation/action template from the *Animation/Action Pool*. After the process of animation retrieval, animation selector will modify the selected animation/action to be suitable to the current situation and send it to the virtual environment interface.

4.4.2 Textual communication

Interaction between the human and the agent involves alternating between textual and behavioural communication. That is to say, the human will send a request message to the agent, and the agent will reply with acceptance or rejection depending on its plan. The agent may also send a request message to the human user asking for help to achieve the task. The human user may reply with acceptance or rejection. The rejection of the agent's request by the human user will lead the agent to modify its plan to the new state of the task. Behavioural communication is also handled in an alternating fashion, and it relies on the agent planning process. As part of behavioural communication, the agent has to monitor the surrounding environment, observe the actions of the human teammate and continuously adapt his/her plan to the new changes.

The agent-human textual communication model (see Figure 4-10) enables the agent to ask the human user to take certain steps to help in achieving the targeted task according to the plan of the agent. The request of the agent will rely on the plan created by the agent planner. The agent will get the answer from the human user either to accept or to reject the request. If the answer of the human user is to accept the agent's proposed step, the agent will go on carrying out the plan and at the same time the agent will give feedback thanking the human for accepting the request. On the other hand, if the answer is rejection, the agent identifies the new action of the human via the behavioural component of the communication model, and then the agent begins changing the plan in accordance with the new action of the human.

Concerning human-agent textual communication (see Figure 4-10), the human can ask the agent to take a certain step to help in achieving the targeted task according to the point of view of the human. When the human selects a request and directs it to the agent, the agent begins the process of *Request Understanding* to identify which request was issued by the human. After identification, the request agent will understand the intent of the human from their request. In order to give a response to the human request, the agent should check his plan to make sure if the request matches the plan. If the request matches the plan, the agent will accept the human request and send an *Expressive* illocutionary act to show that the human's request match agents' intention. If the request does not match the agent's plan, the agent will send *Declarative* illocutionary act to show that the human's requests are either inappropriate to the current situation or not in agent's plan.

To track the agent's role in the communication model, the agent has the option to communicate with a human through doing actions in the VLE, or via sending text messages that contain a request and instructions for the human to follow in order to help achieve the shared task between the agent and human. In the Textual Communication (agent-human) module in Figure 4-10, the agent will sense the information about the current situation through the process *Situation Awareness* and see the next step a human may take to help in completing the task. Based on the information acquired about the current situation, the agent will select and adopt the most suitable request from a pool of requests. The concept behind behavioural communication is that when one partner exhibits a particular behaviour (actions), the other partner will observe the action and deduce what was meant by this behaviour and plan of the partner. In the Behavioural Communication (agent-human) module in Figure 4-10, the agent can communicate with the human via taking a step towards achieving the task and let the human deduce what the agent was thinking.

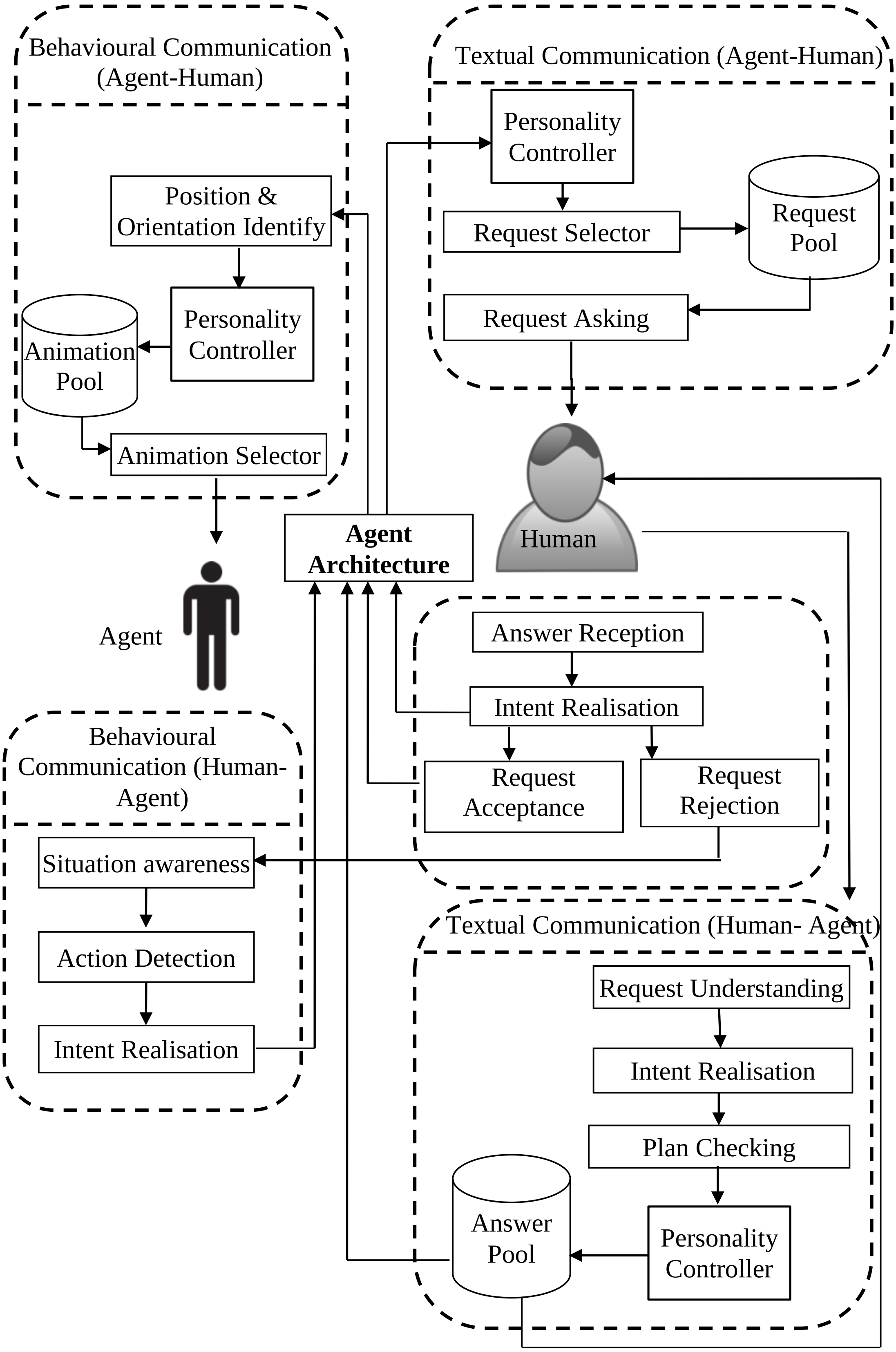

Figure 4-10: The proposed human-agent communication model (HAT-CoM)

To track the human's role in the communication model, the human has the option to communicate with the agent through doing actions in the VE, or text messages that contain requests for the agent to perform. In the *Textual Communication* (human- agent) module, the human will be able to send a message to the agent asking him/her to achieve something that the human thinks it is important for completing the final task. When receiving the human request, the agent will first seek to understand the meaning of the text message through the process *Request Understanding.* After understanding the message, the agent will have to understand what he/she has to do to fulfil the request of the human that is through *Intent Realisation.* After understanding the message, its content and what the agent has to do, the agent should check its plan to see if the request step from the human will match its own plan. Based on the match/mismatch between the human request and the agent's plan, the agent will select the most appropriate reply through *Answer Selecting*. In the *Behavioural Communication* (human-agent) module, the human will convey his/her thought about achieving the task though taking a step and letting the agent monitor and realise what the human is thinking about. When the agent observes the human action, the agent will realise the current situation through *Situation Awareness,* then the changes made by the human will be detected, and the meaning behind the action of the human will be realised through the process *Intent Realisation*.

4.4.3 Behavioural communication

In behavioural communication, both the human and agent will understand what the other did by observing his/her actions while achieving the shared task. It may be easy for the human to understand automatically what the agent aims to do from observing his current actions, but in the case of the agent, the agent should follow some process to have an idea about the intent of the human. Sometimes the agent takes an action without saying something and hence this action will be a non-verbal communication in itself. In this PhD study, agent's action taking is considered one of the non-verbal cues. The first process is *Situation Awareness* where the agent has information about its own location coordinates and orientation, the human's location coordinates and orientation, how many steps were undertaken and whose turn it is to take the next step. In the *Action Detection* process, the agent will be able to detect any changes in the human's location and orientation and the action taken by the human as visible in the virtual environment (VE). Based on information collected in the *Action Detection* process, the agent can understand the intention of the human user and determine whether this intent helps in achieving the agent's plan or the agent may have to use textual communication to direct the human to take a specific step. Hence, human intention realisation in the light of collaborative situation refers to the agent's realisation of whether the human accepts the agent's request and recommendations and so the agent will conclude that human as a productive teammate. Alternatively, if the human frequently rejects the agent's requests, the human will not be considered as a productive teammate. Depending on the agent's conclusion, the agent will adapt how they interact and communicate with his human teammate.

4.5 Two Virtual World Scenarios

Churchill and Snowdon (Churchill and Snowdon, 1998) identified five main characteristics of collaborative virtual environments: transitions between shared and individual activities, flexible and multiple viewpoints, awareness of others, sharing context, negotiation and communication. (Heldal, 2004) described three main processes that occur during collaboration: the social interaction (SI), the interaction via technology (IT), and the chosen techniques to reach the goals (TG). Based on these collaborative virtual environment characteristics and processes, we included the following considerations in the design of the scenarios we created to answer our research questions.

First, the actions of both humans and IVAs must be dependent or interleaved; that is to say, none of them can do the task alone and the contribution of the other teammate is crucial for the success of the task.

Second, the task should be divided into stages or sequences to observe the progress in team behaviour and performance. The order of these stages is not an issue as long as these stages belong to the same theme. The idea of dividing the task into stages was to monitor the effect of the communication on the development of a SMM overtime. If these stages have different themes then at the start of each theme the SMM would begin again to form a shared understanding to this particular stage.

Third, humans must have the option either to conform to the IVA's requests or select a different decision.

Fourth, the verbal and non-verbal communication should be bidirectional, that is the human and agent can send and receive messages.

Finally, communication must be task-oriented. That is to say that social-oriented communication would not be beneficial, however, that was beyond the scope of this study.

Throughout the remainder of the thesis, two virtual world scenarios are referred to, i.e. trapping an animal, and crossing a sequence of obstacles.

The Features of Collaborative Scenarios

A number of attempts have been made to define the elements of collaborative activity. In a series of studies, Dillenbourg et al. (Dillenbourg et al., 1996) identified the features of collaborative tasks that serve to test out the development of a shared understanding:

1. **Sharing of the basic facts about the task**…sharing the beliefs about the task between collaborators. Dillenbourg et al. (Dillenbourg et al., 1996) stressed that it is important to share the basic information not only in an indirect way such as using a whiteboard but also in an intrusive ways such as via dialogues or invitation to perform actions.
2. **Interferences about the task**… the requirement is directly connected to the goal of the collaborative task. The inferences are explicitly negotiated through verbal discussion.
3. **Problem-solving strategy**…As the collaborative activity includes a task to achieve; partners need to have a strategy to accomplish this task. This strategy is individual to each team member, but additionally it should take into account a role to the other partner.
4. **Sharing information about positions**…this element is related to sharing information about the position and progress of each party while achieving the collaborative task. The current position of the partner could be deduced through the partners action, while his/her future position could be communicated though discussion.
5. **Knowledge representation codes**…it is important to use clear notations that represent the required knowledge in the collaborative task. For example, using red label to demonstrate crucial or critical knowledge.

6. **Interaction rules**…the rules the partners agree on to manage the interactions while achieving the task.

In line with these requirements, we proposed a scenario where a human and an IVA should collaborate to achieve a shared task.

4.5.1 The First Scenario: Trapping an Animal[1]

The aim of the scenario. In this scenario-based activity, the human and the agent (a virtual scientist called Charlie) needed to collaborate to trap a virtual animal (called a Yernt) for scientific research.

The human-IVA interaction procedure. The animal is surrounded by eight regions (four pairs of regions). To achieve the collaborative goal, the human and the agent take consecutive turns to select one region at a time to build a fence around the animal, and then observe each other's action, i.e. non-verbal behaviour. Choosing the region requires individual situation awareness and planning and collective negotiation and communication. During the activity there is two-way communication; both parties exchange verbal messages to convey their intention and request a recommended selection (that is where to build the fence next) from the other counterpart. Each time both the human and IVA finish their turn to select a region is called a round or a cycle. Hence, the scenario consists of four cycles until the animal is surrounded by the fence. The idea of dividing the collaborative scenario into cycles or rounds is useful to understand the progress of the study variable. This idea was also used in some other human-agent studies, e.g. (Wissen et al., 2009). In the scenario, the human and the agent should be able to select only neighbouring regions. Neighbouring regions are those adjacent to already selected regions. Any cycle, except the first one, will include exactly two available neighbouring regions (see Figure 4-12). Log files are used to track whether the human demonstrates commitment to their promise of acceptance by performing the action.

Supporting the features of collaborative activities. Our scenario met the requirements (presented in (Dillenbourg et al., 1996)) and introduced above in the following ways:

[1] A link to a video that demonstrates this scenario is enclosed in publication No. 14 (page XI)

1. **Sharing of the basic facts about the task**…At the beginning of the scenario, the agent stated the aim of the task to make sure the human partner is aware of what to do.
2. **Interferences about the task**…Before the turn of the humans, the agent proposes a recommendation to the human to consider before taking the decision about which regions to select. In addition to giving a recommendation, the agent states the reason behind his recommendation. The IVA's recommendation is accompanied by a justification to explain why the IVA believes that this selection is the best option. The human has the option either to reject the IVA's recommendation or accept and promise to honour his approval.
3. **Problem-solving strategy**…the agent uses a particular strategy to select the target region. In our scenario, the human and the IVA need to trap the animal under a given time constraint, and so the agent should always select the neighbouring regions with the shortest path to where the agent stands. Regarding the recommendation to the human teammate, the agent calculates the shortest path to the human's last selection.
4. **Sharing information about positions**…after the completion of each cycle, the agent gives feedback about the humans' selection and the next target. During the scenario, the human is able to observe the IVA's non-verbal communication as represented in the actions taken and/or gestures and based on these actions the IVA's intention is to be deduced. Furthermore, both the IVA and human communicate via exchanging messages. These messages are selected from a pool of messages. In each cycle at the beginning of the human's turn, the IVA recommends one neighbouring region for the human to select. The recommended region is nominated so that the other remaining neighbouring region would be close to where the IVA is currently standing.
5. **Knowledge representation codes**…the selected regions have a different colour to the unselected and the neighbour regions. To make it clear for human users, each region is identified by a coloured marker. Markers could be red, green or grey. Red means a region is unselected and it cannot be selected because it is not yet a neighbouring region. Green region means it is an unselected region and it

could be selected because it is a neighbouring region. Grey means a region has already been selected before and cannot be selected again.

6. **Interaction rules**…Turn taking was managed so that humans and IVAs should take turns. At the beginning of the agent's turn, the agent asks the human partner to propose any recommendation for the agent to consider. The agent has the right to accept or reject this recommendation. When it comes to the human's turn, the agent proposes a recommended region to select. The human may ask the agent to give a reason for the recommendation. It is the human's right to accept/reject the recommendation.

The goal, rules, sequences and possible actions in our scenario are specific to the collaborative task we have designed. However, that is true of most tasks. The user is briefed at the start regarding the tasks, goals, and rules of engagement. The scenario encompasses all of the elements in the human-agent multimodal communication model we have developed and encompasses negotiation, planning, decision-making and situation awareness by the IVA.

Below we use the Game Description Language (GDL), which has been developed for the purpose of formalizing game rules (Schiffel and Thielscher, 2010), to formalize our communication model. Using the GDL to formalize the scenario, three players were defined, namely humanplayer, agentplayer and YerntID. With the init keyword, we initialize the Yernt speed, counter and the first player to begin the first step. "*Next*" and "*does*" keywords are used to state the dynamic components of drawing a line by any player (variable ?player), sending a request message (?message) by one player (?$player_1$) according to his plan (?$plan\_player_1$), sending a reply (?reply) from the other player according to his own plan (?$plan\_player_2$) and monitoring of the human's behaviour by the agent. The agent is going to change his plan in two cases: the first case when the human user rejects agent request, this rejection will contradict the agent's current plan (?reply not match ?$plan\_player_1$), the second case when the agent monitors the human's actions and discovers that these actions do no match the agent's plan (mark ?x_i ?z_i, ?x_j ?z_j not match ?$plan\_player_1$). At the end, terminal and goal keywords define the goal to be achieved and the level of involvement of both agent and human user (goal 100).

;; Roles

1 (role humanplayer)

2 (role agentplayer)

3 (role YerntID)

;; Initial State

4 (init (YerntID slowered))

5 (init (?YerntCounter start))

6 (init (control ?player$_1$))

;; Dynamic Components

;; line

7(<= (next (line ?x_i ?z_i, ?x_j ?z_j ?player))

8 (does ?player (mark ?x_i ?z_i, ?x_j ?z_j)))

;;communication messaging

9 (<= (next (?message ?player$_1$))

10 (does ?player$_1$ (send ?message))

11 (true ?message match ?plan_player$_1$)

12 (true (control ?player$_2$))

13(<= (next (?reply ?player$_2$))

14 (does ?player$_2$ (send ?reply)))

15 (true (?reply match ?plan_player$_2$))

16 (true (control ?player$_2$))

;;communication behaviour

17 (<= (next (line ?x_i ?z_i, ?x_j ?z_j ?player$_1$))

18 (does ?player$_2$ (mark ?x_i ?z_i, ?x_j ?z_j))

19 (true mark ?x_i ?z_i, ?x_j ?z_j match ?plan_player$_1$)

20 (true (control ?player$_2$))

;;message rePlanning

21 (<= (next (?plan_player$_1$?player$_1$))

22 (does ?player$_1$ (change ?plan_player$_1$)))

23 (true (?reply not match ?plan_player$_1$))

24 (true (control ?player$_2$))

;;behaviour rePlanning

25 (<= (next (?plan_player$_1$?player$_1$))

26 (does ?player$_1$ (change ?plan_player$_1$)))

27 (true (mark ?x_i ?z_i, ?x_j ?z_j not match ?plan_player$_1$))

28 (true (control ?player$_2$))

;; Control

29 (<= (next (control humanplayer))

30 (true (control agentplayer)))

31 (<= (next (control agentplayer))

32 (true (control humanplayer)))

;; Legal Moves

33 (<=(legal ?player (mark ?x_i ?z_i, ?x_j ?z_j)))

34 (true (line ?x_i ?z_i, ?x_j ?z_j blank))

35 (true (point ?x_i ?z_i not blank))

36 (true (point ?x_j ?z_j not blank))

37 (true (control ?player))

38 (<=(next(line ?x_i ?z_i, ?x_j ?z_j)))

39 (does ?player (mark ?x_i ?z_i, ?x_j ?z_j))

;; Terminal

40 (<=(terminal 41shape ?x_1 ?z_1, ?x_2 ?z_2,, ?x_n ?z_n, ?x_1?z_1))

42 (<=(terminal

43 (shape not open)))

;; Goals-

44 (<= (goal humanplayer 100)

(shape ?x_1 ?z_1, ?x_2 ?z_2,…, ?x_n ?z_n, ?x_1?z_1))

45 (<= (goal agentplayer 100)

(shape ?x_1 ?z_1, ?x_2 ?z_2,…, ?x_n ?z_n, ?x_1?z_1))

Figure 4-11: Goal Description Language formalization of communication model

4

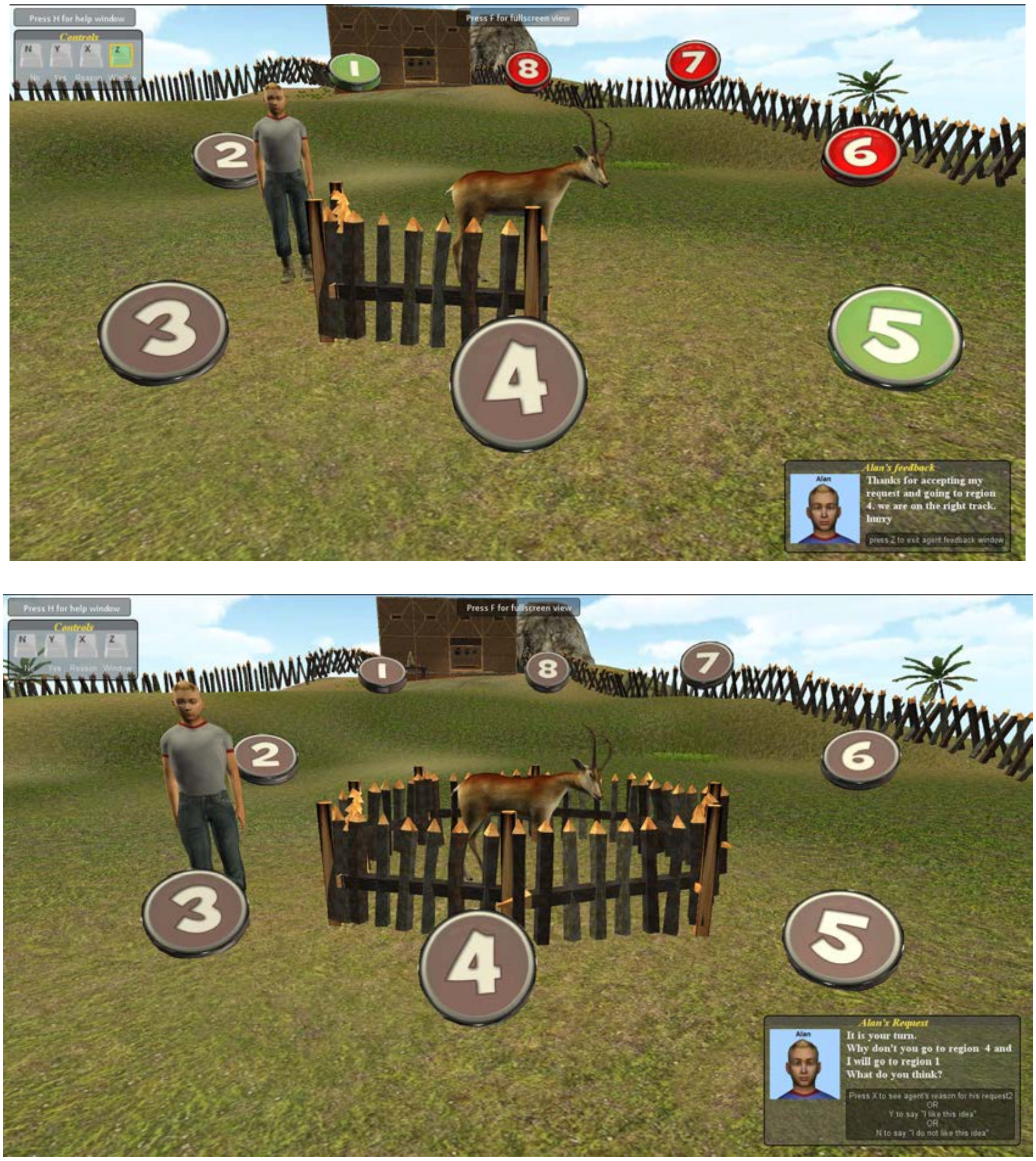

Figure 4-12: Snapshots from the first scenario (trapping an animal)

4.5.2 The Second Scenario: Crossing a Sequence of Obstacles[2]

The aim of the scenario. To pass a sequence of four obstacles to reach their target (scientific laboratory). The four obstacles were a brick wall, a wooden gate, a bush and a hill.

The human-IVA interaction procedure.

In order to get over each of these obstacles both the human and IVA have to select a pair of tools from a toolbox that contains 12 tools (pruning shears, bush hook, hammer, chisel, ladder, rope, matchsticks, matchbox, screwdriver, nipper, shovel and mattock). These tools were picked so that each pair of tools would be complementary, i.e. a single tool cannot work without the function of the complementary tool. For example, the chisel needs the hammer and the matchstick needs the matchbox. In addition, each obstacle could be passed using a different method and the corresponding combination of tools. For example, the bush obstacle could be chopped, burnt or climbed. Hence, there should be agreement between the human and the IVA concerning the best way to overcome the obstacle and to select which pair of tools is most suitable for the task. Human-IVA interaction during the collaborative activity is described in the experimental design (see Figure 4-13).

Supporting the features of collaborative activities. Our scenario met the requirements (presented in (Dillenbourg et al., 1996)) and introduced above in the following ways:

1. **Sharing of the basic facts about the task**…At the beginning of the task, the IVA will state the information about the collaborative situation. This information includes how many obstacles to cross, how many tools to use to overcome these obstacles and the turns to take.

2. **Interferences about the task**…Before the humans take their turn to decide which tool to select; the IVA proposes a recommendation to the human to consider before taking the decision. In addition to giving a recommendation, the agent states the reason behind his recommendation. The IVA's recommendation is accompanied by a justification to explain why the IVA believes that this selection is the best option. The human has the option either to reject the IVA's

[2] A link to a video that demonstrates this scenario is enclosed in publication No. 19 (page XII)

recommended tool to select or accept it. In either cases, the humans promise to honour his approval or rejection.

3. **Problem-solving strategy**…The IVA has a strategy to select the suitable complementary tools. In this scenario, the human and the IVA agree to select the complementary tools that help to cross the obstacle faster, with less pollution and with less noise. The tools with less time to overcome the obstacle have a higher priority than the tools that produce less noise and both have higher priority over the tools make noise.

4. **Sharing information about positions…**During the task, the humans is able to get the information about the current collaborative situation through both of the IVA's communication channels (i.e. verbal and non-verbal). Regarding the non-verbal clues, the human is able to observe the IVA's non-verbal communication as represented in the actions taken and/or gestures and based on the actions the IVA's intention is to be deduced. With the verbal communication, both the IVA and human communicate by exchanging messages. These messages are either an explanation to why the IVA believes the recommended complementary tools are best suited to the current obstacle or why the proposed tools do not suit the current obstacle. These messages are selected from a pool of messages selected according to the personality traits assigned to the IVA.

5. **Knowledge representation codes**…The camera of the scene stops at the obstacle a human and an IVA need to cross. The human user cannot move away from the obstacle to make the user concentrate on completing the task rather than exploring around. In the human's turn, the IVA's proposed tool is highlighted to make it easy to the human user to notice the recommended tool and the complementary tool associated with it. Additionally, after crossing the obstacle, the effect of the selected tools are shown to the user. For example if the human and the IVA agree to burn the bush, some burnt bush and ashes will be displayed instead of the existing bushes.

6. **Interaction rules**…The same interaction rule as the first scenario.

Figure 4-13: Snapshots from the second scenario (crossing obstacles)

4

4.6 Summary

In this chapter, we presented the approaches to answer the proposed research questions (presented in Chapter 1). At the beginning of the chapter, a framework based on AT was presented (MACVILLE) to understand the factors that affect the collaboration activity. Based on the outcomes of the framework, an agent architecture was proposed. In addition to the cognitive ability included in previous agents in the literature, this agent architecture focused on developing a Shared Mental Model with a human teammate. Additionally, a communication model (HAT-CoM) was proposed to represent agent behaviour using verbal and non-verbal cues. At the end of the chapter, two virtual environment scenarios were described that will be used in the next chapters to verify the proposed architecture and communication model and answer the research questions.

CHAPTER 5

Evaluating the Plausibility of the Proposed Agent Architecture and the Communication Model

5.1 Background

There is currently no accepted or well-established method to evaluate and compare cognitive architectures in agents. The lack of a general method to evaluate agent architectures has many reasons. It could be because there is no unified structure to the agents to compare, although many of them generally follow the standards of BDI model. Another reason could be because the focus and purpose of each architecture may differ, and thus the criteria for comparison will differ. As a result, implementation of a proposed architecture to functionally evaluate its plausibility remains an important technique (Logan, 2007). To evaluate our proposed agent architecture and the included communication model, an IVA was created and the agent architecture was integrated. Two studies, described in section 5.3, using the IVA were conducted to evaluate the agent architecture and the communication model, on one hand; and, on the other, the impact of the collaboration between a human and an IVA on the development of a human-IVA SMM.

5.2 The Theory and Research Questions

Figure 5-1 shows the research plan adopted to evaluate the agent architecture and the integrated communication model (HAT-CoM). The plausibility of the agent architecutre and the integrated communication model was divided into two stages. The first stage was to evaluate the plausiblity of agent communiucation. SAT was used as an evaluation tool of HAT-CoM involving measurement of the participants' subjective perception of the communication and also through analysis of log data to provide objective measurement of the SAT concepts. The evaluation question was:

Evaluation Question 1: Can SAT be used as an evaluation tool to evaluate participants' satisfaction with agent multimodal communication?

In the second stage, a functional evaluation of the proposed agent architecture was carried out. In the functional evaluation, the aim was to investigate the impact of the collaboration with the agent on the development of a SMM with the humans. The functional evaluation used an induction method to assess the development of a SMM through tracking the existence of SMM aspects (Kraiger and Wenzel, 1997). These aspects were: anticipating a teammate's decisions, reduced explicit communication, match in cognitive perspective and competence in decision-making (ease of flow of decisions).

Evaluation Question 2: What is the influence of agent architecture/behaviour on the development of a SMM as can be observed in SMM aspects?

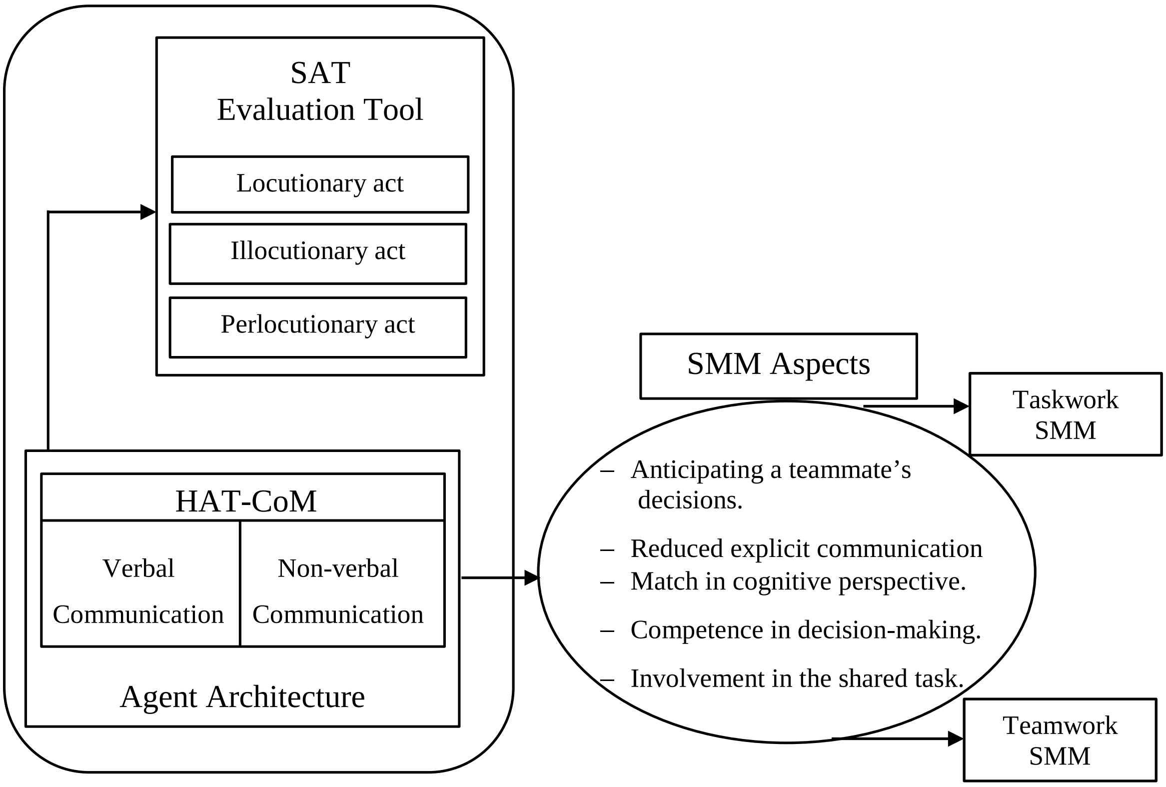

Figure 5-1: The research plan to evaluate the proposed agent architecture

5.3 Methodology

To evaluate the proposed communication model, we extended an existing 3D virtual world known as Omosa Virtual World to include a collaborative activity. Omosa Virtual World was developed using the Unity3D game engine (http://unity3d.com) as part of a larger project. The virtual world is an ecosystem for an imaginary island called Omosa created to help secondary school students to learn scientific knowledge and science inquiry skills. To gain scientific knowledge and skills, students are given the goal to determine why the fictitious animals, known as Yernt, are dying out. The authors' particular focus is on creating a world that encourages human-agent collaboration.

To explain the communication model for collaboration between the human user and virtual agent, we will illustrate the communication model in the scenario in the hunting ground where both the human and the IVA have a shared goal to capture a Yernt by surrounding the animal with an octagon fence (the first collaborative scenario that was described in Section 4.5.1). The design of the scenario has the following characteristics:

- **Collaborative:** and has an explicit goal where the human user can easily consider the changes in the situation.
- **Two-way Multimodal interaction:** The agent (virtual biologist) interacts with the human participant through speech and visual actions and vice versa.
- **SAT as evaluation tool:** SAT is used as an evaluation tool to measure the effectiveness of communication in achieving the designated goal of the communication is an innovative contribution. Prior research used SAT as a reference in designing virtual agent verbal communication, but not evaluation (Bedi and Vashisth, 2011) (Jiang and Zhou, 2008).
- **Real-time:** The agent's plan is generated in real-time as the human participant's actions may vary and lead to unexpected changes in the environment. The result of any action is directly apparent (i.e. observable) in the situation. When the human participant or the virtual user takes the decision about the next step, the execution of the decision will be apparent to the collaborator.
- **Include the effect of multimodal communication** through the human-agent social interaction.

5.3.1 Procedures

Two studies were conducted to evaluate the agent's verbal communication. In the first study, we invited seventy-three second-year undergraduate science students studying animal behaviour to participate in our study. Sixty-six (66) students completed the task and survey questions. The participants were divided into five groups each containing 12 to 15 students, according to the number of computers available in the laboratory. In the second study, twenty (20) secondary school students volunteered to participate in the study. Five students did not complete the post-session survey and so their results were excluded. Participants are described further in section 5.3.3. Gathering data in two studies and from two different cohorts sought to increase the total number of participants, the volume of data for analysis and the generality of results. Equal numbers in both cohorts was not available to us as recruitment was restricted to numbers of students enrolled in a course/class.

In both the studies, each student used the virtual system individually so that the collaboration would be one-on-one between him/herself and the agent. Twenty minutes were dedicated for the study that consisted of three parts in one session. In the first part, participants signed a consent form and provided us with biographical information about themselves. The second part involved participation in the scenario in the virtual scene and the third part was to answer survey questions about the communication and collaboration experience (see section 7.4). In the beginning of the first part of the scenario, the participants were provided with online instructions about the goal of the virtual scenario, the way to select the desired region, and how to select/close the verbal message.

5.3.2 Data Collection and Data Processing

Collecting data for the events and the actions that take place in a VE may require different methods according to the goals of the VE. For the purposes of this study, data were collected by two means as follows:

- The first means was automatic data logging to track the human's and the agent's behaviours, messages and selections and to register any problems experienced by the participants whilst engaging with the agent in the scenario.

- The second means involved the use of surveys, one used before the scenario to collect biographical data and another after the scenario to evaluate the experience.

To define the sample population and assess their suitability as participants, the first biographical section of the study's survey contained questions regarding their:

1. Linguistic skills, which were needed for verbal communication with the agent.
2. Level of computing skills, to make sure of the ease of using the computer's mouse and keyboard.
3. Experience in using computer games and other 3D applications, which may affect their ability to navigate in the VE and their expectations (e.g. regarding graphic quality).

The second section of the survey contained 10 Likert scale items in the first study and 25 Likert scale items in the second study. These items aimed to acquire the users' opinions about the agent's verbal and non-verbal communication and its relevance to the collaborative situation.

The raw data was processed in the following ways:

a) The data in the log files was extracted and organized into two MS Excel files according to their relevance. The first Excel file was for verbal and non-verbal communication interleaving between the human and the agent and the second Excel file was for the timing of each action taken, behaviour performed or intention communicated.

b) Participants' answers to the survey question were coded to show user preferences, impressions and understanding of the virtual agent's verbal and non-verbal actions.

5.3.3 Participants

Sixty-six undergraduate students enrolled in the unit "Introduction to Brain, Behaviour and Evolution" (BBE100) chose to participate in the study. Seven students out of the total participants did not complete the collaborative task due to technical reasons. The data of these students were excluded from the evaluation of the communication model except in calculating the ratio of those who did not complete the task out of the total number. Participants were aged between 18 and 49 years (mean=21.9; SD=5.12).

Concerning participants' linguistic skills, 92.42% were English native speakers. The non-native English speakers had been speaking English on a daily basis on average for 14.4 years. 21.21% of the participants described themselves as having basic computers skills, 16.67% as having advanced skills, while 62.12% said they have proficient computer skills. Concerning their experience in using games and other 3D application, the participants answered the question "How many hours a week do you play computer games?" with times ranging between 0 to 30 hours weekly (mean=4.24, SD=6.66).

In the second study, twenty (20) secondary school students volunteered to participate in the study. Five students did not complete the post-session survey. Participants were in a grade/year 8 class, and aged between 13 and 14 years (mean=13.5). There were equal numbers of male and female participants. We were not able to ask about their English language competency. All of the children were familiar with using computers and playing computer games. Participants' linguistic and computer skills were surveyed to explore if any struggle in the communication with IVA was because of the lack of linguistic or computer skills. In the two studies, English linguistic skills and computer skills did not show statistical differences on the final results which means the variation in linguistic skills and computers skills does not impact on collaboration results.

5.4 The Evaluation of Agent Communication Model using SAT

We wanted to measure the effectiveness of HAT-CoM. Part of this measurement concerns how expressive the agent is in demonstrating his intention. As a first step, we investigated what evaluation methods existed (section 5.4.1). We found that the few existing evaluation techniques were not integrated or comprehensive; meaning that they did not evaluate both the verbal and non-verbal communication channels and even those techniques that evaluated the verbal interaction did not cover syntactic and semantic features of the utterances. The lack of an integrated evaluation tool led us to propose that SAT be used as a communication evaluation tool (section 5.4.2).

5.4.1 Methodologies to Evaluate Agent Communication

Various methodologies have been used to evaluate the effectiveness of verbal or non-verbal communication in conveying the agent's intention towards achieving the goal of communication. These methodologies, introduced below, include formal models of possible features of successful verbal and non-verbal communication (Allwood, 2001), the use of psychological aspects to estimate the personality and internal state of the agent (McRorie et al., 2012), or the use of specific criteria to measure how the agent expresses its intention and internal states (Granström and House, 2007).

The evaluation may consider different properties relevant to the agent and communication context. Among the properties used, (Allwood, 2001) discussed the features of successful verbal and non-verbal communication. Relating to the features of communication, flexibility and conflict prevention emerged as predominant concepts. To establish a successful communication with the concepts of flexibility and conflict prevention, Allwood ((Allwood, 2001), pp.116) stated nine non-mutually exclusive goals. These goals achieve flexibility and conflict prevention in communication: mutual friendliness, lack of tension (tension release), lack of need to defend a position, admitting weakness or uncertainty, lack of attempts to overtly impose opinions on others, coordination of attention and movements, giving and eliciting feedback expressing mutual support and agreement, showing consideration and interest, invoking mutual awareness and beliefs. (McRorie et al., 2012) evaluated the perception of agents' personalities and credibility by human viewers. The authors used Eysenck's theoretical (Eysenck, 1976) basis to explain aspects of the characterization of four different agents. To evaluate the effectiveness of their agent's speech, the study by (Granström and House, 2007) used intelligibility and information presentation, visual cues for prominence, prosody and interaction, visual cues to sentence mode, agent expressiveness and attitude.

(Fabri et al., 2007) introduced the concept of "richness of experience" to evaluate the user's experience and the non-verbal communication between the human user and avatar. The authors postulated that a richer experience would manifest itself through more involvement in the task, greater enjoyment of the experience, a higher sense of presence during the experience and a higher sense of co-presence. The study evaluated the effect of the agent's facial expressions of emotion happiness, surprise, anger, fear, sadness and disgust on the user's richness of experience.

5.4.2 Speech Act Theory as an Evaluation Tool

In recent research work (see subsection 4.1), Speech Act Theory was widely used as a tool to interpret the communication and understand the structure and the meaning of utterances. Novelly, we explore whether SAT could be extended to be used as an evaluation tool for verbal communication. Austin described three characteristics, or acts, of statements that begin with the structuring of words, go through the intention of the speaker from his words and end with the effects those words have on an audience. We propose that by evaluating each act, namely Locutionary acts, Illocutionary acts, Perlocutionary acts, and the verbal section of the communication model we will be able to perform an objective evaluation of the structure, the clarity and the effect of the utterances of the agent. Each act can be evaluated as follows:

a) Locutionary act: the human's impression about utterances structure.

b) Illocutionary act: the human's understanding to the agent's intention.

c) Perlocutionary act: the effects of the uttered words on the interlocutor.

- Locutionary acts: which are equivalent to uttering a certain sentence with building structures. A locutionary act could be verified by asking the interlocutor his/her impression about the structure of the utterances. The interlocutor can be asked whether the sentences are clear, easy to understand and natural. Another way to evaluate the locutionary act is to ask a third person to review and evaluate the form of the sentences.
- Illocutionary acts: which is the illocutionary force or the intention the speaker meant from his/her locutionary act. Illocutionary force could be informing, ordering, requesting, warning, undertaking, etc. The aim of evaluating this act is to determine whether the illocutionary force is clear to the interlocutor. The illocutionary act could be verified via considering an appropriate ratio of using different classes of illocutionary act so that the conversation will have various tones, surveying if the interlocutor perceives the intention behind the locutionary.
- Perlocutionary acts: this is what is achieved by saying something, such as convincing, persuading, deterring, surprising or misleading. Evaluating both the locutionary act and illocutionary act requires surveying the interlocutor's

impression and opinion about the form of the utterances and the meaning behind it. Evaluating the perlocutionary act should go beyond asking the interlocutor to investigate the actual effect of the locutionary act as demonstrated from the behaviour performed. To track the behaviour of the participants in a virtual world, actions should be carefully logged as part of the design and implementation. Table 5-1 summarises the technique of using SAT to evaluate verbal communication.

Table 5-1: The speech acts, their meaning and evaluation

	Locutionary acts	**Illocutionary acts**	**Perlocutionary acts**
Meaning	The structure of the utterances	The intention the speaker	What is achieved by saying something
Evaluation Method	Subjective Method involving analysis of participants' perception of the structural characteristics of the agent's speech.	– Objective method involving analysis of agent's intended meaning. – Subjective method involving analysis of interlocutor's perception of the intention in the agent's messages.	– Objective method involving analysis of agent's achievement due to verbal communication. – Subjective method involving analysis of participants' perception of achievement due to agent's verbal communication.
Evaluation Data	Surveying participants' perception of the structure of the agent's utterance.	– Logging the ratio of participants' acceptance to agent's requests. – Surveying if the participants perceives the intention behind the agent's locutionary acts.	– Logging the completion time of each cycle in the collaborative task. – Surveying how the participants find agent's speech to direct the collaboration.

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To investigate the influence of the agent's verbal communication as evaluated by SAT on human-agent collaboration, the main evaluation question (i.e. *Can SAT be used as an evaluation tool to evaluate participants' satisfaction with agent multimodal communication?*) was divided to the following four sub-questions:

***Evaluation Question 1.1**: Can an agent's illocutionary act be evaluated using objective and subjective methods?*

***Evaluation Question 1.2**: Can an agent's perlocutionary act be evaluated using objective and subjective methods?*

***Evaluation Question 1.3**: Does the human's perception of the agent's illocutionary act impact on the human's perception of the agent's perlocutionary act?*

***Evaluation Question 1.4**: Does human's perception of the agent's illocutionary and perlocutionary acts impact collaboration performance?*

5.4.3 Evaluating the Verbal Part of Communication Model

We aim to present an analysis of the exchanged verbal and non-verbal communication between the human and agent while achieving a collaborative task. To achieve this aim, an analysis of the agent's verbal communication was conducted using SAT. We claim that SAT may be used as an evaluation tool to measure the effectiveness of the verbal communication involved in achieving collaborative tasks.

5.4.3.1 Locutionary act

To evaluate the locutionary act of the agent's speech, a subjective method of data collection was chosen (refer Table 5-1) because we rely on the participants' perception of their interlocutors' locutionary act to determine the plausibility of the speech structure. In the subjective evaluation method, a survey was used to ask participants about their thoughts concerning the structure of the messages (rather than the messages content or meaning) used by the agent. The survey asked, "How would you describe the message used for communication - check all that apply" and a group of words that expressed different opinions about the structure of the utterances of the agents. These words were "clear, ambiguous, natural, awkward, nice, ugly, too short and too long". Ideally, the agent's messages should be clear, natural, nice, and expressed in as few words as possible. When coding the selection/s of the participants, the words were organized into pairs with inverse meanings, that is to say clear versus ambiguous, natural versus awkward and so on. The results, as shown Figure 5-2, demonstrate that the ‘clear’ property was selected by 42.42% of the participants that is twice the ratio of participants that thought the messages were ambiguous. Nevertheless, three times as many participants found the messages ‘awkward’ rather than ‘natural’ and twice as many found the messages to be ‘too short’ rather than ‘too long’. To test the significance of the difference in participants’ perception of the agent’s messages, a Chi square test was utilized. The result of Chi square test showed that, see Table 5-2 the percentage of participants that perceived the agent’s verbal communication as “nice” was significantly different from the percentage of participants that perceived agent’s verbal communication as “ugly”, $\chi^2(2, N=66)= 3.636$, $p < 0.01$.

The percentage of participants that perceived the agent’s verbal communication as “too short” was significantly different from the percentage of participants that perceived the agent’s verbal communication as “too long”, $\chi^2(2, N=66)=66.091$, $p <0.01$. Additionally, the percentage of participants that perceived the agent’s verbal

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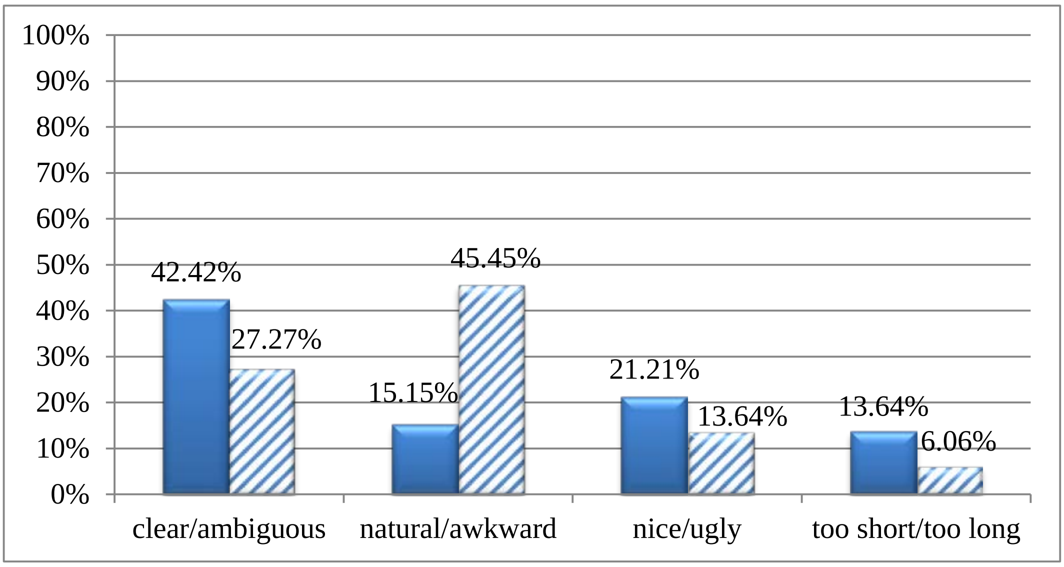

Figure 5-2: Percentage of selecting words to describe the sentences uttered by the agent

Table 5-2: Chi square test for the difference between participants

	Nice_Ugly	Short_Long	Natural_Awakward	Clear_Ambiguous
Chi-Square	30.636	66.091	10.182	2.545
df	2	2	2	2
Asymp. Sig.	0.00	0.00	0.006	0.28

communication as “awkward” was significantly different from the percentage of participants that perceived agent’s verbal communication as “natural”, $\chi^2(2, N=66)=10.182$, $p < 0.01$. Although participants’ perception that the agent’s messages was “clear” was higher than the responses that they were “ambiguous”, there was no significant difference between these perceptions ($\chi^2(2, N=66)=2.545$, $p > 0.01$).

5.4.3.2 Illocutionary Act

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The second component of human speech according to SAT is illocutionary act. Illocutionary act is the intention of the speaker as expressed in the context of the communicative situation. Illocutionary act refers to the type of function a speaker intends to accomplish in the course of producing an utterance. It is an act accomplished in speaking and defined within a system of social conventions. To evaluate the speaker's intention in delivering an utterance, objective and subjective evaluation methods were utilized. The aim of objective evaluation of the agent’s illocutionary act is to make sure that there is a balance, using Searle’s taxonomy (i.e. the five classes), of illocutionary acts. We did not want the majority of the exchanged utterances to be of the same class, i.e. declarative, representative, expressive, directive or commissive. Moreover, objective evaluation aimed to validate that the dominant class of illocutionary act matched the goal of situation. It is worthy to note that we did not tune the agent based on the percentage of each class but merely used the process of classification as a means of reviewing that the dialogue was seeking to convey the agent’s intentions appropriately for that type of scenario. The verbal utterances of the agent were analysed and classified according to Searle’s taxonomy. Table 5-3 showed examples of the locutionary acts uttered by both the agent and the human. Each utterance is labelled according to the meaning and the intention that the agent intended the interlocutor to receive. The labelling

Table 5-3 : The Illocutionary act for each locution act

Actor	Speech act	Illocutionary act classification
Agent	It is my turn	Declaratives
	Do you want to suggest which region I should go to?	Commissives
Human	I have something	Declaratives
	Nothing in mind	Declaratives
Human	I am thinking about regions (1, 2,…, n)	Directives
Agent	Wow, the requested x was what I was thinking about.	Representatives
	The requested region x is a possible choice but far to go to.	Expressives
	Your proposed region x has already taken before.	Representatives
	Well, your proposed region x is not possible because it is not directly connect to edge region.	Representatives
Agent	It is your turn.	Declaratives
	Why do not you go to region x and I will go to region y. what do you do you think?	Directives
Agent (reason window)	I prefer you to go to x because I am closer to y and so I will save the time to move to the far region x.	Directives
Human	I like this idea	Representatives
Human	I do not like this idea	Representatives
Agent	Thanks for accepting my request and going to region x.	Expressives
	We are on the right track.	Declaratives
Agent	It seems you have another opinion.	Representatives
	I have to hurry to another region. that really cost me time	Expressives

of locutionary acts into different illocutionary classes was done by the researcher. Additionally, Table 5-3 showed the message that a user can optionally view to read the reason for agent's request.

Based on the classification presented in Table 5-3, Figure 5-3 shows the ratio of usage of Searle's five classes of illocutionary act in the exchanged utterances. The result demonstrates that the five classes were represented. The scenario used to implement the communication model is a collaborative environment. Both the human and the agent should exchange requests and replies that state requests, opinions or directions. The class directives is used with ratio 16.67% to show the request utterances, while the class representatives with ratio 33.33% is used to give replies to the requests or state a fact about the surrounding environment. The overall result of objective evaluation of the agent's illocutionary act showed dominant representation of both representatives and directives. This dominance suits the nature of this collaborative situation where the human and agent teammates exchange requests and replies about the common task.

To evaluate the participants' understanding of the agent's intentions behind his utterances, participants were surveyed about their perception of the agent's intention. In the first study, participants were asked three questions about the extent to which they considered the agent's intention, as expressed in its requests, replies or feedback, were appropriate to the situation. Participants had to answer on a Likert scale of four (very appropriate to very inappropriate). The result, as can be seen in Figure 5-4, showed that

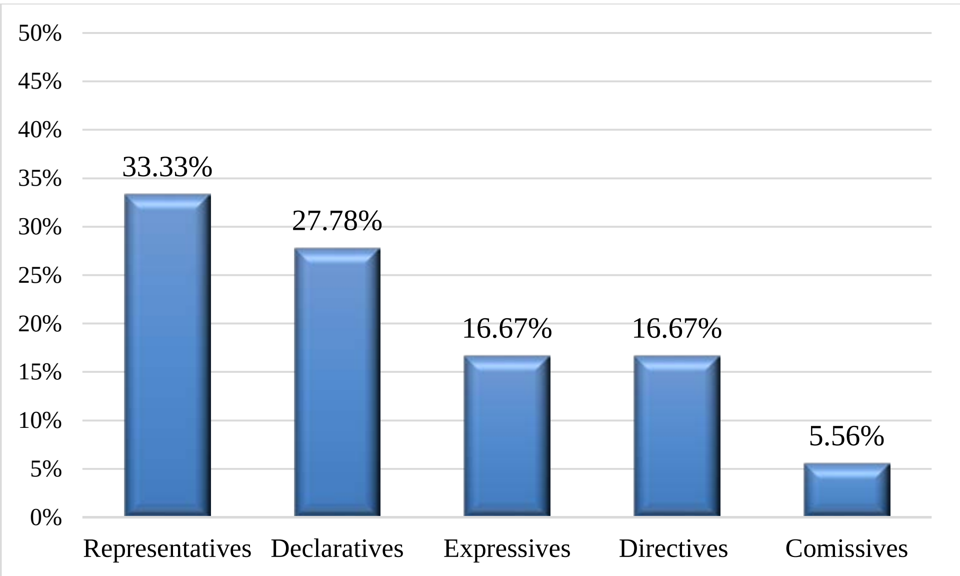

Figure 5-3: Percentage of using Searle's Illocutionary classes

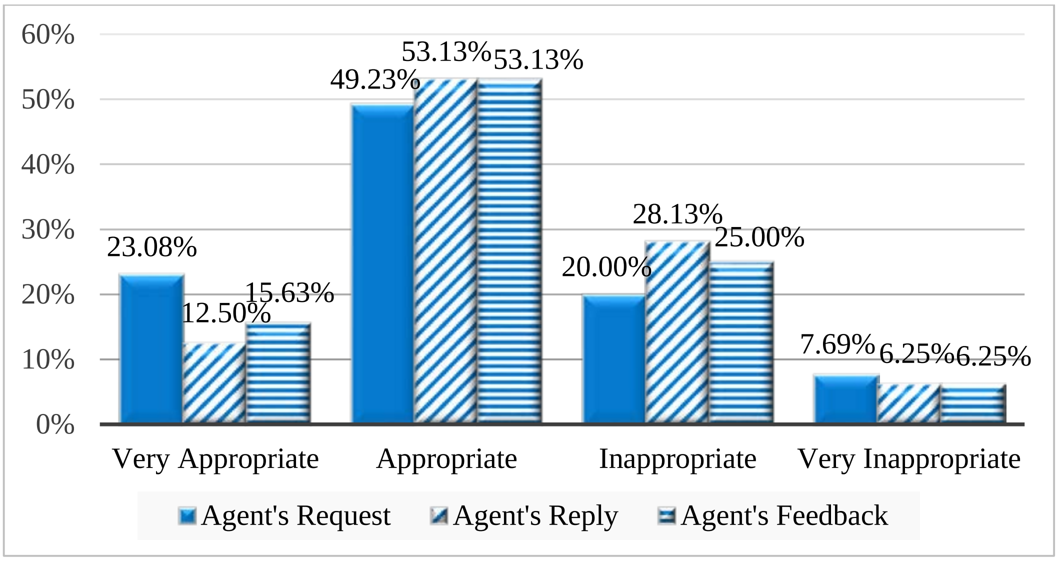

Figure 5-4: How appropriate was the agent's verbal messaging

49.23%, 53.13% and 53.13% of the participants perceived that the agent's intention as expressed in its requests, replies and feedback, respectively, were appropriate to the context in which they were articulated. Moreover, the results showed that 23.08%, 12.50% and 15.63% of the participants perceived that the agent's intention as expressed in requests, replies and feedback, respectively, were very appropriate to the context that they were articulated in.

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To test if participants' perception of the appropriateness of the agent's intention in the situation is significant, a t-test was used. The result of the t-test showed that, as can be seen in Table 5-4, there was a significant difference between participants' perception of the appropriateness of the agent's intention in the situation as expressed in the agent's requests $t(65) = 3.99$, $p < 0.01$. In addition, the results showed that there was a significant difference between participants' perception of the appropriateness of the agent's utterance in response to the situation as expressed in the agent's replies and feedback $t(65) = 2.83$, p < and $t(65) = 3.43$, $p< 0.01$ respectively.

In the second study, participants were asked two questions on a Likert scale of five (strongly agree to strongly disagree) about how clear they found the agent's intention. The results, as can be seen in Figure 5-5, showed that 50% and 25% of the participants agree and strongly agree, respectively, that the agent's intention was clear to them. Using a t-test to evaluate the significance in participants' responses, the results showed that, see Table 5-4, there is a significant difference between participants in their perception of the clarity of the agent's intention ($M=3.84$, $SD=0.68$), $t(15) =22.74$, $p<0.01$. Sixty-six undergraduate students enrolled in the unit of Introduction to Brain, Behaviour and Evolution chose to participate in the study. Seven students out of the total participants did not complete the collaborative task due to technical reasons.

Table 5-4 : T-test to study the difference in participants' perception of the appropriateness of agent's intention as expressed in agent's requests, replies and feedback

	Mean	SD	t	df	Sig. (2-tailed)
Human's Perception of Agent's Illocutionary Act					
The First Study					
Intention appropriateness of agent's request	2.89	0.86	3.99	65	0.000*
Intention appropriateness of agent's reply	2.75	0.78	2.83	65	0.006*
Intention appropriateness of agent's feedback	2.82	0.80	3.43	65	0.001*
The Second Study					
Agent's intention	3.84	0.68	22.74	15	0.000*
Human's Perception of Agent's Perlocutionary Act					
Human's perception of agent's perlocutionary act	3.58	0.75	19.23	15	0.000*
Human's Perception of Collaboration Performance					
The First Study					
Human's perception of agent's flow of actions	2.81	0.83	27.54	65	0.000*
Human's perception of agent's reaction to human's flow of actions	2.62	0.87	24.39	65	0.000*
The Second Study					
Human's perception of collaboration performance	3.96	0.61	26.09	15	0.000*

* Significance at 0.01 level

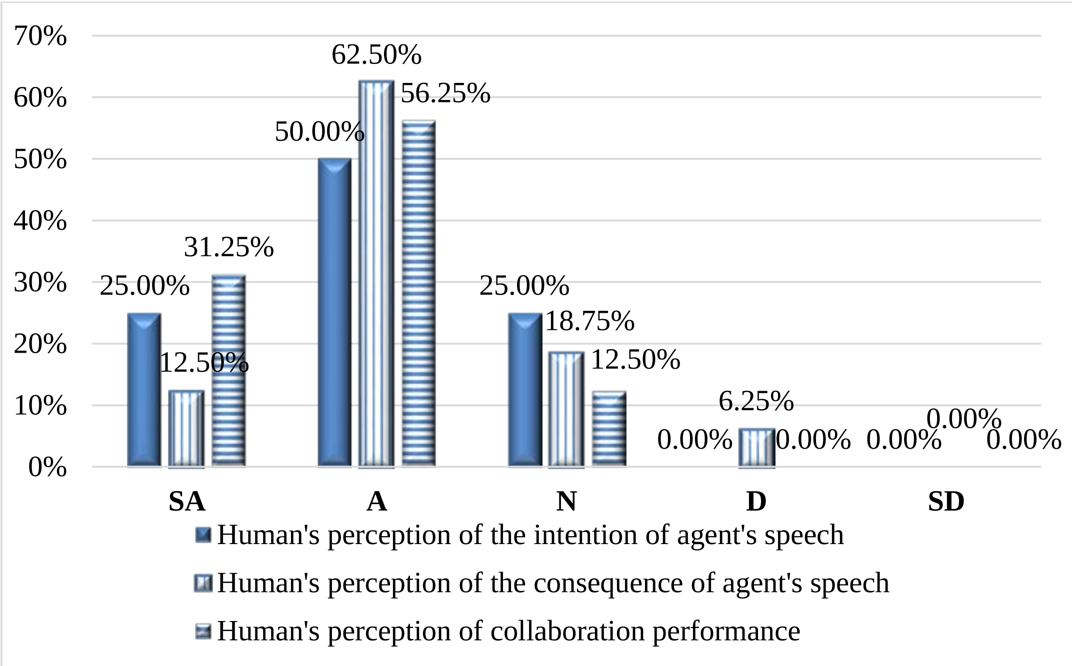

Figure 5-5: Human's perception of the agent's illocutionary act and perlocutionary act

5.4.3.3 Perlocutionary Act

According to SAT, the effect of the illocutionary act appears in the perlocutionary act. This means that to check the effect of the verbal messages of the agent we need to determine the influence of these messages on the current collaborative situation. To evaluate this influence, objective and subjective analysis methods were used. In the objective evaluation of the agent's perlocutionary act, the goal was to measure how successful each of the agent's speech acts were in achieving the agent's intention, i.e. illocutionary act. To conduct this objective evaluation, the data collected in the automatic log files that track the human's actions must be analysed in order to check if the user practically demonstrates understanding and positively responds to the verbal message. The idea behind this technique is to see if after the agent has expressed his intention, the human then takes a decision based on the agent's intention. The result, see Figure 5-6, showed the percentage of the humans' responses to the agent's verbal requests in each cycle. The results show that the human's behaviour reflects the level of human acceptance of the agent's requests in cycle1, cycle2 and cycle3 of 64.41%, 67.80% and 70.69% respectively.

To carry out evaluation of the agent's perlocutionary act, participants' perception to the influence of agent's speech act was surveyed. Participants were asked three questions (on

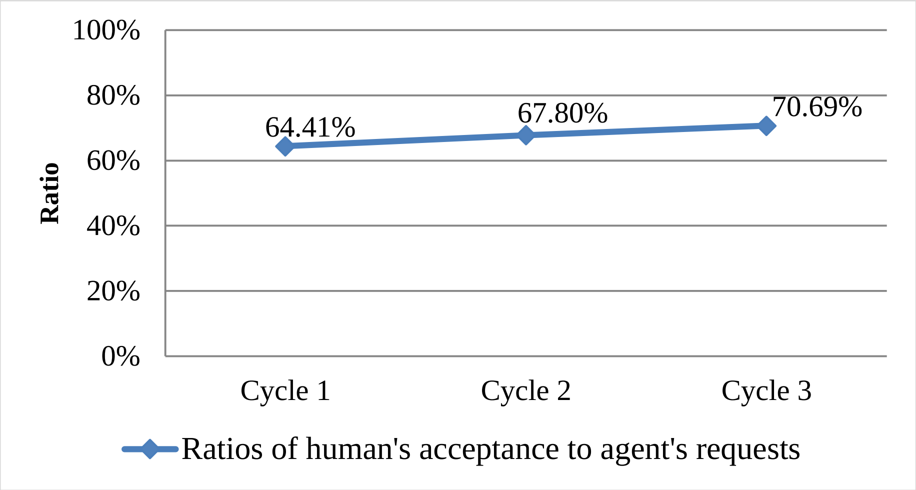

Figure 5-6: Ratio of human's acceptance to agent's requests

a scale of five from strongly agree to strongly disagree) about the level of effectiveness of the agent's speech to direct the collaborative task. The results showed that, see Figure 5-5, 62.50% and 12.50% of the participants agree and strongly agree, respectively, that the agent's speech acts were effective to direct the collaborative task. Using a t-test to evaluate any significant differences in participants' responses, the results showed that, as can be seen in Table 5-4, there is a significant difference between participants in perceiving the consequences of the agent's speech acts (M=3.58, SD=0.75), t(15) =19.23, $p<0.01$.

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5.4.4 Agent's Illocutionary and Perlocutionary act and Collaboration Performance

After using objective and subjective methods to evaluate both the agent's illocutionary and perlocutionary acts, the next step is to measure the impact of the agent's speech acts on the performance of the human-agent collaboration. To evaluate objectively the performance of human-agent teamwork, the time to complete each cycle was recorded. The result of analysing the log files, see Figure 5-7, showed that even though each scenario cycle had the same number of options available to choose from (i.e. two neighbouring regions) the average time to complete consecutive cycles decreased from 51.1 seconds in the first cycle to 33.78 second in the last cycle.

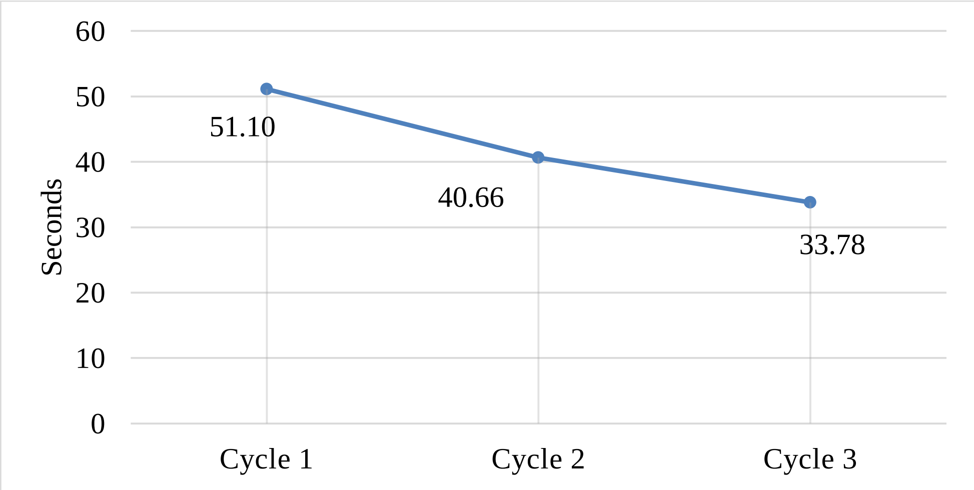

Figure 5-7: Average time to complete each consecutive cycle

In order to measure the performance of human-agent collaboration, human perception of performance was surveyed. In the first study, participants were asked two questions to estimate the final performance of the collaboration. The first question asked the participants to estimate how appropriate they found the flow of collaboration from the agent side. The results showed that, see Figure 5-8, 64.06% and 14.06% of the participants agreed and strongly agreed respectively that the agent's flow of actions were appropriate. Using a t-test to determine any the significant differences between participants' responses, the results showed that, see Table 5-4, there was a significant difference between participants in their perception of the agent's role in collaboration performance $t(65)= 27.54$, $p<0.01$.

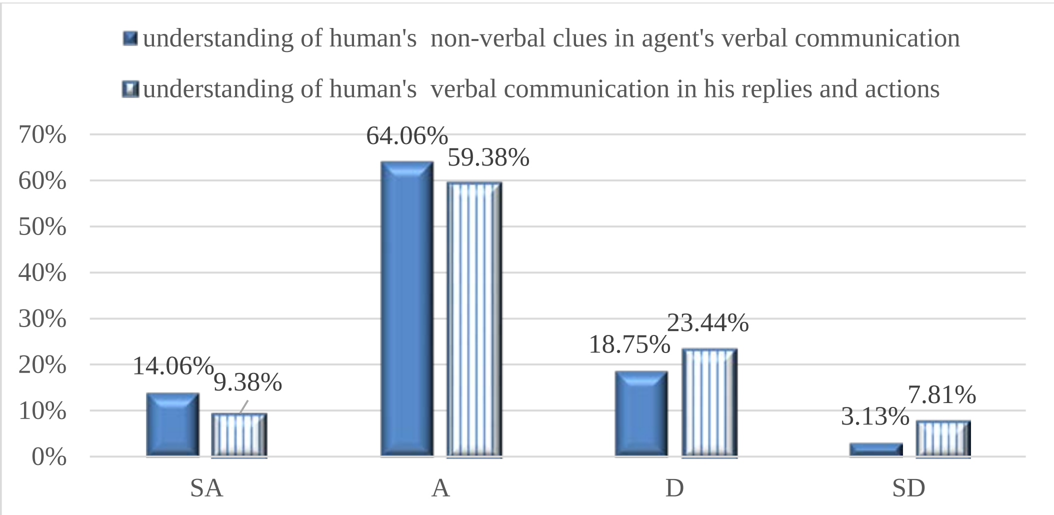

Figure 5-8: Ratio of humans' perception of collaboration performance

The second question asked the participants how appropriate they found the agent's reaction to the human's role in the collaboration. The results showed that, see Figure 5-8, 59.38% and 9.38% of the participants agreed and strongly agreed respectively that the agent's reactions toward the human's role in the collaboration was appropriate. Using a t-test to evaluate any significant differences in participants' responses, the results showed that, see Table 5-4, there was a significant difference between participants in their perception of the agent's reactions to human's role in collaboration $t(65)=24.39$, $p<0.01$.

In the second study, participants were asked five questions each on a scale of five (strongly agree to strongly disagree) to estimate the human's perception of the final performance of the collaboration with the agent. The results showed that, Figure 5-5, 56.25% and 31.25% of the participants agreed and strongly agreed that the collaboration with the agent was successful and the results of teamwork with the agent were satisfactory. Using a t-test to evaluate any significant differences in participants' responses, the results, as can be seen in Table 5-4, showed that there is a significant difference between participants in perceiving the collaboration performance with the agent $t(15)=26.09$, $p<0.01$.

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To measure the strength and direction of association between human perception of the agent's illocutionary act, perlocutionary act and collaboration performance, Spearman's rho correlation method was used. Spearman's rho correlation was selected, as it is more appropriate for small sample sizes or non-normally distributed responses. Table 5-5 presents the means, standard deviations, and correlations for all measures. As shown in Table **5-5**, human perception of the agent's illocutionary act was significantly positively related to human perception of the agent's perlocutionary act ($r=0.620$, $p<0.05$). Moreover, human-agent collaboration performance were significantly positively related to human perception of the agent's illocutionary act and perlocutionary act ($r=0.927$, $p<0.01$ and $r=0.633$, $p<0.01$), respectively.

Table 5-5: Spearman's rho inter-correlations between human perception of the agent's illocutionary act, perlocutionary act and collaboration performance

	M	SD	Cronbach's Alpha	1	2	3
1. Agent's Illocutionary act	3.84	0.68	0.44	1.000		
				.		
2. Agent's Perlocutionary act	3.58	0.74	0.67	0.620*	1.000	
				0.010	.	
3. Collaboration performance	3.96	0.61	0.72	0.927**	0.633**	1.000
				0.000	0.008	.

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Our evaluation sought to go beyond just finding a correlation between human perception of the agent's illocutionary act and perlocutionary act and collaboration teamwork. Regression testing was used to estimate whether it was possible to predict performance of human-agent collaboration based on human's perception of agent's illocutionary and perlocutionary acts. The results of linear regression, see Table 5-6, showed that 48.7% of the variance in human perception of the agent's perlocutionary acts could be accounted for by the human's perception of the agent's illocutionary act. The results indicated that human perception of agent's illocutionary act and human perception of the agent's perlocutionary act was significant (R^2= 0.487, $F (2, 13) =15.24$, $p<0.01$).

Moreover, the results of multiple regression, see Table 5-6, showed that 67.6% of the variance in human's perception of collaboration performance could be accounted for by the human's perception of both the agent's illocutionary act and the agent's perlocutionary act. The result indicated that the human's perception of collaboration performance, on one hand, and the human's perception of both the agent's illocutionary act and agent's perlocutionary act, on the other hand, was significant (R^2= 0.814, $F (2, 13) =16.62$, $p<0.01$).

Table 5-6: Multiple regression of taskwork and teamwork on verbal and non-verbal communication. In addition, team performance on taskwork SMM and teamwork SMM

Model	Unstandardized Coefficients		Standardized Coefficients β	R	Adjusted R^2	F	Sig.
	Unstandardized B	Std. Error of the Estimation					
Agent's Illocutionary act							
Agent's Perlocutionary act	0.796	0.204	0.722	0.722	0.487	15.241	0.002*
Collaboration performance							
Agent's Illocutionary act	0.913	0.191	1.016	0.848	0.676	16.622	0.000*
Agent's Perlocutionary act	-0.212	0.173	-0.26				

* *Significance level p<0.01*

5.4.5 Discussion

This study aimed to analyse the impact of the agent's verbal communication on the collaboration performance of teamwork between humans and agents. To go beyond merely exploring the hypothesized relationship between the agent's verbal communication and collaboration performance, agent's verbal communication was anatomized. In this anatomy, each fundamental component of the agent's verbal communication was evaluated individually and studied in relation to other components. SAT has been a well-known theory for undertsanding human speech, particularly while achieving a task. Although SAT has been used to explore human speech while acomplishing a mission in collaboration with other humans, it has not been utilized before to understand an agent's verbal communication and the impact of that communication on the outcome of the collaboration with human teammate. We claim that this is one of the innovations of this thesis.

SAT was proposed in this thesis to help to answer RQ 1.1 that aims to study the influence of IVA's multimodal communication on the collaboration with the humans and provide a means to analyse human-agent communication. As a first step we validate the effectiveness of SAT, four evaluation questions (EQ 1.1 to EQ 1.4) were proposed. The first two questions inquired how SAT components (EQ 1.1 to EQ 1.4), i.e. illocutionary act and perlocutionary act, could be used to evaluate an agent's verbal communication. These questions included both objective and subjective methods to provide a thorough evaluation. Based on the first two questions, the last two questions go a step further. They asked if the evaluated anatomized components of agent's verbal speech could influence and be a predictor of human-agent performance.

Concerning the evaluation of the agent's locutionary act, the results showed that the participants generally had a positive perspective toward the structure of the utterances said by the agent. We sought to investigate why many found the messages "awkward". By reviewing the script of the sentences and participants' comments, we found that some of agent's utterances seemed to be formal and not similar to everyday natural conversation. Researchers have found that humans' expectations of the abilities of collaborative virtual agents were lower for robot-like agents rather than human-like agents. (Hinds et al., 2004). (Nishio and Ishiguro, 2011) found that the appearance of a virtual agent can have a strong effect on human evaluations of the agent's capabilities; that is to say if virtual agent looks like a human, humans will expect the virtual agent to have other human capabilities such as natural human speech. Improving the structure of the sentences uttered by the agent needs to be continuously revised to make sure they satisfy human expectations.

The evaluation question (EQ 1.1) inquired if the agent's illocutionary act can be measured using objective and subjective methods. The result of measuring illocutionary acts stressed the importance of the balance of the interlocutors's usage of Searle's five classes. Effective speech should not have a specific or singular tone of speech, i.e. representative, declarative, and so on. The results showed that the five classes were used with different ratios in the dialogue between the agent. The dominant ratio is for the representative class because the nature of the dialogue needs both the human and the agent to reply to each request for feedback. Yet, the other illocutionary classes are well represented in the messages exchanged to make the dialogue have more variety. After estimating the balance of the utterances of the agent and the human, a subjective evaluation method was used. Subjective evaluation measured to what extent the participants considered the intention of the agent clear as conveyed by the agent's requests, replies and feedback. Findings in social neuroscience research have demonstrated that understanding the intentions of co-actors is fundamental for successful social collaboration (Newman-Norlund et al., 2007). Similarly, in collaborations involving agents, researchers have found that understanding of intention is fundamental in collaborative tasks (Dindo and Chella, 2013).

The second evaluation question (EQ 1.2) inquired if the agent's perlocutionary act can be measured using objective and subjective methods. The analysis of the tracking data in the log files showed that the participants' acceptance ratio increased from 64.41% of the agent's request to 70.69% in the last cycle. This increase could be explained by the increasing exposure of participants to the agent's verbal communication. A number of studies have argued that the exposure to communication positively affects the degree of coordinated performance attained by teammates.

The evaluation question (EQ 1.3) inquired if human understanding of the agent's intention is associated with human perception of the consequence of the agent's utterance. The result revealed that human perception of the agent's illocutionary act and their perception of the agent's perlocutionary act are significantly correlated. Moreover, the result showed that human understanding of the agent's intention in its speech is likely to be a predictor of human perception of the consequences of the speech. The literature reveals conflicting opinions regarding whether illocutionary acts are sufficient to develop the interlocutor's understanding of the consequences of the speech. Some researchers believe that perception of the collaborative environment is hard to establish via exchanging messages, because message exchange could fail anytime (Halpern and Moses, 1990). Some other work, goes to the other extreme and assumes understanding of uttered messages as a key factor in forming an understanding of the other interlocutors and the incidents in a collaborative sitaution (Traum, 1999). Although our studies did not investigate other possible factors that might contribute to the participants' understanding of the agent's perlocutionary acts, the results showed the importance of participants' understanding of the agent's intention expressed in its locutionary acts to support participants' expectations of the consequences of verbal communication in a collaboration situation.

The last evaluation question (EQ 1.4) sought to use the result of using SAT as an evaluation tool to investigate the impact on collaboration performance. The results demonstrated that there is a significant correlation between human perception of the agent's intention in verbal communication and the consequences of this communication, on one hand, and human perception of collaboration performance, on the other hand. In addition, the results revealed that human perception of the agent's intenion of speech and consequence of speech are likely to be a predictor of human perception of collaboration outcome. In addition, The answer to the second part of the fourth question revealed that participants' perception of agent's illocutionary act contributes more in their perception to collaboration performance. To the best of our knowledge, there is no research work in the literature that studied an agent's illocutionary and perlocutionary act and their impact on a task-oriented collboration with humans. Nevertheless, there is a number of studies that argued the importance of communication as a facilitator in successful teamwork (Smith-Jentsch et al., 1998) improve coordinated performance (Espevik et al., 2006). (Sycara and Lewis, 2004) confirm the importance of the agent in assisting human partners in their activities via communication.

5.5 Evaluating the Impact of Agent Architecture and HAT-CoM on the Development of a SMM

5.5.1 The Theory and Research Questions

The aim of this part of the study is to verify the impact of the proposed agent architecture and the communication model on the development of the SMM between a human and an IVA. We apply a proposed human-agent communication model, HAT-CoM, to verify the effect on the development of the SMM between the human and the agent as teammates. The evaluation process is conducted through analytical and inductive methods. These two evaluation methods are represented as two evaluation questions. The first evaluation research question represents the analytical evaluation. It analyses the components of HAT-CoM, i.e. verbal and non-verbal communication, and the features of SMM, i.e. knowledge about the task and knowledge about the team companion, and studies if there is a relationship between these components and features. The second evaluation research question utilizes the induction method of evaluation. The inductive evaluation method tries to deduce the relationship between HAT-CoM and SMM through tracking the impact of applying HAT-CoM on the outcomes of the SMM. Figure 5-9 shows the research model to evaluate the influence of HAT-CoM on human-IVA SMM. The main evaluation question, i.e. Evaluation Question 2: what is the influence of agent architecture/behaviour on the development of a SMM as can be observed in SMM aspects was divided into the following three sub-questions:

Evaluation Question 2.1*: What is the impact of each of the HAT-CoM components, i.e. the verbal and non-verbal communication, on the development of a SMM between the human and the agent as represented in the team members' knowledge about the teammate and their knowledge about the shared task?*

Evaluation Question 2.2*: What is the impact of applying HAT-CoM on the development of the SMM between the human and the agent as represented in the outcomes of the SMM, namely anticipating a teammate's decisions, reduced explicit communication, match in cognitive perspective and competence in decision-making (easiness in flow of decisions)?*

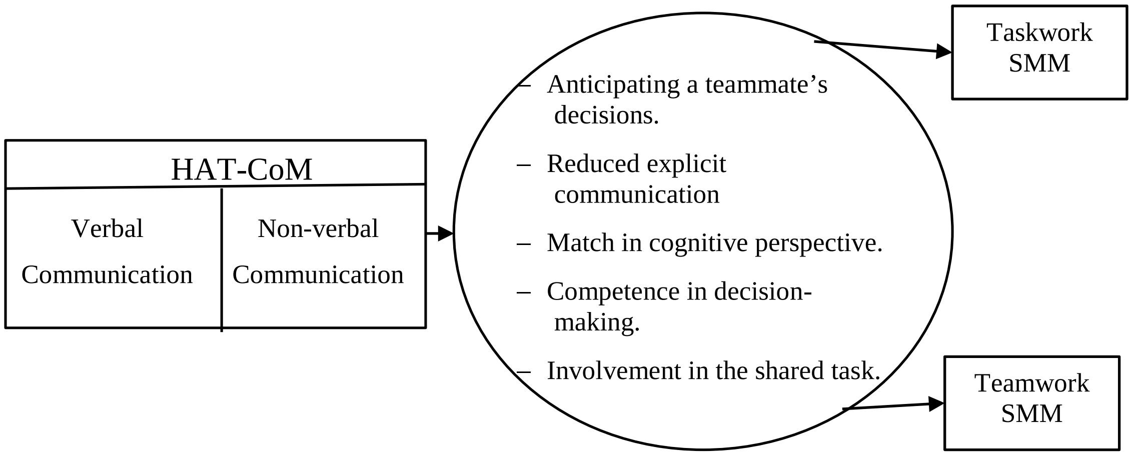

Figure 5-9: The research model to investigate the impact of HAT-CoM on the development of SMM

After proposing questions to evaluate the relationship between HAT-CoM and developing the SMM, we study the impact of an implausible or unreasonable communication between team members on the developed SMM. To determine this impact, we made the agent give the human an invalid request and study the changes on the outcomes of the SMM. We propose a third question to represent the effect of the implausible request.

Evaluation Question 2.3*: What is the impact of an implausible request between the team members on the SMM as represented in the outcomes of the SMM?*

5.5.2 The Result

In this section, we present the results related to understanding the task (5.5.2.1) and companion (5.5.2.2) and the outcomes of establishing (5.5.3) or breaking SMM (5.5.4).

5.5.2.1 Understanding the task

To evaluate the human's perception of the agent's understanding of the task as expressed in the agent's verbal messages, a survey question asked the participants "How well did the exchanged messages show that the character understood the situation?" The aim of this question was to evaluate how the human participant thinks of the understanding of his teammate to the task. The result, see Figure 5-10, shows that over a quarter of the participants thought that the agent clearly understood the situation, while half of the participants thought that the agent showed some understanding of the situation. The result includes the group of participants who experienced the implausible cycle at the end of the task.

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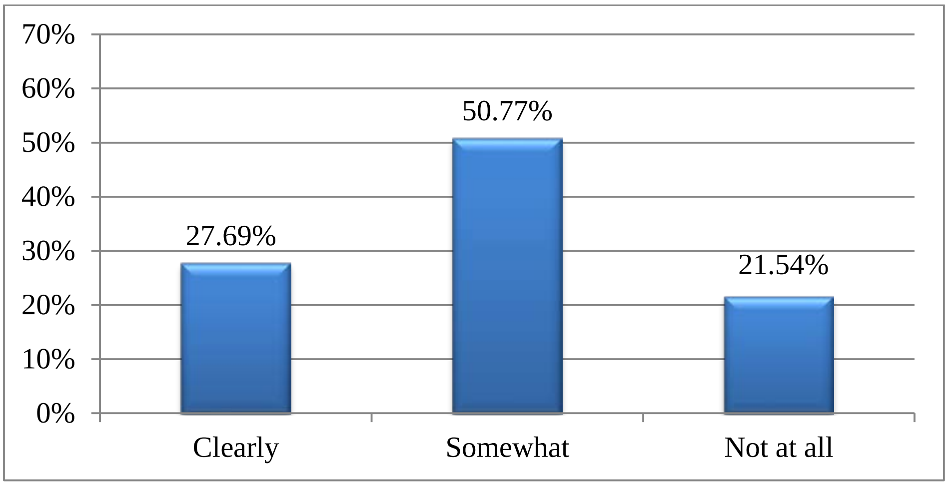

Figure 5-10: The human's perspective of the agent understanding of the situation as expressed in verbal messages

To evaluate the human's perception of the agent's understanding of the task as expressed in the agent's non-verbal actions, a survey question asked the participants "Did the character's behaviour reflect his understanding of the situation and the target to complete?" Figure 5-11 shows that 57.81% and 14.06% of the participants agreed and strongly agreed respectively that the agent's actions reflected his understanding to the situation. The ratio of the cumulative positive attitude (71.87%) reflects the participant's satisfaction with the agent's knowledge about the situation in which the task is carried out.

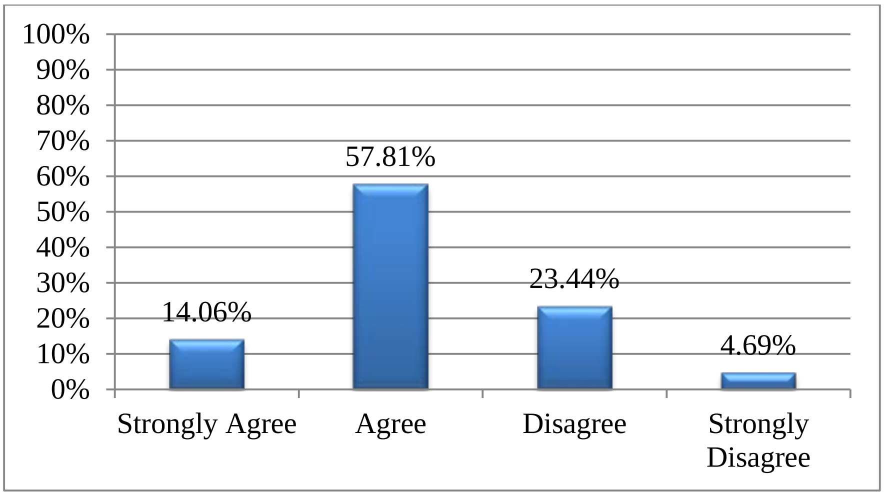

Figure 5-11: The human's perspective of the agent understanding to the situation as expressed in non-verbal cues

5.5.2.2 Understanding the companion

The second factor that characterizes the establishment of a SMM is to understand the knowledge and the cognitive ability of the team companion. To evaluate the effectiveness of HAT-CoM in establishing the SMM between the human and the agent, we measure how the agent has knowledge about the human teammate as expressed in the agent's verbal and non-verbal communication.

It is widely believed that our internal state could be revealed by verbally expressing our thoughts and knowledge (Mutlu et al., 2009). To evaluate the human's perception of the agent's understanding of the human's role and decisions, a survey question asked the participants "Did the character demonstrate understanding of your action in his replies and actions?" Figure 5-12 shows that 59.38% and 9.38% of the participants agreed and strongly agreed respectively that the agent's replies and actions reflected his understanding of the human participant' role and decisions. The ratio of the cumulative positive attitudes (71.88%) reflects the participant's satisfaction, as a counterpart in the team, with the agent's knowledge about his/her role in the team.

Besides being a crucial factor in sharing knowledge about the shared task, verbal communication plays a crucial role in establishing a mutual understanding between the teammates during collaborative tasks. A second sign of establishing the SMM between the human and the agent is to understand the verbal communication. Figure 5-12 shows that 60.94% and 14.06% of the participants have agreed and strongly agreed respectively that the agent's demonstrated understanding of his/her verbal requests. This

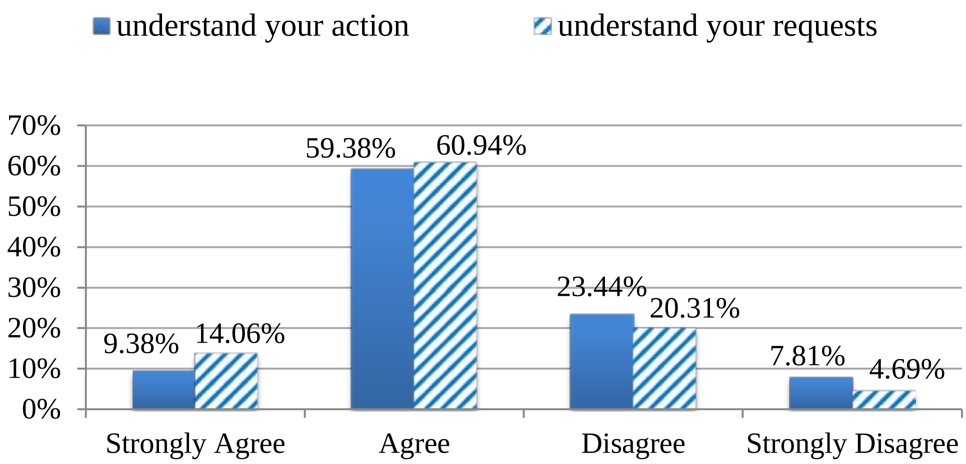

Figure 5-12: The human's perspective of the agent's understanding of the verbal and non-verbal communication

understanding is shown in the agent's reply with either acceptance or rejection of the request, or in his reaction to the request. The ratio of the cumulative positive attitudes (75.00%) reflects the human satisfaction with the level of understanding that the agent has toward human verbal requests.

5.5.3 The outcomes of establishing SMM

The outcomes of establishing a SMM between team members could be used as evidence of successful development of the SMM between team members. Anticipating the teammate's information needs and decision have been found to be key SMM outcomes due to the similarity in knowledge about the situation and the task (Kraiger and Wenzel, 1997).

5.5.3.1 Anticipating teammate's plan

To evaluate the impact of developing a SMM via both verbal and non-verbal means, we used data from the automatic log files to estimate how frequently the human proposes requests to the agent and how close these requests are to the agent's plan to achieve the shared goal. Figure 5-13 shows the results of four cycles plus an implausible request cycle. The results showed that in the first cycle, 17.24% of the human teammate requests matched the agent's plan and the agent accepted them. In the following two cycles, this ratio continuously increased to be 50.00 % and 57.89% in the second and the third cycles respectively.

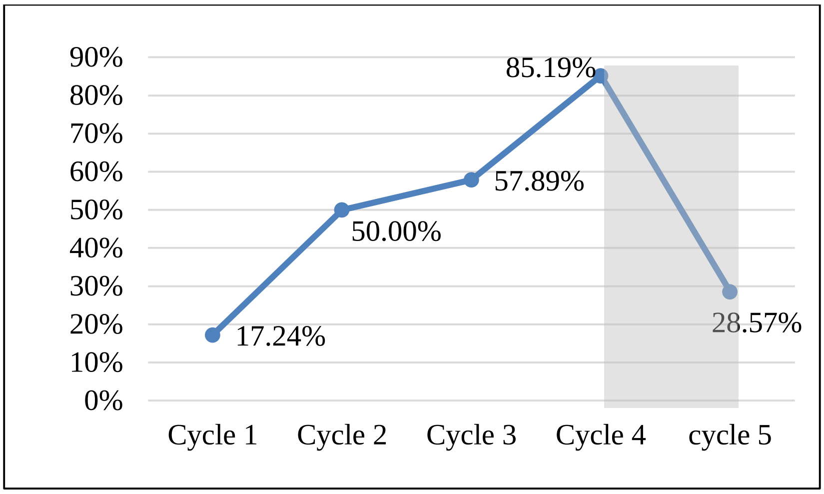

Figure 5-13: The ratios of agent's acceptance to human's requests in the normal cycles plus implausible cycle

5.5.3.2 Reduced explicit communication

Another outcome of the development of SMM between teammates is the reduction of explicit communication while achieving the shared goal. According to some researchers, e.g. (Espevik et al., 2011), the result of anticipating the plan of another team member is that explicit communication will be less, and the more the team members will share each other's understanding about the goal. To estimate the explicit communication between the human and the agent, a tracking mechanism was used to register the human's explanation requests to the agent, when the agent asks the human to take a certain step. Figure 5-14 shows that in the first cycle 67.80% of the participants asked the agent to explain the proposal that the agent made to the human teammate. In the following cycles, the ratios continuously dropped to 32.20% and 25.86% of the participants.

5.5.3.3 Match in cognitive perspective

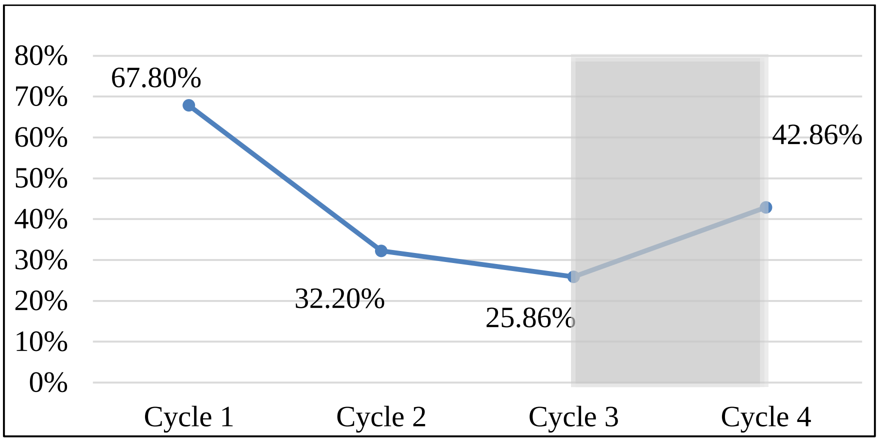

Figure 5-14: The ratios of human's request to an explanation from the agent in the normal three cycle plus implausible cycle

The purpose of a SMM is to foster the development of a shared understanding between team members. The primary impact of a SMM in teamwork is to establish a good level of mutual understanding between teammates that enables them to deduce the other's plan. To evaluate this mutual understanding, we tracked the verbal requests made by the agent and calculated the ratios of acceptance and rejection of these requests during each cycle. Figure 5-15 shows that the percentage of the human acceptance/rejection responses to the agent's verbal requests in each cycle. The results show that the human's behaviour reflects an acceptance level in cycle1, cycle2 and cycle3 to what the agent has requested of 76.27%, 67.80% and 70.69% respectively with an average 71.59%.

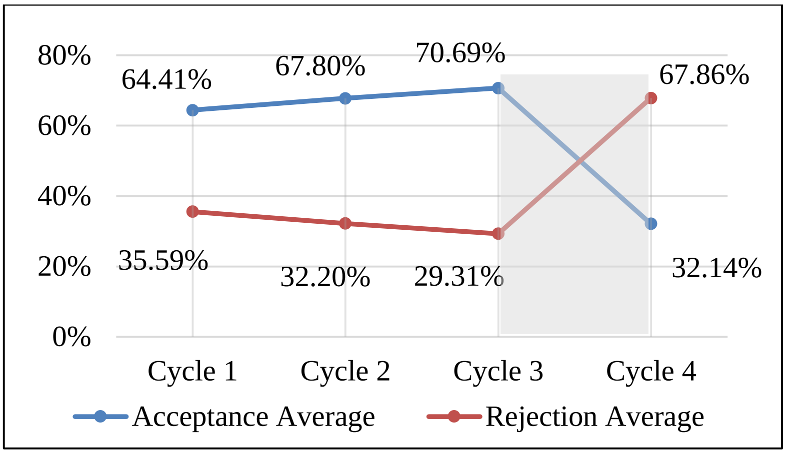

Figure 5-15: The ratios of the human's response to agent's verbal requests in the normal cycles and the implausible cycle

5.5.3.4 Competence in decision making

The ease of decision-making and the speed in performance are considered related signs of competence in achieving a task. To evaluate the progress of the human's performance to complete the different cycles, the average time to complete each cycle is recorded. Figure 5-16 shows that the average time the human participant needs to complete the first cycle is 51.1 seconds. The time decreased in the consecutive cycles to be 40.66 and 33.78 seconds in the second and the third cycles respectively.

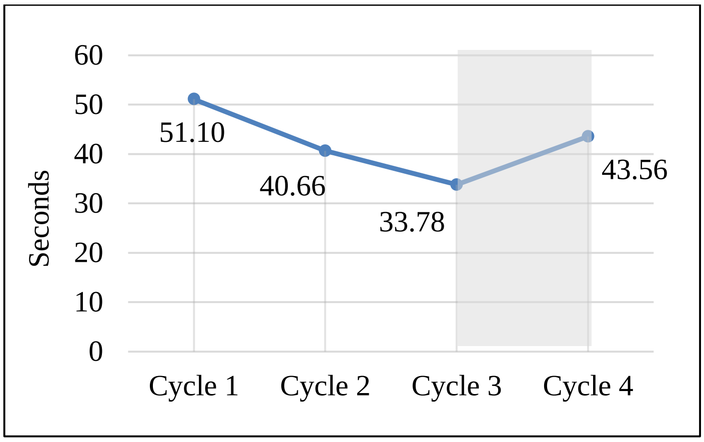

Figure 5-16: The average time to complete each normal cycle besides the implausible cycle

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5.5.3.5 Involvement in the shared task

Besides creating a shared understanding of the goal and the relevant capabilities, an SMM increases the involvement of team members in the shared task. To evaluate the involvement of the human with the agent teammate, we calculated the ratio of the participants who recommended a possible next step that the agent can take. Figure 5-17 shows that in the first cycle only 43.94% of the human participants proposed recommendations for a possible next step that the agent can take. The ratios increased to 54.55% and 57.57% in the second and the third cycles.

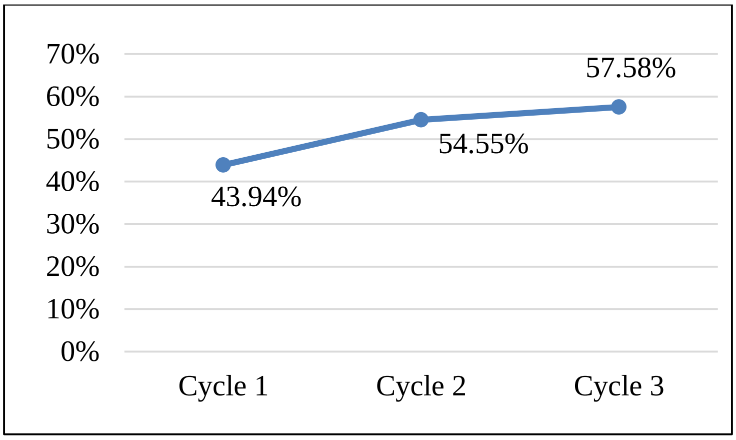

Figure 5-17: The ratios of recommending next step in each cycle

5.5.4 Breaking the Shared Mental Model

SMM is created with effective communication and plausible directions while conducting the actions to complete the shared goal. The plausible directions foster trust between team members. To investigate the effect of proposing unreasonable directions on SMM as demonstrated by its outcomes, we present the results of an additional cycle (fourth cycle) where the agent asks the human to select a region that has already been selected.

The results demonstrate that the agent's satisfaction continuously increases along the four cycles. This satisfaction developed with reasonable requests from the agent and the progression in achieving the goal. Figure 5-14 shows that when the human is faced with an implausible request from the agent, his/her selection does not satisfy the agent's plan. The implausible cycle shows regression for the satisfaction of the agent with the human's action.

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An outcome of developing a SMM between team members is a reduction in explicit communication. Reaching a common understanding about the goal, and the plan to reach the goal, means that the team member does not need to keep asking his counterpart about his/her plan or possible next step. However, when a team member is requested to perform an activity that seems unrelated to the shared goal, the explicit communication to ask for more explanation would be a sign of expressing disagreement. Figure 5-15 shows that 42.86% of the participants clicked 'Reason' button to seek explanation from the agent about his implausible request.

The average of the human's acceptance of the agent's requests in the first three cycles was 71.59%. Figure 5-16 shows that 32.14 % of the participants accepted the implausible request from the agent compared to 70.69 % in the previous cycle that had a reasonable request. The time needed to complete each cycle dropped continuously from 51.1 seconds to 33.78 seconds to complete cycle one to three. The result shows that the average time needed to complete the implausible cycle is 43.56 seconds, as shown in Figure 5-17.

5.5.5 Discussion

According to a number of researchers, the development of a SMM improves teamwork performance (Rouse et al., 1992). In order to study the impact of HAT-CoM on developing a SMM, we posed two evaluation research questions, i.e. EQ 1 and EQ 2. The first evaluation question aimed to investigate the effect of both the verbal and the non-verbal communication of HAT-CoM on developing knowledge about the task and the team. The second research question concerned the effect of HAT-CoM in developing the SMM as it appears in the common outcomes of the SMM.

To answer the evaluation question 2.1, we followed the analytical method to explore the components of the related variables and find whether there is a relation between these components. Regarding the knowledge about task, the result shows that the majority of the participants believed that the verbal communication of the agent as represented in his requests/replies and the non-verbal communication as represented in agent's actions and decisions demonstrated understanding to the situation and the task. Regarding knowledge about the team, the result in section 5.2 shows that the majority of the participants believed that both agent's verbal and non-verbal communication demonstrated understanding of the human's speech and actions. We conclude that HAT-CoM has a positive impact on the development of SMM between the human and the agent as represented in team members' knowledge about the team and their knowledge about the shared task.

EQ 2.2 investigated the effect of HAT-CoM on developing the SMM. This effect appears in the common outcomes of the SMM. The investigation followed the inductive method to study the causal relation between HAT-CoM and SMM through investigating the changes on the outcomes of SMM because of using HAT-CoM. The studied outcomes of SMM are anticipating teammate's decisions, reduce explicit communication, match in cognitive perspective, competence in decisions making.

When evaluating the ratio of the agent's acceptance to the human's requests, the result shows that over the consecutive cycles of the collaborative task the acceptance ratio increases. The increase in the agent acceptance ratio is a sign of having a mutual agreement on the steps to achieve the task. Another outcome of the SMM is the reduction in the explicit communication as the team members go on conducting the task. The result shows that the optional communication regarding the inquiries about the agent's decision is reduced over the cycles. This reduction is assumed to be because of the human's realisation of how the agent is making his decisions. A third outcome of the SMM that we investigated is the match in cognitive perspective. The result shows that the rate of the agent's acceptance slightly increased from one cycle to another. This finding is consistent with other studies (Banks and Millward, 2000) and confirms the development of a SMM between teammates is accompanied with forming a similar expectation and perspective about the outcome of the shared task.

The fourth outcome of SMM is the competence in making a decision while carrying out the shared task. Competence could be represented as efficiency in the time to complete the task. The time to complete each cycle was recorded and an improvement in the efficiency in the time needed to complete the shared task was registered. The result is consistent with other research work that assumed that developing a SMM helps teammates to reach decisions more easily (Noordzij and Postma, 2005). The last outcome of SMM is the involvement in the shared task. We found that the ratio of the participants who optionally recommended steps for the agent to take increased over the cycles as a sign of the human's desire to collaborate more with the agent. Our findings about the involvement in the shared task is consistent with the assumption of a number of studies

(Carpenter et al., 2008) which claimed that developing SMM makes team members more positive about the shared purpose. Our findings in studying the impact of HAT-CoM on the development of a SMM demonstrate improvement in the considered outcomes. These findings answer the posed second question (EQ 2.2).

The third question (EQ 2.3) investigates the effect of insensible request between teammates on the developed SMM. In order to answer this question, we studied the influence of implausible requests between the team members on the SMM as denoted in the outcomes of the SMM. To probe the effect of an implausible request, at the end of the normal cycles, the agent asked the participants to go and select a region that has already been selected before and where a fence has been built.

The first outcome to explore is anticipating the plan of the teammate. The result shows a noticeable drop in agent acceptance ratio to the participants' requests. The degradation from 85.19% in the last cycle of the normal case to 28.57% in the implausible cycle represents the randomness in the choice the human requests the agent to take. The randomness in the choice reflects the difficulty a human faces in predicting the plan of the agent in this situation. Concerning the reduction in the explicit communication as an outcome of developing SMM, the result demonstrates that the continuous reduction in the communication because of establishing a SMM witnessed a sudden reversal in the implausible cycle. This increase in the communication is represented as an increase in the likelihood of demanding an explanation from the agent to his implausible request. Another feature of the SMM that showed noticeable change was the match in cognitive perspective. The result shows that the ratio of the human's acceptance to the agent's request dropped from 70.69% in the last normal cycle to 32.14% in the implausible cycle. This abrupt drop in the human's acceptance ratio assumes that the continuous trust that the participants had to the agent's previous requests is broken when the agent made an implausible request. A final feature of SMM that we studied was the impact of implausible request on the competence in taking decisions. The result shows that the time the participants needed to take a decision in each cycle suddenly surged. The additional time in the implausible cycle demonstrates that when the participants faced an unfamiliar factor in the situation that increased the difficulty in taking a decision.

Relying on our findings in the implausible cycle, we conclude that an implausible request between the team members while participating in a collaborative activity will result in the degradation of the developed SMM. This degradation is apparent in some of SMM features such as inaccurate anticipation of the plan of the teammate, increase in the explicit communication, mismatch in cognitive perspective and difficulty in taking decisions.

5.6 Summary

This chapter aimed to evaluate functionally the proposed agent architecture and the integrated communication model. This aim was carried out on two stages. The first stage aimed to evaluate the plausibility of the agent communication through novelly using SAT as a tool. The second stage aimed to investigate the influence of the agent architecture on the development of a SMM with human teammate. The analytical evaluation investigated the impact of verbal and non-verbal communication portions of HAT-CoM on the development of SMM features, i.e. knowledge about the task and the team. Our results showed that elements of HAT-CoM had a positive impact on the development of the SMM as witnessed by the participants. The inductive evaluation aimed at verifying the impact of HAT-CoM on the development of the SMM through tracing the changes on the outcomes of the SMM. The results showed that HAT-CoM had a positive impact on the development of the SMM as demonstrated in the improvements in SMM features. These improvements witnessed abrupt deterioration of the SMM, when the participants faced an implausible request from the agent teammate.

CHAPTER 6

Evaluating the Impact of Agent Multimodal Communication on Human-IVA Teams

6.1 Background

Most agent-based research concerning teamwork has focused on agent-agent interaction. However, as interest in the use of Intelligent Virtual Agents (IVAs) as companions and/or members of IVA-human teams grows there is increased interest in understanding the ways in which a teamwork bond is built and fostered as this is likely to improve relationships and team outcomes (Prada and Paiva, 2009). Research concerning human teams has identified that a team is not just a gathering of people; team members should have a shared goal, effort coordination, a SMM (Lim and Klein, 2006), high level of trust (Mach et al., 2010), high commitment (West et al., 2003) and effective communication (Smith-Jentsch et al., 1998). Furthermore, conventional human-human teamwork is known to require development of trust which is essential for the quality of the teamwork (Lenz and Machado, 2008). Besides trust, teamwork requires the members to have shared understanding and commitment to the joint activity (Bratman, 1992). There is a paucity of research studies considering these factors (i.e. communication, trust, commitment, SMM) in the context of human-IVA teams.

Psycholinguistic studies (Kendon, 2004) (McNeill, 2005) have affirmed the complementary nature of verbal and non-verbal aspects in human expressions of communication. In the light of these results, several research studies sought to integrate verbal and non-verbal aspects in IVA communication. However, such studies focused mainly on the non-verbal communication of IVAs (Pelachaud and Poggi, 1998) or on implementing synchronization between speech, facial, and body movements in a manner similar to humans (Kopp et al., 2003) (Kakumanu et al., 2006).

The increasing interest in human-IVA teamwork has led researchers to study the variables that may influence such teams (Traum et al., 2003) (Tambe, 1997) (Nair et al., 2004). However, few studies go beyond finding a relationship between two variables and are thus unable to build a more holistic picture of the factors that could affect these teams. Moreover, to the best of our knowledge, there is no study that has investigated the impact of IVA-human multimodal communication, i.e. verbal and non-verbal communication, on certain factors that have been found to impact on the performance of human teams such as a SMM, commitment and trust. To contribute to our understanding of human-IVA teamwork, this chapter aims to investigate the influence of IVA multimodal communication on the development of a SMM between humans and IVAs, and on the establishment of human trust in the IVA's decision. In addition, this chapter aims to study the influence of human trust in IVAs on human commitment to honour their promise to their IVA teammates. Moreover, the chapter aims to explore the impact of human commitment level on overall team performance. These aims are brought together to provide a holistic model of IVA-Human teamwork.

6.2 Aspects of a Teamwork

Studying the factors that impact on teams is not new to human teamwork (Hinds et al., 2000). However, when it comes to heterogeneous teams that include humans and IVAs, the mission becomes difficult as humans and IVAs have different beliefs and different intentions that drive them while participating in teamwork. Research work studying human-IVA teams focus on one of three aspects in teamwork. These aspects are either behavioural aspects, i.e. communication, cognitive aspect, e.g. a SMM, or social aspects, e.g. trust and commitment. Several studies have explored the effect of each of these aspects on team performance; yet, the relationship between these aspects is unknown.

6.2.1 Behavioural Aspects of Teamwork

Regarding the behavioural aspect of teamwork, it is widely known that communication between agents is a challenging research area (Chaib-draa and Dignum, 2002). Horvitz

(Horvitz, 1999) identified a number of challenges in human-machine interaction, including pursuing mutual understanding or grounding of shared activity, identifying opportunities for problem-solving, breaking down problems into sub-problems, resolving sub-problems, joining solutions found by humans and machines, and preserving coordination and communication while achieving these procedures. Ferguson and Allen (Ferguson and Allen, 2007) indicated that true human-agent collaboration needs an agent to exhibit several capabilities including reasoning, communication, planning, execution, and learning. Allwood (Allwood, 2001) mentioned four requirements that characterize agent cooperation, these requirements are: consider each other cognitively in the interaction, have a common objective, interact with each other ethically, and trust each other.

Team communication includes two or more individuals and a meaningful message that a sender attempts to send to the receiver (teammate) either to influence his attitude, discuss tactics or coordinate teamwork. Many research works target designing systems and models that involve human-agent communication. Some of these works focus only on verbal communication, for example, Luin et al. (Luin et al., 2001a) (2001b) presented an agent with natural language accessible navigation skill for a virtual theatre environment where the user can navigate into the environment and the agents inside the system can answer the user's questions. Other scholars are concerned with non-verbal communication such as facial expressions, gesture, and body movement. For example, (Miao et al., 2006a), (2006b) presented a system to train subjects to deal with abnormal situations while driving cars by interacting non-verbally with the agent. A few studies focused on multimodal communication that requires the interlocutors to express their intentions using different channels, that is, verbal and non-verbal. Multimodal communication includes acts such as observing the listener's behaviour, expressing the speaker's beliefs and intention, monitoring the listener's reaction and providing/responding to feedback (Visser et al., 2012).

6.2.2 Cognitive Aspects of Teamwork and SMMs

In recent years, researchers have been interested in studying the role of agents in human teamwork (e.g. (Sycara, 2009)). Special interest has been directed to teamwork between humans and IVAs (Ball et al., 2010) (Bradshaw et al., 2012). Key issues to be addressed in designing agents as a teammate to collaborate with humans include communicating their intent and making results understandable to them (Lewis, 1998) and identifying shared understanding for human-agent coordination (Klien et al., 2004). As a SMM has proven its positive impact on human teams, this notion has found its way into agent studies. Sycara and Sukthankar (Sycara and Sukthankar, 2006) stated that the biggest challenge in human-agent team work is to establish a SMM. In recent years, extending the concept of a SMM to include teams of agents or situations that combine the human and the agent in one team has inspired research effort (Fan and Yen, 2011).

Most research into SMMs concerns human-human teamwork and communication (e.g. (Espevik et al., 2006)). Some research considers a SMM in the context of agent-agent teamwork. In this work, (e.g. (Yen et al., 2006)) agents were designed to use SMM knowledge of the task to communicate information with other agents in a team. In order to design an agent's cognitive structure especially for human-agent teamwork, Fan and Yen (Fan and Yen, 2011) developed a system called Shared Mental Models for all, SMMall. SMMall uses a hidden Markov model (HMM) to help an agent to forecast its human partner's cognitive load status. However, SMMall does not support communication. Our proposed model enables agents on the one hand, to deduce the humans' intention and on the other hand, to communicate their internal state. In other work, Hodhod et al. (Hodhod et al., 2012) proposed a formal approach to construct SMMs between computational improvisational agents and human interactors. The authors used some socio-cognitive studies from human improvisers, in addition to fuzzy rules and confidence factors to allow agents to reason about uncertainty. This approach was presented theoretically and no result was provided to validate the approach. A few studies investigated the relationship between multimodal communication and the degree of coordinated performance attained by teammates which in turn fosters the development of a SMM (Espevik et al., 2006).

Some agent-based research in the area of teamwork has pursued goals similar to ours without the explicit use of a SMM (Bradshaw et al., 2004). For example, the Alelo language and cultural training system (Sagae et al., 2012) allows a human trainee to observe via feedback bars and icons whether they are communicating appropriately within the context of a specific cultural scenario. SMM concepts resemble Traum's use of grounding models (Traum and Allen, 1992) or mutual beliefs between humans and an IVA. Traum's work focused on studying a human's dialogue and creating a conversation system that mimics human verbal communication to establish mutual understanding with a conversational virtual human (Roque and Traum, 2009). However, collaborative activities need more than grounding based only on verbal conversation. Indeed verbal communication alone is partial communication. Grosz's work covered many aspects of agent teamwork including various techniques for collaborative planning (Sarne and Grosz, 2007) and communication (Stern et al., 2013). However, the work was concerned more with agent-agent collaboration where planning and communication is built on shared beliefs and intentions between agents. The work does not use communication to build, maintain and monitor the shared beliefs. Another noteworthy research work that studied agent communication and collaboration was Dignum's work (Oijen and Dignum, 2012) (Jonker et al., 2008) that presented a model for realising believable human-like interaction between virtual agents in a multi-agent system (MAS), but their work handles the communication between agents in the same virtual environment, where agents share the same resources. An interesting stream of work was Pelachaud's work on IVA's multimodal communication in situations with designated goal, For example, Pelachaud and Poggi (Pelachaud and Poggi, 1998) presented a system to automatically select the appropriate facial and gaze behaviours corresponding to a communicative act for a given speaker and listener. Their system focused on adapting the non-verbal behaviour of agents and specifically facial expression during communication. The agent's facial expressions were selected based on Ekman's description of facial expressions. However, this stream of work focused more on the impact of the IVA's multimodal communication (particularly non-verbal) on the human's performance without investigating the interrelationships of the communication with other factors that make communication influential in human-IVA teams.

6.2.3 Social Aspects of Teamwork

The third aspect of teamwork is the social aspect. Research work investigated how to foster trust in human teams (Hinckley, 1981) and strengthen commitment between teammates (Bratman, 1992). A number of studies have investigated commitment between a team of agents (Chopra and Singh, 2009) (Traum, 2008) or in multi-agent systems (El-Menshawy et al., 2013). These studies have taken advantage of being able to design agents that have shared understanding of the common goal as agents share the same world. The social relationship between humans and IVAs has drawn the interest of agent researchers (Prada and Paiva, 2005) (Prada and Paiva, 2009). There has been particular interest in the development of human friendship with emotionally intelligent IVAs that can intentionally establish and strengthen social relations with other agents and humans (Dias and Paiva, 2013). However, very few studies have considered commitment to fulfil a joint task executed by a team of humans and IVAs. In one of these few studies, van Wissen et al. (Wissen et al., 2012) found that humans tend to be unfair and less committed to agent teammates. In their study, there was a simplified means of communication between humans and agents via exchanging text messages with requests/replies. The human's commitment was evaluated by calculating the ratio of fulfilled promises to give an agent a reward agreed on beforehand. Given the importance of commitment in human teams, commitment between agents and humans in heterogeneous teams has been understudied.

Novelly, this study presents a missing link in human-agent interaction studies. To contribute to our understanding of human-IVA teamwork, this study aims to investigate the influence of IVA multimodal communication on the development of a SMM between humans and IVAs, and on the establishment of human trust in the IVA's decision. In addition, this study examines the influence of human trust in IVAs on human commitment to honour their promise to their IVA teammates. Moreover, the study aims to explore the impact of human commitment level on team performance.

6.3 The Theory and Research Questions

The primary thrust of this study explores the relationship between human-IVA behaviour and communication on the development of SMMs, comprised of taskwork and teamwork SMMs as described in section 2.6.1.1. Research Question (RQ 1.1) inquired, "*What is the influence of IVA's multimodal communication on the collaboration with the humans?*" The literature suggested other variables that may interfere and influence human-IVA collaboration. These variables included multimodal communication, trust between team members (Lenz and Machado, 2008) and commitment (Casaló et al., 2011). Figure 6-1 presents a research model that formalises the following sub-research questions that elaborates research question 1.1:

RQ 1.1.1*: Does multimodal communication, verbal and non-verbal communication, influence taskwork SMM between humans and IVAs? Moreover, which method is more effective?*

RQ 1.1.2*: Does multimodal communication, verbal and non-verbal communication, influence teamwork SMM between humans and IVAs? Moreover, which method is more effective?*

RQ 1.1.3*: Do taskwork and teamwork SMMs influence the human's trust in the IVA's decision? Moreover, which one contributes more in trust prediction?*

RQ 1.1.4*: Does the human's trust in the IVA's decision influence human commitment to honour their promises towards achieving the shared task?*

RQ 1.1.5*: Does the human's commitment to honour their promises influence the human-IVA team performance?*

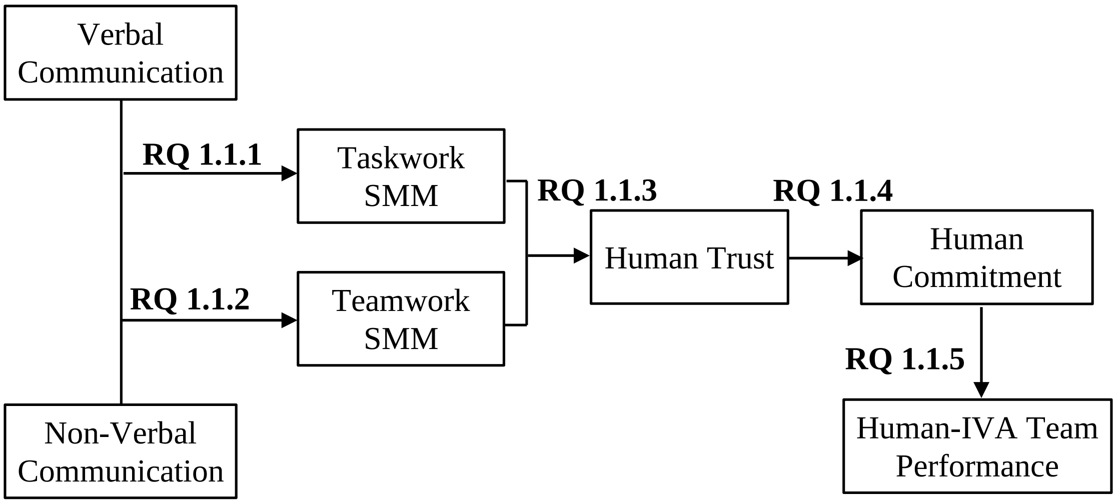

Figure 6-1: Research Model to investigate the influence of multimodal communication and human-IVA team performance

6.4 Materials and Methods

6.4.1 Experimental Design

The study was designed as an observational study where all the participants sits the same condition and the relation between two variables in the condition is observed and analysed. There were one version of the virtual scenario. All the participants use the same treatment, i.e. same version of virtual scenario. The study required the participant to do the following:

1. Complete a biographical survey (e.g. age, gender, frequency of playing video games).
2. Participate in a collaborative activity with the IVA.
3. Answer questions related to the experience and SMM in a post-survey. Surveys have been used to evaluate SMMs in previous studies.

6.4.2 Measurement of Study Variables and Data Collection

Each of the seven research variables, i.e. taskwork SMM, teamwork SMM, verbal communication, non-verbal communication, trust, commitment and team performance, were measured using two means, one subjective involving self-reporting and the other objective involving capture of user actions. The first means was a post-session survey asking participants about their perceptions of their interaction with the agent. The survey included five items for each of the seven variables. The participants were required to indicate their level of agreement with the statement using a 5-point Likert scale (1= strongly disagree, 5=strongly agree). As an example of a survey item to elicit the human's satisfaction with the verbal communication of the IVA (in the scenario the IVA is called Charlie) "Charlie's requests and replies were helpful to complete the task", and IVA's non-verbal communication "*Charlie's actions were suitable to the situation*". In non-verbal cues survey, we tried to ask about the properties of non-verbal communication such as appropriateness, timeliness, clearness, reasonable to the situation it was made for, having helpful influence on the task and reflecting agent's understanding to the situation. Survey items did not specify a specific aspect of non-verbal cues such as facial expression, body position or action taking. Adding survey questions that cover each of these five aspects separately for each type of non-verbal communication (agent's facial expression, physical position and gestures) would make the number of survey items to evaluate non-verbal communication impractical. Moreover, asking the participants to remember too many details about what the agent did in the scenario could be a load on participants and that may lead them to discontinue the participation.

As an example of a survey item about a taskwork SMM, we asked for the participant's level of agreement with the statement "*Charlie and I had a shared understanding about how best to ensure we meet our goal*". As an example of a survey item about a taskwork SMM, we asked for level of agreement with the statement "Charlie and I worked well together". Examples of the survey items used to elicit the level of trust in the IVA's decision include "*Over time, my trust in Charlie's selections increased.*" As an example of a survey item about team performance we asked for level of agreement with the statement, "*I am satisfied with the performance of the teamwork of Charlie and I*". The complete set of survey questions can be found in Appendix A**.**

The second means tracked the participant's behaviour while using the VE. In this study, all inputs from the user were logged to allow recreation of the participants' navigation paths and record inputs such as responses and keystrokes. These inputs included selected regions in the scenario; see section 4.3, exchanged messages between humans and IVAs, human's promises to the IVA and the actual decisions after making the promises. The data in the log files were used to describe the relationships between a SMM, trust, commitment and performance during the collaborative task, while the survey responses were used to show the possible relationships between study variables.

Trust was measured by the ratio of acceptance by the human of the IVA's request. This ratio represents the extent to which the human believes the IVA's requests are the better option to achieve the shared task. A higher acceptance ratio of the IVA's requests is likely to show more trust in the IVA's decisions. Commitment was measured by the ratio of (mis)match between the human's acceptance of the IVA's recommendations and the human's actual decision/action that carries out the acceptance.

The main aim of studying teamwork is to improve overall team performance. Human-IVA team performance was measured by the time needed to complete a single cycle. The time taken to complete each cycle was used as a reference to measure the improvement in team performance. The ratio of time for each cycle from the total time was calculated. Shorter cycles that take less time than the average time taken to complete each cycle are used to show better performance.

6.4.3 Statistical Method

A correlation matrix is a measure of the association between two variables. A correlation matrix indicates if the value of one variable changes reliably in response to changes in the value of the other variable. In order to demonstrate whether any relationships existed between the study's variables, correlation analysis was used. However an additional statistical method was required to answer research questions 1.1.4 and 1.1.5 that ask whether human trust impacts and is likely to predict human commitment and whether human commitment to the goal and to honour their promises impacts on human-IVA team performance.

While correlation analysis quantifies the degree to which two variables are related, regression analysis aims to learn more about the relationship between an independent or predictor variable and a dependent or criterion variable. Linear regression was used as an approach to modelling the relationship between trust and commitment and between commitment and team performance. Multiple regressions were used to investigate the predictive relationship of both verbal and non-verbal communication on humans' perception of a taskwork and a teamwork SMM, and a taskwork and a teamwork SMM and humans' trust in the IVA. IBM SPSS v.20 was used for the statistical analysis, while Microsoft Excel was used to plot the diagrams.

To further analyse the relationship between trust, commitment and team performance over time, human behaviours regarding their trust in the IVA, commitment and team performance were monitored in each interaction cycle required to complete the task to further under-stand the relationships between these variables.

6.4.4 The Virtual Scenario

The first virtual scenario of trapping an animal was presented in Section 4.5.1

6.4.5 The Participants

Twenty (20) secondary school students volunteered to participate in the study. Five students did not complete the post-session survey. Participants were in a grade/year 8 class, and aged between 13 and 14 years (mean=13.5). There were equal numbers of male and female participants. We were not able to ask about their English language competency. All of the participants were familiar with using computers and playing computer games. Participants' linguistic and computer skills were surveyed to explore if any struggle in the communication with IVA was because of the lack of linguistic or computer skills.

6.5 The Results

Our first data analysis involved a number of tests for normality (Section 6.5.1). In order to explore whether the study variables have internal-relationships, a correlation matrix was utilized (Section 6.5.2). To answer the first three research questions (RQ 1.1.1 to RQ 1.1.3), multiple regression analysis was used to investigate the possible relationships (Sections 6.5.3.1 to 6.5.3.3). The fourth research question (RQ 1.1.4) aimed to study the impact of trust on the development of commitment, while the fifth research question (RQ 1.1.5) aimed to investigate the impact of commitment on human-IVA team performance. Linear regression was used to analyse the data and answer these questions (Sections 6.5.3.4 and 6.5.3.5). Section 6.5.4 looks at the development of a taskwork SMM, a teamwork SMM, trust, commitment and team performance over time.

6.5.1 Normality Test for Study Variables

To check if the variables are approximately normally distributed, a number of tests were conducted. These tests included:

1. Skewness and Kurtosis z-values (the normality distributed variable should be in the span of -1.96 to +1.96)
2. The Shapiro-Wilk test p-value (the normality disturbed variable should be above 0.05)
3. Histograms, Normal Q-Q plots and Box plot should visually indicate the data is normally distributed.

The first normality test measured Skewness and Kurtosis, see Table 6-1. The result showed that there is little Kurtosis for all variables but they do not differ significantly from normality. However, for the Skewness measurement, the results showed that the z-value of the two variables teamwork SMM and verbal communication (-2.331 and -2.070 respectively) are not in the span -1.96 and +1.96.

The second normality test used Shapiro-Wilk normality. In the Shapiro-Wilk normality test, the null hypothesis of this test of normality is that the variable is normally distributed. The null hypothesis is rejected if the p-value is below 0.05. The result of Shapiro-Wilk normality, see Table 6-1, showed that for teamwork SMM and verbal communication the p-value were (0.023 and 0.045, respectively) less than 0.05.

Based on the results of Skewness and Kurtosis as well as Shapiro-Wilk we concluded that the two variables teamwork SMM and verbal communication are not normality distributed. Hence, the statistical tests used to answer research question should be non-parametric.

Table 6-1: Normality tests Skewness, Kurtosis and Shapiro-Wilk

	Skewness z-value	Kurtosis z-value	Shapiro-Wilk		
			Statistic	df	Sig.
1. Taskwork SMM	-1.308	0.672	0.902	16	0.086
2. Teamwork SMM	-2.331	1.223	0.865	16	0.023
3. Verbal Communication	-2.070	1.111	0.884	16	0.045
4. Non-Verbal Communication	-1.001	0.136	0.943	16	0.384
5. Trust	-0.886	-0.056	0.916	16	0.143
6. Commitment	-1.404	0.125	0.917	16	0.153
7. Team Performance	-0.881	0.752	0.948	16	0.457

6.5.2 Correlation Results

To measure the strength and direction of association between the seven variables, Spearman’s rho correlation method was used. Spearman’s rho correlation was selected, as it is more appropriate for small sample or non-normally distributed responses. Table 6-2 presents the means, standard deviations, and correlations for all measures. As shown in Table 6-2, verbal and non-verbal communication were significantly positively related to a taskwork SMM ($r=0.901$, $p<0.01$ and $r=0.871$, $p<0.01$ respectively) suggesting a positive association between both verbal and non-verbal communication during a collaborative task on developing common understanding of the taskwork. Moreover, team verbal and non-verbal communication were significantly positively related to a teamwork SMM (r=0.877, p<0.01 and r=0.860, p<0.01 respectively) suggesting a positive association between both verbal and non-verbal communication during collaborative task on developing common understanding of the teamwork.

Table 6-2: Spearman's rho inter-Correlations among variables

	Cronbach's Alpha	M	1	2	3	4	5	6	7
1.Verbal Communication	0.909	3.688	1.000						
			.						
2.Non-Verbal Communication	0.957	3.813	.863**	1.000					
			.000	.					
3.Taskwork SMM	0.888	3.838	.901**	.871**	1.000				
			.000	.000	.				
4.Teamwork SMM	0.777	3.575	.877**	.860**	.890**	1.000			
			.000	.000	.000	.			
5.Trust	0.827	3.922	.732**	.839**	.825**	.691**	1.000		
			.000	.003	.000	.003	.		
6.Commitment	0.889	3.963	.688**	.756**	.796**	.670**	.971**	1.000	
			.003	.001	.000	.004	.000	.	
7.Team Performance	0.893	3.963	.842**	.792**	.858**	.694**	.965**	.941**	1.000
			.000	.003	.000	.012	.000	.000	.

**Correlation is significant at the 0.01 level (2-tailed).

A taskwork SMM was significantly positively correlated to a teamwork SMM (r= 0.827, p<0.01) suggesting that human-IVA teams whose members share similar taskwork mental models are likely to have shared teamwork mental models well. As expected, both taskwork and teamwork SMMs were significantly positively correlated to human-IVA team performance (r=0.858, p<0.01 and r=0.694, p<0.01 respectively). This result suggests the positive association between taskwork and teamwork SMMs and overall team performance.

6

6.5.3 Testing the Research Questions

The following subsections explain how the five research questions (RQ 1.1.1 to RQ 1.1.5), posed in Section 6.3, were evaluated and what answers the evaluation supported. Multiple regression analysis was used to investigate the possible relationship between study variables.

6.5.3.1 Effect of Verbal and Non-verbal Communication on a Taskwork SMM

RQ 1.1.1 inquired if comprehensive verbal and non-verbal communication between a human and an IVA while achieving a collaborative task tends to influence the development of a taskwork SMM. The results, see Table 6-3, showed that 81.4% of the variance in a task SMM could be accounted for by verbal and non-verbal communication between the human and the IVA.

To assess the overall statistical significance of this relation, the result indicated that both verbal and non-verbal communication were significant R^2= 0.814, F (2, 13) =33.80, $p<0.01$. The results thus answer RQ 1.1.1 in the affirmative.

Furthermore, to evaluate which one of the two factors, i.e. IVA's verbal or non-verbal communication, contributes more to a taskwork SMM, the results, as shown in Table 6-3, indicated that standardized coefficient β of IVA's non-verbal communication (0.839) is greater than standardized coefficient β of the verbal communication (0.082), suggesting a stronger effect for non-verbal over verbal communication.

6.5.3.2 Effect of Verbal and Non-verbal Communication on a Teamwork SMM

RQ 1.1.2 asked if comprehensive verbal and non-verbal communication between humans and IVAs while achieving collaborative task tends to influence the development of teamwork SMM. The results showed that 89.1% of the variance in a task SMM could be accounted for by verbal and non-verbal communication between human and IVA. To assess the overall statistical significance of the relation, the result showed that both verbal and non-verbal communication were significant R^2= 0.891, F (2, 13) = 62.07, $p<0.01$. The results thus answer RQ 1.1.2 in the affirmative.

Furthermore, to evaluate which one of the two factors, i.e. IVA's verbal or non-verbal communication, contributes more to a teamwork SMM, the results, as shown in Table 6-3, indicated that standardized coefficient β of IVA's verbal communication (0.752) is greater than standardized coefficient β of the non-verbal communication (0.210), suggesting a stronger effect for verbal over non-verbal communication.

Table 6-3: Regression analysis to answer research questions

Model	Unstandardized Coefficients		Standardized Coefficients β	R	Adjusted R^2	F	Sig.
	Unstandardized B	Std. Error of the Estimation					
Taskwork SMM							
Verbal communication	0.082	0.313	0.082	0.916	0.814	33.802	0.000*
non-verbal communication	0.878	0.326	0.839				
Teamwork SMM							
Verbal communication	0.763	0.242	0.752	0.951	0.891	62.076	0.000*
non-verbal communication	0.222	0.252	0.210				
Human's trust							
Taskwork SMM	0.620	0.145	0.842	0.843	0.666	15.983	0.000*
Teamwork SMM	0.001	0.127	0.001				
Human's commitment							
Human's trust	0.984	0.043	0.987	0.974	0.973	834.86	0.000*
Team performance							
Human's commitment	1.052	0.077	0.964	0.930	0.925	185.99	0.000*

* *Significance level $p<0.01$*

6.5.3.3 Impact of Human Trust on Taskwork and Teamwork SMMs

RQ 1.1.3 inquired if a taskwork and a teamwork SMM between a human and an IVA while achieving a collaborative task tends to influence the human's trust in the IVA's decision. The results showed that 66.6% of the variance in the human's trust could be accounted for by a taskwork and a teamwork SMM between the human and the IVA. To assess the overall statistical significance of this relationship, the result indicated that both a taskwork and teamwork SMM were significant $R^2= 0.666$, $F (2, 13) =15.98$, $p<0.01$. The results thus answer the third research question (RQ 1.1.3) in the affirmative.

Furthermore, multiple regression was used to evaluate which one of the two factors, i.e. a taskwork and a teamwork SMM, contributes more toward human's trust. The results, as shown in Table 6-3, indicated that standardized coefficient β of a taskwork SMM (0.842) is greater than standardized coefficient β of teamwork SMM (0.001), suggesting a stronger effect for a taskwork SMM over a teamwork SMM on human trust.

6.5.3.4 Relationship between Trust and Commitment

RQ 1.1.4 inquired if human trust in an IVA teammate while achieving the shared task is likely to influence the human's commitment to complete the task. The single regression result, see Table 6-3, showed that 97.3% of the variance in task commitment could be accounted for by teammate trust. To assess the overall statistical significance of this relationship, the result indicated that teammate trust significantly effects task commitment $R^2= 0.973$, $F (2, 13) =834.86$, $p<0.01$.

6.5.3.5 Relationship between Commitment and Team Performance

RQ 1.1.5 inquired if the human's commitment toward achieving the shared task tends to influence human-IVA team performance. The results, see Table 6-3, showed that 92.5% of the variance in teammate trust could be accounted for by task commitment. To assess the overall statistical significance of this relationship, the result indicated that task commitment significantly influences team performance $R^2= 0.925$, $F (2, 13) =185.99$, $p<0.01$.

6.5.4 The development of Taskwork SMM, Teamwork SMM, Trust, Commitment and Team Performance over Time

To study how the dependent variables evolved overtime, data collected from the session log file was used to explore the human's behaviour with respect to these variables during consecutive four cycles of interaction. Descriptive analysis results, as can be seen in Figure 6-2, showed that a taskwork SMM progressively increased from 42.51% in the first cycle to 83.33% in the last cycle. Meanwhile, a teamwork SMM increased from 66.67% to 88.40%. Additionally, the humans' trust in IVA's decision was 33.33% in the first cycle and continued to increase to 57.14% in the last cycle. Meanwhile, the human's commitment to execute a promised decision also progressively increased from 38.15% in the first cycle to 71.43% in the last one. Concerning team performance, the results showed a decline in the ratio of time of each cycle divided by the total time to complete the task needed to complete each cycle from 42.51% in the first cycle to 9.57% in the last one. This decline in time ratio indicates an improvement in team performance.

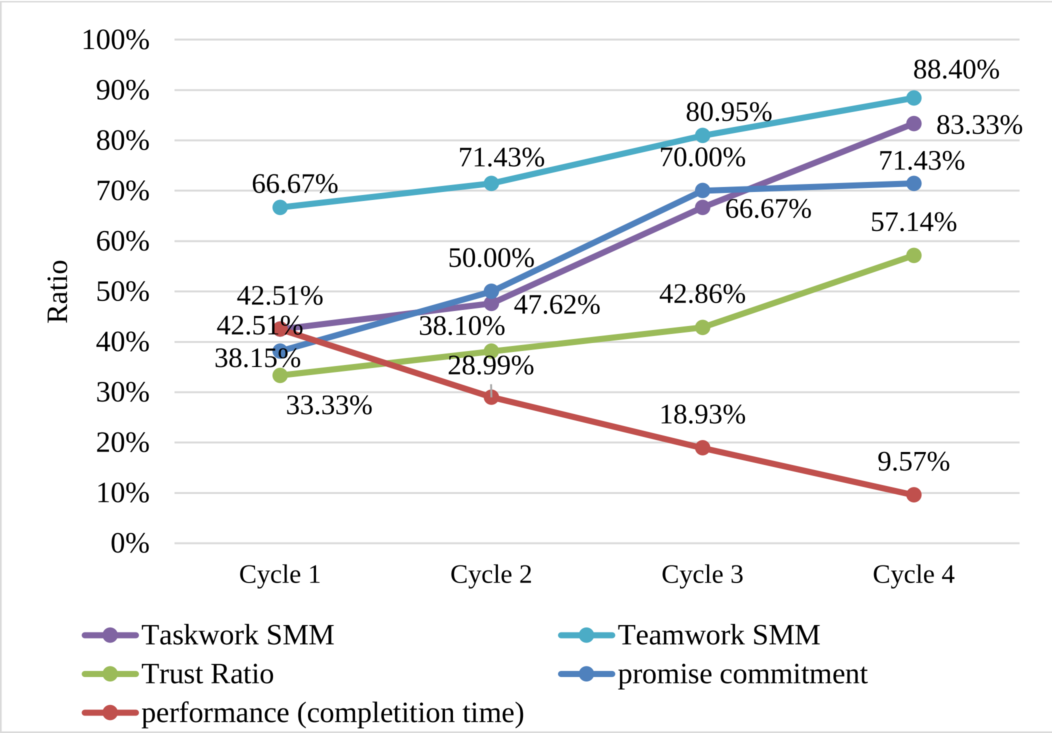

Figure 6-2: Progressive ratios Taskwork SMM, Teamwork SMM, trust in IVA's decision, human's commitment and overall tam performance over four consecutive cycles

6

6.6 Discussion

RQ 1.1.1 enquires whether an IVA's multimodal (verbal and nonverbal) communication is associated with the human's perception of the existence a taskwork SMM with the IVA. The result showed a significant positive association between the IVA's communication, i.e. verbal and non-verbal, and humans' perception of a taskwork SMM as perceived by the human teammate. To answer the second part of the research question about which method is more effective in building a taskwork SMM, the results demonstrated that the IVA's non-verbal communication tends to contribute more towards the prediction of a taskwork SMM rather than verbal communication. This finding suggested that humans are likely to build their understanding of a situation and the nature of the problem based on the actual actions (non-verbal behaviour) of their teammates rather than their teammate's expressed thoughts (verbal behaviour).

A number of research studies have stressed the role of non-verbal communication on the development of a taskwork SMM. In their study about human-robot interaction, Breazeal et al. (Breazeal et al., 2005) found that people tend to develop a task-based SMM with robots that interact with humans from both explicit and implicit non-verbal communication. Explicit non-verbal communication is used when there is an intention to communicate information to the human via actions such as nods of the head and deictic gestures. While implicit behaviour includes how the robot behaves as they carry out the task. Using these descriptions, our experiment used implicit non-verbal communication. Consistent with Breazeal et al.'s finding, Eccles and Tenenbaum (Eccles and Tenenbaum, 2004) studied the relationship between communication and SMMs in human teams and suggested that the task and context characteristics depends on communication and particularly non-verbal communication. Although the relation between non-verbal communication and the perception of a taskwork SMM was studied in human studies, this was the first time to discover this relation in human-IVA teamwork.

RQ 1.1.2 investigated whether an IVA's multimodal communication is associated with the human's perception of a teamwork SMM with the IVA. The result demonstrated a significant positive association between both the IVA's verbal and non-verbal communication and the perception of a teamwork SMM as perceived by human. This result is consistent with the findings of other researchers' who found that human involvement with IVAs was likely to increase the possibilities of communication with IVAs (Gajadhar et al., 2008). Moreover, to answer the second part of the research question about which method is more effective in building a teamwork SMM, the results showed that IVA's verbal communication tends to contribute more to humans' perception of a teamwork SMM. This finding suggested that the exchanged messages give better understanding of the teammate's thoughts and capabilities. Previous studies in human teams suggested that the establishment of shared knowledge about teammate is more likely to occur through verbal communication (Clark and Wilkes-Gibbs, 1986). Yet, this claim was not tested in human-IVA team. Our results support this finding and extend it to human-IVA teams.

RQ 1.1.3 inquired whether the existence of taskwork and teamwork SMMs between humans and IVAs are likely to influence the humans' trust in IVA. Some research work, e.g. (Lenz and Machado, 2008), demonstrated a direct relationship between teammate communication and trust positing that effective communication improves the feeling of trust. However, this work did not explain how communication influences the development of trust between team members. Some studies took a step further to demonstrate the indirect effect of communication on creating a state of trust (Handy, 1995) (Hoonakker et al., 2011). These studies identified that the development of trust between team members is a matter of exchanging norms, experience and common knowledge. In their study with 35 human teams, (Wu Xin, 2005) found that intra-communication between team members positively related with a SMM. In addition, their results showed that a SMM was positively related to the feeling of satisfaction and trust between team members. Our finding is in line with the work reporting that a SMM appears to strengthen and unify teams in VE. This affirmative relationship between a SMM and building trust is consistent with previous work that indicated a SMM between teammates in the workplace tends to foster trust between team members (Hosmer, 1994).

RQ 1.1.4 inquired whether human trust in the IVA's decision and recommendation is likely to effect the human's commitment to accomplish the shared task with the IVA. The results of correlation matrix as well as linear regression analysis showed a positive association between the humans' trust in IVAs and fulfilling their pledge to IVAs. The results affirmatively answer the second research question. The findings related to the first and the second question suggests that human-IVA communication is likely to increase human trust in IVAs and consequently foster their commitment toward the task. This finding appears to be inconsistent with the result in (Wissen et al., 2012) which indicated that human commitment was likely to stay low during a collaborative activity with IVAs. This inconsistency could be explained because in (Wissen et al., 2012) the agent was not visible to the humans and since the communication was very simple it may not have engendered a sense of a shared goal. On the other hand, our result is consistent with other studies which reported that satisfaction with communication provided in the virtual team system significantly tends to increase the level of involvement, trust and commitment (Casaló et al., 2011). This finding sheds light on the importance of an IVA's multimodal communication and especially the non-verbal elements to increase the human's feeling of believability.

The last research question (1.1.5) asked if human commitment to accomplish the task affects human-IVA team performance. The results showed that the increase in human commitment is positively associated with team performance. This result is consistent with other studies in virtual teams that found team commitment influences team satisfaction and performance (Shachaf and Hara, 2008) (Blumberg et al., 2012). This finding indicates that human commitment to a team including IVA team members has the same positive influence on team satisfaction and performance as has been found for virtual teams of humans.

The result of continuous monitoring a taskwork SMM, a teamwork SMM, trust, commitment and human-IVA team performance showed a synchronous increase in these variables overtime. This result went beyond humans' final report of their perception of the existence of a SMM with IVA, trust in IVA's decision and humans' commitment to honour their promises.

Several studies have been working on IVAs' architecture to increase their believability. These architectures included social and collaborative capabilities appraisal/emotion (Dias et al., 2011) adaptiveness (Lim et al., 2008) and personality (Doce et al., 2010). Nevertheless, with the increasing interest in designing and creating an IVA that is able to work with humans in teamwork, more attention to teamwork skills should be taken into account. The results of this study suggested a taskwork SMM and a teamwork SMM as important catalysts that foster humans' trust in their IVA teammate.

With the increasing interest in teamwork involving IVAs, the findings of this study stressed the importance of designing IVAs capable of using communication with humans, as a catalyst to increase human's trust and commitment to collaborate with the IVAs. This commitment would effectively increase team performance.

6.7 Summary

This chapter aimed to investigate the association between an IVA's communication methods and the human's perception of a SMM between him/herself and the IVA. In addition, the study aimed to show the impact of a SMM on humans trust in IVA's decision, humans commitment to honour their promises to the IVA and finally on human-IVA team performance. Our results showed that IVA's multimodal communication positively influences developing a SMM and subsequently influence on human-IVA team performance. This result is not surprising, as it is consistent with tens of other studies in human teams that have tested the relationship between a SMM and team performance and reported significant correlations between higher degrees of shared thinking and positive team performance (e.g. (Guchait and Hamilton, 2013), (Rouse et al., 1992)). One of the contributions of this study is to confirm this result to include human-IVA teams.

CHAPTER 7

The Impact of Virtual Agent Personality on Human-IVA Team Performance

7.1 Background

With an increasing interest in human-IVA heterogeneous teams, many studies focused on personality traits as a factor in teams. (Luse et al., 2013) found that the humans' personalities influenced their preferences to work in teams. A number of studies have investigated the personality of team members as a predictor of both team dynamics and teamwork outcomes (Barrick et al., 1998). Several researchers studied the influence of personality traits on human decision-making while achieving a task. For example, (Schmitt et al., 2008) asked the human subjects to play the ultimatum game. In this game, two players had to reach an agreement about how to divide money through proposing and responding. This work used the Myer-Briggs Temperament Index (MBTI) test to get personality traits of players. The results showed that extravert players indicated a willingness to accept lower offers than introvert players did. In a study to determine what combinations of personalities resulted in the best-performing teams, (Gorla and Lam, 2004) surveyed 92 employees from 20 small software development teams. The results showed that teams with heterogeneous members had no significant effect on team performance.

(Isbister and Nass, 2000) studied the effect of consistency in representing personality via an IVA's verbal and non-verbal communication and human preferences. In addition, human preferences for IVAs with personalities that matched their own personality were investigated. The results showed that humans prefer the personality of an IVA to be consistent in both verbal and non-verbal communication. Moreover, the results indicated that subjects tend to favour a character whose personality was complementary to them. (Kang et al., 2008) explored the relationship between FFM traits of human participants and their feelings of bond when they interacted with an IVA. The results showed that users' personality traits affect users' perception, regardless of the IVA's personality. The results in (von der Pütten et al., 2010) showed that subjects' personality traits influenced their subjective feelings after the interaction, as well as their evaluation of the virtual character and their actual behaviour. (Du and Huhns, 2013) studied whether human behaviour towards other humans and agents is related to their personality types. Although this study used a different personality test, the results showed that humans of different personality types behave differently towards other humans and agents.

7.2 The Theory and Research Questions

Many studies found a positive correlation between the development of a SMM between team members and their team performance (Mathieu et al., 2000). Although some studies have found the strongest correlation is between teamwork SMM and team performance (Lim and Klein, 2006), other studies reported the strongest positive correlation is between taskwork SMM and team performance (Mathieu et al., 2005). The influence of either taskwork or teamwork SMM is likely to rely on the nature of the collaborative situation. In this chapter, we aimed to discover the factors that make a SMM influential in human-IVA team performance.

The second research question (RQ 1.2) inquired; see Section 1.4, "*What is the influence of the IVA's personality and the match/mismatch in personality with the humans on the collaboration?*" To build upon, draw this literature together, and potentially enhance human-IVA teamwork, the following sub-research questions aim to investigate the effect of an IVA's multimodal communication and personality on human-IVA team performance:

> ***RQ 1.2.1**: Are the IVA's personality traits, i.e. extraversion and agreeableness, significantly differentiated by humans?*
>
> ***RQ 1.2.2**: Is the match in human-IVA personality traits, i.e. extraversion and agreeableness, significantly differentiated by humans?*

***RQ 1.2.3**: Does the IVA's multimodal communication significantly influence the humans' perception of the taskwork SMM? Does IVA's personality (extraversion and agreeableness) have an influence on a taskwork SMM?*

***RQ 1.2.4**: Does the IVA's multimodal communication significantly influence the humans' perception of the teamwork SMM? Does IVA's personality (extraversion and agreeableness) have an influence on a teamwork SMM?*

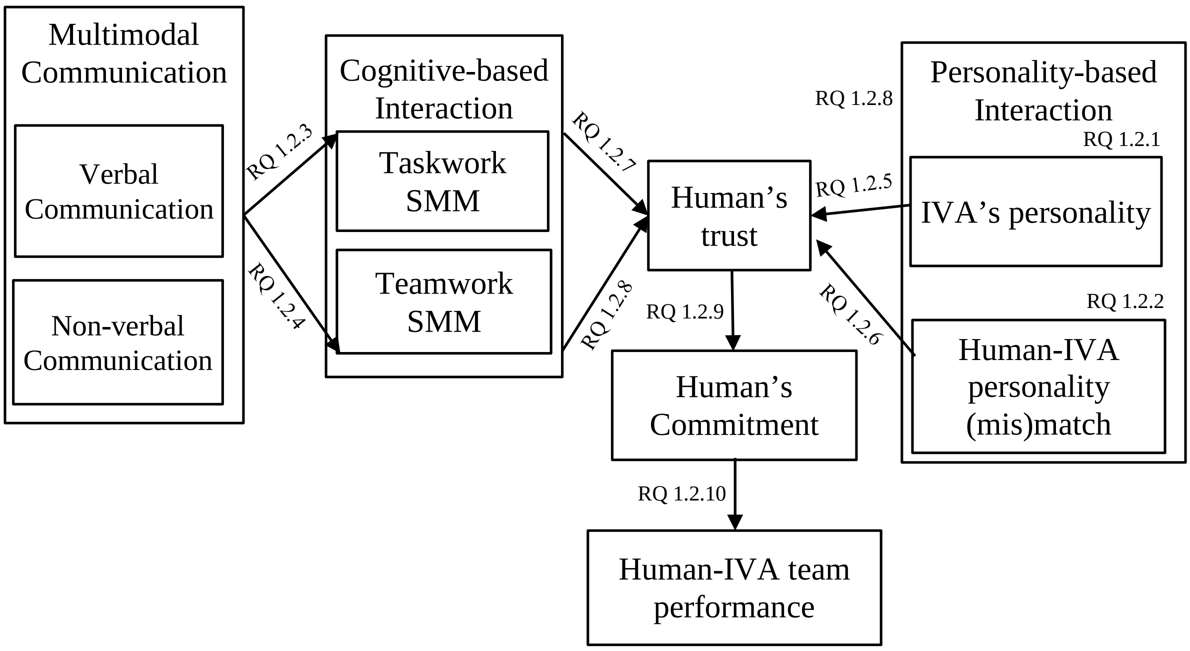

Figure 7-1: Research Model to investigate the influence of personality-based interaction and cognitive-based interaction on human trust and team performance

To investigate the establishment of trust between humans and IVAs the following research questions were proposed:

***RQ 1.2.5**: Does the IVA's personality influence human trust in the IVA?*

***RQ 1.2.6**: Does the match in personality between the human and IVA influence human trust in the IVA?*

***RQ 1.2.7**: Does the IVA's cognitive behaviour influence human trust in the IVAs' decision?*

***RQ 1.2.8**: Does personality or cognitive behaviour of the IVA contribute more towards human trust?*

***RQ 1.2.9**: Does human trust in the IVA teammate influence human commitment to honour their promises towards achieving the shared task?*

***RQ 1.2.10**: Does human commitment to honour their promises influence the human-IVA team performance?*

7.3 Materials and Methods

7.3.1 Participants

Fifty-five (55) second-year undergraduate science students enrolled in a biology unit completed the collaborative task. Participants were aged between 18 and 51 years (mean=22.56; SD=6.95) Fifty-two participants were native English speakers; the remaining three participants had been speaking English on a daily basis on average for 13 years. On a scale with six levels (level 1 the least experienced and level 6 the highest experience), 13 had basic (level 2), 39 had proficient (level 5) and 3 had advanced (level 6) computer skills. Participants played computer games on average 2.73 times a week, with a standard deviation of 4.69.

7.3.2 Collaborative Scenario

The second virtual scenario presented in Section 4.5.2 (Crossing a Sequence of Obstacles) was used.

7.3.3 Data Collection and Data Analysis

The following variables were measured to answer the proposed research questions (RQ 1.2.1 to RQ 1.2.10):

- Participant's personality: participants completed a 7-item personality test to measure the two personality traits using Big Five Inventory (BFI). BFI is a 44-item test, developed by (John et al., 2008, John and Srivastava, 1999) that provides a score for each of the FFM traits, see Appendix C.

- IVA's personality: participants completed a test of the perceived personality of the IVA by answering four items of the Ten-Item Personality Inventory (TIPI) (Gosling et al., 2003), see Appendix D.
- IVA's verbal and non-verbal communication: participants answered ten items. Five items measured the IVA's verbal communication (e.g., "Charlie's requests and replies were helpful to complete the task") and five items measured the IVA's non-verbal communication (e.g., "Charlie's actions were suitable to the situation"), see Appendix B.
- Taskwork and teamwork SMM: Participants answered ten items in a survey. Surveys have been used to evaluate SMMs in previous studies (e.g.,(Lim and Klein, 2006) (Guchait and Hamilton, 2013)). Five items measured human perception of taskwork SMM (e.g., "Charlie and I have a shared understanding about how best to ensure we meet our goal"). Five items measured teamwork SMM (e.g., "Charlie and I value collaborating with each other"), see Appendix B.
- Trust: participants answered five items to question their perception of trust with the IVA (e.g., "I trust Charlie's requests"), see Appendix B.
- Commitment participants answered five items. Commitment has been measured by survey items is previous studies e.g., (Lincoln and Kalleberg, 1990) used five-point Likert scale to measure commitment (e.g., "I feel I am committed to fulfil my promises to Charlie"), see Appendix B.
- Team performance: participants answered five items to measure their perception of team performance with the IVA. (e.g., "The team of Charlie and I finished the task as quickly as possible and did not waste time"), see Appendix B.

Both personality tests, i.e. BFI and TIPI, and the communication and SMM questions used a 5-item Likert Scale, where 1 corresponded to "Strongly Disagree" and 5 to "Strongly Agree" see Appendix C and Appendix D.

In addition to these subjective measures, all inputs from the user were logged to allow recreation of navigation paths and record inputs such as responses and selected tools. These inputs included selected regions in the scenario. Analysis of interaction logs to find the most frequently triggered stimuli in the scenario was used before in other studies (Krishnan et al., 2012).

The statistical package IBM SPSS v.20 was used for the statistical analysis. A number of tests for normality distribution of the study variables were run to determine whether to use parametric or nonparametric tests. Shapiro-Wilk normality test as well as Skewness and Kurtosis were used to test normality distribution of the study variables. Spearman's rho Correlation analysis was used to quantify the degree and the direction to which the study variables are related. To measure the difference between the different experimental conditions, one-way ANOVA test and Kruskal Wallis test were utilized. Regression analysis, linear and multiple, was utilized to model the relationship between two variables. Regression seeks to learn more about the relationship between an independent or predictor variable and a dependent or criterion variable. Before attempting to fit a linear model to observed data, we should first determine whether there is a relationship between the variables of interest by applying correlation between the two variables.

7.3.4 Experimental Design and Procedure

The study was structured as 2X2 between-subject experiment and a control group. Each subject had to take just one condition. The experiment consisted of five different conditions with the same virtual scenario but the IVA had different personalities. One condition was a control with a neutral personality IVA. The other four experimental conditions had the four combinations of the two studied personality traits, i.e. extraversion and agreeableness. The four combinations were extraversion-agreeableness, extraversion-antagonism, introversion-agreeableness and introversion-antagonism. Participants had to access a web-based system that contained the five conditions and managed condition assignment. Each participant was assigned one of the five conditions. The assignment was done by the system sequentially and equally. Participants were divided into five groups each containing 11 students. Participants used the virtual system individually so that the collaboration would be one-to-one between him/herself and the agent. We dedicated twenty minutes for the study that consisted of four parts, as below, in one session.

- Part 1: sign consent forms and complete biographical information.
- Part 2: Complete seven items of BFI.
- Part 3: Participation in the scenario in the 3D virtual scene. In the beginning of the scenario, the participants were provided with online instructions about the goal of

the virtual scenario, the name and the use of each tool in the toolbox and the way to select/close the verbal messages.

- Part 4: Complete 15-item survey (5 items each for verbal and non-verbal communication and 5 items for measuring trust) that measures the participant's perception of the communication and collaboration experience. Additionally, participants completed a test of the perceived personality of the IVA by answering four items of the Ten-Item Personality Inventory (TIPI) (Gosling et al., 2003).

7.3.4.1 Intelligent Personality Traits: Five-factor Model

In the last 50 years, the FFM model of personality has become a standard in the field of classifying personalities. FFM (Goldberg, 1990) claims that personality varies on five factors: Openness, Conscientiousness, Extraversion, Agreeableness and Neuroticism. Openness means being open to experience new things, being imaginative, and intelligent. Conscientiousness indicates responsibility, reliability and tidiness. Extravert personality is outgoing, sociable, assertive and energetic. Agreeableness means a person is trustworthy, kind and cooperative by considering others' goals. A neurotic character is anxious, nervous and prone to depression and lacks emotional stability.

Studies that have explored personality traits and teamwork stress the role of both extraversion and agreeableness to foster inter-relationships between team members. Extraversion and agreeableness were selected in our study because they have been shown to be predominant traits in collaboration and teamwork (Bosch et al., 2012). The extraversion trait influences interpersonal relations through the quality of social connections (Barry and Stewart, 1997) (McCrae and John, 1992). Extraverts are usually active members in teamwork interactions and often popular among their mates (Mann, 1959).

7.3.4.2 Expressing Personality through Verbal Behaviour

Our personality is likely to influence how we speak (Scherer, 1979). Speaking style can reveal certain personality traits; some traits are easier to detect than others (Scherer, 1978). A number of studies have used verbal capabilities to represent different IVA personalities (Krishnan et al., 2012). Neff et al. (Neff et al., 2010) determined a number of aspects that demonstrate the impact of an IVA's extravert personality on the IVA's verbal behaviour. Among the list of aspects mentioned in (Neff et al., 2010), we selected the dominant aspects as the basis of the design of the IVA in our study. Verbal messages were initially designed by the author, reviewed, and revised with supervisors. The messages were designed according to the criteria in Table 7-1.

7.3.4.3 Expressing Personality through Non-verbal Behaviour

A number of studies addressed how the extraversion personality trait can be represented in an IVA's non-verbal signalling. As verbal behaviours have already been identified that show an IVA's personality, Doce et al. (Doce et al., 2010) proposed several non-verbal features that could show personality traits in an IVA, these features include:

- Spatial extent – the required space to perform a non-verbal cue. Extravert individuals use more spatial extent than introverts do.
- Temporal extent – amount of time spent to perform a non-verbal cue.

Table 7-1: Verbal and Non-verbal aspects used to express Introversion/Extraversion in IVA's behaviour

Parameter	Description	Introvert	Extravert
Verbal clues			
Verbosity	Control the number of propositions in the utterance	low	high
Restatements	Paraphrase an existing proposition	low	high
Request confirmation	Begin the utterance with a confirmation of the propositions	low	high
Emphasizer hedges	Insert syntactic elements (really, basically, actually, just) to strengthen a proposition	low	high
Negation	Negate a verb by replacing its modifier by its antonym	high	low
Filled pauses	Insert syntactic elements expressing hesitancy	high	low
Non-Verbal clues			
Spatial extent	the required space to perform a non-verbal cue	low	high
Temporal extent	amount of time spent to perform a non-verbal cue	short	long
Repetitivity	repetition of certain movements	low	high
Body position	close physical postures	far	close

- Fluidity – softness of movements. Introvert individuals have more soft movements and gestures.
- Power – intensity of acting a movement. Power is directly proportional to extraversion.
- Repetitiveness – repetition of certain movements. We designed an extravert IVA with high repetitivity.

Additionally, the IVA's physical position relative to the human's view or their avatar has been investigated. Argyle's (Argyle, 1988) status and affiliation model for animating non-verbal behaviour of virtual agents identified two fundamental dimensions for non-verbal behaviour: affiliation and status. Affiliation can be considered as desiring a close relationship and it is associated with non-verbal clues such as close physical position. Other studies suggested that agents approaching the human's embodied avatar were judged as more extraverted than agents that keep a distance, regardless of other non-verbal cues such as smile and eye gaze (Cafaro et al., 2012). In the design of our agent, we chose the dominant features, shown Table 7-1.

7.4 Results

First, the study variables were tested for the normality distribution in order to determine whether to use parametric or nonparametric tests. Tests for Skewness and Kurtosis showed that the z-value of the variables is in the span -1.96 and +1.96, and thus they do not differ significantly from normality. A Shapiro-Wilk normality test showed that, except for verbal communication variable, all the other variables had p-values less than 0.05. Based on the results of Skewness and Kurtosis as well as Shapiro-Wilk we concluded that the four variables (non-verbal communication, taskwork SMM, teamwork SMM, and team performance) are not normally distributed.

7.4.1 Correlation Results

To measure the strength and direction of association between the five variables, Spearman's rho correlation method was used. Spearman's rho correlation was selected, as it is more appropriate for non-normally distributed responses. To estimate how well the set of items measure each variable, Cronbach's Alpha (α) was used to measure the internal consistency or reliability of these items. The value of Cronbach's Alpha (ɑ) may lie between negative infinity and one. However, only positive values of α make sense. Generally, Cronbach's alpha (ɑ) coefficient ranges in value from zero to one and may be used to describe the reliability of factors. Some statisticians insist on a reliability score of 0.70 or higher in order to assess the studied items are internally consistent. Table **7-2** shows that Cronbach's Alpha (ɑ) for the five variables are over 0.70. We concluded that the survey items to measure each variable are reliable to measure these variables.

Table **7-2** presents the means, standard deviations, and correlations for all the variables. Verbal and non-verbal communication were significantly positively related to taskwork SMM ($r=0.461$, $p<0.01$ and $r=0.351$, $p<0.01$ respectively) suggesting a positive association between both verbal and non-verbal communication during a collaborative task on developing common understanding of the taskwork. Moreover, team verbal and non-verbal communication were significantly positively related to teamwork SMM ($r=0.465$, $p<0.01$ and $r=0.308$, $p<0.05$, respectively) suggesting a positive association between both verbal and non-verbal communication during a collaborative task on developing common understanding of the teamwork. Taskwork SMM was significantly positively correlated to teamwork SMM ($r= 0.704$, $p<0.01$) suggesting that human-IVA teams whose members share similar taskwork mental models are likely to have shared teamwork mental models as well. As expected, both taskwork and teamwork SMM were significantly positively correlated to human-IVA team performance ($r=0.569$, $p<0.01$ and $r=0.489$, $p<0.01$ respectively). This result suggests a positive association between taskwork and teamwork SMMs and overall team performance. The following subsections analyse the data related to the three research questions.

Table 7-2: Spearman's rho inter-Correlations among variables

	Cronbach's Alpha	M	SD	1	2	3	4	5	6	7
1. Verbal Communication	0.852	3.88	0.62	1.000						
				.						
2. Non-Verbal Communication	0.760	3.96	0.50	0.670**	1.000					
				0.000	.					
3. Taskwork SMM	0.793	3.57	0.68	0.461**	0.351**	1.000				
				0.000	0.009	.				
4. Teamwork SMM	0.849	3.42	0.75	0.465**	0.308*	0.704**	1.000			
				0.000	0.022	0.000	.			
5. Human Trust	0.858	3.79	0.52	0.466**	0.402**	0.607**	0.536**	1.000		
				0.000	0.002	0.000	0.000	.		
6. Human Commitment	0.892	3.75	0.46	0.409**	0.396**	0.657**	0.556**	0.864**	1.000	
				0.002	0.003	0.000	0.000	0.000	.	
7. Team Performance	0.730	3.70	0.51	0.368**	0.286*	0.569**	0.489**	0.845**	0.909**	1.000
				0.006	0.034	0.000	0.000	0.000	0.000	.

*** Correlation is significant at the 0.01 level (2-tailed).* ** Correlation is significant at the 0.05 level (2-tailed).*

7.4.1.1 Can Humans Recognize the IVA's Personality?

The first research question inquired if there were significant differences between the five groups of participants in perceiving the IVA's two implemented personality traits. This question was segmented into two sub-questions regarding each personality traits.

RQ 1.2.1 asked if the IVA's introvert/extravert personality trait as presented in the IVA's verbal and non-verbal communication is perceived differently by the human participants. The results of one-way ANOVA, Table 7-3, showed that there was a significant difference $p<0.01$ [$F(2, 52) = 15.014$, $p<0.01$, $\eta^2=0.37$] between the groups of participants in their perception of the personality of IVA, i.e. introvert, extravert or neutral IVA, because of the verbal messages of the IVA. To understand which condition/s accounted for the significant difference in extraversion perception, post hoc comparisons using the Tukey HSD and Bonferroni tests indicated that the mean score for the extravert condition ($M = 4.31$, $SD = 0.29$) was significantly higher than the other conditions introvert (mean difference=0.65) and neutral IVA (mean difference=0.90).

In addition, the results of a one-way ANOVA showed that there was a significant difference $p<0.01$ [$F(2, 52) = 11.424$, $p < 0.01$, $\eta^2=0.31$] between the groups of participants in their perception of different personality of IVA, i.e. introvert, extravert or neutral IVA, because of the non-verbal messages of the IVA. Post hoc comparisons using the Tukey HSD and Bonferroni tests indicated that extravert condition ($M = 4.30$, $SD = 0.28$) was significantly higher than the other conditions introvert (mean difference=0.58) and neutral IVA (mean difference=0.52). The mean of the neutral IVA was not significantly higher than introvert IVA in the last two cases.

7

The second sub-question asked if the IVA's agreeableness/antagonism personality trait as presented in the IVA's verbal and non-verbal communication is perceived differently by the human participants. The results of a one-way ANOVA, Table 7-3, showed that there was a significant difference $p<0.01$ [$F(2, 52) = 6.086$, $p < 0.01$, $\eta^2=0.19$] between the groups of participants in their perception of the IVA's personality, i.e. agreeableness, antagonism or neutral, because of the verbal messages of the IVA. Post hoc comparisons using the Tukey HSD and Bonferroni tests indicated that the mean score for the agreeable IVA conditions ($M = 4.14$, $SD = 0.68$) was significantly higher than the neutral IVA (mean difference=0.72).

In addition, the results of a one-way ANOVA showed that there was a significant difference $p<0.05$ [$F(2, 52) = 3.90$, $p<0.05$, $\eta^2=0.13$] between the groups of participants in their perception of different IVA personality, i.e. agreeableness, antagonism or neutral IVA, because of the IVAs non-verbal messages.

7.4.1.2 Is the Match in Human-IVA Personality Traits Significantly Differentiated by Humans?

RQ 1.2.2 inquired whether the match in personality traits, i.e. extraversion and agreeableness, between the participants and the IVA is significantly perceived by the participants. This question was segmented into two sub-questions regarding each personality traits.

Table 7-3: A summary of one-way ANOVA test to several research questions

	Sum of Squares	df	Mean Square	F	Sig.
Human perception of the personality of introvert, extravert or neutral IVA because of verbal cues (RQ 1.2.1)	7.59	2	3.80	15.01	0.000
	13.16	52	0.25		
	20.75	54			
Human perception of the personality of introvert, extravert or neutral IVA because of non-verbal cues (RQ 1.2.1)	4.17	2	2.08	11.42	0.000
	9.50	52	0.18		
	13.68	54			
Human perception of the personality of agreeableness, antagonism or neutral IVA because of verbal cues (RQ 1.2.1)	3.93	2	1.96	6.08	0.004
	16.82	52	0.32		
	20.75	54			
	3.54	2	1.77	0.90	0.018

Human perception of the personality of agreeableness, antagonism or neutral IVA because of non-verbal cues (RQ 1.2.1)	23.60	52	0.454		
	27.14	54			
development of taskwork SMM according to the difference in IVA's multimodal communication in each condition (RQ 1.2.3)	5.44	4	1.36	3.26	0.01
	20.95	50	0.41		
	26.39	54			
between the groups of participants in their perception to taskwork SMM according to the IVA's agreeableness/antagonism (RQ 1.2.3)	3.54	2	1.77	4.31	0.018
	21.36	52	0.41		
	24.91	54			
between the groups of participants in their perception to teamwork SMM according to the IVA's agreeableness/antagonism (RQ 1.2.3)	6.35	2	3.17	6.94	0.002
	23.78	52	0.45		
	30.13	54			
development of teamwork SMM according to the difference in IVA's multimodal communication in each condition (RQ 1.2.4)	6.79	4	1.69	3.64	0.01
	23.33	50	0.46		
	30.13	54			
difference between the five conditions in human trust in the IVA (RQ 1.2.5)	7.06	4	1.76	11.73	0.000
	7.52	50	0.15		
	14.59	54			

difference between participants in their trust in the IVA based on the IVA's agreeableness/antagonism (RQ 1.2.5)	4.98	2	2.49	13.48	0.000
	9.60	52	0.18		
	14.59	54			
difference between participants in their trust in the IVA based on the IVA's extravert/introvert (RQ 1.2.5)	2.08	2	1.04	4.328	0.018
	12.51	52	0.24		
	14.59	54			
difference in human trust in the IVA in the case of a match in agreeableness personality (RQ 1.2.6)	4.37	1	4.37	22.68	0.000
	10.21	53	0.19		
	14.59	54			

Concerning extravert/introvert personality trait, the results of Chi-square test, Table 7-4, $\chi^2(1, N=55)= 6.04$, and $p < 0.05$, showed a significant difference between the actual match between human and IVA and the correct perception of humans to IVA's extraversion trait.

Concerning agreeableness/antagonism personality, the results of Chi-square, Table **7-5**, test between real match between human and IVA and the correct perception of humans to IVA's agreeableness trait $\chi^2(1, N=55)= 4.035$, and $p < 0.05$ showed a significant difference in the accuracy of the guess of the IVA's agreeableness/antagonism personality trait by human users whose agreeableness/antagonism personality match IVA.

Table 7-4: Chi-Square Tests to show difference between-group in perceiving IVA's Introversion/Extroversion based on match in personality between participants and IVA

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	**6.048[a]**	1	0.014		
Continuity Correction[b]	4.534	1	0.033		
Likelihood Ratio	7.209	1	0.007		
Fisher's Exact Test				0.019	**0.013**
Linear-by-Linear Association	5.938	1	0.015		
N of Valid Cases	55				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.73.

b. Computed only for a 2x2 table

Table 7-5: Chi-Square Tests to show difference between-group in perceiving IVA's Agreeableness/Antagonism based on match in personality between participants and IVA

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	**4.035[a]**	1	0.045		
Continuity Correction[b]	2.896	1	0.089		
Likelihood Ratio	4.303	1	0.038		
Fisher's Exact Test				0.066	**0.042**
Linear-by-Linear Association	3.962	1	0.047		
N of Valid Cases	55				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.27.

b. Computed only for a 2x2 table

7.4.1.3 Does the IVA's Multimodal Communication Significantly Influence the Development of the Taskwork SMM?

RQ 1.2.3 inquired if the verbal and non-verbal communication in the different conditions influences the development of taskwork SMM between humans and IVAs. The result of a correlation matrix, Table **7-2**, showed that verbal and non-verbal communication were significantly positively related to taskwork SMM ($r=0.461$, $p<0.01$ and $r=0.351$, $p<0.01$ respectively) suggesting a positive association between both verbal and non-verbal communication during a collaborative task on developing understanding of the taskwork.

To investigate whether the development of the taskwork SMM is different in the five conditions because of the differences in the IVA's multimodal communication, an ANOVA test was conducted. The results of the ANOVA test, Table 7-3, showed that there was a significant difference $p<0.05$ [$F(4, 50) = 3.26$, $p<0.01$, $\eta^2=0.21$] between the groups of participants in the development of the taskwork SMM according to the difference in the IVA's multimodal communication in each condition. This result was supported by the outcome of the non-parametric Kruskal-Wallis H test ($H=8.309$, $df=4$, $n=55$, $p<0.031$). To understand which condition/s accounted for the significant difference in the taskwork SMM, post hoc comparisons using the Tukey HSD and Bonferroni tests indicated that the mean score for the agreeable IVA conditions ($M = 3.31$, $SD = 0.64$) was significantly higher than the other conditions.

Regarding the impact of the IVA's personality on the development of a taskwork SMM, The results did not show any significant difference between the perception of either the taskwork or teamwork SMM according to the IVA's extraversion personality. The results of the ANOVA test showed that there was a significant difference $p<0.01$ [$F(2, 52) = 4.312$, $p<0.01$, $\eta^2=0.14$] between the groups of participants in their perception to the taskwork SMM according to the IVA's agreeableness/antagonism personality trait. This result was supported by the outcome of the non-parametric Kruskal-Wallis H test ($H=6.725$, $df=2$, $n=55$, $p<0.035$). To understand which condition/s accounted for the significant difference in taskwork SMM, post hoc comparisons using the Tukey HSD and Bonferroni tests indicated that the mean score for the antagonistic IVA condition ($M = 3.36$, $SD = 0.64$) was significantly different than the agreeable IVA condition ($M = 3.88$, $SD = 0.51$) at $p < 0.05$. The latter was significantly different from neutral IVA ($M = 3.36$, $SD = 0.87$) at $p < 0.05$. However, the antagonism condition did not significantly differ from the neutral condition.

7.4.1.4 Does The IVA's Multimodal Communication Significantly Influence the Development of the Teamwork SMM?

RQ 1.2.4 inquired if the verbal and non-verbal communication in the different conditions influences the development of the taskwork SMM between humans and IVAs. The result of correlation matrix showed that team verbal and non-verbal communication were significantly positively related to teamwork SMM ($r=0.465$, $p<0.01$ and $r=0.308$, $p<0.05$, respectively) suggesting a positive association between both verbal and non-verbal communication during a collaborative task on developing understanding of the teamwork.

To investigate whether the development of the teamwork SMM is different in the five conditions because of the difference in the IVA's multimodal communication, an ANOVA test was conducted. The results of the ANOVA test showed that there was a significant difference $p<0.05$ [$F(4, 50) = 3.64$, $p<0.01$, $\eta^2=0.22$] between the groups of participants in their perception of the teamwork SMM. This result was supported by the outcome of the non-parametric Kruskal-Wallis H test ($H=10.869$, $df=4$, $n=55$, $p<0.028$). To understand which condition/s accounted for the significant difference in teamwork SMM, post hoc comparisons tests indicated that the mean score for the extrovert IVA conditions ($M = 3.21$, $SD = 0.61$) was significantly higher than the other conditions.

Regarding the impact of IVA's personality on the development of a teamwork SMM, the results did not show any significant difference between in the perception of either the taskwork or teamwork SMM according to the match in extraversion personality between the human and the IVA teammate. The results of the ANOVA test showed that there was a significant difference $p<0.05$ [$F(2, 52) = 6.94$, $p<0.01$, $\eta^2=0.09$] in the perception of a teamwork SMM between the participants who had an agreeableness IVA ($M= 3.80$, $SD= 0.48$). Moreover, the results showed that there was a significant difference $p<0.05$ [$F(2, 52) = 6.199$, $p<0.05$, $\eta^2=0.105$] in the perception of a teamwork SMM between the participants who had a match in the agreeableness personality ($M= 3.70$, $SD= 0.56$) with the IVA and those who were in mismatch with the IVA ($M= 3.21$, $SD= 0.80$). The results of ANOVA test was supported by the non-parametric Mann-Whitney test based on ranking. The results of Mann-Whitney U test indicated that the participants who matched with the IVA in agreeableness personality were significantly higher than mismatched group in perceiving taskwork SMM ($U=260.5$, $n=55$, $p<0.05$) and teamwork SMM ($U= 232.5$, $n=55$, $p<0.05$).

7.4.1.5 Does the IVA Personality Influence Human Trust?

RQ 1.2.5 inquired if the IVA's two personality traits influenced the human's trust in the IVA teammate. The results of ANOVA test, Table 7-3, showed that there was a significant difference between the five conditions in human trust in the IVA $p<0.001$ [$F(4, 50) = 11.734$, $p<0.001$, $\eta^2=0.48$].

The results of the ANOVA test showed that there was a significant difference $p<0.001$ [$F(2, 52) = 13.487$, $p<0.001$, $\eta^2=0.34$] between the groups of participants in their trust in the IVA based on the IVA's agreeableness/antagonism personality trait. This result was supported by the outcome of the non-parametric Kruskal-Wallis H test ($H=18.857$, $df=2$, $n=55$, $p<0.001$). To understand which condition/s accounted for the significant difference in human trust, post hoc comparisons using the Tukey HSD and Bonferroni tests were used. The post hoc tests indicated that the mean score for human trust in the agreeable IVA condition ($M =4.15$, $SD =0.427$) was significantly higher than the mean score of the participants who had an antagonistic IVA ($M =3.50$, $SD =0.468$) and neutral IVA ($M =3.618$, $SD =0.519$).

Moreover, the results of the ANOVA test showed that there was a significant difference $p<0.05$ [$F(2, 52) = 4.328$, $p<0.05$, $\eta^2=0.14$] between the groups of participants in their trust in the IVA based on the IVA's extravert/introvert personality trait. This result was supported by the outcome of the non-parametric Kruskal-Wallis H test ($H=7.119$, $df=2$, $n=55$, $p<0.05$). The post hoc tests indicated that the mean score for the humans' trust in the extravert IVA condition ($M =4.027$, $SD =0.458$) was significantly higher than the mean score of the participants who had the introvert IVA ($M =3.636$, $SD =0.574$).

7.4.1.6 Does the Match in IVA Personality Influence Human Trust?

RQ 1.2.6 inquired if the match or variation in personalities between the participants and the IVA teammate influences human trust in the IVA teammate. The results of the ANOVA test showed that there was a significant difference in human trust in the IVA in the case of a match in agreeableness personality traits $p<0.001$ [$F(1, 53) = 22.687$, $p<0.001$, $\eta2=0.29$]. The same result was reported using the nonparametric Mann-Whitney U test that indicated that the match in agreeableness personality between the humans and the IVAs are significantly higher in trusting the IVA ($U=119.0$, $n=55$, $p<0.001$). On the other hand, the results of ANOVA and Mann-Whitney tests did not show any significant difference in trust in the case of a match or variation in extraversion personality between the human and the IVA.

7.4.1.7 Does the IVA Cognitive Behaviour Influence Human Trust in the IVAs Decision?

RQ 1.2.7 inquired if the shared knowledge exchanged between the human and IVA during collaboration is likely to have an impact on human trust in the IVA. Linear regression results, Table 7-6 showed that 41.9% of the variance in humans' trust in the IVA could be accounted for by the IVA's shared knowledge. To assess the overall statistical significance of the model, the results showed that the three predictors were significant $R2= 0.419$, $F (1, 53) = 39.963$, $p<0.001$.

7.4.1.8 Does Personality or Cognitive Behaviour of the IVA Contribute More towards Human Trust?

RQ 1.2.8 aimed to investigate whether the IVA's personality or the exchanged knowledge during collaboration was a better predictor of human trust. The results of linear regression showed that the IVA's personality and shared knowledge are predictors of the human's trust in the IVA. The results reported that 41.6% of the variance in human trust in the IVA could be accounted for by both the IVA's personality as well as the shared knowledge.

Moreover, to evaluate whether the IVA's personality or the IVA's shared knowledge contributed more to human trust, further analysis was conducted. The results, as shown in Table 7-6, indicated that standardized coefficient β of the IVA's shared knowledge (0.653) is greater than standardized coefficient β of the IVA's agreeableness/antagonism personality trait (0.075), and greater than β of the IVA's agreeableness/antagonism personality trait (0.077). This finding showed a stronger effect for the IVA shared knowledge rather than personality.

To assess the overall statistical significance of the model, the results shows that the three predictors were significant $R2= 0.416$, $F (1, 53) = 13.84$, $p<0.001$.

7.4.1.9 Does Humans Trust in IVA Teammate Effect on Human Commitment?

RQ 1.2.9 aimed to investigate the influence of human trust in the IVA on a human commitment to honour their promises to carry out the agreed on task. Correlation results showed that there was a significant positive correlation between human trust and human commitment (r=0.864, p<0.01). The results of linear regression, Table 7-6 showed that human trust in the IVA could predict the overall team performance. The results reported that 73.5% of the variance in team performance could be accounted for by the human's trust in the IVA. To assess the overall statistical significance of the model, the results shows that both predictors were significant R^2= 0.735, F (1, 53) = 150.72, p<0.001.

7.4.1.10 Does Human Commitment Impact on Human-IVA Team Performance?

The last research question (RQ 1.2.10) investigated the humans' commitment to honour their promises to the IVA teammate and the overall human-IVA team performance. Correlation results, Table **7-2**, showed that there was a significant positive correlation between the two variables (r=0.909, p<0.01). The results of linear regression showed that

Table 7-6: Regression test between (Human Trust and IVA Cognitive Behaviour), (Human Trust and IVA extraversion, IVA agreeableness, IVA cognition), (Human Commitment and Human Trust) and (Team Performance and Human Commitment)

Model	Unstandardized Coefficients		Standardized Coefficients β	R	Adjusted R^2	F	Sig.
	Unstandardized B	Std. Error of the Estimation					
Human Trust							
IVA Cognitive Behaviour	0.504	0.080	0.656	0.656	0.419	39.96	0.000*
Human Trust							
IVA extraversion	0.053	0.096	0.077				
IVA agreeableness	0.052	0.096	0.075	0.670	0.416	13.84	0.000*
IVA cognition	0.503	0.082	0.653				
Human Commitment							
Human Trust	0.771	0.063	0.860	0.860	0.735	150.72	0.000*
Team Performance							
Human Commitment	1.006	0.056	0.926	0.926	0.855	318.15	0.000*

** Significance level p<0.01*

human commitment could predict the overall team performance. The results in Table 7-6 reported that 85.5% of the variance in team performance could be accounted for by the human commitment. To assess the overall statistical significance of the model, the results shows that both predictors were significant $R^2 = 0.855$, $F(1, 53) = 318.15$, $p<0.001$.

7.5 Discussion

The work reported in this chapter aimed to investigate the influence of an IVAs' personality as represented in its multimodal communication, i.e. verbal and non-verbal, on the human's perception of the SMM with the IVA. To reach this aim, few research questions were proposed. Each question is addressed in a following subsection.

The first research question inquired (RQ 1.2.1) if there was a significant difference between the five condition groups of participants in their perception of the IVA's two implemented personality traits, i.e. extraversion and agreeableness. Data analysis revealed that at a statistically significant level participants identified the multimodal communication, verbal and non-verbal communication, of the extravert IVA as more extravert than the introvert IVA. Moreover, the results showed that the participants recognized the multimodal communication of the agreeable IVA as more agreeable than the antagonist IVA. This finding demonstrated that both verbal and non-verbal communication contribute toward participants' perception of an IVA's personality. This result is consistent with the other studies, e.g. (Arellano et al., 2011) (Sevin et al., 2010), that showed the impact of an IVA's verbal and non-verbal communication aspects on human users' prediction of an IVA's personality. Other researchers have also studied the impact of personality traits on human-agent interaction (Allbeck and Badler, 2002) (Cafaro et al., 2012). Similar to our study, these studies have concentrated on the incorporation of personality traits in an agent (Allbeck and Badler, 2002) and/or whether the human could identify the agent's personality (McRorie et al., 2012). For instance, (Isbister and Nass, 2000) reported that their participants found extraverted IVAs significantly more extraverted than the introverted IVAs. Numerous studies have considered whether human participants are able to perceive an IVA's personality through communication with the IVA. (Doce et al., 2010) presented a model to create an IVA with distinguishable FFM personality traits. Neff et al. exploited the extraversion (Neff et al., 2010) and neuroticism (Neff et al., 2011) traits of the FFM in multimodal characters evaluating the effects of verbal and non-verbal behaviour in personality perception studies. (Cafaro et al., 2012) conducted a study to investigate how IVA's non-verbal communication influence the first encounters between a human and an IVA.

The results showed that there was a significant difference between the participants in the five conditions in the perception of an IVA's agreeableness as expressed by the IVA's verbal behaviour. However, the result did not reveal any significance between participants in differentiating an IVA's agreeableness personality because of the non-verbal behaviour of the IVA. The impact of non-verbal behaviour on humans' perception of an IVA's personality has been a debated topic. Burgoon (Burgoon, 1994) noted that approximately 60-65% of the meaning of a social setting is derived from non-verbal behaviours. Vinciarelli et al. (Vinciarelli et al., 2012) reported that non-verbal behaviour influences our perception of others. Arellano et al. (Arellano et al., 2011) studied the influence of some visual cues of non-verbal communication, head orientation and eye gaze, on human users' perception of certain IVA personality traits: extraversion, agreeableness and neuroticism. The results showed that non-verbal communication visual clues affected significantly the users' perception of the IVA's personality traits. However, in their study about varying personality in spoken dialogue, Rushforth et al. (Rushforth et al., 2009) reported that feedback from the participants suggested that the non-verbal behaviour may have been a confounding factor in their perception of IVA's personality.

Regarding the results of perceiving neutral personality, participants did not get different conditions that would allow them to compare between the personalities of IVAs. They were assigned a single condition and so based on that single experience they perceived the personality of the IVA teammate. Although the neutral personality was meant to be midway between extravert and introvert, participants tended to classify the neutral IVA as either an introvert or extravert. Previous research work has identified the problem of erroneous perception of the neutral emotion and personality, where neutral emotion and personality could be confused with other traits, or other traits could be confused with neutral. In one study, the neutral emotion was easily confused with other emotions such as sadness (Deng et al., 2006). In another study, where pictures of an IVA (Alfred) with different head postures and eye gazes were shown, participants were likely to recognize different head posture and eye gaze as neutral (Arellano et al., 2011).

The results of the second research question (RQ 1.2.2) suggested that in the collaborative context the similarity in personality traits between IVAs and humans is likely to impact on humans' perception of the IVAs' personality. Numerous studies reported different points of views; while Isbister (Isbister and Nass, 2000) found people liked virtual agents that showed a different personality to their own, other researchers (Nass et al., 1995) (Nass et al., 1996) indicated that people favoured computer interfaces (including IVA) that represent a similar type of personality to their own. These differences in findings are probably due to the differences in goals and designs of each of the studies and highlight the complexity of the personality dimension and its effects.

The results of questions three and four (RQ 1.2.3 and RQ 1.2.4) showed a positive relationship between IVA's multimodal communication and the development of a taskwork SMM and a teamwork SMM. This finding was previously noted in Section 5.5.3. The difference is that the results in Section 5.5.3 examined the relationship between the IVA's multimodal communication and a SMM through tracking the impacts of the development of a SMM. In this chapter, the relationship was studied through the direct association between participants' answer to their perception of IVA's multimodal communication and taskwork and teamwork SMMs.

The other part of research questions three and four (RQ 1.2.3 and RQ 1.2.4) inquired whether IVA personality influences the development of a SMM between humans and IVAs. The results showed that the participants who had the agreeable IVA were significantly more likely to develop both a strong taskwork and teamwork SMMs than those who had the antagonistic IVA. Post hoc tests showed the participants who had received the agreeable IVA developed significantly greater taskwork and teamwork SMMs than those who had either the antagonistic or the neutral IVA conditions. This finding indicated that IVAs with an agreeable personality trait tend to develop SMMs with human teammates. Meanwhile, the results showed that participants who had the extravert or introvert IVA condition did not differ in their development of taskwork or teamwork SMMs. This finding indicated that an IVA with an extraversion personality is not likely to influence the development of a SMM.

Although the literature of human-agent interaction has not studied the influence of an IVA's personality on the perception of SMMs with an IVA, some researchers in human teams reported a significant interaction between the trust facet of agreeableness in predicting a shared mental model between team members (Fisher et al., 2012). Barrick et al. (Barrick et al., 2001) suggested that an agreeable personality may predict working well in teams; although no direct relationship between agreeableness and team performance was found. Neuman and Wright (Neuman and Wright, 1999) concluded that agreeableness between team members helps a group come to a consensus on a SMM. An explanation for the findings of our study and other studies in human teams could be that agreeable characters do their best to avoid teamwork disruptions that might occur if there was interpersonal conflict.

While our results did not report a significant impact of extraversion on the development of a SMM, some other studies found extraversion as a factor that affects teams. Givney et al. (Givney et al., 2009) studied the influence of personality on human teams; extraversion was found to have an effect on tasks that did not comply with very short time constraints, while agreeableness was important for tasks where tight collaboration was required. A study of sixty-three (63) teams using a VE found that extraversion was an important personality trait to promote team interaction. Moreover, it was found that teams with lower variances in extraversion levels did better (Barrick et al., 1998).

The fifth research question (RQ 1.2.5) inquired if the two personality traits incorporated in the IVA impact on human trust. The results showed that the humans trusted in the agreeable IVA and not the antagonistic or the neutral IVA. Additionally, the results showed that the humans trusted in the extravert IVA rather than introvert or the neutral IVA. Probably agreeableness is the personality trait that can be identified as the most associated with trust. The reason for this strong association is due to the nature of agreeableness that makes the individual willing to conform to the needs of others. Some researchers have claimed that the propensity to trust is a facet or component of agreeableness (Mooradian et al., 2006). Many studies showed that agreeable IVAs could build a sense of rapport with a human. In their study, (Kang et al., 2008) investigated the association between personalities of human participants and their feelings while interacting with an IVA that is incorporated with personality. Their result indicated that agreeable IVAs create stronger rapport especially with agreeable people.

In the literature, there is no agreement on the impact of an IVA with an extraversion personality on the interaction with humans. While some work found no relationship between extravert IVA and interaction with human, other studies indicated that extravert

IVAs were found to impact on the interaction with humans (Lee and See, 2004). An extravert IVA was found to grab human attention quicker than IVAs with other personality traits (Cafaro et al., 2012). Hence, perhaps an extravert IVA is able to influence interaction with humans in situations where human attention is required.

The sixth research question (RQ 1.2.6) inquired whether the match in agreeableness and/or extraversion between a human and an IVA tends to influence human trust. The results showed that the match in agreeableness is likely to impact on human trust in an IVA. The relationship between the human personality and their tendency to trust has been identified before. (Oleson et al., 2011) noted that the main influences on human trust in a robot teammate included features of both the human and the robot as well as the environment (situation) in which cooperative task was to be performed. Hence, building trust is a two-party process that requires understanding by both parties, i.e. a human and an IVA. According to (von der Pütten et al., 2010), users' personality influences their interaction with an IVA. Additionally, the personalities of the users effect their perception of the IVA's personality and behaviour. Hence, to best understand the influence of an IVA's personality, the personality of human users need to be accounted for and any personality (mis)match with the collaborating IVA should be investigated.

Our finding is consistent with other studies which indicated that the trait of trust is often treated as a subscale of agreeableness (Digman, 1990), (Goldberg, 1990). This association between the match in agreeableness between the human and the IVA could be explained with the reduction of possible conflict. Many studies have documented the association between conflict and its consequences on team trust (Han and Harms, 2010), they indicated that the diversity between team members in decision making are mainly antecedents of team conflict (Curşeu and Schruijer, 2010).

Studies in human teams indicated that the composition of members' personalities influence team interaction and performance (Bradley et al., 2013). However, these studies have not agreed on whether the variation or similarity in personality has a positive effect on teamwork. Some researchers claimed that variation in personality is likely to be associated with variant skills (LePine et al., 2011). Other studies argued that homogeneity in personality traits among team members tends to improve team performance (Anderson, 2009). These contradictory results concerning the role of variation of personality in teams may be due to the nature of the task in which the team members are involved.

Studies have indicated that users' own personality traits affect their behaviour in virtual worlds (Yee et al., 2011). In the literature, matching human-IVA personalities have not been studied in association with SMMs and so our results could not be compared with others. Nevertheless, our findings are in-line with some previous human-computer interaction literature (Reeves and Nass, 1996) that indicated that humans were more likely to prefer IVAs with similar personality. This opinion was supported Nass and Lee (Nass and Lee, 2000) by who indicated that people prefer to interact with other individuals who have a similar personality to them; while other work showed that people preferred IVAs that were complementary to them (Isbister and Nass, 2000). In their study, (Kang et al., 2008) investigated the association between the FFM personality traits of human participants and their feelings when they work with an IVA. Their result showed that agreeable personalities felt strong bond with an agent that represents an agreeable personality.

The seventh question (RQ 1.2.7) aimed to investigate the impact of IVA cognition on human trust. IVA cognition could be represented in many ways. In the current study, an IVA communicates verbally with the human and gives requests, replies and feedback. IVA cognition reflects information that can be obtained by the human and it is useful to achieve the collaborative task. The results indicated a significant influence of IVA cognition on human trust. There is considerable research in agency studies that reflect the cognitive facet of trust (e.g. (Falcone and Castelfranchi, 2001)). In virtual environments, multiple variables besides cognition control human interaction with an agent. Hence, our findings stress that cognition is important in virtual environments, just as it is in other environments.

The eighth question (RQ 1.2.8) was a meta-analysis of the dominant trigger to influence human trust in an IVA. The results indicated that IVA cognition showed superiority over IVA personality in founding trust with a human. While the study provided a general insight about the importance of both personality-based and cognitive-based facet in fostering human-IVA trust, the key insight was that cognitive-based facet is more dominant in establishing human trust. A number of studies investigated which of the personality-based dimension or cognitive-based dimension were factors that contribute to human trust in an IVA. We could not find a support or contradiction in the literature as there is no previous study that compared the effect of both IVA cognition and personality on human trust in an IVA.

The ninth research question (RQ 1.2.9) inquired whether human trust in the IVA's decision and recommendation is likely to effect the human's commitment to accomplish the shared task with the IVA. The results showed a positive association between the humans' trust in IVAs and fulfilling their pledge to IVAs. This result is consistent numerous other studies that stress the importance of trust (Casaló et al., 2011). (Costa, 2003) indicated the positive relationship between team trust and commitment. Hence, the current study provides validation of earlier research regarding the role of human-IVA team trust in establishing a good team performance. Among these studies, (Hancock et al., 2011) noted among the factors that influence human-robot interaction, performance characteristics were found to be strongly associated with trust. Moreover, personality-based trust, cognitive-based trust and institutional-based trust have a dramatic impact on both virtual team satisfaction and virtual team performance (El-Kassrawy, 2014).

The last research question (RQ 1.2.10) examined how human commitment to accomplish the task effects human-IVA team performance. The results showed that the increase in human commitment is positively associated with team performance. This result is consistent with other studies in virtual teams that found team commitment influences team satisfaction and performance (Shachaf and Hara, 2008) (Blumberg et al., 2012). This finding indicates that human commitment to a team including IVA team members has the same positive influence on team satisfaction and performance as has been found for virtual teams of humans. The influence of trust between team members to create a commitment between the members to achieve the shared goal has been identified in human teams. As noted by (O'Sullivan, 2011) there is a positive relationship between the trust between human team members and their leader and team commitment to the shared goal of the team and subsequently an increase in teams productivity. (McNeese-Smith, 1996) found that commitment positively correlates with a team of employees' job satisfaction that enhances the team productivity.

7.6 Summary

Our study sought to go beyond identification of IVA personality to consider the impact of personality on aspects of human-IVA teamwork. In this chapter, we were not arguing for the importance of trust in human interactions because that is too obvious. We aimed to understand factors to empower human-IVA teamwork. This chapter investigated whether an IVA’s personality traits influence the establishment of a SMM with a human teammate. Additionally, this chapter investigated whether the match between IVAs and humans in personality traits influences the establishment of taskwork and teamwork SMMs. Through an experiment, it was found that designing an IVA incorporating personality traits is likely to improve the performance of the human-IVA team. In addition, these findings indicated that, similar to human teams, the personality of both the human and the IVA teammate should to be taken into consideration to foster team productivity. Moreover, the current chapter indicated that the information offered by the IVA (i.e. cognitive-based facet) has a more dominant influence on human trust in the IVA than how the IVA presents this information (i.e. personality-based facet). Moreover, the study stressed the importance of trust in the human-IVA teamwork relationship on improving the performance of this teamwork.

CHAPTER 8

Discussion

This chapter discusses the contributions of this thesis, and possible future directions. In Section 8.1, a brief discussion to the proposed agent architecture is presented. In Section 8.2, we connect the findings of the first two experiments to research question 1.1 that aimed to investigate the influence of IVA multimodal communication on human-IVA teamwork. Section 8.3 associates the findings of the third experiment with research question 1.2 that aimed to study the impact of IVA two personality traits on human-IVA teamwork. In Section 8.4, a final discussion of the overarching human-IVA collaboration context was presented.

8.1 A Summation of the Proposed Agent Architecture with Existing Architectures

There is a vast work in agent-based research that intensively studied the cognitive behaviour of agents. The BDI model has often been used by researchers to model this behaviour (Buford et al., 2006) (Luo et al., 2010). The BDI model represents the agent as an entity that is aware of its surrounding environment and able to reason to find an optimal way to fulfil determined goals. A number of extensions have been carried out on the BDI model to add more features to the agent. For example, Buford et al (Buford et al., 2006) extended the BDI agent model to allow an agent's beliefs to be dynamically updated in real-time. Others extend BDI-agent to add time-critical and uncertainty situations (e.g. (Luo et al., 2010)). All the extensions were helpful in adding more capabilities to the agent; nevertheless, in the majority of cases these extensions were to improve the cognitive aspects of the agent. Although there are many varied attempts to extend agent abilities, the ability to collaborate remains a challenge due to the nature of collaboration. With the popularity of the BDI and other cognitive models, this point of view of the agent was transferred to IVA design. Nevertheless, as the agent is going to collaborate with a human, the reasoning aspect of the agent should not be the only interest.

This gap in research has challenged several researchers to consider collaboration in IVA design. For example, (Jakobson et al., 2008) presented a BDI-based agent architecture that considers not only the individual belief, desire and intention of the agent, but those of other agents. According to their design when a situation is recognised by a reaction layer an existing plan is invoked or a trigger is automatically generated to create a plan from a specification embedded in the situation. This architecture had a collaboration layer that was intended to enable collaboration. The new layer is composed of two elements: either Collaboration Manager receives a request for collaboration from other agents or from its inner intention; the second element is called Inter-Agent Collaboration Models that includes scenario or policy-based collaboration. This model was originally designed for agent-agent collaboration. It was difficult to extend it to human-agent collaboration for many reasons; first: the collaboration manager receives the requests of collaboration from two sources either an external goal from another agent or from intention execution after the completion of executing the agent's own plan. This architecture considers the collaboration as a matter of requests from other entities or something to be considered after the execution of agent's own plans. This point of view violates the elements of AT that considers the community as a way towards achieving the collaborative goal. Moreover, this architecture does not show a clear method of using the tool that is to say of communicating. Perhaps showing an arrow in the design to represent the flow of knowledge from an agent to another could be acceptable in agent-agent communication as both collaborative entities belong to the same world (electronic world); nevertheless, this is far from being applicable in human-IVA collaboration. Another point, according to the proposed architecture the agent will react to the collaboration requests according to the pre-existing collaboration models. Hence, the agent's behaviour is controlled by existing collaboration plans that are not always manageable when collaborating with humans with unpredictable behaviour.

The collaborative agent architecture of (Jakobson et al., 2008), like other agent-agent collaborative architectures show the need to present an agent architecture that is designed specially for human-IVA collabroation. Human-agent teamwork faces many obstacles that make the collaboration a challenge. First, both humans and IVAs belong to two different worlds, that is to say humans belong to the physical world, while IVAs belong to virtual/electronic world. This difference means there is no resource/knowledge that a human and an IVA teammate can share. In contrast, agent-agent collaboration has several approaches related to agent collaboration and sharing of knowledge including Tuple-Spaces, Group Computation, Activity Theory and Roles (see Section 3.4). Thus, the ability to cordinate in agent teamwork is more straightforward.

Second, BDI agent architecure relys on the predictablity of the current situation and the similiarity with the situation stored in the knowledge base. The collaboration between humans and IVAs tends to be dynamic and prone to the spontaneous behaviour of humans. IVAs need to manage the coordination between human-agent team members. IVAs need to adopt the flexibility of human behaviour, as users may not necessarily strictly follow the rules of coordination.

An example of an agent architecture that considered agent behaviour in a team was SGD model. As presented in Section 3.2.2.3, the SGD model tends to take a socio-psychological perspective towards human-IVA teamwork. The shared cognitive state between team members was not a studied using the SGD model. Moreover, the role of IVAs' monitoring of the collaboration progress was not presented. Thus, there further studies were needed to investigate the balance between the social and cognitive aspects of human-IVA collaboration.

In more recent research work, Barange et. al. (Barange et al., 2014) proposed a collaborative and conversational BDI agent architecture (C^2BDI). In their proposed architecture, the agent has a dialogue manager that allows the agent to share its knowledge with other team members using natural language communication. The dialogue manager supports both reactive and proactive conversation behavior. However, this architecture has the following limitaitons:

1. C^2BDI architecture has a perception module to percieve virtual world changes, however, the collaboration with humans requires more than receiving the incidents of the VE in general and going to focus on the behaviour of the human teammate.
2. The dialogue manager does not take into the account the fact that people differ in percieving the verbal communication depending on the personality traits of the sender and the reciever. The personality of the sender forms an effector on creating the communication cues, while the personality of the receiver influences the interpretation of the received cues.

3. This architecture presents the IVA as a conversational agent hence the cordination between the verbal and non-verbal communication is not settled.

Our proposed agent architecture included the properties in C^2BDI; additionally, our proposed architecture had the following merits:

- One of the main merits is that our architecture includes the agent's personality as a factor that manages the IVA's communication. Our personality tends to influence how we express our intentions verbally and non-verbally. This fact was considered for two reasons: First: to increase the believability of the IVA. Second: to investigate which IVA personality (i.e. introvert/extravert, agreeable/disagreeable) and which personality match/mismatch between humans and IVAs is likely to foster the collaboration.
- It separates the cognitive, memory and social processes for the clarity of interaction between these processes on one hand; and on the other hand for ease of modifying the architecture for changing requirements.
- It separates the communication model to guarantee the coordination between the verbal and non-verbal communication channels. Moreover, separating the communication model will enable the agent to coordinate the verbal and non-verbal behaviour of the human teammate that helps in human's *Intention Realisation*.
- Our system includes a *Partner Progress Evaluation* module to perceive how committed the human is towards the collaboration. For example, if the human teammate confirms that s/he will take a particular action and then s/he takes another action, the agent will compare what the human said with what s/he actually did. Based on the comparison the agent will take a decision, and update its plan, based on the current perception of the human's commitment to honour his/her promises.

8.2 IVA Multimodal Communication and Collaboration with Humans

RQ 1.1 inquired whether the IVA's multimodal communication influences collaboration with the humans. This question was separated into questions focussing on the influence of multimodal communication during the collaborative task and what is the influence on the final output of the collaboration. In other words, this main question was split into 1) what is the influence of IVA's multimodal communication on the continuous development of the collaboration with the humans and 2) what is the influence of IVA's multimodal communication on the final development of the collaboration with the humans?

We aimed to understand the influence of multimodal communication in a time-based manner that is to say the influence on the collaboration from one point in time to subsequent point in time, to further understand the accumulative influence of IVA's multimodal communication on the output of collaboration. Our aim was put the pieces of the puzzle together and get the whole picture. To achieve this task, the collaborative virtual scenario was designed in a manner that has checkpoints. Each checkpoint is considered as a sub goal. The merits of designing the collaborative task designed as sub goals are:

First: the progress of the collaboration could be monitored easily.

Second: the quality/quantity of communication could be studied.

In the literature, SMM, the shared knowledge about the task and about the team member, is considered as a sign of an effective collaboration. To measure the progressive and final collaboration, we used two different approaches. Regarding the progressive development of a SMM, we used some outcomes that represent the development of a SMM. These outcomes were anticipating a teammate's decisions, reduced explicit communication, match in cognitive perspective, competence in decision-making and the involvement in the shared task. Regarding the measurement of the final output of establishing a SMM, we used a survey to ask the human users about their perception of the developed taskwork and teamwork SMM with the IVA. Both ways of measuring the developed SMM sought to give an insight into the close relationship between the IVA's multimodal communication and SMM both as a progressive and final output.

These findings build on the previous studies (Espevik et al., 2006) in declaring the importance of designing IVAs with both verbal and non-verbal communication to foster a shared understanding between humans and IVAs. While other studies indicated the importance of IVA's comprehensive communication to support the users' feeling of believability, involvement in a virtual system (Gajadhar et al., 2008) and overall satisfaction about the flow of communication (Corradini et al., 2004), our studies investigated other aspects of the collaboration and showed that an IVA's communication tends to be associated with a SMM. This mutual understanding had an impact on the team's performance while achieving a collaborative task. The concept of mutual understanding between agents has been considered in other research (Yen et al., 2006). Approaches to agent-agent mutual understanding, such as those introduced in Section 3.4, use shared spaces/processes that do not seem appropriate for a human-agent SMM. To provide a more humanlike and plausible approach, that is appropriate when studying two teammates from two different worlds, i.e. physical and virtual, we recommend that more attention be given to providing comprehensive verbal and non-verbal communication to allow a SMM to be developed and maintained by both parties.

Regarding the relationship between the IVA's multimodal communication and the final development of a SMM, the results of our studies demonstrated a significant positive association between both the IVA's verbal and non-verbal communication and the human's perception of a teamwork SMM. This result is consistent with the findings of other researchers who found that human involvement with IVAs was likely to increase social bond with an IVA (Gajadhar et al., 2008). Moreover, to answer the second part of the research question about which method is more effective in building teamwork SMM, the result showed that an IVA's verbal communication tends to contribute more to humans' perception of a teamwork SMM. This finding suggests that the exchanged messages give a better understanding of the teammate's thoughts and capabilities. Previous studies in human teams suggested that the establishment of shared knowledge about a teammate is more likely to occur through verbal communication (Clark and Wilkes-Gibbs, 1986). Yet, this claim was not tested in human-IVA teams. Our results support this finding and extend it to human-IVA teams.

To further understand how the multimodal communication influences the development of a SMM, literature was surveyed and the factors that emerged were reported. Among these factors, trust and members' commitment were found to influence the teams. We closely monitored the possible subsequent influence of the IVA's multimodal communication. Data collected from the session's log files was used to explore the human's behaviour with respect to these variables during four consecutive cycles of interaction. The results showed that these variables evolved together over time. That is to say when as an IVA continues to use multimodal communication, the human's trust in the IVA's decision and recommendation increased, human's commitment to honour their promises increased and finally an increase in taskwork and teamwork SMM.

8.3 IVA Personality and Collaboration with Humans

Regarding RQ1.2, many IVA researchers have suggested that building an IVA requires not only incorporating cognitive and reasoning aspects but also incorporating personality and psychological aspects that characterize human beings (Rushforth et al., 2009). Personality has been found to be an important factor that influences the dynamics of human teams and has an effect on team performance. In line with these findings, researchers have identified personality traits as one of the most important requirements for producing believable agents interacting with humans (Loyall and Bates, 1997).

Many studies have found that team performance is influenced by team members' personalities (Bradley et al., 2013); however, the link between team members personalities and performance was not discovered. Furthermore, the relationship between trust and team performance was found to be mutual. Some studies looked at trust as a way to improve the quality of interaction with the autonomous system (Rajaonah et al., 2006) and other studies pointed out that expectations of performance are important factors in trust (Jøsang and Presti, 2004). Although this was not confirmed in the study by (Aubert and Kelsey, 2003), our study found that trust improves human-IVA team performance and is in line with the body of literature, see Section 3.8 that identified the positive association between team members' trust and team performance.

In the literature, many studies included personality in the IVA's responses and cues. This inclusion may give the impression that the IVA has a personality in its responses. In this dissertation, we aimed to create an IVA with personality that controls not only the visible cues of an IVA, but also the decision making core of the IVA. Perhaps the visible representation of personality, such as facial expression, can more readily be noticed. In our study, in addition to creating an IVA that displays personality in its visible behaviour, we aimed to enable personality traits to influence the IVA's planner to select among different options. The strength of using personality traits over the method of scripting behaviour is flexibility in different dynamic situations that an IVA may face. For example, a personality trait like extraversion could be integrated in an IVA through scripting, then a technique like decision trees should be utilized to decide which cues to express. Using

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personality traits as an effector to take a decision as well as expressing this decision allows developers to create IVAs that can dynamically manage their behaviour and thereby give humans a deep feeling of believability of the IVA personality.

The impact of team members' personality composition on team performance is likely to be dependent on task characteristics. For example, in the case of tasks that require social interaction between team members, a high level of extraversion would be a predictor of team performance. With tasks that require decision-making a high level of agreeableness tends to be a predictor of team performance (LePine et al., 2011). In a task that required reasoning and decisions, our results showed that the match in agreeableness personality between the human and the IVA influenced human trust. This finding could be explained by the Psychology and team dynamics literature. Studies have found that team members with an antagonistic personality are likely to be self-centred and not open to others' opinions (Anderson, 2009), while agreeable members tend to take steps to preserve teamwork cohesion (Venkataramani and Dalal, 2007). Although extraverted individuals tend to be friendly with others; when they work in a team some problems may arise regarding division of roles within the team (Prewett et al., 2009).

8.4 Human-IVA Collaboration Context

Relevant to this study is consideration of the factors that influence human-computer interaction; the studies presented have investigated many aspects of human-computer interaction. Due to the increasing use of virtual environments in many aspects in human life, human-IVA interaction offers a good example of human-computer interaction.

The studies that explored the relationship between humans and IVAs focused on different aspects of this heterogeneous relationship, some studying the IVA's role as a facilitator or guide to the human while they use the virtual environment, while in other studies the IVA took an on interventionist or more controlling role. Depending on the IVA's role, the focus of the study is directed to the requirement of designing an IVA to match the situation. For instance, studying the role of an empathetic IVA while interacting with humans, requires the exploration of the role of emotions on the interaction. Hence, the IVA's design focuses on the emotional appraisal. While if the aim of the study is to investigate the role of IVA as a guide/recommender to humans, the focus of the study would be on the cognitive aspects of the IVA and how to produce what is considered as the most rational or suitable recommendation to the current situation.

Perhaps one of the most sophisticated aspects of interaction between humans is working in a team. Working in a team requires a balance between cognitive, personal and social aspects. The simulation of working in a team in human-IVA interaction is more sophisticated, as combining these aspects in an IVA in real-time manner is hard. Moreover, introducing an IVA that wins the humans' attention, interest, respect, trust and commitment to pursue the collaboration is a challenging task. In this situation, an IVA needs to have a balance between the cognitive, personal and social aspects.

In this study, we aimed to explore the factor(s) that contribute to the strength of this sophisticated human-IVA collaboration. The study began with a high-level research question (RQ 1) concerning the factors that influence human-IVA collaboration. The literature examined a number of factors that range from psychological, personal, social, cognitive, and environmental to management. As an IVA is meant to simulate the behaviour of real humans and to collaborate with humans, it was important to study how human collaboration is studied. Activity Theory has gained widespread acceptance as a framework to understand the requirement of collaboration. AT is a framework or descriptive tool for a system. According to AT, people are socio-culturally actors. They are not merely knowledge processors or components in a system.

AT was selected because of many reasons. First, it is well known and used successfully in previous studies. Second, it considers multiple aspects that may effect on the collaboration. Third, it is a general framework that could be adapted to suit variant situations; this is a particularly important reason as human-IVA collaboration in a virtual environment is different from collaboration in the physical world. Fourth, AT has three of levels of activity. The first level of activity towards an objective (goal) carried out by a community because of a motive (need) that may not be conscious social. The second level of an activity towards a specific goal that is conscious and carried out by achieving a group of possible sub-goals. The third level of operation structure of activity that is typically automated and not conscious concrete way of executing an action. The second level of activity is particularly interesting, as the collaboration with an IVA requires goal-driven behaviour towards a set goal.

These two classes of factors point to the importance of designing IVAs that consider two aspects: First: the means of interaction to convey the cognitive partnership with the human. This aspect related more to the cognitive content of the IVA's proposition and how the IVA presents its proposition. Second: the social dynamics that influence how the human perceives the cognitive content from the IVA. IVA design should consider these two required aspects, namely the content and the manner of communication on one hand and the social dynamics on the other hand.

8.5 Summary

In the result chapters, i.e. chapters five, six and seven, we presented a detailed discussion of the findings of the sub-research questions that analytically answer the main research questions RQ 1.1 and RQ 1.2. In this chapter, we presented a more general view of the impact of multimodal communication in the proposed agent architecture on the human-IVA team. The results showed that multimodal communication of the presented agent positively influenced team performance. Additionally, we discussed the effect of two personality traits included in the agent architecture on the human-IVA team. The results showed that an IVA personality and the match in agreeableness traits positively influenced team performance. Human-IVA match in extraversion did not show a significant impact on team trust and hence on team performance.

CHAPTER 9

Conclusion

Researchers have found that the concepts that manage human-human interactions could be used to study the interaction between humans and agents (Nass et al., 1996). This thesis aimed to study the effect of certain factors on teamwork that includes humans and IVAs. A number of factors were explored and were found to influence teams and affect the team's performance. Among these factors communication between team members and member's personality were found to have significant influence on team performance. Section 9.1 presents what has been achieved towards studying human-IVA collaboration. To formalise this goal, we phrased one main question that was later elaborated into two research questions. Section 9.2 reviews how the research questions have been answered. The limitations to the current study are presented in Section 9.3. Section 9.4 notes future directions to the current study. A final remark is presented in Section 9.5.

9.1 Summary of Contributions

At the beginning of this dissertation, we described our main goal to understand and elaborate the teamwork between humans and IVAs. A summary of the main contributions are presented below.

9.1.1 A Framework for Human-IVA Collaboration based on AT

Our key goal was to understand and to enhance the performance of a heterogeneous team that includes a human and an IVA. To reach this understanding, we deployed AT as one of the well-known and accepted frameworks to comprehend the collaborative situation. In other studies, AT was used mainly for human collaboration, and later it was utilized in human-computer interaction. Novelly, we used the main components of AT to extend its focus to human-IVA collaboration in the virtual environment. AT is a theoretical framework that was presented to understand human interaction in a collaborative situation through the use of tools and artefacts. AT provides a holistic insight and a conceptual way to discover the controlling tools in the collaborative situation in the light of the rules that regulate the situation, division of labour that organises the situation and the community that guides the subjects. AT itself does not present defined tools, rules, division of labour and community that could be applied to all collaborative situations. It offers a general and theoretical structure that should be adjusted to suit each situation. AT has already found its way into the Computer Science and Information Systems fields; however, we used AT in a novel way to understand the growing research subfield of human-agent collaboration.

In this PhD study, the AT framework and related literature were utilised to initially understand the collaboration between a human and an agent. The outcome of this utilisation was the MACVILLE framework which was the implementation of AT in the human-agent collaboration. Our proposed AT-based framework, i.e. MACVILLE, was the starting point to motivate the rest of the study. We cannot say AT influenced the results, but we can say AT made us understand the research area and directed the study to other literatures such as the literature of agents' communication, SMM, agent's personality, human's trust in agents, and human's commitment to collaborate with an agent.

9.1.2 An Agent Architecture that was Built to Maintain Teamwork with Humans

To manage agent reasoning and human-IVA collaboration and communication, we designed and implemented an agent architecture with a supporting communication module. This architecture consisted of two main modules. The first module included intelligent and cognitive processes, while the second one comprised the social and collaborative processes. Cognitive processes included the reasoning model that the agent has to perform in the situations s/he faces. Collaborative processes comprised the process to monitor the development of a shared understanding with the humans. The processes in the cognitive module were similar to other previously presented architectures in the literature; nevertheless, the processes to continuously monitor and evaluate partner's progress and to evaluate the development of a SMM with human partner are claimed to be novel compared to other agent architectures. Additionally, the architecture included personality traits to control the agent's decision-making process.

9.1.3 A Communication Model that Included Multimodal Communication Influenced by Personality for Teamwork

To handle the challenge of the development of characters that can respond autonomously to the unpredictable, open-ended changes in their environment, we have presented a communication model for human-agent teamwork communication (HAT-COM). Previous research work focused on agent-to-agent communication or human-to-agent communication in a role-specific static environment. The presented model includes two types of communication, namely verbal and non-verbal. Previous research work focused on either verbal or non-verbal; even the few works that combine both are directed to agent-to-agent communication. The presented model uses speech act theory (SAT) as a reference in designing the verbal communication. SAT has been shown to be a useful analysis tool for verbal communication.

9.1.4 Discovering the Impact of the Agent Architecture and Multimodal Communication on Human Trust, Commitment and Team Performance

This dissertation investigated the impact of an IVA's multimodal communication on building a bridge consisting of SMM, trust and commitment from the human's side to the IVA's. The study indicated the positive influence of both trust and commitment on human-IVA team performance. Our main finding was that high performing heterogeneous human-IVA teams use a combination of aspects including cognitive (i.e. a SMM), behavioural (i.e. communication), and social aspects (i.e. trust and commitment) to produce the desired outcomes and performance. We argued that SMM, which is a fundamental element in human teams, is an important notion to consider when developing an IVA to be a teammate with a human. However, SMM is a very complex concept to demonstrate its effect on the final team performance. Hence, this study aimed to analyse the indirect relationship between SMM and human-IVA team performance. Although many studies have investigated some factors that foster human-IVA teamwork, this study aims to go beyond finding the relationship between two variables and collect some of the pieces that make up the puzzle of human-IVA teams.

9.1.5 Discovering the Impact of Agent Personality on Human Trust, Commitment and Team Performance

Given the importance of a SMM for human teams and influence of personality in human teams, we addressed this by conducting a study to investigate the effect of the combined human and IVA personalities on the development of a SMM and their team performance. This dissertation investigated the influence of an IVAs' personality as represented in its multimodal communication, i.e. verbal and non-verbal, and the (mis)match with human collaborator on the human's perception of the SMM with the IVA.

9.2 Answering the Research Questions

This dissertation aimed to study the nature of the collaboration between a human and an IVA in virtual environments. As a first step, we aimed to find out the main factors that influence this heterogeneous collaboration; therefore, a main research question (RQ 1) was proposed:

What are the factors that influence human-IVA collaboration?

To answer the main research question, we used Activity Theory (AT) as a framework to infer the nature of the interactions in a collaborative context. Based on the application of AT to human-IVA teamwork, multimodal communication was found to play an essential role in collaboration; hence, the first research question (RQ 1.1) was as follows:

What is the influence of IVA's multimodal communication on the collaboration with the humans?

This question was answered in Chapter 6. The results showed that the IVA's multimodal communication in the proposed agent architecture significantly influenced the development of a SMM between humans and IVAs. The relationship between multimodal communication and SMM was tracked through monitoring the sequential relationship between communication and the human's trust in the IVA's capabilities. The influence of the human's trust in the IVA on the humans' commitment to honour their promises was studied. Finally, the effect of humans' commitment to honour their promises on the performance of the collaboration was investigated. The results showed that an IVA's multimodal communication positively influenced the humans' trust in the IVA's capabilities. Additionally, the results showed this trust positively affected the humans' commitment to fulfil their promises to achieve their roles in the collaborative task. Humans' commitment was found to influence positively the performance of humans-IVA teamwork.

Nevertheless, humans may differ in how they produce and perceive communication acts according to their personality traits. The second research question (RQ 1.2) was as follows.

> *"What is the influence of the IVA's personality and the match/mismatch in personality with the humans on the collaboration?"*

This question was answered in Chapter 7. The results showed that working in a team with an IVA with the agreeableness personality trait is likely to foster human trust in the IVA's decisions and requests which influenced human commitment to fulfil his/her promises to pursue the agreed upon decisions and consequently human-IVA team performance.

9.3 Limitations

In this section, we summarize here the major limitations concerning the theoretical stances taken, the design and outcome of the evaluation studies presented in our theoretical framework.

9.3.1 Theoretical Limitation

AT was initially proposed as a theoretical framework to describe the components in collaborative situation. Research in human teamwork used AT and over the time this framework gained validation and popularity. In this dissertation, we extended AT and presented a framework (MACVILLE) that included the components that are in the virtual environments and the tools that could be used between the human and the IVA teammate. Nevertheless, MACVILLE requires further study against the human-IVA interaction branch to further tune the framework with the latest discoveries about the tools that the human could use to interact with IVAs.

9.3.2 Evaluation Limitation

In this dissertation, we presented three theoretical structures. These theoretical structures were: a human-agent collaboration framework based on AT, an architecture for a collaborative agent that included a process of monitoring the development of a SMM as well as inclusion of personality in decision-making and finally a communication model that comprised personality traits. In order for these structures to be widely accepted, they should be evaluated against existing benchmarks. Although there are several agent architectures, there is a lack of a thorough evaluation benchmarks. (Belsis et al., 2014) presented an attempt to create an agent based benchmark to evaluate agent architectures. However, Belsis' benchmark monitors only the performance of the agent.

9.3.3 Technical Limitation

One of the limitations of this thesis was not using an existing agent reasoning model/language. In this dissertation, we aimed to create an IVA that has both reasoning ability and collaborative skills. This IVA was meant to exist in a web-based VE. Although there are existing toolkits to deploy agents in virtual worlds such as Pogamut (Gemrot et al., 2011) and CIGA (Oijen and Dignum, 2012), these toolkits either did not support our chosen game engine (unity 3D) or web-based virtual environments.

9.4 Future Directions

This study presents an exploratory look at the nature of human-IVA teamwork and the impact of communication and personality traits on shared cognition and team performance. Much more work is needed to shed light on an area of inquiry that lies between two established disciplines. The first discipline is the Intelligent Virtual Agent branch and the second discipline is the Social Sciences. Regarding IVA branch of knowledge, more research work is needed to extend agent architectures to include other processes to foster the collaboration in addition to SMM and personality that were studied in this dissertation. Regarding the Social Sciences, although there are some early studies that report that humans tend to consider computers as a human (Nass et al., 1996), more studies are required to show whether all human-human teamwork factors apply to human-agent teams.

Another avenue of research that would contribute to knowledge building in this area would be to study other personality traits. In this dissertation, we studied two personality traits, i.e. extraversion and agreeableness, which are known to impact on working in a team. Other personality traits in the FFM could be studied to build a thorough understanding of which personality trait and which personality traits combination tends to encourage humans collaboration with IVAs. Similarly, other personality theories could be studied and compared with the results reported using FFM.

A third direction for future research on this question could employ different collaboration settings. (Gal et al., 2007) found out that different collaboration settings influence the behaviour of individual involved in collaboration. These settings include collaboration for entertainment, in serious games and emergency-responder collaboration. Moreover, the proposed approach of utilizing personality traits in IVA planning opens up various paths for future research work in agent planning. One possible path is to study the difference between agent personality-based and non-personality-based decisions on the human's acceptance and perception of believability.

Another direction for future work could be using another classification of Agent's non-verbal communication. In this PhD study, we classified all the messages sent by the agent as verbal communication and any action performed by the agent as a non-verbal cues. Another possible classification of the communication could be task actions (communication related to the progress of the task), verbal utterances and non-verbal cues. This PhD will study the impact of agent's non-verbal communication without the influence of actions related to the task.

Another direction could be using a different way to collect the subjects' responses about verbal and non-verbal communication. In this PhD study, we had five survey items to ask about some aspects of either verbal or non-verbal communication modals. These aspects included appropriateness, timeliness, clearness, and appropriateness to the situation, having helpful influence on the task and reflecting agent's understanding to the situation. As a future work, detailed non-verbal cues such as the agent's facial expression, physical position and gestures could be surveyed to investigate the weight of these cues on the human's perception of the agent's non-verbal communication.

9.4.1 Collaborative Agent Architecture

While this study was limited to a single task-based scenario, the findings from our two studies with different populations suggest that a Human-IVA SMM can help to develop human trust in an IVA teammate and improve the results of human-IVA team performance. Therefore, we believe that measuring the existence and development of a SMM over time should be considered when creating or extending existing agent architectures. Furthermore, as there is a higher demand for IVAs capable of interacting with humans in a team context, SMM and trust need to be considered in existing agent architectures, e.g. FAtiMA (FearNot! Affective Mind Architecture) agent architecture (Dias and Paiva, 2005). In the FAtiMA agent architecture a new submodule could be included in the *Deliberative* level in both the *Appraisal* and *Coping* modules. The *Deliberative* level in the *Appraisal* module would need to continuously sense/monitor the development of a SMM between humans and agents while achieving the collaborative task. In the situation where the agent senses a fluctuation in the development or maintenance of a SMM with humans, agents would need to employ the *Deliberative* level of the *Copying* module that will consequently manipulate the agent's effectors to employ multimodal communication to foster a SMM.

9.5 Closing Remarks

At the start of this thesis project, we envisioned an IVA that is able to collaborate with humans. Not only that, but also an IVA that communicates its intentions and thoughts in a manner to foster human trust in the IVA's abilities as a teammate and increase human commitment to work with that IVA. We proposed an agent architecture that considers collaboration in teams and developing a shared mental model with the teammate as the main driver for its behaviour. In addition to the importance of the cognitive ability to share knowledge and directions in working in a team, personality traits were found to have an influence. Therefore, in addition to the cognitive ability of the envisaged IVA to develop a shared understanding with humans, we recommend that IVA's possess personality traits, at least those that are known to impact on working in a team. These personality traits should influence both IVA communication as well as cognitive aspects such as decision making and monitoring the work in a team.

Thus in this thesis, we have looked at the different essential aspects, i.e., cognitive and personal, of IVAs and what was presented in the literature to come up with an agent architecture that models effective team behaviour. Two experiments were conducted with an IVA implemented with the proposed architecture. In these experiments, we aimed first to improve the plausibility of IVA behaviour as a teammate. We measured the plausibility of IVA behaviour by both surveying the human participants' satisfaction with the IVA as a teammate and by objective measures of the criteria that show the development of SMM and improved team performance.

In the near future, studying and learning, business, health services, entertainment and even social life will happen in association with IVAs. These IVAs will have superior cognitive and social skills to help humans to accomplish their daily activities. For learning activities, IVAs will help the learner to learn, find required information through searching in huge knowledge bases and even demonstrate complex scientific experiments. For medical services, IVA will help humans to quit smoking, lose weight and provide medial consultations anytime and anywhere. For social life, IVA will be the human's best friend, not dogs, and perhaps a wife or a husband. Towards a future where IVAs become true teammates and partners with humans, we hope our proposed collaborative agent architecture and the results of the conducted experiments will be helpful to IVA researchers seeking to build more social and collaborative IVAs.

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Appendix A: The Survey of the First Scenario

1=Disagree strongly	2 = Disagree	3=Neither agree nor disagree	4 = Agree	5=Agree strongly

Verbal Communication survey items:

1. Charlie’s requests and replies were reasonable.
2. Charlie’s requests and replies were suitable to the situation.
3. Charlie’s requests and replies came on time to guide our teamwork.
4. Charlie’s requests and replies were helpful to complete the task.
5. Charlie’s requests and replies reflect his understanding to the situation and the goal.

Non-verbal Communication survey items:

1. Charlie’s actions were reasonable.
2. Charlie’s actions were suitable to the situation.
3. Charlie’s actions came on time to guide our teamwork.
4. Charlie’s actions were helpful to complete the task.
5. Charlie’s actions reflect his understanding to the situation and the goal.

Taskwork SMM survey items:

1. Charlie and I have a shared understanding about what to do to trap the Yernt.
2. Charlie and I have a shared understanding about the main goal of trapping the Yernt.
3. Charlie and I have a shared understanding about how best to ensure we meet our goal.
4. Charlie and I are in agreement about the best next step to trap the Yernt.

5. Charlie and I are in agreement about how best to ensure we trap the Yernt as quick as possible.

Teamwork SMM survey items:

1. Charlie and I Work well together
2. Charlie and I Accept decisions made by each other.
3. Charlie and I Effectively communicate with each other during the task
4. I would like to participate with Charlie in future tasks
5. Charlie and I Value collaborating with each other

Trust survey items:

1. In the beginning of the task, I was not sure if Charlie’s requests were reasonable.
2. Over time, my trust in Charlie’s requests increased.
3. In the beginning of the task, I was not sure if Charlie’s actions were reasonable.
4. Over time, my trust in Charlie’s selections increased.
5. My trust in Charlie developed while accomplishing the task.

Team Performance survey items:

1. The team of Charlie and I reached our goal and trapped the Yernt.
2. The team of Charlie and I finished the task as quick as possible and did not lose time.
3. The result of the collaboration between Charlie and I was successfully to trap the Yernt.
4. The communication between Charlie and I helped to improve the performance of our teamwork.
5. I am satisfied with the performance between Charlie and me.

Appendix B: The Survey of the Second Scenario

1=Disagree strongly	2 = Disagree	3=Neither agree nor disagree	4 = Agree	5=Agree strongly

Verbal Communication survey items:

1. Charlie’s requests and replies were reasonable.
2. Charlie’s requests and replies were appropriate for the situation.
3. Charlie’s requests and replies came on time to guide our teamwork.
4. Charlie’s requests and replies were helpful to complete the task.
5. Charlie’s requests and replies reflected his understanding to the situation and the goal.

Non-verbal Communication survey items:

1. Charlie’s actions were reasonable.
2. Charlie’s actions were appropriate for the situation.
3. Charlie’s actions came on time to guide our teamwork.
4. Charlie’s actions were helpful to complete the task.
5. Charlie’s actions reflected his understanding to the situation and the goal.

Taskwork SMM survey items:

1. Charlie and I had a shared understanding about what to do to cross the sequence of obstacles.
2. Charlie and I had a shared understanding about the main goal of crossing the sequence of obstacles.
3. Charlie and I had a shared understanding about how best to ensure we meet our goal.

4. Charlie and I were in agreement about the best tool to cross each obstacle.
5. Charlie and I were in agreement about how best to ensure we crossed the sequence of obstacles as quickly as possible.

Teamwork SMM survey items:

1. Charlie and I worked well together.
2. Charlie and I accepted decisions made by each other.
3. Charlie and I effectively communicated with each other during the task.
4. I would like to participate with Charlie in future tasks.
5. Charlie and I valued collaborating with each other.

Trust survey items:

1. In the beginning of the task, I was not sure if Charlie's requests were reasonable.
2. Over time, my trust in Charlie's requests increased.
3. In the beginning of the task, I was not sure if Charlie's actions were reasonable.
4. Over time, my trust in Charlie's selections increased.
5. My trust in Charlie developed while accomplishing the task.

Commitment survey items:

1. I felt I am committed to fulfil my promises to Charlie
2. I felt my contributions are valuable to the collaborative activity.
3. Over time, my care to fulfil my promises to Charlie increased.
4. During the task, I knew what was expected from me and I am dedicated to do it.
5. The devotion to achieved Charlie's recommendation was a reason to complete the task.

Team Performance survey items:

1. The team of Charlie and I reached our goal and crossed the sequence of obstacles.
2. The team of Charlie and I finished the task as quickly as possible and did not waste time.
3. The result of the collaboration between Charlie and I was successfully to cross the sequence of obstacles.

4. The communication between Charlie and I helped to improve the performance of our teamwork.
5. I am satisfied with the performance between Charlie and I.

Appendix C: The Big Five Inventory (BFI)

1=Disagree strongly	2 = Disagree	3=Neither agree nor disagree	4 = Agree	5=Agree strongly

____1. Is talkative	____23. Tends to be lazy
____2. Tends to find fault with others	____24. Is emotionally stable, not easily upset
____3. Does a thorough job	____25. Is inventive
____4. Is depressed, blue	____26. Has an assertive personality
____5. Is original, comes up with new ideas	____27. Can be cold and aloof
____6. Is reserved	____28. Perseveres until the task is finished
____7. Is helpful and unselfish with others	____29. Can be moody
____8. Can be somewhat careless	____30. Values artistic, aesthetic experiences
____9. Is relaxed, handles stress well	____31. Is sometimes shy, inhibited
____10. Is curious about many different things	____32. Is considerate and kind to almost everyone
____11. Is full of energy	____33. Does things efficiently
____12. Starts quarrels with others	____34. Remains calm in tense situations
____13. Is a reliable worker	____35. Prefers work that is routine

_____14. Can be tense	_____36. Is outgoing, sociable
_____15. Is ingenious, a deep thinker	_____37. Is sometimes rude to others
_____16. Generates a lot of enthusiasm	_____38. Makes plans and follows through with them
_____17. Has a forgiving nature	_____39. Gets nervous easily
_____18. Tends to be disorganized	_____40. Likes to reflect, play with ideas
_____19. Worries a lot	_____41. Has few artistic interests
_____20. Has an active imagination	_____42. Likes to cooperate with others
_____21. Tends to be quiet	_____43. Is easily distracted
_____22. Is generally trusting	_____44. Is sophisticated in art, music, or literature

Scoring:

BFI scale scoring (“R” denotes reverse-scored items):

Extraversion: 1, 6R, 11, 16, 21R, 26, 31R, 36.

Agreeableness: 2R, 7, 12R, 17, 22, 27R, 32, 37R, 42.

Conscientiousness: 3, 8R, 13, 18R, 23R, 28, 33, 38, 43R.

Neuroticism: 4, 9R, 14, 19, 24R, 29, 34R, 39.

Openness: 5, 10, 15, 20, 25, 30, 35R, 40, 41R, 44.

Appendix D: Ten Item Personality Inventory (TIPI)

1=Disagree strongly	2 = Disagree	3=Neither agree nor disagree	4 = Agree	5=Agree strongly

I see myself as:

1. _____ Extraverted, enthusiastic.

2. _____ Critical, quarrelsome.

3. _____ Dependable, self-disciplined.

4. _____ Anxious, easily upset.

5. _____ Open to new experiences, complex.

6. _____ Reserved, quiet.

7. _____ Sympathetic, warm.

8. _____ Disorganized, careless.

9. _____ Calm, emotionally stable.

10. _____ Conventional, uncreative.

TIPI scale scoring ("R" denotes reverse-scored items):

Extraversion: 1, 6R.

Agreeableness: 2R, 7.

Conscientiousness; 3, 8R.

Neuroticism: 4R, 9.

Openness: 5, 10R.

Appendix E: The Pool of the Verbal Messages the Second Scenario

The order of the tools that was used in the verbal message coding

Tool Order	Tool Name	Tool Image
1	Shears	
2	Bush Hook	
3	Hammer	
4	Chisel	

5	Ladder	
6	Rope	
7	Matchsticks	
8	Matchbox	
9	Scrolldrive	
10	Nipper	

11	Shovel	
12	Mattock	

The pool of messages in each situation for each personality

Wall situation			
	Break the wall	Climb the wall	Other selected tools
Introvert-Agreeableness	I suppose so. I will grab + tools [human_selected_tool==3?4:3]+ to help	That is fine, I will grab "+ tools [human_selected_tool==5?6:5]+" to help	Maybe, but I do not think "+ tools[human_selected_tool]+ " will be of any use. Please, select another tool. What about climbing? Agree?
Introvert-Disagreeableness	I was thinking to climb the wall. What do you think of this idea?	Okay, I guess I have to grab "+ tools [human_selected_tool==5?6:5]+" then.	I was thinking of climbing the wall. You'd better select another tool.
Extrovert-Agreeableness	Hmmm, Good idea, I was thinking of climbing the wall, but… when I come to think about it, I believe breaking the wall is fine too. I will grab the "+ tools [human_selected_tool==3?4:3]+" to help you to break the wall	Wow, it is an Excellent idea, I was thinking of climbing the wall too. Hmmm, it's also much faster than breaking that wall. I will grab "+ tools[human_selected_tool==5?6:5]+" to help you in tying a ladder.	Hmmm, I'd like to work with that but I'm not sure what I can select. Are you sure "+tools[human_selected_tool] + " will be useful with this wall? How about we put our heads together and select another tool?

Extrovert-Disagreeableness	Oh, are you kidding? Do you know how long it is going to take to break that wall? I was thinking I'd climb the wall instead. That'll take less time and effort. What do you think? Do you agree with me?	Wow, you stole that idea from me. I was thinking I'd climb the wall too. Hmmm, it's also much faster than breaking that wall. I will grab "+ tools[human_selected_tool==5?6:5]+" to get that ladder tied up.	Hmmm, what am I supposed to do now? How do you think "+tools[human_selected_tool] + " will be useful with this wall? You'd better think harder and select another tool.
Neutral	It will be hard to break the wall, can you think of another way to get over this obstacle. What about climbing the wall?	Good idea, it will be less time and effort. I will grab "+ tools[human_selected_tool==5?6:5]+" to help you in tying a ladder.	Are you sure "+tools[human_selected_tool] + " will be useful with this wall? Would you please select another tool? What about climbing the wall?

Gate situation					
	Open the gate	Break the gate	Burn the gate	Climb the gate	Other selected tools
Introvert-Agreeableness	good idea, I will grab "+ tools[human_selected_tool==9?10:9]+" to help	Not a bad idea, I will grab "+ tools[human_selected_tool==3?4:3]+" to help	Seems a smoky option, Anyway, I will grab "+ tools[human_selected_tool==7?8:7]+" to help	Not a bad idea, I will grab "+ tools[human_selected_tool==5?6:5]+" to help	Maybe but, I do not think "+tools[human_selected_tool] + " will be of any use. Please, select another tool. What about opening the gate?
Introvert-Disagreeableness	Fine, I will grab "+ tools [human_selected_tool==9?10:9]+" then	I was thinking of opening the wooden gate. Don’t you agree?	I was thinking in opening the wooden gate. Don’t you agree?	I was thinking of opening the wooden gate. Don’t you agree?	I do not think "+tools[human_selected_tool] + " will be of any use. You’d better select another tool.

Extrovert-Agreeableness	Wow, great minds think alike; that's exactly what I was thinking... Opening the gate was the obvious choice for me, glad you thought so too. Hmmm, it is also much faster than breaking that gate. I will grab "+ tools[human_selected_tool==9?10:9] +" to help you in opening the gate.	Okie dokie, so you prefer to break the gate. Breaking the gate will need more effort than opening or burning it. It will definitely take more time than opening the gate, but maybe less than burning it. Fine with me anyway. I will grab the " + tools[human_selected_tool==3?4:3]+" to help you to break the gate	Ah, you want to burn the gate. Hmmm, I guess you do not prefer to spend effort in crossing this gate. To tell the truth me too. But. Burning the gate may take more time until we can cross it. Anyway,..I will grab the "+ tools[human_selected_tool==7?8:7] +" to burn the gate with you	Wow it is an Excellent idea, I was thinking of climbing the gate too. Hmmm, it is also much faster than breaking or burning that gate. I will grab "+ tools[human_selected_tool==5?6:5] +" to help you in tying a ladder	Hmmm, I really want to work with you, but that makes it really difficult for me to select any other tool to help you. Are you sure "+tools[human_selected_tool] + " will be useful with this gate. Let us think again and select another tool.

Extrovert-Disagreeableness	Wow, when I thought about it, opening the gate was the obvious solution, I didn't know if you'd come to that conclusion. Hmmm, it's also much faster than breaking that gate and I didn't want to waste my time doing that. I will grab "+ tools[human_selected_tool==9?10:9] +" to get that damn gate open..	Oh, are you kidding? Do you know how long it is going to take to break that wooden gate? I was thinking of opening the gate. Opening the gate will save lots of time and effort. Don't you think so? Don't you agree with me?	Oh, are you kidding? Do you know how long it is going to take to burn that wooden gate? I was thinking I'd open the gate. Opening the gate will save time and effort. What do you think? Don't you agree with me?	Oh, are you kidding? Do you know how long it is going to take to climb that wooden gate? I was thinking of opening the gate. Opening the gate will save time and effort. What do you think? Don't you agree with me?	Hmmm, what am I a supposed to choose now? You're really making it difficult for me to select any other tool. Are you sure "+tools[human_selected_tool] + " will be useful with this gate. You'd better think again.
Neutral	Good idea, it will save effort and time. I will grab "+ tools[human_selected_tool==9?10:9] +" to help you to open the gate	It will be hard to break the gate, would you please think of another way to get over this obstacle?	It will be hard to burn the gate, would you please think of another way to get over this obstacle?	Good idea, it will save effort and time. I will grab "+ tools[human_selected_tool==7?8:7] +" to help you to climb the gate	Are you sure "+tools[human_selected_tool] + " will be useful with this gate. Would you please select another tool?

Bush situation				
	Chop the bush	Burn the bush	Climb the bush	Other selected tools
Introvert-Agreeableness	Alright, I will grab "+ tools[human_selected_tool==1?2:1]+" to help	Alright, I will grab "+ tools[human_selected_tool==7?8:7]+" to help	Alright, I will grab "+ tools[human_selected_tool==7?8:7]+" to help	Maybe, but I do not think "+tools[human_selected_tool] + " will be of any use. Please select another tool
Introvert-Disagreeableness	That is fine, I will grab "+ tools [human_selected_tool==9?10:9]+" then	I was thinking of chopping the bush. Don't you agree?	I was thinking of chopping the bush. Don't you agree?	I do not think "+tools[human_selected_tool] + " will be of any use. You'd better select another tool. What about chopping the bush?

Extrovert-Agreeableness	Ah, you want to chop the bush. Mmm… perfect, I had the same idea. Chopping the bush may take less time to cross it. Definitely chopping the bush won't end up being all smoky like if we burnt it. And, chopping the bush will be less effort than climbing it. Okie dokie, I will grab the "+ tools[human_selected_tool==1?2:1]+" to help you to chop the bush with you	Okkie dokie, you want to burn the bush. Hmmm, I guess you prefer not to spend lots of effort in crossing this bush. To tell you the truth, I...I was thinking of chopping the bush. However... chopping the bush may take more time to cross it. Anyway… I will grab the "+ tools[human_selected_tool==7?8:7]+" to burn the bush with you	Okkie dokie, It is a good idea, I was thinking chopping the bush was the best option. However, after some thinking, I believe you are right...climbing the bush may be faster. In addition, it will save our effort more than burning or chopping the bush. I will grab "+ tools[human_selected_tool==5?6:5]+" to help you in climbing the bush.	I do not think "+tools[human_selected_tool] + " will be of any use. I was thinking of chopping, burning or climbing the bush. Let's find another alternative. There's plenty of options. What about chopping the bush?

Extrovert-Disagreeableness	Ah I guess you don't have to a rocket scientist to realise chopping the bush is the best option.. Chopping the bush may take less time to cross it. Definitely chopping the bush won't end up being all smoky like if we burnt it. And, chopping the bush will be less effort than climbing it. I will grab the "+ tools[human_selected_tool==1?2:1]+" to get that stupid bush chopped to pieces	Oh…no way, do you really want to burn the bush! That's going to produce a whole lot of smoke. How am I going to breath? Mmm, I was thinking the best option is to chop the bush that will be clean and fast. What do you think? Don't you agree with me?	Oh no way…climbing the bush! How do you think I'll be able to get up there and not fall down and break my neck? Seems like much too much effort to me... Mmm, I was thinking the best option is to chop the bush that will be clean and fast. What do you think? Don't you agree with me?	No, I don't think "+tools[human_selected_tool] + " will be of any use. I was thinking of chopping, burning or climbing the bush. Anything but your suggestion. You'd better think again and select another tool. What about chopping the bush?
Neutral	Chopping seems a good idea compared to burning or climbing it. I will grab "+ tools[human_selected_tool==1?2:1]+" to help	It will be hard to burn the bush, would you please think of another way to get over this obstacle.	Good idea, it will save effort and time with no smoke. I will grab "+ tools[human_selected_tool==7?8:7]+" to help you to climb the bush.	Are you sure "+tools[human_selected_tool] + " will be useful with this bush. Would you please select another tool? What about chopping the bush?

Hill situation			
	Dig the hill	Climb the hill	Other selected tools
Introvert-Agreeableness	Good, I will grab "+ tools[human_selected_tool==7?8:7]+" to help	Good, I will grab "+ tools[human_selected_tool==7?8:7]+" to help	Maybe, but I do not think "+tools[human_selected_tool] + " will be of any use. Please select another tool. What about digging the hill?
Introvert-Disagreeableness	That is fine, I will grab "+ tools [human_selected_tool==11?12:11]+" then	I was thinking in digging the hill. Don't you agree?	I do not think "+tools[human_selected_tool] + " will be of any use. You'd better select another tool. What about digging?
Extrovert-Agreeableness	Wow, that's an Excellent idea, I was thinking of climbing the hill too! Hmmm, it is also much faster than digging that hill. Okkie dokie, I will grab "+ tools[human_selected_tool==5?6:5]+" to help you to dig the hill.	Oh, you want to climb that hill. Hmmm, to tell you the truth, I...I was thinking that digging our way into the hill would be less effort for us, but as long as you prefer to climb this hill...mmm... Okie dokie,..I will grab the "+ tools[human_selected_tool==11?12:11]+" to dig the hill with you	I do not think "+tools[human_selected_tool] + " will be of any use. It really doesn't help us very much. Let's put our thinking caps on and come up with something else. Any other suggestions?

Extrovert-Disagreeableness	Wow, it is an Excellent idea, it makes a lot more sense to dig the hill than climbing such a bit obstacle. Unfortunately, I'm going to need you to work with me to get it done. Are you up to it? I will grab "+ tools[human_selected_tool==5?6:5]+" to get the hill dug up and out of my way.	No, Come on, climbing the hill will take a whole lot longer than digging it. Frankly, I prefer to dig a way into that hill. What do you think? Don't you agree with me?	No, I do not think "+tools[human_selected_tool] + " will be of any use. I was thinking of digging a way into that hill. You'd better think again and select another tool? What about digging?
Neutral	Good, digging the hill seems a good idea compared to climbing it. I will grab "+ tools[human_selected_tool==1?2:1]+" to help	It will be time consuming to climb the hill. I was thinking in digging the hill. Do you agree with this idea?	Are you sure "+tools[human_selected_tool] + " will be useful with this hill. Would you please select another tool? What about digging the hill?

Appendix F: Pseudocode

Pseudocode for agent architecture

While the task is not complete

Set turn to ‘human’

Set agent state to ‘waiting’

Print a prompting message to ask human to take the turn

Call function planning_agent_selection

IF human select an option

Call function update_environment_variable

Call function decide_on_human_selection

Endif

Set turn to ‘agent’

Set agent state to ‘active’

Print prompt the human to give recommendation

Agent select the calculated optimal solution

End While

Function planning_agent_selection

Pass In: environment variables

Pass In: available options

Select optimal option based on selection criteria

Pass out: optimal selection

Endfunction

Function update_environment_variable

Pass In: Selected options list

Pass In: unselection options list

Pass In: human or agent selection

Update Selected options list

Update Unelected options list

Pass out: Selected options list

Pass out: Unselected options list

Endfunction

Function Decide_on_human_selection

Pass In: human selection

Pass In: optimal selcton

IF human selection equal optimal selection

Print a supporting message from the pool of message

Else

Print a disappointment message from the pool of message

Call function planning_agent_selection

Endfunction

>>>>>>>>>>>>>>>>>> **Psudeocode the first scenario** >>>>>>>>>>>>>>>>>>>>

While the task is not complete

Set turn to ‘human’

Set agent state to ‘waiting’

Print a prompting message to ask human to take the turn

Call function planning_agent_selection

IF human select an option

Call function update_environment_variable

Call function decide_on_human_selection

Endif

Set turn to ‘agent’

Set agent state to ‘active’

Print prompt the human to give recommendation

Agent select the calculated optimal neighbouring region

End While

Function planning_agent_selection

Pass In: selected region list

Pass In: neighbouring regions list

Select the pass out of call function shortest_path_selection

Pass out: the closest neighbour region

Endfunction

Function shortest_path_selection

Pass in: neighbour region list

Set distance 1 equals the calculated distance to neighbour region 1

Set distance 2 equals the calculated distance to neighbour region 2

IF distance 1 greater than distance 2

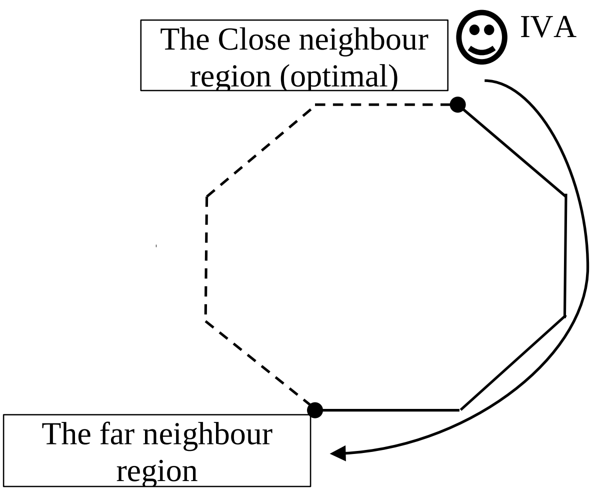
Set optimal region as distance 1

Else

Set optimal region as distance 2

Pass out: optimal region

Endfunction



Function update_environment_variable

Pass In: selected regions list

Pass In: unselected regions list

Pass In: human or agent selected region

Update selected regions list

Update unelected regions list

Pass out: Selected regions list

Pass out: Unselected regions list

Endfunction

Function Decide_on_human_selection

Pass In: human selection

Pass In: optimal neighbour region

IF human selection equals optimal neighbour region

Print a supporting message from the pool of message

Else

Print a disappointment message from the pool of message

Call function planning_agent_selection

Endfunction

>>>>>>>>>>>>>>>>>>> **For the second scenario** >>>>>>>>>>>>>>>>>>>>

While the task is not complete

Set turn to ‘human’

Set agent state to ‘waiting’

Print a prompting message to ask human to take the turn

Call function planning_agent_selection

IF human select an option

Call function update_environment_variable

Call function decide_on_human_selection

Endif

Set turn to 'agent'

Set agent state to 'active'

Print prompt the human to give recommendation

Agent select the calculated optimal tool

End While

Function planning_agent_selection

Pass In: the current obstacle

Pass In: tools in the toolbox

Pass In: selection criteria for this obstacle

Select the tool which best fit selection criteria

Pass out: the optimal tool

Endfunction

Function Decide_on_human_selection

Pass In: human selection

Pass In: optimal tool

Pass In: agent's personality

IF human selection equals optimal tool

Print a supporting message from the pool of message

Else IF human selection does not equal optimal tool

And agent's personality is agreeable

Print a disappointment message from the pool of message

Else IF human selection does not equal optimal tool

And agent's personality is agreeable

Print a disappointment message from the pool of message

Call function planning_agent_selection

Else IF human selection does not equal optimal tool

And agent’s personality is disagreeable

Print a rejection message and prompt the user to selectnanother tool

Endfunction

FIPA pseudocode for Agent communications

// Start conversation

```
(request
:sender virtual-agent
:receiver human-user
:content
(action virtual-agent
(start-conversation
(:user human-user)
(:user-conversation-id conv1)
(:modality io-mode)
)))
```

// Stop conversation

```
(request
:sender virtual-agent
:receiver human-user
:content
(action virtual-agent
(stop-conversation
(:user-conversation-id conv1)
)))
```

// Present

// first cycle agent prompt user to take a region

```
(request
:sender virtual-agent
:receiver human-user
```

:content

(action virtual-agent

(**present**

(:user human-user)

(:output-ontology ascii-text)

(:output-to-user

"***agent prompt user to take a decision***")

(:constraint

(and (:cycle 1) (:language en)))

)))

// agent ask for suggestion

(request

:sender virtual-agent

:receiver human-user

:content

(action virtual-agent

(**present**

(:user human-user)

(:output-ontology ascii-text)

(:output-to-user

"***agent prompt the user to take decision***?")

(:constraint

(and (:cycle 1) (:language en)))

)))

// supporting human request

```
(request
:sender virtual-agent
:receiver human-user
:content
(action virtual-agent
(present
(:user human-user)
(:output-ontology ascii-text)
(:output-to-user
"agent express positive feedback")
(:constraint
(and (:cycle n) (:language en)))
)))
```

// express disappointment

```
(request
:sender virtual-agent
:receiver human-user
:content
(action virtual-agent
(present
(:user human-user)
(:output-ontology ascii-text)
(:output-to-user
" agent express negative feedback")
(:constraint
```

```
(and (:cycle n) (:language en)))
)))
```

// agent gives reason

```
(request
:sender virtual-agent
:receiver human-user
:content
(action virtual-agent
(present
(:user human-user)
(:output-ontology ascii-text)
(:output-to-user
"the agent gives reason to the user")
(:constraint
(and (:cycle n) (:language en)))
)))
```

Listen

```
(request
:sender virtual-agent
:receiver human-user
:reply-with human-selection
:content
(action virtual-agent
(listen
```

(:user human-user)

(:input-ontology ascii-text)

)))

// I am thinking about "*agent preferred region*"

(inform

:sender human-user

:receiver virtual-agent

:in-reply-to human-selection

:content

(**result**

(action virtual-agent (listen …))

(:input-from-user "***get input from the user***")

))

// Do you agree to accept my recommendation

query-if-user

(request

:sender virtual-agent

:receiver human-user

:reply-with prompt-confirm

:content

(action virtual-agent

(query-if-user

(:user human-user)

(:output-ontology ascii-text)

(:output-to-user

"***agent inquire if user accept the recommended decision?***")

)))

(inform

:sender human-user

:receiver virtual-agent

:in-reply-to prompt-confirm

:content

(result (action human-user (query-if-user …))

(:input-ontology ascii-text)

(:input-from-user “**true/false**”)

))

<><><><><><><><><><><><><><> example <><><><><><><><><><><>

Start conversation

(request

:sender virtual-agent

:receiver human-user

:content

(action virtual-agent

(start-conversation

(:user human-user)

(:user-conversation-id conv1)

(:modality io-mode)

)))

Stop conversation

(request

:sender virtual-agent

:receiver human-user

:content

(action virtual-agent

(stop-conversation

(:user-conversation-id conv1)

)))

Present

// first cycle agent prompt user to select a region

(request

:sender virtual-agent

:receiver human-user

:content

(action virtual-agent

(**present**

(:user human-user)

(:output-ontology ascii-text)

(:output-to-user

"It is your turn, why do not you select a region closer to you")

(:constraint

(and (:cycle 1) (:language en)))

)))

// agent ask for suggestion

(request

:sender virtual-agent

:receiver human-user

:content

```
(action virtual-agent
(present
(:user human-user)
(:output-ontology ascii-text)
(:output-to-user
" Do you want to suggest which region I should go to?")
(:constraint
(and (:cycle 1) (:language en)))
)))
```

// supporting human request

```
(request
:sender virtual-agent
:receiver human-user
:content
(action virtual-agent
(present
(:user human-user)
(:output-ontology ascii-text)
(:output-to-user
" Wow, the requested x was what I was thinking about")
(:constraint
(and (:cycle n) (:language en)))
)))
```

// express disappointment

```
(request
:sender virtual-agent
:receiver human-user
:content
(action virtual-agent
(present
(:user human-user)
(:output-ontology ascii-text)
(:output-to-user
"The requested region x is a possible choice but far to go to.")
(:constraint
(and (:cycle n) (:language en)))
)))
```

// agent gives reason

```
(request
:sender virtual-agent
:receiver human-user
:content
(action virtual-agent
(present
(:user human-user)
(:output-ontology ascii-text)
(:output-to-user
"I prefer you to go to x because I am closer to y and so I will save the time to move to the far region x")
```

```
(:constraint
(and (:cycle n) (:language en)))
)))
```

// Listen

```
(request
:sender virtual-agent
:receiver human-user
:reply-with human-selection
:content
(action virtual-agent
(listen
(:user human-user)
(:input-ontology ascii-text )
)))

(inform
:sender human-user
:receiver virtual-agent
:in-reply-to human-selection
:content
(result
(action virtual-agent (listen …))
(:input-from-user " I am thinking about regions (1, 2,…, n)")
))
```

// query-if-user

```
(request
```

```
:sender virtual-agent
:receiver human-user
:reply-with prompt-confirm
:content
(action virtual-agent
(query-if-user
(:user human-user)
(:output-ontology ascii-text)
(:output-to-user
"Do you agree to accept my recommendation?")
)))

(inform
:sender human-user
:receiver virtual-agent
:in-reply-to prompt-confirm
:content
(result (action human-user (query-if-user …))
(:input-ontology ascii-text)
(:input-from-user “true/false”)
))
```

Appendix G: Ethics Application Approval

05/01/2016 Ethics Application 5201200768 - Final Approval

Ethics Application 5201200768 - Final Approval

Dear Prof Richards,

RE: Ethics Application Entitled: "The use of simulation tools for improving the acquisition of difficult concepts in animal behaviour studies" Reference number: 5201200768

The Faculty of Science Human Research Ethics Sub-Committee has reviewed your application and granted final approval, effective 23rd October 2012. You may now commence your research.

This research meets the requirements of the National Statement on Ethical Conduct in Human Research (2007). The National Statement is available at the following web site:

http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/e72.pdf

The following personnel are authorised to conduct this research:

Professor Deborah Richards

Dr Jennifer Clarke

Mr Nader Hanna

Ms Meredith Taylor

Mr John Porte

NB. STUDENTS: IT IS YOUR RESPONSIBILITY TO KEEP A COPY OF THIS APPROVAL EMAIL TO SUBMIT WITH YOUR THESIS.

https://outlook.office.com/owa/?ver=16.1027.13.1880268&cver=16.1027.13.1880268&cf=1&vC=0&forceBO=false#viewmodel=ReadMessageItem&ItemID…

Please note the following standard requirements of approval:

1. The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Human Research (2007).

2. Approval will be for a period of five (5) years subject to the provision of annual reports.

Progress Report 1 Due: 23rd October 2013

Progress Report 2 Due: 23rd October 2014 Progress Report 3 Due: 23rd October 2015

Progress Report 4 Due: 23rd October 2016

Final Report Due: 23rd October 2017

NB. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. If the project has been discontinued or not commenced for any reason, you are also required to submit a Final Report for the project.

Progress reports and Final Reports are available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

3. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report and submit a new application for the project. (The five year limit on renewal of approvals allows the Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).

4. All amendments to the project must be reviewed and approved by the Committee before implementation. Please complete and submit a Request for Amendment Form available at the following website:

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/forms

5. Please notify the Committee immediately in the event of any adverse effects on participants or of any unforeseen events that affect the continued ethical acceptability of the project.

6. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University. This information is available at the following websites: http://www.mq.edu.au/policy/

http://www.research.mq.edu.au/for/researchers/how_to_obtain_ethics_approval/human_research_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide the Macquarie University's Research Grants Management Assistant with a copy of this email as soon as possible. Internal and External funding agencies will not be informed that you have final approval for your project and funds will not be released until the Research Grants Management Assistant has received a copy of this email.

If you need to provide a hard copy letter of Final Approval to an external organisation as evidence that you have Final Approval, please do not hesitate to contact the Ethics Secretariat at the address below.

Please retain a copy of this email as this is your official notification of final ethics approval.

Yours sincerely,

Richie Howitt, Chair

Faculty of Science Human Research Ethics Sub-Committee

Macquarie University

NSW 2109