Human and Virtual Beings as Intelligent Collaborative Partners in Computer Games

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Abstract

For humans, collaboration is a natural and beneficial medium with which to carry tasks, negotiate and achieve goals. In computer games, human players have worked together to achieve their objectives and many computer games today foster the need of being cooperative.

Non-human entities in computer games are used predominantly as props, plot devices and adversaries. The motivation of this thesis however, is to explore and examine virtual beings engaging as equal partners with humans in collaborative computer games, resulting in richer, realistic emergent game play.

To address this, the following research questions have been identified:

1. Can human and virtual beings, being heterogeneous agents, interact cooperatively in the context of computer games and what are the desirable attributes required for them to perform this collaboration as functionally equal partners?

2. What computer game framework would be required to facilitate collaboration amongst functionally equal partners?

3. How could such a collaborative computer game be designed and implemented in order to support human and virtual players engage collaboratively?

To answer these questions, a number of concepts were developed to create a framework for collaborative human and virtual beings. This was then expanded upon by the design, development and implementation of a collaborative computer game called TeamMATE that supports human and virtual beings as functionally equal partners.
By addressing these questions the thesis demonstrates that it is possible to design engaging computer games for entertainment, education and business where virtual beings are active participants resulting in richer computer game experiences. The TeamMATE computer game was implemented using the framework established by this work. Utilising these concepts and desirable attributes, four case studies were developed to determine whether human and virtual beings could indeed interact cooperatively in the context of computer games.
Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Daniel I. Thomas

Date
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For Kara, William and Christopher
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## Acronyms and Abbreviations

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<th>Description</th>
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<tbody>
<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>BP</td>
<td>Baseline Partner</td>
</tr>
<tr>
<td>COG</td>
<td>Centre of Gravity</td>
</tr>
<tr>
<td>FEP</td>
<td>Functionally Equal Partner</td>
</tr>
<tr>
<td>FP</td>
<td>Fuzzy Partner</td>
</tr>
<tr>
<td>FPS</td>
<td>First-Person Shooter</td>
</tr>
<tr>
<td>HBI</td>
<td>Human Being Interface</td>
</tr>
<tr>
<td>LOQ</td>
<td>Levels of Quality</td>
</tr>
<tr>
<td>MAS</td>
<td>Multi-Agent Systems</td>
</tr>
<tr>
<td>MMOG</td>
<td>Massively Multiplayer Online Game</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
</tr>
<tr>
<td>VBI</td>
<td>Virtual Being Interface</td>
</tr>
<tr>
<td>WCF</td>
<td>Windows Communication Foundation</td>
</tr>
<tr>
<td>WoW</td>
<td>World of Warcraft</td>
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1 Introduction

Alan Turing once remarked that “We may hope that machines will eventually compete with men in all purely intellectual fields” (Turing, 1950). Whilst it may not be fully realized today, the integration of virtual beings into human organizations and society evoke powerful images of both positive and negative possibility. When the average person is confronted with the term “Artificial Intelligence” it is more likely to conjure images of science fiction than science fact (Khan, 1998) yet throughout the daily lives of many humans, various degrees of artificial intelligence are experienced in such mundane devices as washing machines and refrigerators. Despite the technology that surrounds many people today, humans continue to use the imagery of science fiction to strive to create more intelligent machines capable of autonomous decisions.

In this work, the possibility of virtual beings emerging as partners rather than tools used by humans in various collaborative situations are explored. Unlike past revolutions of mechanical automation, the presence of virtual beings should not imply a redundancy for human partners, but rather a complimentary relationship. Group decision-making including both humans and virtual beings as equals increases the diversity of the knowledge pool (Dunbar, 1995), improving the likelihood of positive outcomes. To explore this further, computer games provide an ideal framework within which collaboration amongst human and virtual beings can be studied and applied further.

With billions of dollars spent annually on computer game entertainment (Beinisch, Paunov, Vickery, & Wunsch-Vincent, 2005), there is nobody that can contest the fact that the computer games industry is a serious business. Most intriguing about these figures is the rise of Multiplayer Games as a significant game type. According to this OECD (Organisation for
Economic Co-operation and Development) report prepared by Beinisch et al (Beinisch, Paunov, Vickery, & Wunsch-Vincent, 2005), the attracting factor of this game type is its socially-oriented gaming experience.

Given the social aspect of these games, enhancing the social and collaborative experience would increase the attractiveness of games for entertainment. Interestingly, augmenting the social and collaborative nature of (entertainment style) games can also provide an enhanced learning experience for educational and training games based upon similar concepts.

1.1 The Challenge

Computer games offer a wealth of opportunities for research as computer game “worlds” offer varying degrees of sophistication with which to investigate a particular area of interest. Of particular note are computer games that have within them social elements of engagement between players. In these types of games, a number of players come together to solve a particular problem collaboratively. These multiplayer games engage multiple participants in a wide variety of ways from entertainment to education and training.

For humans, collaboration is a natural and beneficial medium with which to carry tasks, negotiate and achieve goals. In computer games, human players have worked together to achieve their objectives and many computer games today foster the need of being cooperative.

Non-human entities however, are used predominantly as props, plot devices and adversaries. The challenge therefore of this thesis is to determine what would be required to promote non-human entities to first-class citizens of the computer game world and collaborate with humans instead of merely being used by them. Effectively this means that in terms of the computer
game world, humans and virtual beings would collaborate together to meet the objectives of the game.

This challenge provides a basis to investigate and explore how virtual beings may engage with humans to create richer and novel computer game experiences across a wide variety of computer game application areas. This work therefore is of value to computer game developers in entertainment to create compelling social interactions, in education to facilitate group based training exercises and in business to bring together information across an enterprise in order to enhance organisational decisions and group decision-making processes.

In order to meet this challenge, a number of questions must therefore be addressed.

1.2 Research Question

Computer game development offers a compelling platform for such research and development. As each new computer game produced pushes the boundaries of technical possibility, it should come as no surprise that academia and the game industry have frequently cross-pollinated each other’s efforts.

In this context, three research questions were developed and presented here. These questions explore and examine the potential to engage human and virtual computer game players as collaborative partners, working together to achieve common goals as opposed to the current situation where non-human entities in computer games are used as props, plot devices and information delivery tools.

Addressed within this thesis are games that involve text-driven information exchange facilitating collaboration among players in order to achieve the goals of the computer game. Games that involve graphical manipulation as well as games based on coordination or physical movement, are not within the scope of this work.
To this end, a collaborative computer game called TeamMATE was designed, developed, prototyped and explored for the purpose of investigating interactions and collaborative engagements of human and virtual beings in the context of interactive multiplayer games. By investigating the nature of functionally equal partners, concepts of collaboration and facilitating architecture, it is possible to address the following questions:

1. Can human and virtual beings, being heterogeneous agents, interact cooperatively in the context of computer games, not necessarily aware of the nature of their fellow players and what are the desirable attributes required for them to perform this collaboration as functionally equal partners?

2. What computer game framework would be required to facilitate collaboration amongst functionally equal partners?

3. How could such a collaborative computer game be designed and implemented in order to accommodate functionally equal interactions among human and virtual players?

This work explores these questions and what is required in order to engage human and virtual players collaboratively in computer games.

1.3 Thesis Structure
This thesis is divided into 6 chapters that deal with a particular facet of human and virtual being collaboration in computer games and addressing the research questions identified.

1.3.1 Chapter Overview

Chapter 1 Introduction, is the current chapter and outlines this body of work, research questions and structure of this thesis.
Chapter 2  *Literature Review*, provides an overview of other work in the field of collaborative computer games. This review covers three areas of relevance to this work. Firstly, much research into collaborative computer games has a background in multi-agent systems (MAS). Second, research related specifically to collaborative computer games is discussed. Thirdly, different computer game “archetypes” are discussed in relation to current collaboration amongst human players.

In this thesis a picture has emerged of the importance of social interaction in computer games in order to collaborate and achieve game goals. It can be seen that there is the potential to create engaging computer games through the use of virtual players, which can interact, collaborate and “play the game” as a human would.

From this basis, a need has been identified to explore how human and virtual beings may collaborate. The attributes identified resulted in the definition of a *Functionally Equal Partner*.

Chapter 3  *Concepts of FEP Collaboration*, addresses the second research question, and describes the process by which humans and virtual beings acting as functionally equal partners may engage with each other in the context of computer games. The first concept introduced is the Collaborative Process, a mechanism by which FEPs may engage collaboratively. A Layered Collaborative Architecture was then designed and developed to facilitate this process and collaboration amongst FEPs.
The high level structure of a Collaborative Computer Game system is also presented. This provides detail of the systems design of a collaborative computer game, providing detail of the mechanisms which were implemented in the TeamMATE collaborative computer game.

**Chapter 4**  
*Collaborative Computer Game Implementation* describes the implementation of a collaborative computer game that is explored and addressed in three parts. Each of these sections contributes to addressing the third research question.

The first section focuses on the architectural details of virtual FEP’s cognitive abilities, detailing how this intelligent decision-making layer senses, interprets then acts upon information received.

The next section expands on the cognitive layer design concepts to demonstrate how a virtual FEP’s decision making abilities may be implemented in software, applying various generic problem-solving techniques to create an effective virtual partner.

The final section of this chapter relates to the software processes involved in TeamMATE in further detail, showing the software process flows and primary interface structures required to develop a collaborative FEPs computer game.

**Chapter 5**  
*Case Studies*, brings four collaborative computer game play scenarios implemented using TeamMATE. Each scenario demonstrates the attributes required in a collaborative computer game using FEPs, as well as showing application across a cross section of what are considered computer games;
ranging from entertainment style computer games, to business and educational style games.

Chapter 6  

Conclusion provides a recap of this body of work, describing what has been achieved and exploring potential areas of study for which this work may be expanded upon into the future. The conclusion also identifies how the work presented in this thesis addresses the first research question.

Furthermore, the contribution of this work is identified and discussed.

1.3.2 Appendices

Following the main body of work, the appendices provide further background information pertaining to supporting materials and topics.

Appendix A  Fuzzy Logic in Collaborative Decision-Making: An Overview provides a simple background to the concepts of Fuzzy Logic and how it can be used.

Appendix B  Key Computer Game Attributes Facilitating Collaborative Game Research provides background into determining the desirable attributes of a collaborative computer game and the virtual beings that would engage within it.

1.3.3 Definitions and Terms

The following section identifies key terms used throughout this thesis and provides definitions to assist the reader in understanding the context in which these terms are applied. The Acronyms and Abbreviations section immediately prior to the introduction provides additional definitions for the acronyms and abbreviations used in this thesis.
**Cognitive Layer** is part of the layered collaborative architecture and relates to the processes by which a functionally equal partner may make decisions and collaborate with other players.

**Collaborative Gap** is the difference between the outcomes of groups of human and virtual entities in a collaborative decision-making scenario, where both sets of entities have the same beliefs and objectives.

**Collaborative Process** involves the interaction of FEPs to achieve defined outcomes. The process involves questions, responses, actions and negotiation.

**Communication Layer** is part of the layered collaborative architecture and encompasses the technical protocols used to pass messages amongst players and the computer game world.

**Functionally Equal Partner (FEP)** is an intelligent entity that performs tasks cooperatively with other FEPs (human or virtual). These beings are not necessarily aware of the nature of their fellow partners.

**Group Collective Knowledge** is information that is presented to a group of FEPs collaboration.

**Influence** amongst FEPs is the ability of a FEP during collaborative negotiation, to align another FEPs response with their own.

**Intelligent Tools** are intelligent virtual entities that are utilised by humans but do not impact any collaborative decision-making process via social influences.

**Layered Collaborative Architecture** is a concept related to the design and implementation of collaborative computer games.

**Physical Layer** is part of the layered collaborative architecture and defines the entities and objects within the computer game world. It also provides sensors and effectors for players.
Social Acceptance of Virtual FEPs is the ability of human FEPs to accept these Virtual FEPs into the collaborative process and influence, and be influenced by these entities.
2 Literature Review

The concept of human and artificial beings engaging in collaborative activities is nothing new, with this notion appearing in both fictional and non-fictional sources. Early science fiction has proved a rich source of speculation, with terms such as mechanical brain and machine intelligence appearing in this literature (Pringle, 1997). The term “Artificial Intelligence” (AI), coined in 1955 (McCarthy, Minsky, Rochester, & Shannon, 2006) is the accepted term to describe decision-making processes undertaken by artefacts.

The field of artificial intelligence itself is very broad with the definition of AI having different meanings to different people across a range of topic areas such as psychology, philosophy, linguistics and engineering (Cawsley, 1998). Russel and Norvig describe this spectrum of definitions occupying two dimensions (Figure 1): Thought versus behaviour; and human-like versus rational (optimal/ideal). They go on to focus on the concept of an Intelligent Agent: A rational agent (the Latin root agere, literally “to do”) that “can be viewed as perceiving its environment through sensors and acting upon that environment through actuators” (Russell & Norvig, 2009).
This definition in turn has led to the term autonomous agent, which is further explored in Section 2.1.

In this thesis, the promotion of an autonomous agent (that builds upon the foundations of AI research) to that of a collaborative and functionally equivalent virtual being in the context of computer games is essential to understanding how to engage these virtual beings collaboratively with humans. When referring to computer games in terms of human and virtual player collaboration, it is in regard to “mental” style collaborative computer games. That is, collaborative computer games that require cognitive problem solving (as opposed to hand/eye coordination, reaction time or chance) in order to achieve the goals of the game. It should be assumed throughout this thesis that references to computer games relate to this aspect; that is, collaborative problem-solving using simple text-based information exchange. Other computer games that rely heavily on graphics, multimedia and physical interactions (for
example, games relying on movement popularised by such game consoles as the Nintendo Wii®, Playstation Move® and Xbox Kinect®) are not within the scope of this thesis.

This chapter focuses on, and explores the literature pertaining to collaborative computer games. The first section provides a background context in showing how much of the work in collaborative computer games was borne out of Multi-Agent Systems (MAS) research. The second section provides an exploration of collaborative computer game literature over the last decade. The third section provides a brief overview as to the types of computer games that have been used in computer game research.

The fourth section builds upon this knowledge in order to define a concept that involves humans and virtual beings engaging collaboratively in a computer game setting. It is from this concept that the requirements, design and implementation of a collaborative computer game facilitating such collaboration can be realised.

Finally, this chapter concludes with a summarised discussion of the areas covered in the review and the need to investigate and explore aspects of human and virtual being collaboration as functionally equal partners.

2.1 Background

Computer games have been found to be an effective means of pursuing academic research questions, with calls for working towards cohesive interaction between industry and academia (Johnson & Wiles, 2001).

It is important to provide a context within which collaborative computer game research has developed. The literature discussed here is not exhaustive, but rather provides the necessary background to specifically focus in on how collaborative computer game interest has developed over time and how this identifies a need to engage in further research. For much of
this work, the frameworks within which studies have occurred stem from fields of Artificial Intelligence (AI) research primarily; Autonomous Agents and Multi-Agent Systems (MAS).

Definitions of autonomous agents are many and varied. In particular, the definitions attempt to describe agents in terms of the attributes that they exhibit. For example, the definition of an autonomous software agent presented by Bradshaw (Bradshaw, 1997) builds upon the properties of agents by enumerating the attributes of agents as espoused by Etzoni and Weld (Etzioni & Weld, 1995) and Franklin and Graesser (Franklin & Graesser, 1997). This description of the properties allows for many and varied classifications of systems under the “umbrella term” of agent, as Nwana (Nwana, 1996) calls it. Franklin and Graesser describe a “taxonomy” of agents, providing their definition of an agent:

An autonomous agent is a system situated within and part of an environment that senses that environment and acts on it, in pursuit of its own agenda and so as to effect what it senses in the future. (Franklin & Gaesser, 1996)

This definition highlights key attributes of autonomous agents; the concepts of autonomy, reactivity, perception, goal-directed behaviour and the concept that the agent has some understanding of time. The most common frame for autonomous agents is the definition presented by Jennings and Wooldridge (Jennings & Wooldridge, 1995). They describe agents in terms of weak notions of agency (the attributes exhibited by autonomous agents) and strong notions of agency that draw upon the Belief-Desire-Intention (BDI) model of agent behaviour (Bratman, 1987).

2.2 Collaborative Computer Games

Computer games in research have seen many developments over the last decade. Earlier work in the field of virtual players (commonly referred to as “Bots”) tended towards the adversarial variety such as Laird’s Quakebot (Laird, 2001). In the same year, Adobbati et al. presented the
Gamebots virtual world test bed based upon the Unreal Tournament 3D game engine (Adobbati, Marshall, Scholer, & Tejada, 2001). Gamebots was developed using principles of Multi-Agent Systems design, specifically developed as a research platform. To achieve this, they applied the principles of agent architecture development presented by Hanks et al. (Hanks, Pollack, & Cohen, 1993)

While the Quakebot could produce a team member in an adversarial first person shooter, it was by no means a collaborative participant. The Gamebots computer game being a research platform was a good example of providing a simulation environment that could be used for collaborative engagement.

Interactive fiction and storytelling is a special type of computer game where players engage in a story-driven experience where their decisions affect the outcome of the story as a whole (Magerko, Laird, Assanie, & Stokes, 2004), (Riedl, Saretto, & Young, 2003). This was another area in which players could work together to achieve outcomes. These computer games were directed by a virtual director which controlled the story and interactions of the human players with NPCs situated within the game world. Using software agents to regulate the progression of a collaborative computer game has also been applied to difficulty levels within the game so as not to frustrate or bore the human player (Tsai, Lee, Chang, Ho, & Hsu, 2008)

Social interaction and collaboration in human teams has been identified as a strong motivating factor for engagement in computer games (Manninen, 2002) (Nardi & Harris, 2006). Creating believable Non-Player Characters has been a highly motivating objective of much research into human and virtual player interaction (Prada & Paiva, 2005). The social believability of a “synthetic character” (as Prada and Paiva refer to them) is a key factor in collaboration since the higher the social standing of the player, the more likely they are to obtain agreeable outcomes.
Collaborative computer games used in educational scenarios provided some very interesting approaches to facilitating collaborative education (Conati & Klawe, 2002). In particular, the proposed use of a virtual collaboration manager to facilitate group learning. The manager was also responsible for finding student partners that could include virtual agents designed to fill specific roles within a collaborative activity.

What can be seen from the research presented above is that collaborative computer games involving human and virtual players sit between two larger fields: The development of human-like believable virtual players, and purely human collaboration in computer games.

2.3 Computer Game Archetypes
There are many different types and genres of computer games. This section provides a broad classification of the kinds of computer games that can be utilised across entertainment, education and business. The word archetype is used to describe the computer game classifications below as typical of the types of computer games utilised in entertainment, education and training.

2.3.1 Social and Casual Gaming
Social and Casual gaming is a classification of games that consist typically of smaller simple games such as those played within web browsers and on portable devices such as mobile phones. This has been identified as a major growth area (Beinisch, Paunov, Vickery, & Wunsch-Vincent, 2005) and with companies such as PopCap boasting one billion downloads of their simple games since 2000 and a deployment of a single game to 50 million mobile phones it is obvious that small games are big business (PopCap Games, Inc., 2008). These numbers may seem staggering; however these numbers are easily eclipsed by casual games such as Farmville which has, as at June 2010 over 60 million users as reported by AppData (Inside Network, 2010). The company responsible for Farmville, Zynga (Zynga, 2010) boasts over 200 million
users of its social networking games. To put this in perspective, the current world population is approximately 6.6 billion humans. This equates to approximately 3% of the entire world’s population having exposure to Zynga’s games at one time or another.

2.3.2 The “god” game
The “god” game, where the player takes on the position of a commander, mayor, ruler or deity controlling the resources at their disposal to accomplish their objectives. Given the nature of this style of game, the player is not in direct control of a single unit/entity within the game, but instead “orders” the entities to perform tasks. Novel use of intelligent entities is not new to this genre with such games as Black & White (Lionhead Studios, 2001) introducing the concept of a “pet” that learned behaviours based upon what the player rewarded or punished.

2.3.3 The First Person Shooter (FPS)
The First Person Shooter (FPS) epitomises a particular style of gameplay where the player’s computer screen represents the field of vision of the player situated in the game. That is, seeing the action through the eyes of the player’s avatar/representation within the game environment. The most famous examples of this kind of computer game include Id Software’s Doom and Quake (id Software, 2010), Valve’s Counterstrike (Valve Software, 2010) and Bungie Studio’s Halo (Bungie Studios, 2010).

2.3.4 Massively Multiplayer Online Games
Currently, Blizzard Entertainment (Blizzard Entertainment, 2010) holds the crown of the largest massively multiplayer online game (MMOG, however is more commonly shortened to MMO): World of Warcraft (WoW). With over ten million players, it is one of the most successful games of all time. Yee’s (Yee, 2004) observation that “MMORPGs are a very unique environment, in that you would almost never, in real life, find high-school students, housewives, retirees and early adult professionals together in any sort of collaborative decision-making task.” sums up
the appeal of the genre. For many MMO players, the social experience is the compelling factor (Choi, Kim, & Kim, 1999).

Today’s massively multiplayer games provide very rudimentary AI and scripted/stilted non-player characters (NPCs). There has been acknowledgement that this field of computer games has been underdeveloped, with techniques for traditional game AI being variations on common patterns, with little new approaches utilized (Nareyek, 2007).

There has however been developments with these types of games in terms of content generation within the computer game (Trion World Network, 2009) and virtual actors (Magerko, Laird, Assanie, & Stokes, 2004).

Massively Multiplayer games that involve hundreds and thousands of participants are of a far larger scale than can be reasonably accommodated by a collaborative group decision-making process. Computer games involving human and virtual beings collaboratively solving problems operate at a far smaller scale than the large social interactions of MMOs. Therefore, this form of computer game is beyond the scope of this work.

### 2.4 Functionally equal partners (FEPs)

From the literature presented, the field of Multi-Agent Systems provides an ideal foundation from which to create a virtual computer game player. In addition, this definition also holds true for human game players, in that they too are autonomous, have social ability, can react and be proactive.

When observing developments in collaborative computer games, there has been much work done on adversarial AI players and progress in the field of interactive fiction. When this is also coupled with research related to the social nature of computer games and the rise of Social Networking games and Massively Multiplayer games, there is a compelling argument for
developing a concept of intelligent virtual players that are able to interact and participate
collaboratively with human players in order to enhance the game experience, injecting realism
into interactions with non-human entities in the computer game world.

To engage human and virtual beings as equals in a computer game setting requires interaction
beyond treating the virtual partners as sophisticated tools, but rather requires a degree of
social acceptance and cohesion. In such a heterogeneous group of partners, virtual beings
must be able to articulate their perspectives and opinions, while taking on board the
knowledge and opinions of others. For social acceptance and societal influence to occur the
virtual being needs to become acceptable within the social system: Society, organization or
group (Kelman, 2006).

In making the transition to societal acceptance of virtual beings, there are great challenges
both technical and social. To better study virtual beings as collaborative partners, it is possible
to focus on a smaller, group social setting, with an assumption of social acceptance (and
therefore the capability to influence) collaborative group decision-making. For this reason,
computer games provide an excellent environment for understanding how humans and virtual
beings can positively influence outcomes in a collaborative group situation.

The nature of an independent virtual being participating alongside humans collaboratively in
computer games is strongly influenced by the notion of intelligent autonomous agents in
computer games. The concept of an intelligent autonomous agent as described by Jennings
and Wooldridge (Jennings & Wooldridge, 1995) is appropriate for application to the
characteristics of human and virtual beings that engage collaboratively as equal participants in
computer games. An intelligent autonomous agent, being situated within a collaborative
computer game enjoys the following abilities:
1. Is Autonomous; operating without the direct intervention of humans or other entities, having control over their internal state.

2. Situated in, and aware of its environment (the game) and is able to interact with this environment through their sensors and effectors.

3. Has some kind of Social Ability; interacting with other human and virtual beings via the use of a communication language.

4. Is able to perceive changes within the (game) environment and react to these changes in a timely fashion.

5. Agents are also Proactive; being able to exhibit goal-directed behaviour (taking the initiative) and directly affecting the game and other entities in order to achieve these goals.

There have been many instances in the past where virtual players have controlled an in-game character as a human would (Laird, 2001). In these instances, the virtual player has typically participated as an opponent. In addition, there are many games where simple virtual players have worked as part of a human player’s “team” where they interact with these entities through simple commands.

Building upon these principles, one can consider that if virtual players were able to participate and collaborate within a computer game setting, while having their own internal goals (that is, the ability to play a game as a human would), that these games would have an increased perception of realism and “life” as the interactions between human and virtual beings is not static, scripted or based upon the scenario at hand, but rather changes as these beings interact
and collaborate with each other over time to affect change upon the game world that they are situated within.

To this end, human and virtual beings can be considered *functionally equal partners* (FEPS) that collaborate to achieve a set of shared goals or outcomes (Figure 2). This thesis considers this concept as complementary to other uses of autonomous agents as opponents (Laird, 2001) or as interactive story characters (Magerko, Laird, Assanie, & Stokes, 2004). Unlike the FEPS, non-player virtual characters are typically able to interact with (or provide simple assistance to) the human players, but do not participate as intelligent collaborative entities, equal in functional ability to a human being in a computer game.

Within a collaborative computer game setting, the idea that humans and virtual beings work as equals implies a functional equivalence within the computer game. This does not imply equality at a cognitive level, but rather that these heterogeneous partners may participate equally within the scope of the computer game.

Therefore, humans and virtual beings interacting collaboratively in computer games as functionally equal partners enjoy the following attributes:

1. Do not treat human and virtual players differently during interaction.

2. Can work cooperatively with other functionally equal partners (human or otherwise);

3. “Play” the game as a human would;

4. Do not work to a defined script or take centralized behavioural direction from an agent “director” such as those described by Magerko et al. (Magerko, Laird, Assanie, & Stokes, 2004) and Riedl et al. (Riedl, Saretto, & Young, 2003) and;
5. Are not necessarily aware of the nature of other FEP beings (human or virtual in nature).

Simply, a *Functionally equal partner (or FEP)* is an intelligent entity that performs tasks cooperatively with other FEPs (human or virtual). These beings are not necessarily aware of the nature of their fellow partners.

![Figure 2 Humans and Virtual beings as collaborative functionally equal partners](image)

**2.5 Conclusion**

This chapter has involved an exploration of the literature relating to collaborative computer games which is done in three parts. Firstly, the roots of collaborative computer games that involve virtual players can be traced back to research in the Multi-Agent Systems (MAS) field.
Once this background was explored, research into collaborative computer games themselves was investigated. This investigation led to the identification of a need to undertake exploration of human and virtual beings as equal participants in collaborative computer games.

In addition, the collaborative and social aspects of various computer game archetypes were investigated to understand the opportunities provided and whether there was potential to have virtual beings as equal collaborative players.

Through this investigation, a hypothesis was developed where human and virtual players could collaborate as equals in computer games. In developing this concept further, a new term was presented based on the concepts of autonomous agents. In computer games where human and virtual players are:

1. Provided the same abilities when interacting,

2. Able to perform any role available to players and

3. Able to collaborate together to achieve the goals of the game without any special knowledge of the nature (human or virtual) of their fellow players,

are said to be Functionally Equal Partners or FEPs. It is this definition that is then used in subsequent chapters to design, develop, prototype and explore collaborative computer games involving FEPs.
3 Concepts of FEP Collaboration

Humans and Virtual beings are vastly different entities in terms of their cognitive abilities and complex interactions. This poses a number of challenges when moving from artificial computer game characters as adversaries, tools, props and plot devices to engaged societal equals to humans. A framework is required to facilitate equal engagement in a collaborative computer game. This chapter addresses the second research question: What computer game framework would be required to facilitate collaboration amongst functionally equal partners?

The answer to this question is addressed in four primary concepts that form a framework within which collaborative FEP engagements can take place. The first concept addressed is the collaborative engagement itself that describes in a formal manner the elements required for such an engagement to take place.

Once this has been described, the second concept introduces a framework within which the engagement takes place. This framework is known as the Collaborative Process. The process itself treats all players as engaged equals (but not necessarily equals in cognitive capacity). This allows the execution of computer game play scenarios with varying proportions of human and virtual players, as well as allow for substitutability.

The third concept builds upon the details of the Collaborative Engagement and the Collaborative process to present a Layered Collaborative Architecture to facilitate the previous two concepts. Once this architecture has been defined, it is possible to describe how the layers interact and the interfaces required to facilitate collaborative engagement and the collaborative process from the point of view of the three key computer game subsystems. This forms the fourth concept of FEP Collaboration.
This chapter concludes with a summary of how this research question has been addressed.

3.1 Collaborative Engagement

Consider a group of functionally equal partners $P$ engaged in the collaborative process $c$. There will be a set of outcomes $O$ met at the conclusion of the process. The set is based upon the set of defined goals $G$ defined at the beginning of the process and the ability of the partners to collaborate towards the desired outcomes. However there is not a 1:1 ratio of outcomes to goals, and the set of objectives may even be empty.

$$O = c(P, G)$$

Equation 1

Each partner $p_k$ is either Human $h_i$ or Virtual $a_j$. The collaborative group is the union of the Human and Virtual functionally equal partners.

$$P = \{p_1, \ldots, p_k\}$$
$$p_k = \{h_i | a_j\}$$
$$A = \{a_1, \ldots, a_j\}$$
$$H = \{h_1, \ldots, h_i\}$$
$$P = A \cup H$$

Equation 2

During the collaborative process, any partner $p_l$, where $l \neq k$, may ask a question $q_m$ of any other partner $p_k$ in order to receive a response $r_m$, where $m = j+i$

$$r_m = f(p_k, q_m) \text{ where } q_m = g(p_l)$$

$$r_m = f(p_k, g(p_l))$$

Equation 3
The response may contain facts or partial knowledge that can be collected and added to the collective knowledge obtained by the group. The collaborative process of the group in order to obtain a set of outcomes is then consensus based upon the interpretation of the group collective knowledge in order to identify whether the partners have achieved (or partially achieved) the initial goals of the group.

The set of Group Collective Knowledge \( K \) obtained by the group through the collaborative process is a subset of the responses obtained during the collaborative process.

\[
K \subseteq R \\
K \subseteq \{r_1, \ldots, r_m\} \\
\{k_1, \ldots, k_q\} \subseteq \{r_1, \ldots, r_m\}
\]

Equation 4

For simplicity, assume that all responses \( r_m \) are components of group collective knowledge \( K = R \). This means that all results contribute to the set of collective knowledge and that all partners are aware of this knowledge.

\[
K = R \\
\{k_1, \ldots, k_q\} = \{r_1, \ldots, r_m\} \\
\text{i.e. } q = m
\]

Equation 5

Outcomes of the collaborative group are a result of the collaborative process between the group of functionally equal partners and the goals of the collaborative process.
\[ O = c(P, G) \]
\[ O = c(P, G) \]
\[ O = \{o_1, \ldots, o_n\} \]
\[ o_n = s(P, n(G, K^P)) \]

Equation 6

Where \( s \) is a function of all partners \( P \) applied to an interpretation function \( n \) of the set of goals \( G \), the set of group collective knowledge across the entire set of partners \( K^P \), resulting in an outcome \( o_n \).

### 3.1.1 Goals

Understanding the various types of goals that can exist within a collaborative computer game is imperative to understanding the outcomes of the game. Typically, the goals that can be found in such a game are: individual goals, goals of the collective (group) scenario and goals of the play scenario.

### 3.1.2 Roles

Roles are the ingredients of a linking mechanism between the cognitive layer and the physical layer. Within the collaborative FEP architecture, roles define specific functions or duties to be performed by FEPs fulfilling the role. A FEP’s role can also affect the sensors and effectors available to the being participating in the game.

While this collaborative computer game concept has been designed to operate without the assistance of an overall agent “director”, as is the case with work in the field of interactive fiction games (Magerko, Laird, Assanie, & Stokes, 2004), an authority role has been developed: The Leader.

The Leader typically is responsible for the organization, initiation and conclusion of a play scenario or defined objective within a collaborative computer game. A Leader may have to
organize a team for a single task or may have to organize groups of FEPs over the entire playtime of the game.

Depending on how the collaborative computer game has been designed, multiple roles can be defined. In keeping with the FEP concept, a human or virtual being is permitted to perform any role defined.

3.2 The Collaborative Process

The Collaborative Process is used to facilitate a framework of interaction between computer game players acting collaboratively. The process is independent of implementation and underlying communication methods utilized between players (for example, non-verbal, audio or symbolic communication instead of text-based English phrases). Maintaining this level of abstraction allows the process to be applied to a variety of collaborative applications. The following figure (Figure 3) defines the collaborative process employed within the cognitive processing of participating FEPs:
Each element of the collaborative process encapsulates particular stages within the collaborative engagement.

### 3.2.1 Invitation

In a collaborative computer game, participation is by invitation to engage in a collaborative task. Invitations themselves may be controlled by a player or set of pre-requisite criteria, or by self-invitation. This process can also include the scheduling of a pre-defined “play time” as well as the roles of the invited FEPs.
3.2.2 Attendance
Once a collaborative computer game has been initiated, participating FEPs are able to “join” the game. Attendance can also occur internally, as human and virtual beings already participating within the game may attend and participate in many play scenarios.

3.2.3 Initiation
At a point determined by the leader (typically when all participants are present, or the scheduled meeting time has been reached) they will declare the play scenario “started”. It is at this point that the play scenario can commence. Initiation of the play scenario is actually a special action (actions are described in more detail later).

3.2.4 Definition of Goals
Before any meaningful collaboration can be achieved between the participating FEPs, it is necessary to define the goals of the current play scenario. This defines the framework for the conversations that will occur during the process. These goals can also be used to determine the success or failure of a particular play scenario (or whether additional game play is required).

3.2.5 Presentation
All communication and collaborative behaviour within the computer game takes place in the form of “Conversations”. Conversations involve the presentation of some instructions, positions, statements, or questions that require additional facts and opinions from the FEPs involved in the collaborative process. The presentation step may involve physical actions or statements by the partners.

3.2.6 Conversation
Collaborative behaviour within the computer game takes place as the result of “Conversations” that engage two or more players. This involves the interpretation of the Truth/Facts revealed during the conversation process. Conversations between FEPs engaged in
a collaborative process involve the transfer of information using different types of conversation elements. As the conversations occur, partners are able to collect truths as well as opinions/positions stated by the other partners. The resulting collection of information is recorded as collaborative group knowledge, which may be used to analyse, evaluate and act towards achieving the desired goals of the computer game.

3.2.6.1 Questions
Questions are used to obtain truths, facts and perceptions. Questions in a collaborative computer game are any communications made by FEPs that result in an outcome (for simplicity, statements or instructions are also considered “questions”). When an agent proposes a question, there are three possible outcomes: A response (which may be itself another question), an Action or No Response.

3.2.6.2 Response
A response is given when a FEP receives a directed question, or perceives (through their sensors) the necessity to respond to a question or action. As a response may happen through non-directed communication, but through the perception of other events within the collaborative computer game, a response may itself initiate a new conversation/negotiation. A special type of response that requires the use of effectors not directly related to inter being communication is called an Action.

3.2.6.3 Actions
Actions are special responses to questions that result in a transition of some item or process from one state to another. For example, if a FEP asked the question “I require a technician for Project X”, a possible resulting outcome may be that another participant in the play scenario may perform an action that results in the commencement of a recruitment process to hire a skilled technician for Project X.
Actions tie the collaborative process to the defined physical layer as only those actions available within the physical layer may be enacted to change a defined entity’s state. Thus, the introduction of cognitive layer elements results in the ability to enact complex/abstract actions based on perceived physical layer effectors rather than a defined set of actions available for a defined role being enacted by a FEP.

3.2.6.4 No Response
In some instances, a question may not require a response.

3.2.7 Negotiation
Negotiation involves the willingness of one or more parties involved in the conversation to accept a compromise position. Previously collected facts or collaborative group knowledge, are then used by players in the negotiation process in order to influence or determine outcomes aligned to the earlier stated goals of the collaborative process.

The negotiation process involves the process of conversation that the partners engage in and allows the FEPs to discover a best fit outcome based upon the goals stated during the definition of goals phase.

Collaborative FEPs may create an affinity with one or more entities and are more likely to accept their position during negotiation. Possible methods for obtaining an affinity with one or more FEPs include:

In human to human interactions, many forces can be seen at play that influence one person to agree or take the side of another in a discussion. These influences need to be taken into account when collaborative work is undertaken. Even the size of a group (Fay et al, 2000) can change the way in which partners are influenced, and by whom.
Collaborative FEPs may create an affinity with one or more entities and are more likely to accept their position during negotiation. Possible methods for obtaining an affinity with one or more FEPs include:

1. The degree to which one FEP’s responses convey a perception/opinion that matches that of another FEP. The more that a partner’s position matches that of another partner, it becomes more likely that the partner will “trust” the statements of that partner.

2. Some arbitrary/authoritative influence factor that has the partner tending towards the position of one or more other partners. An example in a business sense might be seniority and/or position within an organization.

3. Trade: changing a given position in order to influence another partner’s position on another item in the collaborative process.

4. A pre-existing relationship (for example a friendship) that exists beyond the scope of the collaborative process

The scope of the play scenario discussed shall focus on two forms of influence, that of arbitrary/authoritative influence and common interest.

During the collaborative process, any partner $p_l$, where $l \neq k$, may ask a question $q_m$ of any other partner $p_k$ in order to receive a response $r_m$, where $m = j+i$

$$r_m = f(p_k, q_m)$$

Equation 7
The set of Group Collective Knowledge $K$ obtained by the group through the collaborative process is a subset of the responses obtained during the collaborative process.

$$K \subseteq R$$
$$K \subseteq \{r_1, \ldots, r_m\}$$
$$\{k_1, \ldots, k_q\} \subseteq \{r_1, \ldots, r_m\}$$

Equation 8

To influence group collective knowledge, resulting responses $r_m$ that contribute to $K$ must be changed in some way. Assuming that all responses contribute to collective knowledge:

$$K = R$$
$$\{k_1, \ldots, k_q\} = \{r_1, \ldots, r_m\}$$

i.e. $q = m$

Equation 9

During the negotiation phase, an influence function changes the response for a given partner’s initial decision based on the degree of influence the other partners have with the first partner. The influence function that is used here is simply the sum of the proportion difference between one partner’s response (obtained during the conversation process) and that of another partner:

$$i(q_{pk}) = \sum_{1 \neq m \neq k} p_{nf}^*(r_{mn} - r_{pk})$$

Equation 10
Where $i(r_{pk})$ is the influenced response which is the sum of all influence factors $p_{nf}$ multiplied by the response difference partner $p_n$ and the partner under influence $p_k$. FEPs using this influence function cannot influence themselves.

3.2.8 Assessment
At the conclusion of the negotiation phase, the Leader provides a summary of the collaborative engagement. Based on the information obtained, each goal may be evaluated in terms of the resulting outcomes. The assessments are relayed to the participating partners.

3.2.9 Conclusion
At either a specified time, or when the objectives of the play scenario have been completed successfully, the leader is able to enact a special action that concludes the play scenario.

Prior to the conclusion, the leader or another nominated partner is given the opportunity to summarize or present the outcomes of the scenario to the other participating human and virtual beings. Outcomes can include gauging the success/failure of the play scenario based on the goals defined at the beginning by the leader; can also result in actions required beyond the scope of the current play scenario and could also be the determination that additional play scenarios are required.

3.3 Introducing a Layered Collaborative Architecture
Within collaborative computer games, a collaborative computer game architecture consisting of three distinct layers (Figure 4) is introduced. This layered approach provides a framework within which the necessary attributes required starting from atomic technical concepts through to abstract concepts of the cognitive layer are formalized. Since each layer that creates an additional abstraction is built upon the previous layer, it is important to provide a firm understanding of each layer’s function within a collaborative computer game.
This approach to a layered collaborative computer game architecture for FEPs is referred to as the TeamMATE Architecture. Each layer of the TeamMATE Architecture is described in the following sections, demonstrating how this layered approach to collaborative FEPs permits a socially driven environment to exist comprising of human and virtual partners in a heterogeneous relationship.

![Diagram of the TeamMATE Architecture](image)

**Figure 4** The three architectural layers of a collaborative FEP system

### 3.3.1 Communication Layer

The communication layer is a very fundamental element of a collaborative computer game. This layer defines the technical protocols used to convey information from the game or other entities from or to the FEP beings situated within the computer game.
The communication layer is effectively a low level transport layer used to pass information from one place to another for example: DirectPlay, TCP/IP, radio signal etc. These protocols, along with the format of the data being transmitted are then available to a FEP’s sensors. A FEP may also transmit using these communication protocols via their defined effectors.

### 3.3.2 Physical Layer

The physical layer within a collaborative computer game defines a FEP’s available sensors and effectors within the context of the game. The term “physical” is used to refer to this layer as it defines the characteristics of sensors, effectors and entities within the computer game. Before it is possible to work with the abstract cognitive layers of TeamMATE, it is necessary to define a layer that:

1. Is able to define the physical objects of the collaborative computer game;

2. Provides a common pattern of sensor and effector abilities available to human and virtual beings situated within the game and;

3. Defines the possible actions that may be performed using the available sensors and effectors;

Human and virtual partners must be able to work with the appropriate rules/constraints of the specific play scenario being undertaken. Physical rules for a given play scenario consist of information about objects in the computer game and how they may be used. Using or enacting some change upon an entity using the defined effectors is referred to as performing an Action.

Take as an example, a simple play scenario that contains these physical layer rules (Table 1):
When working with more complex games, and also collaborative games that may occur within
the physical world, defining all objects and all actions is not feasible. However, it is possible to
define the available sensors and effectors for a FEP, while the task of relating objects and
actions becomes a function of the cognitive layer.

While a collaborative computer game and the human and virtual beings that are situated
within a given play scenario may share a common physical layer, it is not necessarily required
that the manifestation of the physical layer will be the same.

For example, in order for a human being to interact with the sensors and effectors provided by
the physical layer, it would be necessary to provide a mechanism to interact with the sensors
and effectors through a human user interface. Likewise, if a virtual FEP was to interact with
other beings within a collaborative computer game, the physical layer would possibly be
accessed as some form of software interface.

### 3.3.3 Cognitive Layer

The Cognitive Layer describes the intelligent mechanisms within a human or virtual being that
are capable of manipulating, communicating and collaborating intelligently using the defined
sensors and effectors provided by the physical layer. The cognitive layer also defines the roles,
goals and processes by which FEPs can collaborate within a computer game and provides methods for expressing this information in a meaningful manner in order for decision-making to occur.

Human players engaged in computer games are assumed to have an innate cognitive ability, and that a human player engaged in a computer game does so through an interface that presents sensor and effector information in a meaningful way. This interface for human players is what they would simply perceive as the computer game’s user interface.

Unlike a human player, a virtual being’s cognitive layer is designed to include decision-making processes as opposed to an innate ability to make intelligent decisions within a collaborative context (Figure 5). The following section describes how a virtual being’s cognitive layer may be constructed.
3.3.4 Additional Considerations

There are also many architectural design features (both implicit and explicit) that support FEPs in collaborative computer games. Some of these desirable features that support a computer game as a collaborative FEP element were identified (Appendix B). The result of this work was determining key software design attributes necessary to facilitate effective collaboration within computer games. These attributes are an effective guide when designing collaborative computer games from a practical perspective. These characteristics, while desirable, are not necessarily mandatory when developing a collaborative computer game and reflect the nature and complexity of the game being produced.
Exogenous events: (Hanks, Pollack, & Cohen, 1993) in order to emulate the adaptive, collaborative and cognitive abilities of real world (embodied) beings within a collaborative computer game, an element of unexpected change to the state of play (or, as is the case with experimentation, manufacture these unplanned events if required) must be introduced into play scenarios.

Causal Structure: a complex causal structure is necessary to imitate the complex cause and effect actions and reactions of real-world scenarios. This approach provides a causality structure necessary to exhibit complex collaborative (and cognitive) abilities in the FEPs situated within the game. Causality is realized through rules defined by the physical layer, as well as more complex rules determined by the cognitive layer.

A Concept of Time: The collaborative computer game and the FEPs situated within it must be able to operate within a linear time environment. For the purposes of the game, a play scenario defined by the physical layer may have a very simple time structure (based on a sequence of events and/or triggers) or a more complex real-time system where effective collaboration may require the ability to respond within a finite time span.

Support for Experimentation: having the ability to control the conditions within the game, thus allowing for repeatable, quantifiable play scenarios (Vincent, Horling, & Lesser, 2000);

A well-defined interface between the collaborative computer game and beings that are situated within it is necessary to support true autonomy of the FEPs within the game and encourages collaborative behaviour.

In addition to these desirable features that support a collaborative computer game were also a number of practical considerations identified when selecting or constructing a collaborative
computer game. While not directly related to supporting a layered architecture approach, practical features will affect the embodiment of a collaborative computer game:

**The Availability and Cost** of infrastructure and development tools required;

**The Learning Curve** required in order to be completely familiar with the underlying infrastructure used to construct human and virtual software interfaces;

**Environmental Complexity** was also identified as an important factor in creating an effective collaborative computer game. This becomes more of an issue for the scalability of complex elements (especially the causal structure), as play scenarios move from simpler to the more complex, introducing sophisticated elements to the cognitive layer.

**Documentation** (or lack thereof) is a strong factor for and against a particular tool or infrastructure. When selecting the necessary tools to construct a collaborative computer game, availability of adequate reference material and support structure is imperative so as not to detract from constructing an effective realization of the concept with distracting technical issues.

Further details relating to these attributes in a collaborative computer game context can be found in Appendix B which covers earlier work relating to desirable attributes of collaborative computer games and environments.

**3.4 Collaborative Architecture: Layers and their Interfaces**

To facilitate collaboration amongst human and virtual FEPs a Layered architecture consisting of Communication, Physical and Cognitive layers was created. Each of these layers provides a level of abstraction from each other, allowing elements within each layer to be replaced and/or modified without affecting the others (Figure 5).
From a practical perspective, the current implementations of this collaborative computer game architecture have been developed using Microsoft Visual Studio 2008 in Visual Basic. Some related technologies utilized in development include Windows Communication Foundation (WCF) as a data transport method; and SQL Server Compact Edition, a lightweight database for storing configuration, rules and domain related game data.

Some examples of this abstraction include changing parts of the communication layer from utilizing Microsoft DirectPlay to Windows Communication Foundation (WCF). The most important abstraction for engaging human and virtual partners is the cognitive layer. By providing this layer of abstraction, FEPs can interact with equal ability while their decision making processes are vastly different.

This layered approach allows the resulting computer game to facilitate collaboration while supporting many desirable features of multi-agent environments such as exogenous events, causal structures (Hanks, Pollack, & Cohen, 1993), concepts of time (Vincent, Horling, & Lesser, 2000), experimental support as well as many practical features that allow the environment to be worked with effectively.

To satisfy these requirements and facilitate FEP collaboration, an embodiment of this architectural concept was developed around the notion of an Electronic Boardroom. This computer game infrastructure provides a virtual “sandbox” within which it is possible to investigate various scenarios and elements of FEP collaboration.

3.4.1 Architectural Overview
The game is decomposed into the primary software systems required to create a collaborative computer game. Each of these parts embodies the layered architecture elements in different ways depending on their function within the collaborative educational/training game.
The Electronic Boardroom is designed to embody a layered architecture for collaborative computer games. As Figure 6 shows, human and virtual beings are situated within the electronic boardroom. This facilitates the interaction and cooperation between FEPs by situating these entities within a collaborative computer game.

The collaborative computer game system is divided into three distinct parts (Figure 6.):

- An interfacing system that allows human beings to join (become situated in) and engage others within the computer game;

- An interfacing system that allows virtual partners to do likewise and;

- The game play environment which manages the “world” within which the partners are situated.
These three elements form the basis of the technical architecture within which FEPs interact and collaborate. Each of the three software systems that combine to form a collaborative computer game must apply the principles of the layered collaborative architecture.

3.4.2 Game Play Environment

Functionally equal partners are situated within their environment and interact with this environment through a well-defined interface (Jennings & Wooldridge, 1995). The game play environment provides this as well as mechanisms that allow FEPs to interact with the game and effectively communicate with each other. As FEPs, human and virtual beings require a game environment that provides support for exogenous events, complex causal structures, a concept of time and support for experimentation.
3.4.2.1 Communication Layer
The electronic boardroom game itself forms the backbone of the communication layer. As functionally equal partners interact with the game and each other, the low level communication signals that pass from the beings’ interfaces are managed by the collaborative computer game.

In the case of manipulation of entities other than other functionally equal partners, the game is also responsible for passing information from effectors to the entities and back (if there is some form of response). In order to operate correctly, all communication with human and virtual beings must use the same communication signals.

These communication signals, in the case of the computer game, were originally implemented using Microsoft DirectPlay, however the layer was re-implemented using Windows Communication Foundation (WCF) and a simple XML protocol. These signals are interpreted by the physical layers of the game and the functionally equal partners. By maintaining a discrete interface between the layers, it was possible to make this replacement with minimal effort.

3.4.2.2 Physical Layer
In the layered architecture for collaborative computer games, a physical layer is used to define sensors, effectors and game “world” actions for these interfaces. This means that the physical layers are game scenario specific as each may have varied sensors and effectors.

Each Physical Layer defines the sensors and effectors that are available for each situated being. They can then utilize these sensors and effectors in order to interact with items within the game or other beings situated within the game.

In essence, this allows us to not only define a play scenario, but the entire “game world” in which these play scenarios take place. The advantages of this method are the ability to create play scenarios within the same game but with:
1. Different causal structures

2. Differing concepts of time

3. Varying basic goal structures.

The collaborative computer game may also have actions defined within the physical layer. At its most basic, these will be defining actions available to sensors and possible reactions of non-being entities situated within the game. However, actions in more complex games can include, for example, physics rules that can be applied to interactions within the game.

### 3.4.2.3 Cognitive Layer

The cognitive layer defines the language and process available to the game participants. The game itself does not operate a cognitive layer (as this would be contrary to the autonomous nature of virtual FEPs) but facilitates its use amongst participants. Communication between the game play environment and the virtual partners is done through a well-defined interface, keeping these two systems separate (Figure 7):
3.4.3 Human Being Interface

The Human Being Interface (HBI) facilitates the interaction between human and all other beings situated within the collaborative computer game. It provides a Social Ability mechanism as well as a well-defined interface to permit interaction and cooperation within the bounds of the collaborative computer game (Figure 8).

![Diagram of Human Being Interface structure](image)

Bringing all these elements together is a central “core” infrastructure of the HBI. This manages the communication, user interface processing and the management of physical layers for game scenarios. The human being is considered the cognitive layer, and exists separately of the rest of the HBI. The HBI itself provides the other two layers.

3.4.3.1 HBI Communication Layer

The communication layer within the human being interface corresponds to the low level signals transported to and from the electronic boardroom. These signals are then interpreted by the physical layer.

3.4.3.2 HBI Physical Layer

It is necessary to provide a well-defined interface between the human being and the human being interface as well as between the same interface and the electronic boardroom. Humans are only able to interact with the game using the sensors and effectors provided by the HBI.
Humans can be considered completely autonomous and are able to use the defined sensors and effectors provided by the HBI in both reactive and proactive ways to achieve their goals.

3.4.3.3 HBI Cognitive Layer
When working with the human being interface, it is apparent (Figure 8) that the intelligent, cognitive layer exists within the human being and separate of the HBI, which acts as the conduit between the human being’s cognitive abilities and the collaborative computer game.

3.4.4 Virtual Being Interface
The Virtual Being Interface (VBI) is actually very similar to the HBI. The difference however, is that the cognitive abilities required to interact and collaborate with other FEPs are contained within the VBI as the cognitive layer (Figure 9). Unlike the HBI, which allows a human being (acting as the cognitive layer) to interact with the collaborative computer game, the VBI itself can be considered to encapsulate all layers of the functionally equal partner. The VBI:

1. Contains features that allow the virtual being to be situated within the electronic boardroom game.

2. Is autonomous; Interaction with the computer game is through a well-defined interface.

3. Provides the necessary Social Ability elements such that the virtual being may interact and cooperate with other FEPs.

4. Is able to act reactively based on the information provided by sensors

5. Is able to act proactively in order to achieve its goals

While the VBI can be considered as an autonomous entity from the viewpoint of the game “world”, it is not necessarily true that it cannot exist within the same runtime system as long
as its interactions are via the interface sensors and effectors. As stated earlier, a number of networking technologies have been utilized by the collaborative computer game, and in some instances a virtual network protocol has also been used.

3.4.4.1 VBI Communication Layer
As with the human being interface, the communication layer is the transport system utilized by all elements of the collaborative computer game.

3.4.4.2 VBI Physical Layer
While the HBI operates as a conduit, providing an actual graphical user interface to the human being, and representing the available sensors and effectors used within the collaborative computer game, the virtual being simply requires a software interface directly between the physical layer (of sensors & effectors) and the virtual being’s cognitive layer (Figure 9).

In doing this, it can be demonstrated that the human and virtual FEPs have an equivalence in terms of their interaction with the computer game, while the implementation of this equivalence is quite different.

3.4.4.3 VBI Cognitive Layer
The virtual being cognitive layer is responsible for providing the “Intelligence” required to collaborate within a computer game as a FEP. This is where the decision-making processes of
the virtual being reside. This subsystem is able to take interpreted sensor information
(provided by the physical layer) and perform reactive and proactive decision making processes.
If decisions require action, these actions are interpreted in terms of the computer game’s
physical layer attributes and passed as actions (via the communications layer) to the game.

In order to adequately experiment with cooperative FEPs, the cognitive layer is designed
(conceptualized) as an encapsulated software component. As a practical example, one of the
decision-making processes utilized in the VBI cognitive layer uses T-Function (Yan, Ryan, &
Power, 1994) fuzzy logic algorithms with a small-footprint database storing the linguistic terms
and variables.

Combining this decision-making process with a language interpreter allowed the virtual FEPs to
interact with their human partners.

3.5 Conclusion
This chapter has provided detail of the four concepts of FEP collaboration. Each of these
concepts allows for the conceptualisation of a computer game framework that supports
human and virtual beings engaging as functionally equal players. In doing this, this chapter
addresses the second research question: What computer game framework would be required
to facilitate collaboration amongst functionally equal partners?

Firstly, the collaborative engagement is defined, outlining the process by which partners
produce outcomes collaboratively, and can be expressed formally as equal partners \( P \) engaged
in the collaborative process \( c \) from which a set of outcomes \( O \) are met from the defined goals
\( G \) (Equation 1).
The process by which partners deliver outcomes based upon defined goals is achieved through the Collaborative Process: a process within which heterogeneous FEPs may engage to deliver outcomes.

Putting this all together, a collaborative computer game is achieved thanks to the decision to create a multiple layers based architecture which, consisting of the three major elements (Cognitive, Physical and Communication layers), offers flexibility and enables consistency in achieving functional equality among human and virtual game players.

This layered collaborative architecture concept is also applied while designing the game play environment (World), the human being interface (HBI) and Virtual Being Interface (VBI).

This framework differs from many other computer games that include intelligent virtual players in the following ways:

1. Provides a layered collaborative architecture

2. Does not treat virtual players differently to human players

3. Engagement between human and virtual players is not adversarial

4. Does not utilise a “Director” to coordinate virtual player reactions

Together, these concepts form a framework required to facilitate collaboration amongst functionally equal partners in computer games.
4 Collaborative Computer Game Implementation

In this thesis a picture has emerged of the importance of social interaction in computer games in order to collaborate and achieve game goals. It can also be seen that there are opportunities to create engaging computer games through the use of realistic virtual players, which can interact, collaborate and “play the game” as a human would. From this need, the concept of Functionally Equal Partners was defined.

To support this concept, Chapter 3 defined a number of framework elements that would be required to engage human and virtual beings collaboratively as functionally equal partners. Specifically, the Collaborative Process, Layered Collaborative Architecture and the architectural subsystem interfaces required for the computer game to function.

In this chapter, the implementation of a collaborative computer game is explored and addressed in three parts. The first section explores and establishes the design of a virtual being’s cognitive layer and defines interactions among game components (its subsystems).

The second section of this chapter explores the technical aspects of integrating problem-solving techniques into a virtual player’s cognitive layer, showing the technical interfacing requirements and definitions.

Section 4.3 provides technical detail of the software processes and interfaces required in order to implement a collaborative computer game.

This chapter concludes with a discussion of the design and implementation of a FEPs-based collaborative computer game and how this addresses the third research question.
4.1 Cognitive Layer Design

The virtual being’s cognitive layer encapsulates the intelligent decision-making components required to engage in collaborative computer games. This layer comprises the perception, analysis, decision-making and action elements required to participate in intelligent collaborative tasks.

The cognitive layer interprets and evaluates sensor messages that are passed to it via the physical layer and then determines an appropriate response, be it another message, or an action. The response is then relayed to the physical layer effectors.

Figure 10 The Cognitive and Physical layers and their interaction
Figure 10 depicts the process by which the cognitive layer receives information from the computer game that it is situated within. The physical layer receives stimulus from sensors (via the communication layer) which is then transformed and passed to the cognitive layer. The cognitive layer then interprets this physical sensor stimulus, along with inter-partner messages and determines the appropriate response. Messages are conveyed to other game partners (either virtual or human beings), from the cognitive layer as physical layer items in order to interact with other partners and objects within the computer game. Virtual FEPS receiving information via their sensors have no control of the information relayed to the cognitive layer. This means that actions and messages sent to all participating FEPS are received by the virtual partner. From a collaborative point of view this is of vital importance as it allows the virtual partner to collect data through the computer game engagement for later utilization in their decision making.

At this point it is possible to breakdown the details of a virtual being’s cognitive processes. The cognitive layer can be divided into the following high-level subsystems (Figure 11):

![Figure 11 High level elements of the cognitive layer](image-url)
Each subsystem or element of the cognitive layer plays a part in taking input stimuli in the form of physical layer sensor information to produce outcomes in the form of physical actions, messages to other partners or in some cases, no response at all.

The operational elements within the cognitive layer fall into four broad categories of operation: Perception, Analysis, Decision-Making and Action. Supporting these functional elements is a cognitive data store which provides supporting information to the operational elements.

4.1.1 Perception

The cognitive layer receives information from the virtual partner’s sensors and can communicate (an action or message) via its effectors. Perception of the computer game situation involves making sense of messages received from these sensors. To achieve this, the virtual partner requires a basic knowledge of the world in which it operates. This knowledge of the world is provided by a scenario Model which represents an instance (point in time) state of the scenario. Messages received from the physical layer’s sensors fall into two categories: verbal and non-verbal messages. Verbal messages encompass text and speech types of communication. Non-verbal messages represent all other messages perceived by the physical layer’s sensors.

To collaborate with other partners, the virtual partner’s cognitive layer must have a basic knowledge of the communication language being utilized. This communication language may take the form of a human language, symbols or some other agreed common language for communication. In addition, the virtual partner requires an understanding of the medium under which the language is conveyed; for example, textually or via sounds (speech). In the context of the collaborative computer game presented here, simplified English is used as the communication language and these messages are conveyed textually.
It would be presumptuous to suggest that the implementation of the perception elements of the cognitive layer presented here represent a next-generation Natural Language Processor, but there is however some rudimentary language processing that must take place in order to make sense of the messages communicated.

To achieve this interpretation, the following constraints are applied to inter-partner messages:

1. Only items within the world and actions upon these items may be discussed

2. A limited set of “General Concepts” provides additional language elements and meanings that may be used across multiple collaborative scenarios

3. Messages are constrained to Simple English

4. The interpretation process is not always expected to be correct

5. Corrections and clarifications may be made in order to assist with future interpretation.

Once the interpretation process is concluded, the messages received from the sensors have been transformed into a simple internal structure that represents the interpreted concepts. The structure contains two types of concepts: General Concepts and Game-Specific Situation information.

Likewise, information received from the physical layer must be interpreted in the context of the world in which the collaborative FEP is situated. As part of the operation of the physical layer, sensor information is already transformed into a structure that represents the sensor data in terms of any world-specific concepts, allowing this information to pass to the cognitive layer.
World-Specific information types are the forms defined by the game scenario. These include physical layer items, their attributes and actions that can be performed on them. General information types are “joining” concepts that attach special meaning to items or associate items together in various ways. The purpose of these two structure form types is to ascribe meaning to the messages received. Once a message can be transformed into a structured form of the original message, analysis can occur.

4.1.2 Analysis

The Analysis subsystem supports the process of taking interpreted information from the Perception subsystem, analysing the input and providing information for the Decision-Making subsystem to formulate a response based on the information available.

Once a message is perceived and translated into a simple internal structure, the Analysis subsystem associates definitions, groupings and context to the message elements. For example, consider the following sequence of collaborative events:

[David] - Action 'PRESENT' effected on 'TENDER' by David

[Cathy] - SenseAction: David performs action 'PRESENT' on 'TENDER'

[Cathy] - Action: A new tender is being presented

[Cathy] - Action 'READ' effected on 'TENDER' by Cathy

[David] - Cathy, what is your assessment?

At this point, the partner Cathy has received a number of sensed messages, both verbal and non-verbal which need to be analysed. The analysis phase can draw upon knowledge of previous events to help infer context. By the end of this process, the analysis subsystem has determined that an enquiry is being made of Cathy as to an assessment of the tender she has
just read. Since the tender has been read, the information contained within this tender document is also related.

At the end of the analysis process, the message structure has been associated with definitions and meanings that have been stored in the cognitive data. Consequently, this message shall also be recorded, as well as the resulting decision and action for future reference.

4.1.3 Decision-Making
Once each type of message has been analysed, a decision must be determined as to what response is to be taken. The analysis stage provides additional information to the Decision-Making stage about the sensed message. By this point, the sensed message has been classified as one of the following message types: A Statement, Enquiry, Directive or Action.

4.1.3.1 Statements
A Statement is a communication between one or more partners that expresses a perceived observation made by the originating partner. Statements therefore must be tested as part of the decision-making process. Statements may be directly or indirectly tested.

Direct testing relies on the partner being able to perform tests upon the statement and recording the result. Statements tested in this manner shall have a higher degree of influence placed on the results, which in turn will affect the influence of the originating source.

Indirect testing relies on secondary sources of information that the partner has collected from other partners. When a statement is tested against these sources, the degree of influence placed on the results will be lower than directly tested statements. However, the influence of a statement is increased when the number of secondary sources that agree increases.
Based on the degree to which a statement can be validated or invalidated by the Decision-Making process, this can influence the way in which the virtual partner perceives and is influenced by the originating partner.

### 4.1.3.2 Enquiries and Directives

An Enquiry is a question directed to one or many partners with the expectation of some form of verbal response. A Directive is a request for some form of response by one or more partners. An Enquiry is a special type of directive where the expected response is specifically verbal in nature. An enquiry or directive is required in the case of insufficient information to address the current collaborative exchange. This is particularly important when various FEPs engaged in a collaborative process have access to different sets of knowledge. In order to achieve an outcome, information has to be requested and shared with the rest of the group. This process of knowledge sharing also grows each partner’s set of indirect test data for statement assessment.

### 4.1.3.3 Actions

An Action is a non-verbal message enacted by an external party (another partner or the computer game itself) and sensed by the partner’s sensors. Actions are performed upon objects within the computer game environment. An action changes the state of an object from one form to another. Consider the following:

[Cathy] – Action 'READ' effected on 'TENDER' by Cathy

Cathy is performing the read action upon the tender object within the computer game. The read action will trigger a state change with the virtual partner’s internal model of the tender within the computer game (from Read to Reading) and further information to be received by
Cathy’s sensors (reading the contents of the tender). Once the reading is completed, the virtual partner shall change the internally held tender state from Reading to Tender Read.

4.1.3.4 Making a Decision

The response to each type of message is the responsibility of the Decision-Making subsystem.

The responses that are available include Statements, Enquiries, Directives, Actions or No Response at all. Consider the following exchange:

[Cathy] – Action 'READ' effected on 'TENDER' by Cathy

David: Cathy, what is your assessment?

Cathy: I require additional information from Project Management.

Cathy: Ljubo, what are your figures for Available Skills?

Ljubo: Based on AVAILABLE SKILLS, we have 63 Percent Availability.

David: Cathy, Do you have enough information for your assessment?

Cathy: Yes I do.

David: Cathy, what is your assessment?

Cathy: From a Human Resources perspective, this Tender is a Low Risk because of Percentage Recruitment Required and Available Skills.

In this exchange, Cathy required additional information from another partner before a final decision could be made. The first response to the assessment question made by David was to state that additional information was required from another source. David does not reply to this statement, but Cathy continues to enquire upon Ljubo for the additional information required. Once this process is completed, David has repeated the question, only this time the available information required for a decision has been retained by Cathy.
Decisions can be made using a wide variety of methods. In the context of the computer game presented, the Decision making subsystem utilized a Fuzzy Logic processor and database in order to enact decisions.

4.1.3.5 Influence
In addition to decisions, there is an additional process contained in this subsystem known as the influence process. Influence can modify the decision of a collaborative partner so it is either in more agreement or less agreement with another partner. As the collaborative computer game scenario is executed (and executed many times), influences between the partners emerge. These influences form forces upon the decision made by the partner causing the decision to shift slightly based on the influencing forces.

4.1.4 Action
The Action subsystem is the process of changing the response of the Decision-Making process into a form that may be conveyed to other collaborative FEPs via the Physical Layer effectors. This process is undertaken for all verbal and non-verbal messages. The decision-making process outputs the results in the same structured message format used within the cognitive layer.

This process is essentially the opposite process to the Perception processes, changing the internal message structure into messages that can be transmitted by the physical layer’s effectors. In the case of verbal communication however, the process is more complex as the internal message structure must be converted to a form that is understandable to all partners. Since human and virtual partners can collaborate within the context of a computer game of this type, the conversion process involves moving the structure to a simple English textual format, which is then conveyed as a message via a physical layer verbal effector.
4.1.5 Cognitive Data
Supporting these subsystems are the various data elements required in order for the cognitive layer to interpret, evaluate and act upon the information received via its sensors (including messages between partners): The game scenario instance or model is created from a game scenario definition, along with the information required to understand and manipulate the model. The cognitive data store also maintains lists of common concepts that are used to assist in perceiving and manipulating the game scenario model.

Historical actions and the results of decisions made are also preserved for further use in cognitive processing. When a statement is tested, the corresponding results and influences are updated for future reference.

4.2 Enabling Virtual Beings
Integrating a problem solving technique into a collaborative computer game involves several steps. When integrating a new problem-solving technique into an already existing computer game, many of the following elements shall already be defined. Due to the nature of some techniques, it is important to ensure that each element is addressed to verify whether changes may be required as part of the integration process.

1. **Scenario Definition**: Define the computer game scenario. If the computer game play scenario has already been defined, include this for reference.

2. **Definition of Goals**: Clearly identify the goals of the play scenario

3. **Definition of Roles**: Identify that the roles of the participating players have been defined.

4. **Collaborative Process**: Define each phase within the collaborative process in terms of the computer game play scenario. Specify each phase of the collaborative
process (Figure 3). Depending on the computer game complexity, some phases may be transparent/irrelevant to the scenario; however each phase should be documented.

5. **Conversation Phase**: Conversations consist of questions, statements and responses (responses being statements, actions or no response). Define the structure of the conversation phase in terms of the play scenario and the conversation elements. This structure is used by the Leader role to drive this phase in the collaborative process.

6. **Negotiation Phase**: The negotiation phase utilizes the same elements as the conversation phase. Depending on the play scenario and the problem solving methodology being implemented, this phase may or may not be required.

7. **Physical Layer**: Document the physical layer definitions defined for the play scenario. This includes any entities present in the computer game “world” as well as their attributes and the actions that can be performed upon them.

8. **Definition of Sensors and Effectors**: Sensors and Effectors are defined for each player role that will be engaged in the play scenario.

9. **Problem Solving Technique**: Document the problem solving technique to be integrated. From the technique’s definition the inputs required for an outcome are defined. These inputs and outputs form the internal interface: information from the play scenario must be converted into this form. To achieve this, an external interface defines the data required from the scenario in order to satisfy the internal interface.
10. *Integration Summary*: Describes how the problem solving technique is integrated.

### 4.2.1 Integrating a Problem Solving Technique

The cognitive layer is a set of inter-connected subsystems, each responsible for a particular function and partitioned from the other operations (Figure 11).

1. **Perception** – interprets the perceived input from the sensors
2. **Analysis** – associates and retrieves information related to the input
3. **Decision-Making** – Evaluates the provided input and determines an outcome
4. **Action** – converts a decision-making outcome into instructions for use by the effectors

Underpinning these subsystems is the Cognitive Data Subsystem (Figure 12).

![Figure 12 Composition of the Cognitive Data Subsystem](image)
Each subsystem is designed to be modular and therefore replaceable (and replaceable separately of the other subsystems). The following sections detail how a new problem-solving technique may be integrated into a virtual being’s cognitive layer.

**Internal Message Structure**

The internal message structure is used to pass sensor input information between each of the cognitive layer subsystems. In order to integrate a problem solving technique it is important to understand what information is produced by the Perception subsystem and contained in this structure.

Given the modularity of the computer game layered collaborative architecture, this structure has had opportunity to undergo incremental enhancement to facilitate the transfer of progressively richer and more sophisticated information.

A message structure is composed of one or more message items which contain names and value pairs. These simple structures are then combined to form the following technical structure (Figure 13):

![Figure 13 Technical data representation of a Structured Message](image-url)
The final structure operates with the following form:

Partner
  RelatedItem(s)
     Action(s)
       Result(s)
           Reason(s)
     ContextItem(s)
Message Type

Understanding that the Decision-Making subsystem receives sensor inputs in this form via the Perception and Analysis subsystems is important when creating the software interface to the integrated problem solving technique.

4.2.1.1 Cognitive Data
The Cognitive Data Subsystem is where information about a scenario, the current scenario state (as perceived by the player), common concepts and memory (recorded information made by the engaged players during the scenario) is saved for use by all four cognitive layer processing subsystems.

When integrating a new problem-solving technique, it is possible that some changes may be required to the scenario and its related entities.

4.2.1.1.1 Scenario Model
A Scenario Model reflects the internal definitions and state of the computer game play scenario and is a main element of the cognitive data subsystem (Figure 12). It consists of two primary elements: The Scenario Definition and the Scenario Instance.

The Scenario Definition defines the play scenario objectives and information about the types of objects that inhabit the computer game “world”. It provides a definition for the types of
entities involved in the computer game, as well as the scenario objectives. Consider the following definition of a computer game player:

```xml
<ObjectDefinition Name="Chairperson" Description="Chairperson" ObjectType="Player" ParentObjectDefName="" >
  <Actions>
    <Action Name="PresentProject">
      <Attributes>
        <Attribute ObjectAttributeRef="Content">
          <Sequences>
            <StateChange EndState="NULL" StartState="NULL" />
          </Sequences>
        </Attribute>
      </Attributes>
    </Action>
  </Actions>
  <Attributes>
    <Attribute Name="Reader" Description="Read" Value="" AttributeType="Sensor" DefaultValue="" >
      <SensorScope>
        <Register ObjectDefinition="Report" Cascade="true" />
      </SensorScope>
    </Attribute>
  </Attributes>
</ObjectDefinition>
```

The Scenario Instance represents the state of the entities involved in the computer game. While the definition provides a "plan" of the play scenario (e.g. there will be a Chairperson), the instance represents the actual data in the play scenario (e.g. David is the Chairperson)

```xml
<objectInstance id="DAVID" name="David" objectdef="Chairperson">
  <attribute name="" />
</objectInstance>
```
4.2.1.1.2 Rules
The rules stored within the cognitive data subsystem consist of two information sources: The Scenario Rules and Common Concepts. Scenario Rules are defined as part of the scenario definition and as such are specific to each game play scenario. Common Concepts are rules which may be applied across all game play scenarios. An example of such common concepts are the language rules that are to be applied by the Perception subsystem.

4.2.1.1.3 Memory
When sensor inputs are processed by the cognitive layer, the state of entities within the game play scenario is updated within the scenario model (instance information). Outside of this, information supplied by other players during the collaborative process is stored in a memory within the cognitive data subsystem. This allows the cognitive layer to recall information they have received and use in later processing. Collectively, this memory forms part of the group’s collective knowledge (Equation 4), which is discussed in Chapter 3.

4.2.1.1.4 Loading a Game Play Scenario
The Cognitive Data subsystem provides the scenario model, rules and memory which are used by the four processing subsystems of the cognitive layer. To engage in a specific game play scenario, a definition is loaded from a data source (e.g. XML files, Database, etc.). Once loaded into the Cognitive Data Subsystem, the data source is used to create the Scenario Definition and the initial Scenario Instance within the Scenario Model. From here, the Scenario Rules are also created, thus preparing the cognitive data necessary for the Cognitive Layer to engage in the collaborative computer game play scenario.
Perception

While not necessarily involved in the integration of a problem-solving technique, the perception subsystem does create a structured representation of the input received from the defined sensors.

As Figure 14 shows, the perception subsystem takes input from the physical layer sensors and creates an internal message structure which is processed by subsequent subsystems. To achieve this, the perception process interprets the input. Definition and state information stored in the Cognitive Data layer is used to identify and associate information contained in the input.

Analysis

The analysis process involves the association of related data and determining the context of the input message.
From a technical perspective, context and related information is added to the message structure as additional related information.

4.2.1.2 Decision-Making
Once an input obtained from the sensors is relayed to the decision making subsystem, the message structure contains information about the original message in a structured format.

Inside the decision-making subsystem, an interface is provided that allows for the construction of an interfacing component which is used to transfer data between the decision-making module and the supporting elements of the subsystem.

Figure 15 The Analysis subsystem provides additional related information to the message structure

Figure 16 Integrating a problem solving technique into the decision Making subsystem
While other parts of the integration process do not require a highly technical level of expertise, the integration and interface mapping process currently requires some programming skills to map the internal structured message to and from the required interface of the problem-solving technique.

Figure 17 High level diagram of integrating a problem solving technique

Software code is used to implement the interface, allowing the mapping of structured messages to the input requirements of the integrated problem-solving technique.

The following shows a software code example of how this software class creates inputs specific to the problem-solving technique being utilized.

```
Protected Sub DoFuzzyEvaluation()

    _MIMOFuzzyProcessor.FuzzyRules = _MIMOFuzzyRules
    _MIMOFuzzyProcessor.FuzzyInputs = DoPrepareFuzzyInputs()
    _MIMOFuzzyProcessor.FuzzyRuleInputsCount = _MIMOFuzzyRules.NumInputs
    _MIMOFuzzyProcessor.FuzzyRuleOutputsCount = _MIMOFuzzyRules.NumOutputs
    _MIMOFuzzyProcessor.Debug = True
```
Dim results As FuzzyResult = _MIMOProcessor.FuzzyProcessor.DoFuzzyProcess()

Dim results As FuzzyResult = _MIMOProcessor.DoFuzzyProcess()

DoFuzzyProcessFuzzyResult(results)

DoFuzzyProcessFuzzyResult(results)

End Sub

The function “DoPrepareFuzzyInputs” iterates through the structured message and using the scenario definition in the cognitive data layer, maps message items to their fuzzy process counterparts. In order to achieve this, a mapping must be determined between the information found in a structured message, and the specific input requirements of the technique’s software implementation. For example “Daniel, is this coffee affordable?”:

<table>
<thead>
<tr>
<th>Structure</th>
<th>Data</th>
<th>Technique Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partner:</td>
<td>Daniel</td>
<td></td>
</tr>
<tr>
<td>Related Item:</td>
<td>Coffee, $10:</td>
<td>Fuzzy process for: Coffee</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Linguistic variable: Affordable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Crisp Value: 10.00</td>
</tr>
<tr>
<td>Action:</td>
<td>Evaluate: Affordable</td>
<td></td>
</tr>
<tr>
<td>Message Type:</td>
<td>Enquiry</td>
<td></td>
</tr>
</tbody>
</table>

Figure 18 Mapping message structure elements to technique input requirements

Conversely, once results are received from the problem solving technique software, it must then be mapped back to the structured message so that the results may be passed to the Action subsystem which sends instructions to the player’s effectors.

To integrate a new problem solving technique, the following points must be considered:
1. Look at the input requirements of the selected problem solving technique.

2. Cross reference these requirements with what is available as part of the message structure.

3. Items that are not available as part of the message structure need to be evaluated to determine if additional information may be retrieved from the cognitive data layer, or from another external source. In the software code example above, this particular technique assumes that rules are held externally to the process, therefore the interfacing software code obtains this information from a nominated data source and then passes this to the process. From a practical perspective, cognitive layer data and other data required by a particular technique can co-exist in the same data store (for example Microsoft SQL Server).

If a particular technique requires additional external elements beyond the cognitive layer such as the manipulation of another item defined within the computer game “world” (for example, an electronic mediator), the scenario definition must define these items.

4.2.1.2.1 Definition Changes
Integrating a different problem-solving technique may change the way in which the scenario is defined. In particular, adding additional physical items to the play scenario.

To achieve this, new objects (Object definitions) must be added to the scenario. Each object must define the available actions (for example, with an electronic mediator the action is “CALCULATE” based upon the input attributes provided by the player acting in a leader role).

4.2.1.2.2 Maintaining Specific Technique Data
Some decision-making techniques shall rely upon an internal store of information. With the fuzzy-logic example, this data includes all the rules necessary to evaluate input information.
Many software-based techniques provide tools to load and configure input data, or if none are provided, large volumes of import data can typically be loaded via an automated process. In a number of play scenarios using various fuzzy logic techniques, a maintenance dashboard was created to assist with maintaining the required data within the data store (Figure 19):

![Figure 19 A Data Maintenance dashboard used to main scenario and technique data.](image)

**4.2.1.3 Action**

Once the message structure contains the results of the decision-making subsystem, the action subsystem converts the structured message into directives instructing the player’s effectors to perform some form of action. This can be in the form of a response (a message, or manipulation of an entity within the game play scenario), a question or no response at all. Once a structured message has been fully processed by the cognitive layer, it is recorded in memory for possible later use.
4.3 Software Processes and Interfaces

From a high-level perspective, the TeamMATE software has been constructed to facilitate the integration and replaceability of individual software components, providing flexibility for the system to be as simple or as complex as necessary, based upon the computer game requirements.

As discussed in Chapter 3.4, the primary subsystems which constitute TeamMATE are the Human Being Interface (HBI), Virtual Being Interface (VBI) and the Game Play Environment. The combination of the technical architecture and the cognitive layer implementation (Chapter 4.2) form the majority of the TeamMATE system.

The following chapter provides further details of the technical processes which are involved in a TeamMATE collaborative computer game and how each of the three architectural layers interact to achieve a system capable of collaborative interaction.

4.3.1 Game Play Environment

The TeamMATE system consists of three software subsystems: the Human Being Interface (HBI), Virtual Being Interface (VBI) and the Game Play Environment (server). Each of these subsystems are independent software programs. This allows the subsystems to be distributed...
across one or more computers capable of running programs built for the Microsoft .NET Common Language Runtime (CLR) version 3.5.

4.3.1.1 Initialisation

In order for players to interact in game play scenarios hosted by TeamMATE, the Game Play Environment must be initiated. This process involves the creation of a Windows Communication Foundation (WCF) service within the communication layer, which is then able to listen for connections from HBIs and VBIs wishing to engage in a play scenario (Figure 21). Prior to the advent of WCF, earlier versions of TeamMATE utilised Microsoft DirectPlay to handle the transport of asynchronous data between the game server and players.

![Figure 21 The TeamMATE Game Play Environment server](image)

In addition, the list of available scenarios is loaded from a SQL Server Compact Edition database (a lightweight database engine based upon Microsoft SQL server). Once loaded, the game play environment is ready to accept connections (Figure 22).
Once initialised, the server is ready to accept connections by players using either HBIs or VBIs. This process is common to both types of subsystems and involves a connection and “handshake” procedure to ensure all players have access to the current play scenario game state. One of the first parts of the connection process is the perception of already connected players.

**Figure 22 Initialisation of the Game Play Environment**

**Figure 23 The connection process for human and virtual beings.**

### 4.3.1.2 Communication Layer Services

The communication layer is responsible for the technical process of transporting information between the players and the game server. There are two types of messages that pass between
players and the server: Technical messages which are used for logistical processes not directly related to the game play scenario, and Physical messages which represent information perceived by Physical Layer sensors and actions initiated by the Physical Layer’s effectors.

The information and nature of the data that is passed using the physical messages is determined by the scenario definition along with the specification of the sensors and effectors available to players participating in particular game roles.

Figure 24 shows the service interface messages that all player interfaces (human and virtual) must use in order to interact with the game server. The game server is then able to distribute these messages to other players as well as perform actions upon the game model.

![Figure 24 Service interface messages allowing communication between FEPs](image)

The distribution of messages to and from the game server to the participating players is performed via the WCF service interface. This interface is designed for two-way communication between the connecting subsystems. That is, the player interfaces listen for messages from the game server as well as send information via the WCF services.
4.3.1.3 Game Model
During the initialisation process, the game play environment receives information about the
game play scenario the Human or Virtual player will be engaging in. Using the scenario list, the
particular game play model can be loaded. The game play model contains the game-specific
logic and processes that constitute the game and its state.

Each game play scenario must implement the IScenario interface (Figure 25). This allows
the server to initiate the required scenario, as well as send and receive state information from
the game model. Only the game play environment (server) has access to manipulate the game
model, as well as distribute updates to the game’s state to the participating players.

![Figure 25 Interface required integrating a particular game model](image)

4.3.2 Human Being Interface
As stated in Chapter 3.4, the Human Being Interface (HBI) acts as a conduit between the
human being and the game play scenario. This is achieved by presenting information about the
game via a user interface, which can then be acted upon by the player. To achieve this, the HBI
reads the scenario definition from the database and consequently will list the actions and
abilities available to the user (Figure 26).
Once set up and connected to the computer Game Play Environment, the player is then able to receive messages then act upon them using the actions made available to them for this purpose.

Many modern entertainment-style computer games utilise common user interface “engines” to represent the game artefacts, while providing the specific details as game data files that include data, images and models of the game “world”. Creating a play scenario representation for HBI does involve the technical task of representing game information and actions in such a way as to be informative and useable to a human being. In TeamMATE, the process of interpreting received physical layer messages and rendering game state changes has been achieved in two ways in the HBI:

The first method applied was a plugin-style game representation area which is loaded upon choosing the scenario definition. This plugin is aware of the physical layer representations of the physical layer messages and then renders actions and game states upon receiving information from the game server. Figure 27 shows a version of the TeamMATE HBI using a plugin based UI model to render actions and world state for the human player. This method provided great flexibility in the UI representation as the plugin was scenario-specific, operating within the HBI framework.
The second method applied to the HBI was a data-driven approach to play scenario management. User interface elements for the scenario were loaded based on the selected scenario definition from a database, then represented as lists of available options to the human player on screen. The advantage of this approach was that there was no additional software development required to maintain/represent the scenario for a human being, while the disadvantage is that the user interface constrains how that information can be represented (Figure 28).
4.3.3 Virtual Being Interface

The Virtual Being Interface (VBI), while similar from a conceptual level to the HBI is far more complex due to the fact that the virtual being’s cognitive layer resides within the VBI subsystem. In discussing the technical processes and interfaces required for the VBI, it is also necessary to detail the software processes and interfaces that are required for the function of each of the cognitive layer subsystems.

In many respects, the initialisation of the VBI is similar to the HBI. Once initialised, the technical (TechnicalRequest and TechnicalResponse) and physical (PhysicalRequest and PhysicalResponse) messages are passed via the WCF partner service to the game server. Since the request and response objects utilised by the game services are identified as being serializable (that is the object state can be saved as a file, and can be reconstituted from the saved file), the data can be transported via the WCF services as...
XML. Once received, the XML data is then used to recreate the object state on the other side of the service transaction.

When a message is sent to the VBI via the communication layer, it is passed to the Artificial Controller which is responsible for receiving and dispatching communication layer messages, as well as maintaining the operation of the VBI subsystem. It maintains a Physical Layer model of the computer game play scenario as well as a cognitive layer component. The cognitive layer process of Perception, Analysis, Decision-Making and Action can only be enacted once the communication layer messages are received by the controller and sensed by the physical layer (Figure 29).

![Artificial Being Interface – Receiving Messages](image-url)

*Figure 29 The artificial controller receives communication layer messages and routes these to the physical layer*

Once the messages have been received and allocated to the appropriate Physical Layer sensors, the virtual being’s play scenario state is updated. The sensor information from the physical layer can then be perceived by the cognitive layer.
Upon determining an action, the virtual being sends the action to the appropriate effector. This effector information is then converted into communication layer messages for transport to the game server, which then updates the game state and relays the effector information and state changes to the other participating FEPs.

The cognitive layer implements an interface called `ICognitivePartner`. This interface exposes a very narrow set of interface functions: Essentially the ability to sense and effect information (as well as some purely technical functions). The function `DoProcessCognitiveMessage` is the process that then engages the four cognitive layer processes (Figure 30).

![Figure 30 The ICognitivePartner Interface](image)

### 4.3.3.1 Perception
Once a message has been received from the virtual being’s physical layer, the perception process commences. The perception process takes input perceived by the sensors and creates a structured message which can be processed by the analysis subsystem (Figure 31).
The processing is divided into two primary processing flows dependent on whether the perceived sensor information is textual (language based) or not. Non-textual sensor messages are associated with their definition and current state. Once this information has been obtained and the new state information received by the sensor, it is combined together into the internal cognitive message format (Figure 13).

The second flow involves the conversion of the textual based message into the cognitive message format. This process is divided into a number of steps. The first step is the loading of the language store. This is a collection of play scenario independent definitions of English words and mappings to general concepts used within the cognitive layer. The language store may be as simple or as complex as required by the play scenario. At its simplest, this can consist of entire English phrases to be used in the play scenarios.
Once the language store is loaded, the message is divided into tokens (words) which are then cross-referenced against the scenario definition to identify scenario-specific identifiers (names, objects, actions etc.). Finally, the remaining tokens are associated with the scenario-specific identifiers to produce an identification of the message as being a Statement, Enquiry, Directive or Action. This process then results in the creation of the cognitive message.

This process however, is designed with replaceability in mind. The textual message may be passed to a dedicated language interpretation library which can then handle the processing of the textual language message into the cognitive message format.

4.3.3.2 Analysis
The analysis process associates further details with the internal cognitive message. This process provides contextual information which is required for the decision-making process (Figure 32).

![Cognitive Layer - Analysis](image)

Figure 32 The analysis process

Firstly, each item’s scenario definition is loaded as well as the last known state of the item. In addition, the last known cognitive layer process state is also retrieved (the last known state of the cognitive process being undertaken). Finally, the messages stored in memory (as cognitive messages) are retrieved and associated with the cognitive message based on two factors: the number of related keywords in the stored messages and the position in the message stack: the
more recent a message, the higher the chance it provides contextual information about the current message.

4.3.3.3 Decision-Making
The decision-making process involves processing the cognitive message as Statements,

Enquiries, Directives or Actions. The decision-making process also involves the use of a problem-solving technique in order to evaluate a particular enquiry (Figure 33).

The primary complexity of the Decision-Making process involves the type of cognitive messages being processed. Statements must be tested and added to the group collective
knowledge within the cognitive data subsystem. Enquiries prompt the player for some information. This process involves the use of a given problem solving technique. Each problem solving technique has different requirements which therefore require the implementation of a problem solving interface. It is also assumed that some techniques may require their own backing stores of data (for example: Fuzzy rules) which may be stored and maintained independently of the play scenario data definitions.

The interface implementation is then responsible for converting the cognitive message data into elements that the particular problem-solving technique is capable of dealing with. Once a result is evaluated, the decision based upon the values determined is integrated into the cognitive message within the Results object structure from which the action subsystem may produce an output.

### 4.3.3.4 Action
The action subsystem transforms cognitive messages back into actions for the physical layer to perform. All responses are raised to the physical layer via the EffectAction function on the ICognitivePartner interface. As with the perception process, the action subsystem performs additional processing on actions determined to have a textual message as the required output. Using the language store, a new textual message can be constructed which can then be relayed via the associated physical layer effector.
Once the new physical layer effector action has been constructed, the cognitive layer’s internal scenario instance state may be updated to reflect the change made by the effector action as well as recording the cognitive message (including the physical layer action output) in the message history.

4.4 Conclusion

In this chapter, a collaborative computer game has been designed and implemented in order to support the engagement of human and virtual beings in collaborative gameplay and addresses the third research question of this thesis, being: *How could such a collaborative computer game be designed and implemented in order to accommodate functionally equal interactions among human and virtual players?*

To address this question, three specific areas were addressed. Firstly, the virtual being’s cognitive layer was designed and implemented as four subsystems supported by a cognitive
data repository. The four elements in a virtual being’s cognitive layer consist of the Perception, Analysis, Decision-Making and Action subsystems.

Extending upon the virtual being’s cognitive layer, the process of integrating a problem-solving technique was addressed and how it fits within the design and implementation of the cognitive layer.

Finally, all elements of the implemented collaborative computer game are discussed in detail including the computer game’s three primary elements: The Game play environment, the Human Being Interface and the Virtual Being Interface. This included detailed process information, interfaces, software platforms and data.
5 Case Studies

So far, this thesis has explored how human and virtual beings may engage in collaborative computer games as functionally equal partners. The architectural attributes that are desirable in a collaborative computer game as well as how FEPs engage within these games via the collaborative process have also been discussed. Added to this, the technical requirements of the communication, physical and cognitive layers within humans, virtual beings and the computer game itself have been explored with particular attention to the technical implementation if a virtual player’s cognitive layer.

Each of the topics discussed in the preceding chapters has addressed a particular element of the research questions presented. To demonstrate how these principles are dealt with in practice, a number of game play scenarios are presented here to demonstrate how FEPs engage in collaborative problem-solving. The decision to use case studies as a research method was to provide practical examples of collaborative FEPs across a number of computer game application areas. This decision is supported by the use of practical case studies involving computer games such as those identified earlier. These case studies too, span a wide variety of computer game types from entertainment (Laird, 2001) (Adobbbati, Marshall, Scholer, & Tejada, 2001) (Magerko, Laird, Assanie, & Stokes, 2004) to education (Conati & Klawe, 2002).

To answer the questions presented in this thesis, four case studies were selected as examples of different computer game application areas. Each of the play scenarios implements the principles of a collaborative FEP computer game, but in addition demonstrates a particular aspect of the concept.

The first case study chosen is a classic entertainment style computer game called Hammurabi. The game itself is very simple, which provides an opportunity to observe group decision-
making among FEPs. Hammurabi in particular demonstrates the application of different
problem-solving techniques used within a virtual player’s cognitive layer, alongside the
performance of humans.

The second case study is an educational type computer game called Holiday Destination that
involves the selection of an optimal holiday for a group of players based upon their
preferences. This Case study demonstrates how the perceptions of the participating FEPs add
additional complexity to the group decision-making process. That is, one player identifies a
holiday as “Expensive” while another identifies the same holiday as “Cheap”.

The third case study is called Tender Assessment and is a business type computer game. In this
scenario, a management team representing various departments within an organisation must
assess each potential project to determine the least risky option. In many situations,
information available to the participants is incomplete and further details must be sought and
added to the group’s collective knowledge. In this case study, each departmental
representative is able to provide useful data from their specific field in order for the whole
group to reach a decision collaboratively.

The final case study presented is called Project Planning. A large Australasian software
company undergoes a planning exercise for potential projects of its infrastructure group. This
group provides software to the business product teams that then create enterprise business
software. The objective of the planning exercise is to prioritise the most important work that
will fit within the allotted development cycle. Of particular focus in this case study was the
impact of influence amongst the decision-makers and how this affected the eventual project
plan. This was particularly interesting when compared to the actual planning exercise
undertaken by this organisation.
Each scenario engages players in scenarios that must be resolved collaboratively; with each play scenario exploring one or more attributes of FEPs engaged in collaborative computer games.

5.1 Hammurabi

Those well versed in computer programming and in particular computer game history will be aware that Hammurabi is considered one of the oldest kingdom building style games and a forefather to many modern strategy and planning games (Egenfeldt-Nielsen, Smith, & Tosca, 2008). This particular game was chosen due to the simple game play but intelligent decision-making required on behalf of the players. This combination allows us to focus on the details of the virtual partner’s cognitive layer in action.

The original game itself is simple. A player acting as the ancient Sumerian king Hammurabi aims to survive a 10-year period (turns) in office by managing resources of grain to ensure their people were fed, and that there was enough land for cultivation.

Each player starts with 100 people, 1000 acres of land and 2800 bushels of grain. Each year (turn) the player determines how many bushels of grain to feed to their people, buying or selling land and how much grain to cultivate in the fields. There are a number of basic rules that determine game play:

1. The game lasts up to ten years (turns) unless the player is impeached for poor performance. Impeachment occurs if the following conditions are met in any given turn:

   a. The number of population starved is greater than 33%

   b. Acres per person of population ratio is less than 7:1
2. Every person requires 20 bushels of grain to survive for a year. If a person does not receive 20 bushels of grain, they starve.

3. Each acre of land requires 1 bushel of grain for cultivation

4. Every year, a price to buy and sell land is determined

5. Each person can cultivate up to 10 acres of land

6. If a player lasts 10 turns, they are evaluated to determine how successful their term in office was

Each turn, a set of exogenous events occur that determine the resources available to the player for the next turn:

1. Each year, the population grows due to migration and natural growth

2. The price of land to buy or sell fluctuates between 17 and 26 bushels of grain per acre.

3. The crop yield for the turn ranges between 1 and 5 bushels per acre of cultivated land

4. There is a percentage chance each year that rats will eat a proportion of the harvested bushels of grain

5. There is a percentage chance that the kingdom shall suffer a plague which kills half the population
5.1.1 Scenario

Hammurabi’s Boardroom is built upon the classic game Hammurabi, but expands the game to include multiple collaborative partners providing an additional mental challenge as they must collaboratively make decisions to achieve a successful outcome. The game consists of a group of up to four players. One player is Hammurabi who is responsible for commanding the Royal Steward to buy and sell land, feed the people from the granaries and order cultivation of the fields based on the council’s decision. While Hammurabi is the head of state and responsible for sending the decree to the Royal Steward; in this game a Council consisting of Hammurabi and three wise officials elected by the country have equal say in the decisions made.

![Figure 35 Hammurabi’s Boardroom Game Cycle](image)

Once the council has arrived at a collaborative decision, Hammurabi informs the Royal Steward of their commands. Once the Royal Steward receives the command to act from Hammurabi, the decision of the council is performed. Once the commands enacted by the steward are performed, the turn “ends” (representing a year). The steward then receives a report on the performance of the country that is then brought before the council (Figure 35).
Typically, each turn would result in a random assortment of exogenous events (in the form of crop yields, migrations, deaths, land price etc.). This particular game has been designed to allow specific turn results to be recorded and played back, allowing the scenario to be repeatable.

The following table shows the factors that were applied to Hammurabi's Boardroom for each turn cycle. These factors were taken from the random values produced in an initial game run:

<table>
<thead>
<tr>
<th>Turn</th>
<th>Population Increase Factor (1 – 10)</th>
<th>Plague Factor (-3 – 17)</th>
<th>Rat Population Factor (0 – 1)</th>
<th>Crop Yield (1 – 5)</th>
<th>Land Trading Price per Acre (17 – 27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>10</td>
<td>0.09</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>9</td>
<td>0.16</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
<td>0.41</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>16</td>
<td>0.52</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>3</td>
<td>0.15</td>
<td>2</td>
<td>21</td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>0</td>
<td>0.55</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>-2</td>
<td>0.69</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>-2</td>
<td>0.62</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>-2</td>
<td>0.62</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>-2</td>
<td>0.62</td>
<td>4</td>
<td>22</td>
</tr>
</tbody>
</table>

5.1.2 Technical Game Implementation

The computer game “world” within which the partners are situated is a reimplementation of the original Hammurabi game in Microsoft Visual Basic .Net. Interaction between players and the game have been abstracted so as to allow the game to “plug in” to a generic computer game server implemented using Microsoft Windows Communication Foundation. Player client
interfaces are able to interact with the game and each other via the services provided by the implemented communication layer. A scenario definition provides instruction to the client interfaces as to the available sensors and effectors available to each player involved in the computer game.

5.1.2.1 Cognitive Layer Implementation

5.1.2.1.1 Perception
Given the simple nature of this game, the perception process is relatively simplistic. Each FEP is able to perceive the ancient Sumerian game world via two sensors defined by the scenario definition: A message sensor which permits communication between the partners, and a report sensor which allows the partner to “Read” the results of their decisions.

5.1.2.1.2 Analysis
The analysis process takes the input messages and adds related information to it. For example, when Hammurabi sends the following message to Hanish:

Hammurabi: Hanish, what are your recommendations for this year?

The perception process is able to determine that Hammurabi is making a “query” for a “recommendation” from “Hanish”. At this point the analysis process relates the “recommendation” to something. To achieve this, the analysis module must search backwards through the message history to associate a context with the message. Combining this historical information with the scenario definition allows the term “recommendation” to be associated with the last perceived Steward report:

Action: READ performed on StewardReport by Hanish

The details of the last steward report are then related to the directive from Hammurabi for a recommendation. The steward’s report (previously read via the reading sensor) contains
information about the result of the previous year’s decisions coupled with the modifying factors:

Table 3 An example annual report

<table>
<thead>
<tr>
<th>Annual Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Starved: 13</td>
</tr>
<tr>
<td>Population Growth: 3</td>
</tr>
<tr>
<td>The City's Population is now: 90</td>
</tr>
<tr>
<td>The City now owns 971 acres.</td>
</tr>
<tr>
<td>Crop yield was 3 bushels per acre</td>
</tr>
<tr>
<td>Rats ate 591 bushels</td>
</tr>
<tr>
<td>You now have 2933 bushels available in storage.</td>
</tr>
<tr>
<td>Land is trading at 23 bushels per acre.</td>
</tr>
</tbody>
</table>

Once associated with the current message from Hammurabi, the decision-making process receives from the Analysis process, a directive for a recommendation based on the annual report.

5.1.3 Decision-Making

There are many methods by which decision-making can be achieved. As part of the architectural implementation, each process of the layered collaborative architecture is designed to allow replacement. Two techniques were applied to Hammurabi’s Boardroom: A fuzzy logic process and a second decision-making process based around levels of quality. For the fuzzy logic approach, a MIMO type Fuzzy Logic process (Passino & Yurkovich, 1997) was utilized consisting of three input linguistic variables, and three resulting linguistic variables:
The decision making process within each virtual partner results in a recommendation about how many people to feed, acres to trade and grain to store. This decision is then passed to the Action processor.

In addition to the fuzzy approach, a second decision-making group was also implemented which instead made collaborative group decisions based on levels of quality (LOQ) that each partner brought to the decision making process. This approach is based around using a completely neutral process or mediator to deliver an outcome based upon the decisions of all partners. Each partner reviews a set of alternative decisions each turn (in the case of this computer game, the alternatives are evaluated and put forward by the partners themselves) and the group provides their decisions to the mediator based upon the levels of quality they have nominated. This electronic mediator then determines the outcome which satisfies the decisions of the collaborative group using an order-consistent achievement function (Vlacic, Wierzbicki, & Matic, 1986). The electronic mediator in the context of this computer game is the Royal Steward who enacts the outcomes of the council’s decisions.

5.1.3.1 Action
Based on the decisions made in the previous process, an action, group of actions or no action at all are performed in response to the original information received via the sensors. The
action process forms an interface between the decision of the virtual partner and any outcome actions. Essentially, this is the process that carries out the instructions of a given decision.

5.1.4 Results
The computer game was constructed as a set of loosely coupled functional modules and subsystems. The Hammurabi game module itself is responsible for creating exogenous game events and managing game play. To verify the correctness of the solution, a suite of unit tests was performed in order to ensure the validity of the computer game model.

Verification requires benchmarks, testing and a consistent point of reference. A single reference implementation\(^1\) of the original Hammurabi was used to generate testing outcomes with which to verify the results generated by the game.

Firstly, a Baseline Partner (BP) was used to determine a benchmark position for game play. This baseline partner used strict constraints to ensure the goal of zero population loss per turn. Two collaborative groups were also tested: A Fuzzy Logic based collaborative group and a group collaborating using levels of quality and an electronic mediator. Finally, a human partner was also included in testing to verify the solution approach.

\(^1\) Reference implementation used is available at http://www.hammurabigame.com/hammurabi-game.php
Figure 36 shows the resulting populations over the duration of the game. Notice that turns 7 to 10 involve plagues (which instantly reduce the population by half) and that turn 8 had a significant population increase, which offset the plague in that turn. In terms of population, the Baseline Partner (BP) tracked closely with the Human player until turn 6, at which point the populations diverged as the BP tracked closer to the Levels of Quality (LOQ) group. It should be noted that (as Figure 37 later shows) the divergence at turn 6 follows a significant “selling down” of land to maintain population growth. The Fuzzy Partner (FP) group roughly matched the performance of the LOQ group by the end of the game however, for much of the game duration this group was roughly half way between the BP and the LOQ collaborative group.
The bushels available to players each turn shows a significant difference in approach between the Human player, the Fuzzy Partner (FP) group and the LOQ players (Figure 37). The Human in this case took advantage of the significant trading price per acre of land in turn two while the LOQ partners reduced their stored bushels to amounts consistently below 50 bushels per turn. By the end of turn 10 however, the human partner had comparable stored bushels. The cause of this was the rat plague factors. Essentially, the game’s rat/plague algorithm is 1 rat eats 1 bushel of grain. The calculation used to determine this each turn is:

\[ \text{grain consumed} = \text{number of rats} \times \text{rat factor} \times \text{bushels available} \]

Therefore, the perceived gains made by the human player in turn 2 were literally “eaten” in subsequent turns. Since the BP and LOQ partners had lower grain reserves, rat consumption of grain was negligible.

The FP collaborative group, tracked in a completely different manner to the Human, BP and LOQ groups. The heuristic information used by the FP group of players resulted in a steady
decrease in stored grain until turn 6, then an upward trending amount until the conclusion of the game.

![Figure 38 Number of acres available to players each turn](image)

There is significant divergence in Acres available across all partners in Figure 38, with the number of acres trending down over time. The Human and BP engaged in significant sell-downs of land in order to maintain their respective populations. The BP achieved zero deaths due to starvation in their population by utilizing the available land as a ready source to trade for grain. The Human player also engaged in this practice, but sold off land far more aggressively resulting in population increases, which outstripped that of the BP. The clear performer in terms of land available was the LOQ collaborative group that had significantly more land than the other game players by the conclusion of the game. The FP collaborative group’s acre amount tracked roughly halfway between the best and worst performers. This steady selling down of land matches well with the FP group’s ability to maintain steady levels of stored grain during the game.
The following table shows the results at the end of each game. The underlined values represent the “winner” of each game attribute (population, bushels and acres):

<table>
<thead>
<tr>
<th>Player/s</th>
<th>Population</th>
<th>Bushels</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>57</td>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td>Fuzzy Partners</td>
<td>22</td>
<td>697</td>
<td>502</td>
</tr>
<tr>
<td>LOQ Partners</td>
<td>20</td>
<td>16</td>
<td>771</td>
</tr>
<tr>
<td>Baseline Partner</td>
<td>16</td>
<td>3</td>
<td>261</td>
</tr>
</tbody>
</table>

Table 5 Results at the conclusion of the Game for each Partner/s

What can be seen in Table 5 is that each of the Human, FP and LOQ strategies in the game resulted in each achieving a significant benefit over the others for a particular attribute. Interestingly, while the Baseline Partner achieved zero deaths due to starvation, it achieved a consistently lower result than any of the other game groups across all attributes.

In addition, to demonstrate how the LOQ collaborative group achieved their outcomes Table 6 shows the individual virtual partners involved in the LOQ engagement after playing the game again as individuals. This illustrates how the quality levels nominated by each of the decision-makers results in the overall collaborative decisions of the LOQ group.
Table 6 Individual virtual players game achievements

<table>
<thead>
<tr>
<th>Player/s</th>
<th>Population</th>
<th>Bushels</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammurabi</td>
<td>18</td>
<td>0</td>
<td>390</td>
</tr>
<tr>
<td>Shullat</td>
<td>22</td>
<td>16</td>
<td>624</td>
</tr>
<tr>
<td>Hanish</td>
<td>23</td>
<td>0</td>
<td>692</td>
</tr>
<tr>
<td>Delondra</td>
<td>21</td>
<td>16</td>
<td>774</td>
</tr>
</tbody>
</table>

5.2 Holiday Destination

The Holiday Destination computer game scenario is a simple educational exercise to demonstrate how a group of game players can engage collaboratively to achieve a desired outcome. In this particular instance, the selection of a ski holiday destination is required.

This play scenario is useful in demonstrating a collaborative engagement due to its simple objective and use of fuzzy logic as the problem-solving technique.

5.2.1 Scenario

A group of board members have decided to take a ski holiday together. However due to work commitments that have made some unavailable to meet in person, they have decided to use an electronic meeting room to decide on a ski holiday destination. Each board member has their own ideas about what the ideal ski holiday will be, and have decided (previously) that the three most important things in their decision are the Cost, Accommodation Quality and the Number of Days Skiing.

Unperceived by other board members in the group, some have been called away on urgent business, and been replaced by virtual beings at the electronic meeting. These virtual beings possess similar preferences to the humans that they shall be replacing at the meeting.
What all the board members must decide at the meeting is what would be the most ideal holiday for the group. They have decided that for the holiday choice to be a success, it cannot be what they consider a Shabby or Extravagant destination, but rather something considered Good by the group.

The collaborative process of the electronic meeting room board members will involve two roles. All functionally equal partners are members of the Board member role and contribute to the outcome of choosing a holiday. In addition, one member of the group shall be nominated the Presenter and the Negotiator (P&N); which is the Leader role in this scenario. The P&N is responsible for obtaining holiday information and presenting it to the rest of the group for critique. The P&N is part of the decision making process and is responsible for the successful completion of the process however he/she is not expressing a personal view point and assessment on the topics under consideration.

The following table lists the six participating board members and their role:

<table>
<thead>
<tr>
<th>Functionally equal partner</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ljubo</td>
<td>P&amp;N</td>
</tr>
<tr>
<td>Daniel</td>
<td>Board member</td>
</tr>
<tr>
<td>Kara</td>
<td>Board member</td>
</tr>
<tr>
<td>Martyn</td>
<td>Board member</td>
</tr>
<tr>
<td>Janet</td>
<td>Board member</td>
</tr>
<tr>
<td>Mark</td>
<td>Board member</td>
</tr>
</tbody>
</table>
Ljubo, as the presenter was required to provide brochures of the possible holiday destinations.

He provided the following brochures with the following holiday package information:

Table 8 Brochure Information to be Presented

<table>
<thead>
<tr>
<th>Destination</th>
<th>Queenstown (New Zealand)</th>
<th>Wanaka (New Zealand)</th>
<th>Silverstar (Canada)</th>
<th>Whistler (Canada)</th>
<th>Perisher (Australia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost (AUD$)</td>
<td>3398</td>
<td>2490</td>
<td>7681</td>
<td>6452</td>
<td>3280</td>
</tr>
<tr>
<td>Accommodation Quality</td>
<td>4.5</td>
<td>2.5</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Days Skiing</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>7</td>
<td>3</td>
</tr>
</tbody>
</table>

The cognitive layer is defined in terms of a fuzzy logic based system. For functionally equal partners that are virtual beings, this process is used to determine the resulting decision made during the collaborative process.

5.2.2 Technical Game Implementation

5.2.2.1 Scenario Collaborative Process

The collaborative process involved in this play scenario involves selecting a ski holiday. By using the collaborative process it is possible to model the process involved in selecting a holiday destination by the board members of the electronic meeting room. The following figure highlights how the play scenario is compatible with the collaborative process.

---

Note: While the destinations listed are real, for the purposes of this case study, the package information was simplified and does not reflect the original source materials.
Table 9 A Breakdown of the collaborative process

<table>
<thead>
<tr>
<th>Collaborative Step</th>
<th>Play Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invitation</td>
<td>All partners have accepted the invitation to meet and discuss the ski holiday destination</td>
</tr>
<tr>
<td>Attendance</td>
<td>All partners log into the electronic meeting room.</td>
</tr>
</tbody>
</table>
| Initiation         | Once all partners have entered the electronic meeting room, the presenter starts the meeting. 
                   | Presenter: performs the start meeting action. |
| Definition of Goals| The presenter states the goals of the electronic meeting. 
                   | Presenter: "Based upon Cost, Accommodation Quality and Number of Days Skiing, we must choose the best holiday for us all." |
| Conversations:     | The conversations that take place within the play scenario are structured in a formal conversation procedure detailed in 3.2 The Collaborative Process. The conversations continue until there are no more holiday destinations to evaluate by the partners. |
| Negotiation        | Once there are no more destinations to evaluate, the negotiation process commences. At this point, the Presenter shall establish a baseline for negotiation. Opinions are collected in terms of the baseline terminology. |
| Conclusion         | The Presenter begins the conclusion phase once all negotiation has been completed. At this point, the presenter provides a summary of the collaborative process. The presenter can then determine the best ski holiday. The decision is relayed to the participating partners. 
                   | Finally, the Presenter concludes the meeting with the Finish Action |

The conversations required for the Ski Holiday collaborative process must be defined prior to the construction of the play scenario. The electronic meeting room will not be utilising “open” (Human-Like) conversations or actions, but for simplicity shall operate within a constrained conversation structure. Figure 39 describes this structure, as well as the questions and actions that occur every time a new travel destination brochure is presented to the group of partners.
Once all brochures have been observed and comments given, the Presenter will then announce that Negotiation is to occur. In the electronic meeting room, this process is essentially a repeat of the question process (without the re-presentation of the brochure) however in this instance, the influence factor has been applied to each partner’s response.

5.2.2.1 Design Assumptions
For this play scenario that is being designed, a number of assumptions have been made about the electronic meeting room and the behaviour of the functionally equal partners (the group of board members) situated within it.

Firstly, the virtual beings do not possess intimate/familiar knowledge of the human that they replace. The intention of the virtual being is to replace a human, giving them the same ability to perform decision-making within the play scenario, but not necessarily the same/equal cognitive capabilities and thus not to using the meeting room as a form of Turing Test (A Turing test, made famous by Allan Turing, is a test used to determine if an artificial intelligence is indistinguishable from a human being. A person presents questions to a human and artificial participant that they cannot see, and can only communicate with via a computer terminal. The person presenting questions must then choose which of the interviewees is human).

Secondly, the number of the decision makers has been limited to five functionally equal partners.

Finally, the concept of functionally equal partner influence has been reduced to simple factors for the purposes of this case study. Depending on a particular virtual being’s affinity with another functionally equal partner, it is more likely that that virtual being would choose their position.

5.2.2.1.2 Architecture
The architecture of the electronic meeting room is designed around supporting the collaborative process. As such it embodies a layered collaborative architecture. Each layer is interlinked with the next providing a foundation for the collaborative process.

While the layered collaborative architecture is evident across the entire electronic meeting room computer game, the game itself consists of three parts. Firstly, the management of the
The electronic meeting room is handled by a central meeting room (server) component. The other two parts allow human and virtual functionally equal partners to interact using the meeting room component (Figure 6).

Each of these three parts implements the layered approach. In the design of the electronic meeting room the communication layer handles the transport of information between the electronic meeting room and the functionally equal partner interface components. The meeting room, virtual being interface and human being interfaces operate as independent software components which may exist in a distributed form. Information is transported between each of these components in an XML structure. This allows the discrete separation of information pertaining to each layer.

![Diagram of layered information](image)

Each layer is then dealt with in a different manner. Communications layer information is used to handle software-level information such as connections and infrastructure information. The physical layer conveys information about the electronic meeting room and the manipulation of objects within the room (such as a chair, document etc.). Finally, the cognitive layer conveys...
messages between each functionally equal partner so that the collaborative process may occur.

In the play scenario that being constructed, information about the physical layer and what affect it may have upon holiday choosing process requires definition.

For the purposes of this play scenario, the physical layer has been limited to four possible collaborative interactions.

Table 10 Functionally equal partner Roles and their actions

<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Begin</td>
<td>Starts the meeting</td>
<td>P&amp;N</td>
</tr>
<tr>
<td>Finish</td>
<td>Concludes the meeting</td>
<td>P&amp;N</td>
</tr>
<tr>
<td>Present Brochure</td>
<td>Presents a holiday destination brochure to the other partners.</td>
<td>P&amp;N</td>
</tr>
<tr>
<td>Read brochure</td>
<td>Reads/Perceives information about a presented brochure</td>
<td>Board Member</td>
</tr>
</tbody>
</table>

The cognitive layer is defined in terms of a fuzzy logic based system. For functionally equal partners that are virtual beings, this process is used to determine the resulting decision made during the collaborative process.

5.2.2.2 Technical Architecture
Each human functionally equal partner that has joined the electronic meeting room perceives the room via the human interface component. They see visually themselves placed at the meeting room table along with the other partners. By default, partners only see a silhouette of all other board members in the meeting room.
To include virtual beings to replace human beings within the play scenario, each of the board members was asked their opinion about each of the inputted linguistic terms. This was used to provide perspectives for each virtual functionally equal partner that attended the electronic meeting room:

Table 11 Virtual Being Perceptions

<table>
<thead>
<tr>
<th></th>
<th>Cost Crisp</th>
<th>Cost Fuzzy</th>
<th>Quality Crisp</th>
<th>Quality Fuzzy</th>
<th>Skiing Crisp</th>
<th>Skiing Fuzzy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daniel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>Cheap</td>
<td>3</td>
<td>Poor</td>
<td>2</td>
<td>Short</td>
<td></td>
</tr>
<tr>
<td>3000</td>
<td>Reasonable</td>
<td>4</td>
<td>Good</td>
<td>4</td>
<td>Ideal</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>Expensive</td>
<td>5</td>
<td>Luxurious</td>
<td>6</td>
<td>Long</td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Cost Crisp</td>
<td>Cost Fuzzy</td>
<td>Quality Crisp</td>
<td>Quality Fuzzy</td>
<td>Skiing Crisp</td>
<td>Skiing Fuzzy</td>
</tr>
<tr>
<td>-------</td>
<td>------------</td>
<td>------------</td>
<td>---------------</td>
<td>---------------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Kara</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1500</td>
<td>Cheap</td>
<td>2.5</td>
<td>Poor</td>
<td>3</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>2500</td>
<td>Reasonable</td>
<td>4</td>
<td>Good</td>
<td>7</td>
<td>Ideal</td>
</tr>
<tr>
<td></td>
<td>3500</td>
<td>Expensive</td>
<td>5</td>
<td>Luxurious</td>
<td>9</td>
<td>Long</td>
</tr>
<tr>
<td>Martyn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2500</td>
<td>Cheap</td>
<td>3.5</td>
<td>Poor</td>
<td>6</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>5000</td>
<td>Reasonable</td>
<td>4</td>
<td>Good</td>
<td>12</td>
<td>Ideal</td>
</tr>
<tr>
<td></td>
<td>6500</td>
<td>Expensive</td>
<td>5</td>
<td>Luxurious</td>
<td>18</td>
<td>Long</td>
</tr>
<tr>
<td>Janet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4000</td>
<td>Cheap</td>
<td>4</td>
<td>Poor</td>
<td>5</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>5000</td>
<td>Reasonable</td>
<td>5</td>
<td>Good</td>
<td>10</td>
<td>Ideal</td>
</tr>
<tr>
<td></td>
<td>7500</td>
<td>Expensive</td>
<td>5</td>
<td>Luxurious</td>
<td>15</td>
<td>Long</td>
</tr>
<tr>
<td>Mark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1500</td>
<td>Cheap</td>
<td>2</td>
<td>Poor</td>
<td>3</td>
<td>Short</td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>Reasonable</td>
<td>3</td>
<td>Good</td>
<td>5</td>
<td>Ideal</td>
</tr>
<tr>
<td></td>
<td>3000</td>
<td>Expensive</td>
<td>4</td>
<td>Luxurious</td>
<td>7</td>
<td>Long</td>
</tr>
</tbody>
</table>

From this point on, the behaviour of the virtual functionally equal partners within the play scenario is discussed. To demonstrate this, the entire play scenario was conducted again with virtual functionally equal partners.
All virtual partners in the play scenario utilised the same set of fuzzy rules. In order to reduce the complexity of the rule set, the number of linguistic terms used by each functionally equal partner was reduced to three. This leads to a fuzzy rule table consisting of twenty-seven rules. Given that each virtual partner may have a different perspective when applying the fuzzy rules to each of the five holiday destinations, it can be quickly seen that there is a significant number of rules to be designed and evaluated.

The following table shows the fuzzy rules that were constructed from heuristic information provided by a number of human experts:

Table 12 Table of Play Scenario Fuzzy Rules

<table>
<thead>
<tr>
<th>RULE</th>
<th>IF</th>
<th>Cost =</th>
<th>Quality =</th>
<th>Days Skiing =</th>
<th>THEN</th>
<th>Destination =</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IF</td>
<td>Cheap</td>
<td>Poor</td>
<td>Short</td>
<td>THEN</td>
<td>Shabby</td>
</tr>
<tr>
<td>2</td>
<td>IF</td>
<td>Cheap</td>
<td>Poor</td>
<td>Ideal</td>
<td>THEN</td>
<td>Shabby</td>
</tr>
<tr>
<td>3</td>
<td>IF</td>
<td>Cheap</td>
<td>Poor</td>
<td>Long</td>
<td>THEN</td>
<td>Average</td>
</tr>
<tr>
<td>4</td>
<td>IF</td>
<td>Cheap</td>
<td>Good</td>
<td>Short</td>
<td>THEN</td>
<td>Average</td>
</tr>
<tr>
<td>5</td>
<td>IF</td>
<td>Cheap</td>
<td>Good</td>
<td>Ideal</td>
<td>THEN</td>
<td>Good</td>
</tr>
<tr>
<td>6</td>
<td>IF</td>
<td>Cheap</td>
<td>Good</td>
<td>Long</td>
<td>THEN</td>
<td>Good</td>
</tr>
<tr>
<td>7</td>
<td>IF</td>
<td>Cheap</td>
<td>Luxurious</td>
<td>Short</td>
<td>THEN</td>
<td>Unlikely</td>
</tr>
<tr>
<td>8</td>
<td>IF</td>
<td>Cheap</td>
<td>Luxurious</td>
<td>Ideal</td>
<td>THEN</td>
<td>Unlikely</td>
</tr>
<tr>
<td>9</td>
<td>IF</td>
<td>Cheap</td>
<td>Luxurious</td>
<td>Long</td>
<td>THEN</td>
<td>Unlikely</td>
</tr>
<tr>
<td>10</td>
<td>IF</td>
<td>Reasonable</td>
<td>Poor</td>
<td>Short</td>
<td>THEN</td>
<td>Shabby</td>
</tr>
<tr>
<td>11</td>
<td>IF</td>
<td>Reasonable</td>
<td>Poor</td>
<td>Ideal</td>
<td>THEN</td>
<td>Shabby</td>
</tr>
<tr>
<td>12</td>
<td>IF</td>
<td>Reasonable</td>
<td>Poor</td>
<td>Long</td>
<td>THEN</td>
<td>Average</td>
</tr>
<tr>
<td>13</td>
<td>IF</td>
<td>Reasonable</td>
<td>Good</td>
<td>Short</td>
<td>THEN</td>
<td>Average</td>
</tr>
<tr>
<td>14</td>
<td>IF</td>
<td>Reasonable</td>
<td>Good</td>
<td>Ideal</td>
<td>THEN</td>
<td>Good</td>
</tr>
<tr>
<td>15</td>
<td>IF</td>
<td>Reasonable</td>
<td>Good</td>
<td>Long</td>
<td>THEN</td>
<td>Good</td>
</tr>
</tbody>
</table>
16 IF Reasonable Luxurious Short THEN Good
17 IF Reasonable Luxurious Ideal THEN Good
18 IF Reasonable Luxurious Long THEN Extravagant
19 IF Expensive Poor Short THEN Shabby
20 IF Expensive Poor Ideal THEN Shabby
21 IF Expensive Poor Long THEN Average
22 IF Expensive Good Short THEN Average
23 IF Expensive Good Ideal THEN Good
24 IF Expensive Good Long THEN Extravagant
25 IF Expensive Luxurious Short THEN Extravagant
26 IF Expensive Luxurious Ideal THEN Extravagant
27 IF Expensive Luxurious Long THEN Extravagant

In order to evaluate the inputs in terms of the fuzzy rules stated above, a T-Function was utilised to determine the degree of membership each crisp value has to each of the three linguistic terms of each input. To achieve this, each membership function required values for the variables defined in Equation 11. The following values were used:

1. Centre $b$ point: defined as being the value indicated by each partner for each linguistic term in Table 11 (for example: Kara defined Reasonable as being $2500$ and hence is her centre point the Reasonable membership function).

2. To determine the $a$ and $c$ values, a “bandwidth” value was defined for each linguistic variable. The $a$ and $c$ values are equal to $b - \frac{1}{2} \text{bandwidth value}$ and $b + \frac{1}{2} \text{bandwidth value}$ respectively:
5.2.3 Decision-Making

In this scenario, the virtual collaborative FEPs utilize fuzzy logic to determine how to respond during the collaborative process conversations. It is also used to interpret the responses of other partners and to obtain an outcome from the play scenario (the choice of a Ski Holiday destination).

The play scenario has three inputs by which functionally equal partners may determine their response to a given holiday destination: Cost, Accommodation Quality and Days Skiing. The following Linguistic Terms are to be used to describe these three inputs. For simplicity, each input has its linguistic variable limited to three rules.

Table 14 Input Linguistic Variables and Terms for the Play Scenario

<table>
<thead>
<tr>
<th>Cost Measure: Dollars</th>
<th>Accommodation Quality Measure: Stars</th>
<th>Days Skiing Measure: Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheap</td>
<td>Poor</td>
<td>Short</td>
</tr>
<tr>
<td>Reasonable</td>
<td>Good</td>
<td>Ideal</td>
</tr>
<tr>
<td>Expensive</td>
<td>Luxurious</td>
<td>Long</td>
</tr>
</tbody>
</table>
The output decision of each partner is articulated using the Destination Opinion Linguistic Variable. Unlike the input variables, the Destination Opinion consists of five linguistic terms:

Table 15 Output Linguistic Variable and Terms

<table>
<thead>
<tr>
<th>Destination Opinion</th>
<th>Crisp Output Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlikely</td>
<td>1</td>
</tr>
<tr>
<td>Shabby</td>
<td>2</td>
</tr>
<tr>
<td>Average</td>
<td>3</td>
</tr>
<tr>
<td>Good</td>
<td>4</td>
</tr>
<tr>
<td>Extravagant</td>
<td>5</td>
</tr>
</tbody>
</table>

5.2.4 Results

During the conversation phase, each functionally equal partner was able to comment on each of the presented destinations. Internally, within each virtual FEP a set of fuzzy rules are applied
based upon their internal perceptions of the linguistic terms. Table 16 shows the final result of each conversation showing the linguistic term and the centre of gravity that resulted in the selection of that final output term:

Table 16 Results of the Conversation Process

<table>
<thead>
<tr>
<th>Name</th>
<th>Daniel</th>
<th>Kara</th>
<th>Martyn</th>
<th>Janet</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queenstown</td>
<td>COG</td>
<td>3.68</td>
<td>3.79</td>
<td>2.31</td>
<td>2.41</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Good</td>
<td>Good</td>
<td>Shabby</td>
<td>Shabby</td>
</tr>
<tr>
<td>Wanaka</td>
<td>COG</td>
<td>3.14</td>
<td>2.75</td>
<td>2.30</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Average</td>
<td>Average</td>
<td>Shabby</td>
<td>Shabby</td>
</tr>
<tr>
<td>Silverstar</td>
<td>COG</td>
<td>5.00</td>
<td>5.00</td>
<td>3.67</td>
<td>4.50</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Extravagant</td>
<td>Extravagant</td>
<td>Good</td>
<td>Extravagant</td>
</tr>
<tr>
<td>Whistler</td>
<td>COG</td>
<td>4.40</td>
<td>4.07</td>
<td>3.17</td>
<td>3.75</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Good</td>
<td>Good</td>
<td>Average</td>
<td>Good</td>
</tr>
<tr>
<td>Perisher</td>
<td>COG</td>
<td>3.02</td>
<td>3.15</td>
<td>2.27</td>
<td>2.63</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Average</td>
<td>Average</td>
<td>Shabby</td>
<td>Average</td>
</tr>
</tbody>
</table>

This particular scenario also included a simplified negotiation phase within the collaborative process via the use of an influence factor. By taking into account the influences of the other FEPs upon each other, it was possible to obtain a final set of terms to be used during the conclusion phase of the process.
Table 17 Table of Influences

<table>
<thead>
<tr>
<th>Influence</th>
<th>Daniel</th>
<th>Kara</th>
<th>Martyn</th>
<th>Janet</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daniel</td>
<td>0</td>
<td>0.25</td>
<td>0.1</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>Kara</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Martyn</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>0.1</td>
</tr>
<tr>
<td>Janet</td>
<td>0.05</td>
<td>0.05</td>
<td>0.25</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Mark</td>
<td>0.1</td>
<td>0.05</td>
<td>0.1</td>
<td>0.05</td>
<td>0</td>
</tr>
</tbody>
</table>

Note that with the influences applied, a number of values have changed to a new linguistic term.

Table 18 Results after Negotiation with changes shaded

<table>
<thead>
<tr>
<th>Name</th>
<th>Daniel</th>
<th>Kara</th>
<th>Martyn</th>
<th>Janet</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queenstown</td>
<td>COG</td>
<td>3.55</td>
<td>3.71</td>
<td>2.66</td>
<td>3.38</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Good</td>
<td>Good</td>
<td>Shabby</td>
<td>Shabby</td>
</tr>
<tr>
<td>Wanaka</td>
<td>COG</td>
<td>2.90</td>
<td>2.83</td>
<td>2.40</td>
<td>2.74</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Average</td>
<td>Average</td>
<td>Shabby</td>
<td>Average</td>
</tr>
<tr>
<td>Silverstar</td>
<td>COG</td>
<td>4.84</td>
<td>4.98</td>
<td>4.14</td>
<td>4.59</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Extravagant</td>
<td>Extravagant</td>
<td>Good</td>
<td>Extravagant</td>
</tr>
<tr>
<td>Whistler</td>
<td>COG</td>
<td>4.21</td>
<td>4.18</td>
<td>3.61</td>
<td>4.21</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Perisher</td>
<td>COG</td>
<td>3.03</td>
<td>3.12</td>
<td>2.58</td>
<td>3.13</td>
</tr>
<tr>
<td></td>
<td>Term</td>
<td>Average</td>
<td>Average</td>
<td>Average</td>
<td>Average</td>
</tr>
</tbody>
</table>
The final part of the collaborative process is the conclusion phase. In the electronic meeting room, the final decision based on the feedback provided by all partners is to be made by the Presenter. The following process is used to determine a final outcome of the electronic meeting room:

1. An average COG is determined for each destination.

2. Since the outcome is to obtain a destination within the Average to Good range of destination opinions, the averages for each destination are then evaluated using the membership functions for Average and Good linguistic terms. Recall that the $b$ Point for Average and Good are 3 and 4 respectively with a bandwidth of 3.

3. The resulting Centre of Gravity across the Average and Good linguistic terms determines the final outcome value.

4. The final destination as determined by the group is the destination that is closest to the final determined COG.
Table 19 Conclusion Process determining a final outcome

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>T Function Good</th>
<th>T Function Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queenstown</td>
<td>3.42</td>
<td>0.61</td>
<td>0.72</td>
</tr>
<tr>
<td>Wanaka</td>
<td>2.77</td>
<td>0.18</td>
<td>0.85</td>
</tr>
<tr>
<td>Silverstar</td>
<td>4.68</td>
<td>0.55</td>
<td>0.00</td>
</tr>
<tr>
<td>Whistler</td>
<td>4.15</td>
<td>0.90</td>
<td>0.23</td>
</tr>
<tr>
<td>Perisher</td>
<td>3.06</td>
<td>0.37</td>
<td>0.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Good Area</th>
<th>Good B Point * Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queenstown</td>
<td>1.27</td>
<td>5.10</td>
</tr>
<tr>
<td>Wanaka</td>
<td>0.49</td>
<td>1.96</td>
</tr>
<tr>
<td>Silverstar</td>
<td>1.19</td>
<td>4.77</td>
</tr>
<tr>
<td>Whistler</td>
<td>1.49</td>
<td>5.94</td>
</tr>
<tr>
<td>Perisher</td>
<td>0.91</td>
<td>3.62</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total Area</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Queenstown</td>
<td>5.35</td>
<td>21.40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Average Area</th>
<th>Average B Point * Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queenstown</td>
<td>1.38</td>
<td>4.15</td>
</tr>
<tr>
<td>Wanaka</td>
<td>1.46</td>
<td>4.39</td>
</tr>
<tr>
<td>Silverstar</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Whistler</td>
<td>0.62</td>
<td>1.86</td>
</tr>
<tr>
<td>Perisher</td>
<td>1.50</td>
<td>4.49</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total B Point Area</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Queenstown</td>
<td>4.97</td>
<td>14.90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Total Area</th>
<th>Total B Points * Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queenstown</td>
<td>10.32</td>
<td>36.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Final COG</th>
<th>Final Destination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queenstown</td>
<td>3.52</td>
<td>Queenstown</td>
</tr>
</tbody>
</table>
By following through the collaborative processes within the electronic meeting room play scenario, it has been possible to ascertain the final destination as chosen by the group of board members: Queenstown.

5.3 Tender Assessment

The Tender assessment game play scenario is an example of a business-oriented application of collaborative FEPs in computer games. It also highlights how different partners are able to contribute different pieces of knowledge to the group as a whole. The approach applied in the computer game play scenario presented here is a combination of the collaborative process in which all partners share the decision making, and an electronic mediator based upon the concept of multi-criteria decision-making. This approach ensures that all partners participate directly in the outcomes of a collaborative process. Given the neutrality of the electronic mediator, changes to the outcome of the decision-making process become a result of additional negotiation and influence amongst the involved FEPs.

The electronic mediator achieves a collaborative outcome from the engaged FEPs by having each specify their particular aspirations (that is the desired level of quality) and reservations (the lowest level of quality that must be achieved) for each attribute contributing to the evaluation. By defining the reservation and aspiration levels for each attribute, the mediator can apply an achievement function to determine an outcome value. This however is not simply a case of selecting tolerances with the result obtained strictly satisfying the criteria of a membership function. The achievement function also encapsulates the concepts of overachievement and underachievement. That is, if an attribute is beyond a partner’s aspiration level, then some trade-offs can occur if another attribute is below a partner’s reservation level.
The origins of this particular concept have grown out of observing the human quasi-satisficing approach to decision making, where trade-offs can occur when the achievement of a certain attribute is maximized (Wierzbicki, A Mathematical Basis for Satisficing Decision Making, 1982). This is achieved by adding modifiers to the membership function to promote over-achievement and demote under-achievement (Wierzbicki, Negotiation and Mediation in Conflicts, II: Plural Rationality and Interactive Decision Processes, 1985). In addition, weighting coefficients can be utilized to assist in determining the trade-offs that can be applied.

5.3.1 Scenario
When an organization produces a tender document, requesting submissions from vendors to provide a solution, the submissions undergo a vendor selection process. Despite best efforts, many information technology projects still fail to produce on-time, on-budget solutions. There are many reasons for this with examples ranging from poor planning, unproven technology to inability of the vendor to meet commitments (Whittaker, 1999).

Conversely, a software vendor should select potential projects to pursue by applying a selection process to the tenders that they receive. The selection process must not be simply driven by profit, but also by the capability of the vendor to deliver upon their commitment. For a vendor, careful selection of projects to submit a response is vitally important as selecting the wrong project may cost the business dearly financially as well as their reputation.

To ensure the selection of projects with the lowest potential risks while maximizing profit, the vendor engages a number of representatives across their organization with various skills and insights to evaluate any tenders that may have been announced. Each member of the assessment team represents the interests of a different business group, providing information and assessments based around their area of expertise.
The tenders presented to the group are represented in a manner that is relevant to the selection criteria of the organizations producing the tender (Table 20).

Table 20 Tender Attributes as Produced by the Source Organizations

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>The amount the source organization has set as the cost of the project</td>
</tr>
<tr>
<td>Announcement Date</td>
<td>The date that the successful vendor shall be announced</td>
</tr>
<tr>
<td>Commencement Date</td>
<td>The date that the project is to be started</td>
</tr>
<tr>
<td>Delivery Date</td>
<td>The date that the project is to be completed</td>
</tr>
<tr>
<td>Business Analysts required</td>
<td>Estimated number of business analysts required that have expertise in the business area of the organization</td>
</tr>
<tr>
<td>Developers required</td>
<td>Estimated number of software developers required to produce the project's deliverables</td>
</tr>
<tr>
<td>Business Area</td>
<td>Describes the business area that the project is related to</td>
</tr>
</tbody>
</table>

It is up to the vendors to produce a set of tender attributes that makes sense to them. This is achieved by treating tender information as constituent sub-attributes which are combined with knowledge obtained from the various business units within the vendor organization to produce a set of tender attributes which then contribute to the decision making process (Table 21).
Therefore, the collaborative engagement undertaken within the computer game has two goals:

1. The derivation of tender attributes relevant to the vendor and;

2. The selection of a tender based upon these attributes.

The first objective of the game is to obtain a set of tender attributes for assessment. Each FEP represents a particular business unit which contributes either at the attribute or sub-attribute level (Table 22). For example, the FEP representing the Financial department is able to provide the Profit Attribute during the process however, this FEP requires information from other department representatives to obtain the required sub-attributes. In this example, a query may be made by the Financial FEP to the Human Resources (HR) department representative to obtain Staff Costs. This representative would then use HR specific information relating to staff compensation, coupled with information obtained from the tender about the number of

---

**Table 21 Tender attributes to be obtained during the game**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Sub-Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profit</td>
<td>Staff Costs</td>
</tr>
<tr>
<td></td>
<td>Training Costs</td>
</tr>
<tr>
<td></td>
<td>Hire Costs</td>
</tr>
<tr>
<td></td>
<td>Revenue</td>
</tr>
<tr>
<td>Time</td>
<td>Lead Time (Time between vendor announcement and start of the project)</td>
</tr>
<tr>
<td></td>
<td>Time to Hire Staff</td>
</tr>
<tr>
<td></td>
<td>Time to Train Staff</td>
</tr>
<tr>
<td>Resources</td>
<td>Utilization</td>
</tr>
<tr>
<td>Business Area</td>
<td>Tender Business Area</td>
</tr>
<tr>
<td></td>
<td>Vendor Business Area</td>
</tr>
</tbody>
</table>
analysts and developers required to provide this information back to the Financial FEP as the Staff Costs sub-attribute.

Table 22 Attributes and Sub-Attributes provided by the different departments

<table>
<thead>
<tr>
<th>FEP Representing Department</th>
<th>Attribute</th>
<th>Sub-Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finance</td>
<td>Profit</td>
<td></td>
</tr>
<tr>
<td>Human Resources</td>
<td>Resources</td>
<td>Utilization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Staff Costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hiring Costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time to Hire Staff</td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td>Training Costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time to Train Staff</td>
</tr>
<tr>
<td>Project Management</td>
<td>Time</td>
<td>Lead Time</td>
</tr>
<tr>
<td>Executive</td>
<td>Business Area</td>
<td>Vendor Business Area</td>
</tr>
</tbody>
</table>

Once the attributes of each tender have been determined, it is possible for the participants in the computer game to engage in the decision making process and select a preferred tender.

Figure 43 A Virtual FEP
5.3.2 Technical Game Implementation

In order to adequately experiment with cooperative FEPs, the cognitive layer is designed (conceptualized) as an encapsulated software component. As a practical example, one of the decision-making processes utilized in the VBI cognitive layer uses T-Function (Appendix A) fuzzy logic algorithms with a small-footprint database storing the linguistic terms and variables.

Combining this decision-making process with a language interpreter allowed the virtual FEPs to interact with their human partners.

5.3.3 Decision-Making

Group decision making can be achieved in many different ways. However if the process by which a decision is reached is not considered neutral or equitable, it may possibly lead to conflict amongst collaborative partners (Wierzbicki, Negotiation and Mediation in Conflicts, II: Plural Rationality and Interactive Decision Processes, 1985). It is therefore important that a formal method for collaborative decision making underpins the outcomes of the collaborative computer game.

In some collaborative games utilizing fuzzy logic, the collaborative process involved a neutral party which would aggregate the decisions of the involved partners. This type of collaborative decision-making left the management of outcomes to this neutral party. However, this introduces the risk of bias (potentially on the part of the neutral partner) as well as the partners providing decisions on constituent attributes rather than the final outcomes of the process; essentially rendering the partners advisors rather than decision-makers.

The approach applied in the computer game play scenario presented here is a combination of the collaborative process in which all partners share the decision making, and an electronic mediator based upon the concept of multi-criteria decision-making. This approach ensures
that all partners participate directly in the outcomes of a collaborative process. Given the neutrality of the electronic mediator, changes to the outcome of the decision-making process become a result of additional negotiation and influence amongst the involved FEPs.

The electronic mediator achieves a collaborative outcome from the engaged FEPs by having each specify their particular aspirations (that is the desired level of quality) and reservations (the lowest level of quality that must be achieved) for each attribute contributing to the evaluation. By defining the reservation and aspiration levels for each attribute, the mediator can apply an achievement function to determine an outcome value. This however is not simply a case of selecting tolerances with the result obtained strictly satisfying the criteria of a membership function. The achievement function also encapsulates the concepts of overachievement and underachievement. That is, if an attribute is beyond a partner’s aspiration level, then some trade-offs can occur if another attribute is below a partner’s reservation level.

Making the group decision a formalized calculation based upon the input of the collaborating group ensures the neutrality of the decision while exhibiting a more human-like approach to attribute assessment and decision making. By combining the electronic mediator with a collaborative process, the responsibility to change the outcomes rests with discussion amongst the engaged FEPs.

5.3.4 Results

By this point, the FEPs in this computer game have engaged in a collaborative process consisting of two goals which then form the basis of the one outcome: The selection of a project tender which is most appropriate for their business to bid for. It should be noted that it has not been necessary for any of the participating FEPs to reveal whether they are human or
virtual in nature, nor is it evident to the group if a new FEP has replaced another during the process.

<table>
<thead>
<tr>
<th>Partner</th>
<th>Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Martyn:</td>
<td>Our final collaborative decision scores are as follows:</td>
</tr>
<tr>
<td></td>
<td>Northern Council: 4.948</td>
</tr>
<tr>
<td></td>
<td>Consolidated Logistics: -6.39</td>
</tr>
<tr>
<td></td>
<td>Granite Belt Exploration: -1.71</td>
</tr>
<tr>
<td></td>
<td>Therefore, our final decision with a score of 4.948 is Northern Council</td>
</tr>
</tbody>
</table>

### 5.4 Project Planning

In order to investigate influence in the collaborative process, a play scenario was devised based upon a documented real-world project planning process from industry. The scenario is used as a training exercise for management candidates to investigate their negotiation skills in representing their business group’s interests in a collaborative situation.

#### 5.4.1 Scenario

The scenario involves a particular enterprise software developer that utilises a common infrastructure upon which all its enterprise solutions are based. When a new version of the infrastructure is to be developed, the managers and architects of this business unit formulate a list of potential projects that can be pursued within the next version’s development timeframe. Each project has an estimated development time budget.

Unfortunately, the list of potential projects greatly exceeds the number of development days available within the new version development period.
In order to satisfy the needs of the enterprise product business groups, the manager responsible for infrastructure therefore, contacts the managers of the various enterprise products to obtain their feedback on what projects are most desirable in their respective areas.

Since there are timeframe limitations, and the enterprise products address different business needs, a significant amount of time is involved in negotiating a “best fit” for all parties. As such each of the business group managers wants to influence the decisions of the others in order to broker the inclusion in the development plan of their highest priority requirements.

The following table documents the business units involved:

<table>
<thead>
<tr>
<th>INF</th>
<th>Infrastructure Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIN</td>
<td>Financial Application</td>
</tr>
<tr>
<td>SM</td>
<td>Student Administration</td>
</tr>
<tr>
<td>PR</td>
<td>Property Management</td>
</tr>
<tr>
<td>CRM</td>
<td>Customer Relationship Management System</td>
</tr>
<tr>
<td>PM</td>
<td>Project Management</td>
</tr>
<tr>
<td>BI</td>
<td>Business Intelligence</td>
</tr>
<tr>
<td>HRP</td>
<td>Human Resources Management System</td>
</tr>
<tr>
<td>PS</td>
<td>Custom Application Development</td>
</tr>
<tr>
<td>CI</td>
<td>Custom Integration and Interfacing</td>
</tr>
<tr>
<td>TS</td>
<td>Technical Services</td>
</tr>
</tbody>
</table>
The play scenario is calibrated against the original business data that was collected prior to the meetings. Each business group was requested to review the list of potential projects (88 in total) and place a numbered priority next to each item until the development days from the items totalled approximately 400 days.

When a candidate undertakes the training scenario, they must represent their business group’s interests, maximising the number of inclusions within the project.

Unlike a regular play scenario, the following exercises have been undertaken with virtual FEPs only, in order to investigate their effectiveness in influencing the final outcomes. The following influence methods were undertaken:

1. No Influence (baseline)
2. Arbitrary Influence
3. Common Interest

5.4.2 Technical Game Implementation
The technical game implementation for the project planning scenario is very similar to the Holiday Destination scenario. The primary difference between this scenario and the Holiday Scenario are the higher number of participants, and the particular focus on the different types of influence.

5.4.3 Decision-Making
The participating FEPs utilize a collaborative fuzzy logic process to determine the responses given during the collaborative process.

In order to determine influence between the FEPs involved, the following methods are applied:
An arbitrary percentage influence between 0 to 10 percent was allocated to each business unit representative. As the collaborative process progressed, the responses by each representative were influenced by the other ten member’s influence. The breakdown of the allocated influence is (Table 25):

Table 25 Organisation Unit Influence Factors

<table>
<thead>
<tr>
<th>INF</th>
<th>FIN</th>
<th>SM</th>
<th>PR</th>
<th>CRM</th>
<th>PM</th>
<th>BI</th>
<th>HRP</th>
<th>PS</th>
<th>CI</th>
<th>TS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.06</td>
<td>0.1</td>
<td>0.05</td>
<td>0.03</td>
<td>0.04</td>
<td>0.02</td>
<td>0.09</td>
<td>0.08</td>
<td>0.01</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Common interest influence was determined by informing each FEP of the other member’s “Top 5” projects. If a project matched one of the other’s in the top five, an influence percentage was awarded between 1 and 5 percent. This influence was allowed to compound if more than one project was in common. A 5 percent influence was awarded when there was a total match (i.e. Partner A’s first project choice is the same as Partner B), reducing to zero percent the further away a project was in terms of order (i.e. Partner A’s project is ranked 3, and partner B’s project is ranked 5, therefore the influence is 3 percent). The following table documents the common influence factors across the business units:
### Table 26 Table of Influence across all Organisation Units

<table>
<thead>
<tr>
<th></th>
<th>INF</th>
<th>F1N</th>
<th>SM</th>
<th>PR</th>
<th>CRM</th>
<th>PM</th>
<th>BI</th>
<th>HRP</th>
<th>PS</th>
<th>CI</th>
<th>TS</th>
</tr>
</thead>
<tbody>
<tr>
<td>INF</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>F1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.01</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.01</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>SM</td>
<td>0.0</td>
<td>0.0</td>
<td>0.04</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.04</td>
<td>0.04</td>
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<td>0.06</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
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<td>0.02</td>
<td>0.04</td>
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<td>0.0</td>
<td>0.0</td>
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</tr>
<tr>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.14</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.06</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>CI</td>
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<td>0.0</td>
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<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>TS</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

#### 5.4.4 Results

After completing each run of the play scenario, the results were compared to the actual results collected during the industry process.
Across the 88 projects identified, approximately seventy percent of projects were common to all results. It can also be seen from the captured results, that influence does impact the final makeup of the projects to be included within the allowable project budget timeframe.

Table 27 Collaborative Decision-Making Results

<table>
<thead>
<tr>
<th>Included Project Days</th>
<th>% Match with Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry Results</td>
<td>409</td>
</tr>
<tr>
<td>No Influence</td>
<td>397</td>
</tr>
<tr>
<td>Arbitrary Influence</td>
<td>400</td>
</tr>
<tr>
<td>Common Interest</td>
<td>400</td>
</tr>
</tbody>
</table>

While the percentage of match with the industry results is fairly high, of more interest are the reasons of difference between the industry and the play scenarios. As stated earlier, factors
such as trade and pre-existing relationships affect influence in the decision-making process. In addition, given the business unit group size of eleven, there may also be factors of influence such as the group size (Fay, Garrod, & Carletta, 2000). Subsequent play scenarios will require the incorporation of these additional factors. Closing this “collaborative gap” between a human social group and a virtual social group with the same goals and objectives is a compelling area of research, and a large step along the road to achieving social acceptance of artificial beings as FEPs.

5.4.4.1 Industry Results
As noted earlier, the data collected for this play scenario is sourced from real-world business data. As such, the collected data does not have the rigour of true experimental collection. For example, the business groups involved in the real process interpreted the ranking instructions sent out by the infrastructure team in different ways. While the scenario itself was a compelling real-world case, further work on industry scenarios will require more explicit information to ensure the resulting data collection is of experimental quality.

5.5 Conclusion
The case studies presented in this chapter demonstrate that the developed TeamMATE computer game can be effectively used to support collaborative functionally equal partners in a variety of play scenarios such as entertainment; educational and business (corporate) decision-making type computer games.

Each case study implemented the concepts required to support FEPs in collaborative game play. In addition each case study explored a different attribute of collaboration, contributing to the understanding of the use and implication of the developed collaborative game concept. Specifically:
1. The Hammurabi case study demonstrated the application of different problem-solving techniques within a collaborative computer game.

2. Holiday Destination addressed the problem of perception amongst the players when collaborating.

3. Tender Assessment showed that when making decisions, each player has the opportunity to provide additional knowledge to the group in order to arrive at a more informed collaborative decision.

4. The Project Planning case study demonstrated the impact of influence amongst the participating human and virtual beings.

These case studies demonstrate that the developed TeamMATE computer game enabled human and virtual beings to interact cooperatively as functionally equal partners in the context of collaborative computer games. It has also been shown that cooperation between FEPs can be achieved in computer games using the collaborative process and a layered collaborative architecture.

Finally, these case studies also show that TeamMATE as an implementation of boardroom style collaborative computer games may be used in entertainment, educational and business computer game applications.
6 Conclusion

This thesis has explored the principles of engaging human and virtual beings in intelligent collaborative computer games, the purpose being to provide engaging and effective methods by which collaborative outcomes may be achieved.

During an analysis of available literature related to collaborative computer games, a hypothesis was developed to investigate and explore whether virtual beings might collaborate with humans as equals within the context of computer games. This leads to the potential development of richer and more realistic collaborative engagements within computer games.

From this position, a framework was defined for human and virtual beings to be considered functionally equal partners (FEPs). That is, intelligent entities that perform tasks cooperatively with other FEPs (human or virtual), are replaceable, and not necessarily aware of the nature of their fellow players.

Expanding on this concept, three research questions were identified. The first research question relates to this work as a whole; a question of whether human and virtual beings, being heterogeneous agents, interact cooperatively in the context of computer games, not necessarily aware of the nature of their fellow players and what are the desirable attributes required for them to perform this collaboration as functionally equal partners. Each chapter contributes to addressing this question.

The second and third research questions however can be related directly to the work presented in Chapters 3 (Concepts of FEP Collaboration) and 4 (Collaborative Computer Game Implementation) respectively.
To facilitate the engagement of FEPs in computer games, the collaborative process provides a structure within which players of different natures and levels of intelligence may collaborate effectively. The TeamMATE system supports this process by implementing a layered collaborative architecture. The communication, physical and cognitive layers are used to cohesively facilitate collaboration, with each layer having a level of abstraction beyond that of the previous layer.

Humans are considered intelligent entities by nature, something that must be emulated or constructed within a virtual being. The virtual being is able to enact intelligent decisions via its cognitive layer subsystem. Contained within this cognitive layer are the abilities to perceive, analyse, make and then enact decisions, the results of which are conveyed to other players via sensors and effectors. The decision-making processes required within the cognitive layer can be replaced by other problem-solving techniques offering a flexible and extensible platform for intelligent decision-making.

Four different game play scenarios were presented utilising the TeamMATE computer game platform. Hammurabi demonstrates an entertainment style game as well as the application of a number of different problem-solving techniques. Holiday Destination is a simple educational game applying fuzzy logic to the collaborative process, along with demonstrating players with different perceptions of the information presented. Tender Assessment is a business-style game demonstrating how each player can contribute unique perspectives to group collective knowledge as well as the use of a neutral mediator. Finally, Project planning demonstrates influence in the collaborative process and how it can affect the result of a collaborative engagement.

What this demonstrates, is that human and virtual beings are able to interact cooperatively as functionally equal partners in the context of computer games, and are capable of being
substituted one with the other. It has also been shown that cooperation between FEPs can be achieved in computer games using the collaborative process and a layered collaborative architecture. Further, TeamMATE as an implementation of boardroom style collaborative computer games, is appropriate for entertainment, educational and business applications.

6.1 Points of Difference

It is quite apparent through the literature that the driving motivator for research in computer games is to create more believable virtual beings that exhibit human-like behaviour. One point of difference between the work presented here and that of other research in the field, is that collaborative engagement between human and virtual beings in computer games should occur independently of the “believability” of the virtual beings. Virtual beings, believable or otherwise should be able to collaborate with humans regardless of whether the humans know their virtual nature or not. This allows for virtual beings of varying degrees of sophistication to engage in collaborative game play. To facilitate this, a collaborative process was presented (Chapter 3)

Furthermore, the work presented here considers human and virtual beings as functionally equal partners or FEPs. This means that human and virtual players are considered equally, and virtual players are not present as mere props or supporting Non Player Characters (NPCs), but occur as first-class citizens within the computer game. In a collaborative computer game utilising FEPs, humans and virtual beings are considered substitutable, one with another. The human player is not considered a “centre of attention” but rather part of a greater collaborative group.

6.2 Limitations

While collaborative functionally equal partners in computer games has been demonstrated to address the research questions presented in this thesis, there are opportunities to expand
upon the scope of this body of work to a greater depth. Specifically, there are two areas that require further exploration:

1. Commercial Viability of FEPs in entertainment, education and business computer games.

2. In this thesis, the first research question postulates that engaging FEPs are not necessarily aware of the true nature of their fellow players. However, if a human player becomes aware of the virtual nature of a fellow player, the psychological aspects of that human’s perceptions and acceptance of virtual players as functionally equal partners has not been addressed.

Commercial Viability of this concept has not been explored. While there are opportunities identified to enhance immersion and realism within collaborative computer games, this has not been tested in the market, nor implemented within an existing commercial computer game.

While humans engage every day in social activities inside and outside computer games, this thesis has not addressed the psychological aspects of collaborative decision making between human and virtual computer game players. For example, business managers use many Business Intelligence (BI) tools to extract information and provide recommendations and business advice. It is as yet unclear how a virtual partner would be received if actively participating in the decision making process. Beyond overcoming the technical challenges of integrating virtual beings into collaborative partnerships with humans, there are also these challenges of acceptance. Pre-conceived notions of science fiction (Khan, 1998) and cultural perceptions between different cultures (Kaplan, 2004) are some of these challenges. The positive benefits of collaborative virtual FEPs also face challenges of negative perceptions.
within different social groups and societies. Addressing these issues effectively shall ensure that collaboration amongst human and virtual beings is an effective method of group decision-making.

### 6.3 Contributions of this Thesis

In this work, the concept of human and virtual computer game players engaging collaboratively as *functionally equal partners* was investigated. The nature of functionally equal partners, concepts of collaboration and facilitating architecture were explored and stated:

1. Can human and virtual beings, being heterogeneous agents, interact cooperatively in the context of computer games, not necessarily aware of the nature of their fellow players and what are the desirable attributes required for them to perform this collaboration as functionally equal partners?

2. What computer game framework would be required to facilitate collaboration amongst functionally equal partners?

3. How could such a collaborative computer game be designed and implemented in order to support human and virtual players engage collaboratively?

This thesis asserts through the work presented, that it provides a contribution to the body of knowledge in regard to a method by which human and virtual beings may engage collaboratively to achieve outcomes within the context of computer games. Specifically, this thesis has addressed the research questions stated above having:

1. Introduced the concept of functionally equal partners (FEPS) in the context of collaborative computer games by which human and virtual beings engage as equals.
2. Defined a collaborative process that facilitates the engagement of human and virtual beings as FEPs in a computer game setting.

3. Presented a layered architecture for collaborative computer games, describing how each of these layers supports the process of collaborative engagement.

4. Designed, developed, prototyped and explored the TeamMATE collaborative computer game. This computer game was developed using a layered collaborative architecture and the concepts of FEP collaboration were tested using a number of different play scenarios.

5. Demonstrated the applicability of the developed collaborative computer game concept across a variety of computer game play scenarios that encompass entertainment, education and business management game play.

In addition, these contributions have been presented to the community in the form of peer-reviewed conference papers, journal articles and book chapters. The following list represents the contributed works that have been produced as a result of this thesis:


6.4 Implications and Relevance
The implication of effective collaboration between FEPs extends beyond computer games and the virtual environment, to physical real-world applications. At present, TeamMATE and its underlying concepts have been applied to entertainment, education and business style computer games. However, there is the potential to move into physical or embodied applications that require collaboration. One such potential area of application is in the integration of automated transportation systems into transport networks currently operated by humans. This becomes an attractive prospect when considering safety in automated transport, as well as integration and acceptance of these technologies into mainstream transport systems without the need for dedicated networks leading to cost savings in introduction and deployment.

Given the collaborative nature of the FEPs concepts, there is also potential for its use in applications requiring social networking. In particular, as a part of a suite of tools that can be utilized by clinical professionals in the area of social development and behavioural studies. The application of AI in creating virtual and physical avatars has already played a role in this area. There may be some potential for collaborative interactions such as those in TeamMATE to also play a part in the medical field.

Within the computer game field, there are many compelling opportunities to engage human and virtual beings as fully equal partners across a wide variety of application areas. There are many opportunities to utilize FEPs across a range of computer games, from entertainment to training and assessment games oriented towards business processes.
Whatever the future holds for virtual beings, as FEPs they will no longer be props or plot devices in virtual worlds; but will be the players, teammates and co-workers of the future, working alongside their human counterparts.
References


http://www.gamasutra.com/resource_guide/20040920/yee_01.shtml

Appendices
Appendix A  Fuzzy Logic in Collaborative Decision-Making: An Overview

Fuzzy logic is a problem solving concept that enables the use of human heuristic knowledge about a given problem and is capable of solving ill-defined problems. In traditional Boolean logic, answers are either true or false. When dealing with a fuzzy logic, a value may still effectively evaluate to true (1) or false (0), but may also evaluate to any value between the two, giving us “partially true” or “mostly true” values. It is this concept that makes fuzzy logic a useful tool when dealing with complex problems. Fuzzy rules can simplify complex processes by evaluating inputs in order to achieve “best fit” outputs without the need to have exhaustive/complete knowledge of the process. This concept mimics how humans solve problems using heuristic knowledge.

Fuzzy systems encapsulate human expert knowledge of a problem in simplified descriptive rules. The language that is used to describe attributes of a fuzzy system has a certain vagueness to it (hence the use of the term fuzzy) as the language that is used to articulate an attribute’s magnitude may apply to more or less of a degree to the attribute being described. Words that are used to describe attributes in a Fuzzy System reflect the way that humans articulate magnitudes. Words such as “cool”, “old” and “slow” are used to describe values and are known as Linguistic Terms. Just like human experts would describe a value, a linguistic term can describe any input value referred to as a Crisp Value, over the universe of discourse. A crisp value however, is more accurately described by some terms than others. This is known as the Degree of Membership (DOM) to which a crisp value falls within the range of a linguistic term. For example, Table 28 shows a five term linguistic variable for the temperature required to brew coffee:
Table 28 Linguistic Variable Temperature and its Terms

<table>
<thead>
<tr>
<th>Crisp Value (Temperature °C)</th>
<th>Linguistic Term</th>
<th>DOM</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 87</td>
<td>Cold</td>
<td>0</td>
</tr>
<tr>
<td>88</td>
<td>Warm</td>
<td>0.25</td>
</tr>
<tr>
<td>93</td>
<td>Brewable</td>
<td>0.5</td>
</tr>
<tr>
<td>98</td>
<td>Hot</td>
<td>0.75</td>
</tr>
<tr>
<td>≥ 98</td>
<td>Boiling</td>
<td>1</td>
</tr>
</tbody>
</table>

The DOM to which a crisp value falls within a linguistic term is taken over a numeric range of zero to one.

In order to describe attributes as linguistic terms, the original input values, referred to as *Crisp Values*, are *Fuzzified* and articulated as linguistic variables, for example “temperature”, “age” and “speed”.

Once fuzzy rules have been applied and there is a result (as a linguistic variable), the fuzzy result must then be *Defuzzified* in order to obtain a crisp output value that can then be applied to the problem.

Take for example a control system that regulates the temperature of an automatic coffee machine. If the ideal temperature of the water being used to brew the coffee needs to be maintained at 93°C, then the software needs to measure the temperature of the water within the reservoir and either heat it using an element, or turn off the heating element for a certain amount of time. The temperature sensor takes a reading of 89 °C (The crisp value). A set of Fuzzy Rules can be used to describe this process. These rules are described in an IF-THEN form:
IF temperature = warm THEN heating element = medium

In the above example, when the temperature of the water is “warm” the heating element will be turned on for a “medium” amount of time. In the above case, the “medium” may equate to sustaining a current to a heating element for 1 minute.

The important thing to remember is that when a crisp value is converted into a linguistic term (for example “cold”, “warm”, “brewable”, “hot”, “boiling”) it will be evaluated based on the Degree of Membership (DOM) that it belongs to each term (Table 2)

This appendix shall consider a Multiple Input Single Output (MISO) fuzzy system as opposed to more complex Multiple Input Multiple Output (MIMO) systems.

The Fuzzification Process
Fuzzification is the process of converting crisp real-world values into linguistic terms. A crisp value may be a member of a number of linguistic terms. The degree of membership that a crisp value has within any one term is determined by the membership function $\mu$. This function can take many forms, but result in obtaining a value between 0 and 1 for the crisp value within the universe of discourse.

![Figure 45 Determining the degree of membership](image-url)
In the above example (Figure 45), the membership function for considering a temperature “Hot” has resulted in the crisp value having a degree of membership of 0.75. Each linguistic term has its own membership function. When a crisp value is fuzzified, the degree of membership determines the likeliness of the match between the crisp value and the linguistic term.

There are many types of membership functions that are used to describe a linguistic term. The example in Figure 45 shows a Gaussian-shaped membership function. There are many types of membership functions that may be applied (they do not even need to be symmetrical); the choice depends upon the application. For the purposes of this work and for simplicity, a triangular membership function is used (Figure 46). The triangular membership function (or T-Function) is defined as (Yan, Ryan and Power 1994):

\[
T(u; a, b, c) = \begin{cases} 
0 & \text{For } u < a \\
\frac{(u - a)}{(b - a)} & \text{For } a \leq u \leq b \\
\frac{(c - u)}{(c - b)} & \text{For } b \leq u \leq c \\
0 & \text{For } u > c 
\end{cases}
\]

Equation 11

Where \( u \) is an input value from the universe of discourse, while \( a \) and \( c \) are the lower and upper bounds of the membership function and \( b \) is the midpoint (Figure 46).
Fuzzy Rules

As stated earlier, Fuzzy rules are described in terms of IF-THEN conditions. These rules cover all linguistic terms for the required inputs and match them to conclusions:

\[ \text{IF } x \text{ is } A \text{ THEN } y \text{ is } B \]

As one can imagine, the more linguistic terms there are for a given universe of discourse (crisp input) and the number inputs greatly affects the size of the rule set. In order to determine to what degree a rule applies to the input parameters, a rule’s fire strength may be calculated. There are many methods that can be used to determine the fire strength of a rule. One method for determining the fire strength of rule is the MAX-MIN.

The MAX-MIN method of determining the fire strength of a particular rule involves taking the degree of membership values for each input into the rule. The fire strength is then determined by the smallest of the fire strengths.

Defuzzification: Obtaining a “Real” output
Once an outcome from the application of the fuzzy rules is achieved, the resulting fuzzy set values must be converted into a real crisp value. There are a number of methods for selecting an appropriate crisp value including Centre of Gravity, Max Criterion, Mean of Maximum, Centre of Area and Centre-Average.

In this work, a Centre of Gravity (COG) method has been used to determine an appropriate crisp output. The COG method is used in many fuzzy systems given its low computational cost. To obtain a $u^{crisp}$ value, the following function can be applied to obtain the centre of gravity (Passino and Yurkovich, 1998):

$$u^{crisp} = \frac{\sum b_i \int \mu_{(i)}}{\sum \int \mu_{(i)}}$$

Equation 12

The function $\int \mu_{(i)}$ is used to represent the function required to calculate the area underneath the fuzzy membership function $\mu_i$ (where $i$ indicates the $i^{th}$ rule) and $b_i$ is the position where the membership function is at its peak (i.e. has a value of 1). Since it has been indicated that the triangular membership function shall be used in the fuzzy systems involved with the collaborative process, the calculation of the area underneath the triangular membership function becomes (Passino and Yurkovich, 1998):

$$\int \mu_{(i)} = w \left( h - \frac{h^2}{2} \right)$$

Equation 13

Where $w$ is the width of the triangle’s base and $h$ is the fire strength of the fuzzy rule.
Using Fuzzy Logic in a Collaborative System

Coming back to the collaborative process, there are a number of areas where different fuzzy algorithms may be used within a collaborative group of FEPs. The following section shows how a virtual partner would be able to integrate into a collaborative group of FEPs. This assists in the understanding of:

- How partners respond during the collaborative process
- How partners interpret group collective knowledge
- How partners obtain outcomes from the collaborative process via negotiation.

FEPs may have differing perceptions of the same input values. In order for collaboration to occur effectively, there must be an alignment of perspective. When dealing with a collaborative FEP scenario, it is entirely possible for one partner to refer to something as “large” while another may refer to the exact same source as “small”.

The second application of fuzzy logic is in the approximation of one FEP’s perspective of scale with their own. As responses in the form of knowledge are articulated to the group of partners, each partner is then able to “align” the response with their own internal perspective.

FEPs participating in the collaborative process are able to approximately align their responses with that of the other partners. It should also be noted that in the responses of the given partners, only one justification has been given for their response. In this work, the justifications used in the play scenario have been constrained to one reason. In this case, the justification of a response can be characterized as:
The response \( r_m \) (where \( r_m \) is a piece of knowledge) implies a fuzzy justification \( j_F \) where \( j_F \) in this case is the linguistic term with the highest degree of membership across all inputs.

The resulting fuzzy justification is essentially the conveyance of a linguistic term to other members of the group. This in turn allows the other FEPs to evaluate the responses of other partners in relation to their own.

The justification works on the assumption that while each FEP may have a differing perception for the same inputs, all FEPs articulate their responses in the same linguistic terms (and in the same order). This allows the FEPs to measure the responses of others in relation to their own perception.

For example, if a partner \( p_k \) converses with partner \( p_j \) using a five term linguistic variable for temperature as defined in Table 29 Differing Perspectives on the Same Input with the crisp value of the temperature being 90°C:

<table>
<thead>
<tr>
<th>Question</th>
<th>Response and Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_k )</td>
<td>“Turn the coffee brewer on?”</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>( p_j )</td>
<td>“Turn the coffee brewer on?”</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The difference in perception can be simplified to the difference between the linguistic term of one FEP versus another’s perception. In this example, \( p_j \) would be able to use the justification of \( p_k \) to extrapolate a model of the perception of \( p_k \) of the given problem, allowing the FEP to interpret the collective group knowledge supplied by \( p_k \). This then allows \( p_j \) to articulate during the negotiation phase of the collaborative process in terms of the perception of inputs by \( p_k \).

Perception does not need be an expensive process in simple scenarios. If all partners articulate their perceptions of the given inputs in the same linguistic terms, the true intention of the FEP is articulated.

The Third area within the collaborative process of FEPs that can utilize fuzzy logic is in the negotiation process. At this point, all partners have evaluated the questions and made responses based upon their internal fuzzy reasoning, and all other partners have been able to form a perception of the other partner’s responses. The negotiation phase of the collaborative process takes the collective group knowledge accumulated during the question process and evaluates the set of outcomes based on the initial goals stated at the beginning of the process.

Recall that \( o_n = s(P, n(G, K^p)) \). A goal \( g_i \) must be interpreted against the set of group collective knowledge related to that goal \( K_i \):

\[
\begin{align*}
o_n &= s(P, n(G, K^p)) \\
G &= \{g_1, \ldots, g_i\} \\
K^p &= \{K^p_1, \ldots, K^p_i\} \\
o_n &= s(P, n(\{g_1, \ldots, g_i\}, \{K^p_1, \ldots, K^p_i\})) \\
o_n &= s(P, \{n(g_1, K^p_1), \ldots, n(g_i, K^p_i)\})
\end{align*}
\]

Equation 15
The interpretation function involves setting a baseline with all group collective knowledge interpreted relative to the baseline. In practice this if all partners articulate their perception using the same linguistic terms, this is a trivial operation.

Once the baseline has resulted in a set of Knowledge for the group of FEPs, this set of knowledge can be applied against each goal that the items are related to the goal: \( n(g_i, K_i^p) \).

In order to satisfy the outcome on, the collaborative function \( s \) involving all partners and the group collective knowledge interpreted against the baseline is required.

While each FEP will be articulating the group collective knowledge against the baseline, this is not enough to achieve an outcome. Negotiation involves the ability to compromise. In this example, negotiation is simulated through the use of an influence factor. This influence factor constraint attracts the partner’s decision toward that of another FEP thereby influencing their resulting opinion.

Consider four FEPs that are baristas brewing coffee. The brewing machine has a heating element used to heat water to the right brewing temperature. Using the following linguistic variable to articulate an outcome:

\[
\text{Input: Temperature} = \{\text{Cold, Warm, Brewable, Hot, Boiling}\}
\]

\[
\text{Output: Make Coffee} = \{\text{Heat, Brew, Heat Off}\}
\]

Suppose partner \( p_1 \) has had two fuzzy rules that fire based on a temperature input in the form:

\[
\text{IF } x \text{ IS A1 THEN the outcome is B1}
\]

\[
\text{IF } x \text{ IS A2 THEN the outcome is B2}
\]
With each rule firing for partner $p_1$, a final Centre of Gravity of 3.5 that relates to a linguistic term of *Make Coffee* is achieved. Suppose the following partners have also evaluated the same rules and determined separate centres of gravity:

<table>
<thead>
<tr>
<th>Partner</th>
<th>COG</th>
<th>Linguistic Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_2$</td>
<td>4.4</td>
<td>Heat</td>
</tr>
<tr>
<td>$p_3$</td>
<td>3.7</td>
<td>Brew</td>
</tr>
<tr>
<td>$p_4$</td>
<td>1.2</td>
<td>Heat Off</td>
</tr>
</tbody>
</table>

During the negotiation phase, an influence function can be applied to change the COG of a given partner’s initial fuzzy decision based on the degree of influence the other partners have with the first partner. The influence function that is used in this example is simply the sum of the proportion difference between one partner’s COG (obtained during the conversation process) and that of another partner:

$$i(COG) = \sum_{1\neq j\neq i} p_{nf} \times (COG_{pn} - COG_{pi})$$

Where $i(COG)$ is the influenced centre of gravity which is the sum of all influence factors multiplied by the difference between the centre of gravity of partner $p_n$ and the partner under influence $p_i$. FEPs using this influence function cannot influence themselves.

The following example shows how the other partners can influence partner $p_1$’s resulting centre of gravity. This in turn can potentially change a linguistic term and outcome of the collaborative process.
Table 31 Resulting influence on partner p1

<table>
<thead>
<tr>
<th>Influence</th>
<th>p2</th>
<th>p3</th>
<th>p4</th>
</tr>
</thead>
<tbody>
<tr>
<td>COG</td>
<td>4.4</td>
<td>3.7</td>
<td>1.2</td>
</tr>
<tr>
<td>p1 Value</td>
<td>3.5</td>
<td>0.225</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Once the negotiation phase has been completed, the resulting feedback by all FEPs on the particular outcome can then be evaluated to achieve an outcome. There are many methods for achieving an outcome. In a simple scenario, the outcome can be evaluated by a single partner (normally the leader). In more complex scenarios, a democratic system may be called for requiring the group to reach a majority position.
Appendix B  Key Computer Game Attributes Facilitating Collaborative Game Research

This appendix contains detailed information about the desirable attributes of a collaborative computer game.

In order to understand the distinct and desirable attributes of a computer game used in collaborative research, it is necessary to arrive at a common set of properties that can be used for comparison. Taking into account all the necessary and beneficial properties of each environment, the comparisons can be divided into three primary areas: Properties of the Game Environment, Properties of the Agent (player) and Practical/Development attributes.

The Game Environment

The first step in identifying the beneficial properties of a game environment is to analyse the computer game itself. Beneficial properties that should be present in an environment include:

- The ability to control the conditions within the environment, thus allowing for repeatable experimentation (Horling, Lesser and Vincent, 1999/2000);

- An environment that includes exogenous or unplanned events in its model (Cohen, Hanks and Pollack, 1993);

- The environment should have a causal structure. That is an event that happens within the world will affect changes in other aspects as well;

- Time constraints on “Thinking”; that is the agents cannot think for too long about something as the conditions may change or update faster than their
decision making processes. Therefore there is an element of performance considerations that must be made with regards to the agents.

In order to obtain these beneficial properties in a simulation environment, it is necessary to have these elements contained in the design of the system:

- A clean and well-defined interface, that is, the environment and the agent are separate entities, the interaction taking place through the interface only;
- A concept of time where there is the necessity to design a world that will not wait for an agent to make a decision but will continue to evolve over time (in particular, real-time systems). This also ties to aspects of causality in an environment;
- The environment should support the notion of experimentation. That is, experiments and initial starting conditions should be able to be reproduced at a later date to verify findings. In addition, the ability to record conditions and actions of agents within the world is also necessary.

**Support for Experimentation**

The final consideration for designing a simulation environment as stated by Cohen et al. (1993) is the necessity for the environment to support experimentation:

> **Supporting Experimentation** Testing an agent architecture amounts to assessing its performance over a variety of sample problems and conditions. Controlled experiments require problems and environmental conditions be varied in a controlled fashion. A testbed should therefore provide a convenient way for the experimenter to vary the behaviour of the worlds in which the agent is to be tested (Cohen, Hanks and Pollack, 1993).

Finally, the simulation environment as stated by Cohen et al. (1993) should provide facilities to monitor and control the conditions within the simulation environment. This allows for
repeatable experiments, which will expedite a more effective prediction of behaviour given similar conditions in the physical world.

Horling et al. (2000) adds the concept of deterministic experimentation. That is:

> To accurately compare separate [simulation] runs, we must be sure that the experimental parameters that are those which produce different outcomes (Horling, Lesser and Vincent, 2000).

This means that if the parameters are known that caused a certain behaviour and outcome in one simulation (such as the number of agents, the exogenous events that occurred, climatic conditions etc.), it follows then that if these parameters were used again, a similar (if not the same) result should occur. It would be reasonable to use this to form a basis for comparing the differences in simulation runs performed.

In order to be useful, the environment must support the purpose of experimentation and should be designed in such a way as to give the experimenter the ability to control input parameters in order to affect the outcomes of the simulation.

There are many benefits that component-based technology brings to a collaborative computer game. Primarily, the ability to substitute components with the same interface allows the designer to “mix and match” components. The ability to test the effectiveness of different combinations is one of the strongest reasons to design and develop a component-based collaborative computer game environment. Components give versatility to the environment, and to the composition of the agents operating within it.

The benefit that component technology gives to a case such as embodiment of the ICSL concept for cooperative autonomous agents is clear. The ability to substitute any and/or all the elements of the environment, the physical robots, sensors and the software within the agent, leads to a wealth of possibilities for controlled experimentation.
Exogenous/Unplanned Events

Cohen et al. (1993) specify several issues that must be considered when undertaking the preparation of a simulation environment for experimentation:

Exogenous Events Perhaps the most limiting assumption of the classical planning worlds (most notably the Blocksworld) is that no exogenous, or unplanned events can occur. Relaxing this assumption makes the process of predicting the effects of plans more difficult and also introduces the need to react to unplanned events as they occur at execution time. The time cost of planning becomes important in a world that allows unplanned changes: the longer the agent takes to plan, the more likely it is that the world has changed significantly between the time the plan was generated and the time it is executed. (Cohen, Hanks and Pollack, 1993)

From what is stated here, an agent must react to unpredictable events occurring in the environment, but must continue to react “in a timely fashion” (Wooldridge 1997) whether the event was expected or not. This may mean that an agent may have to re-evaluate its situation and current set of goals, or form new goals in order to negate an unexpected event. Moving to a more overall view, this would also apply to cooperative goals, which may require a change in goal, or perhaps communication with other agents requesting assistance.

Complex Causal Structure

Cohen et al. (1993) continues; a second desirable attribute of a simulation environment is the:

Complexity of the World A realistic world has many features. Even a simple block has color, mass, texture, smell and so on, although many of these features will be irrelevant to many tasks. A realistic world also has a complex causal structure: changes in one aspect may change many other aspects, even though most of those changes may again be irrelevant to any particular problem. Reasoning about more realistic models of the world requires the ability to represent and make predictions about complex mechanisms, as well as the ability to recognise and focus attention to those aspects of the world relevant to the problem at hand. A testbed for exploring realistically complex planning problems should itself provide a complexity and diversity of features (Cohen, Hanks and Pollack, 1993).

In essence, every action should have some set of reactions associated with it. Most would probably be irrelevant to the simulation but depending on the context that the agents are
operating within, causal events can affect multi-agent systems to a greater or lesser degree.

Consider a simulation of agents designed to do coal mining. What would happen if the agents started mining the supporting rock? Or perhaps a group of agents displace a boulder that was obstructing their path, only to have it roll over and crush several agents in the process.

**Real Time Environment**

Secondly, in discussing the design issues in developing a simulation environment Cohen et al. (1993) state that there should be:

> **A Well Defined Model of Time** Testbeds must present a reasonable model of passing time in order to simulate exogenous events and simultaneous action, and to define clearly the time cost of reasoning and acting. (This is a general problem in simulation and modelling. See [Law and Kelton 1981], for example.) On the other hand the testbed must somehow be able to communicate how much “simulated time” has elapsed. Making sense of experimental results requires a way to reconcile the testbed’s measure of time with that used by the agent (Cohen, Hanks and Pollack, 1993).

In the context of this investigation, a well-defined model of time is extremely important in relation to cooperative autonomous agents. Timing of actions in order to cooperatively fulfil a task is necessary to allow such cooperative behaviour (Divide and Conquer) as stated by Arkin and Balch (1998) to be coordinated. Coordination within the temporal framework of the environment allows for the prioritisation, queuing and determination of critical paths of activity to satisfy goals. Since agents are operating independently of each other and are asynchronous, tasks can be prioritised by their importance and dependencies. Thus many activities can be occurring at the same time and in an order that will ensure the most effective use of resources in the least amount of time.

Consider a simple example two robotic agents that have the task of moving an object that is far too large for any one agent. If the agents coordinate their actions and push *at the same time and in a coordinated manner*, then they will successfully move the object. If they push the
object at different points in time, then they will both fail in their task. However in this example, they must also move this object before another robotic agent can take a soil sample from underneath the object. It would not be efficient to have the agent waiting to take the sample when it could be performing other tasks in the meantime.

It can therefore be seen that any activities undertaken by an agent or a group of agents will take time. Additional tasks will have to be queued or transmitted to an agent that is available. Every activity undertaken by the agents in the simulation environment must have a time associated with it. Even internal computations and planning must not be overlooked. If the agent is to operate in the physical world then decision-making time could mean the difference between success and failure of agent goals.

A defined sense of time in a simulation also allows for the occurrence of exogenous events at random times (or even simultaneously) during the simulation.

**An Autonomous Agent**

In order to produce a virtual being capable of collaboration with humans, it is necessary to identify the desirable properties of an agent. The concept of an Agent taken is based upon that of Jennings and Wooldridge (1995) and provides a frame from which the concept of a collaborative virtual being may be developed:

- An agent is *Autonomous*, has direct control over its internal state and can only experience interaction through a *well-defined* interface;

- The agent must have some form of *social ability*, that is the ability to communicate intelligently with other agents and/or humans;
• An Agent must also have the ability to be Reactive, responding to changes in its environment (perceived through its interface) in a timely fashion.

• Once given a goal, the Agent will be pro-active and will be able to fulfil its goals by taking initiative using the information at hand to make decisions and act upon them.

The properties defined by Jennings and Wooldridge above are considered the desirable properties of a collaborative partner. The properties of agency that shall be searched for are:

• Autonomy – that the agent is distinct from the environment.

• Social Ability – Agents have the ability to communicate with each other and interact in meaningful ways with other entities (Agents or Humans). Thus the environment must support some form of communication protocol/mechanism

• Reactivity – are able to interact to changes in the environment “in a timely fashion” – this can be best tested when the environment itself is a real-time system.

• Proactivity – the agents are able to “take initiative” to achieve their goals. By having an environment with specific success goals, this desirable property of agency can be investigated.

Thus, when looking at the environments, the properties the agent will have within these environments shall be looked for.
Autonomy

The concept that an agent exhibits autonomy is a common and widely accepted property of an agent (Bradshaw 1997, Franklin & Graesser 1996, Jennings et al. 1998). That is, the notion that an agent has independent control of its internal processes and are not interfered with by systems that are external to the agent. Hitchings, Kajitani and Vlacic (1999) state in the context of robotics, that for a system to be called autonomous: “…a system would need some means of identifying, isolating and correcting faults….” Also that the system once a fault has been isolated, should “… continue to function at reduced efficiency” (Hitchings et. al., 1999). The definition of an agent’s autonomy provided by Jennings and Wooldridge allows for an agent to internally identify, isolate and correct faults as the agent has control over its internal state.

Wooldridge refines later the definition of autonomy to state that:

Agents encapsulate some state (that is not accessible to other agents), and make decisions about what to do based on this state, without the direct intervention of humans or others (Wooldridge, 1997)

By refining the original definition, Wooldridge has made it possible for the agent to not only make decisions about its operation, but it can be inferred in the context of the research of cooperative autonomous robotic agents that this would also apply to internal maintenance.

Naturally, this autonomy has limits, and catastrophic failure must be dealt with externally to the agent.

To properly simulate the behaviour of an agent that may eventually be used in an open environment (the physical world), the independence of the agent is very important. When investigating this desirable property, the following elements are sought after to indicate autonomy:

- Does the agent have access to information through a well-defined interface (Wooldridge, 1995)?
• The agent should not have access to any information about the state of the world that they cannot gather through their sensors/interface (i.e. A global view of the world).

Social Ability

The *social ability* stated by Jennings and Wooldridge (1995), is the ability to communicate with other systems external to itself, and that this communication should *make sense* to both parties. In order to exhibit the attribute of collaborative behaviour as stated by Bradshaw (1997), an agent must first be able to communicate in a meaningful way with other systems. If communication does not make sense to the parties involved, then any collaboration by the systems would be virtually impossible. Thus the social ability of an agent is very important, and in the context of cooperative robotic agents, essential. Wooldridge, in his refined definition, goes on to explicitly state this:

> Agents interact with other agents (and possibly humans) via some kind of agent-communication language, and typically have the ability to engage in social activities (such as cooperative problem solving or negotiation) in order to achieve their goals (Wooldridge, 1997).

Cooperative agents require communication in order to coordinate their actions. Thus this definition is suitable for forming the basis of cooperation. If an agent cannot communicate with another – how can they cooperate?

The following properties will be used in order to determine the adequacy of the environment to facilitate this property of agency.

• Does the environment provide a medium for communication

• Can the agents access this medium (for both sending and receiving)
Reactive

Wooldridge refined the original definition of reactivity in his paper “Agent Based Software Engineering” (1997) to define reactivity as being that:

Agents are situated in an environment, (which may be the physical world, a user via a graphical user interface, a collection of other agents, the internet, or perhaps many of these combined), are able to perceive this environment (through the use of possibly imperfect sensors), and are able to respond in a timely fashion to changes that occur in it (Wooldridge, 1997).

From this definition, it is possible to conclude that an agent must have some framework or environment in which to operate, and that the agent must be able to make sense of the information it receives from this environment. While Wooldridge’s attribute of social ability can apply to the communication between systems, there is not that luxury when considering an environment – especially when considering that the eventual application of a cooperative autonomous agent system will be in the real world. Thus the agent must have some means of perceiving this environment which does not rely on the information collected by the agent being of a consistent form. In fact, when Wooldridge states that the sensors of the agent can be “possibly imperfect”, the agent must still make sense and react even when the information that it uses to enact some kind of action is distorted or imperfect. This is a very real and important concern for the context of this thesis.

In order for the agent to be considered reactive within an environment, it must be able to react to stimuli within the world that they inhabit. However, this is a property of an Agent that does not find any expression within a simulation environment other than the environment’s ability to provide stimuli. Since it is important to identify that agents can respond in a “timely fashion” to stimuli, the environment should also provide stimuli in a “timely fashion”. Thus an environment that executes in real-time is more desirable.
Proactive

Finally, Jennings and Wooldridge state in the original definition that an agent exhibits *pro-activeness*. This original definition does not change in the later definition stated by Wooldridge. However, this is a very important attribute that must be explained carefully by examining the context in which an agent can be said to be pro-active. It can be rightly stated that an agent is never pro-active as it will always react to some form of input; be it the information it receives through its sensors, communication with other agents or the original goal it was provided with. When the original goals of the agent are included as an input then agents are purely reactive systems. Given the information they have access to, they will react in the according fashion. Jennings and Wooldridge (1995) state that it is more useful from a high-level point of view to say that an agent is pro-active.

Jennings and Wooldridge (1995) go on to discuss in more detail agents as intentional systems. This gives a reason as to why the concept of pro-activity and the animistic association of the term with *initiative* would be used:

> Put crudely, the more we know about a system, the less we need to rely on animistic, intentional explanations of its behaviour. However, with very complex systems, even if a complete, accurate picture of the system’s architecture and working is available, a mechanistic, design stance explanation of its behaviour may not be practicable. (Jennings and Wooldridge, 1995)

If one forms such a condition about the ability to which an agent is *pro-active* and *takes initiative* it is possible to use these terms to simplify the overall perspective of the mechanism by which an agent accomplishes its goals. Thus the following constraints can be used:

1. That the agent’s goals are considered different to other inputs to the system.
2. That the agent, when using the previously stored data to form plans/sub-goals/tasks from its internal sets of rules is considered differently to other inputs to the system.

If these constraints are used when considering an agent, from a high-level perspective of its actions the system can be considered *pro-active*, in order to simplify concepts of its behaviour.

It is also important to note that this type of simplification should only be applied to complex situations. Shoham (1990) as cited by Jennings and Wooldridge (1995) states; “it does not *buy us anything*” to explain a system using animistic terminology if a simple mechanical description of its behaviour exists.

Within the scope of cooperative autonomous robotic agents, at this point in time it is easier to discuss agents as not being pro-active entities because a simpler mechanical description exists. It is more useful to consider an agent using various input information to perform actions, and may well use previous information and goals, however they should all be considered inputs.

For this reason, pro-activeness, while being left as part of the Wooldridge (1997) definition for completeness, will not be considered in this thesis as an important property of cooperative autonomous robotic agents and will not be addressed in the same manner as the other properties.

In order for an agent to exhibit proactive behaviour (based on their internal goals) there must be a number of goals to accomplish within the environment, or some form of success/failure indicator.

**Practical/Development Properties**

When selecting a simulation environment for research, one particular area that at times is overlooked is the practical considerations when using an environment. Horling, Lesser and
Vincent (1999/2000) state that the need for simulation is important because of the amount of time and energy resolving issues that are “orthogonal to the initial goals of the research”.

This principle can also be extended to also include selecting the right simulation environment in the context of the project/experiment. With this in mind, a number of important questions can be raised about the environment. Given context and the nature of the research, the following points require addressing:

**Complexity of the World**

A Simulation environment can be complex in numerous ways. In terms of the desirable properties of a simulation environment, causality, exogenous events and the concept of time contribute to the complexity of the world. In addition, the representation of the environment also adds a degree of complexity. Researchers must identify their needs within simulation and attempt to match these against the environment in order to strike the right balance complexity: That is, complex enough so as not to simplify experimentation (in particular, those that would model physical-world systems) whilst not being overly complex; wasting time and effort on tasks that do not affect the experiment to any discernable degree.

The factors that have been selected as those that affect the complexity of a simulation environment have been taken from both the desirable properties and also the representation of a simulation environment:

- Causality (Changes to the world based on internal events)
- Exogenous Events (Changes to the environment that are random/non-predictive)
- Concept of Time (time-step versus real-time)
• World Representation (two versus three dimensional)

Platform availability

The availability of an environment for a given platform can also affect the decision use one simulation environment over another. Depending on the equipment at the disposal of the researcher, some environments may be more attractive than others.

Many environments are known as “cross-platform” which means in terms of a software-based simulation environment, that it may be used across a number of different Operating Systems (the “OS” being the platform)

Another factor that can affect development is the choice of the programming language. For example, programs created using Microsoft’s .Net framework languages cannot be executed on non-Microsoft platforms, while developing cooperative agents in Java will allow their execution across a number of Operating Systems. If the researcher has a “desired development language” this may affect the choice of environment based on the platform it is available for.