

Beyond Multiplayer Games: Engaging Cognitive Virtual Partners in Collaborative Decision-Making and Problem-Solving Situations

Ljubo B. Vlacic
Intelligent Control Systems Laboratory
Griffith University
Brisbane, Australia
L.Vlacic@griffith.edu.au

Daniel I. Thomas
TechnologyOne Ltd
Brisbane, Australia
Daniel_Thomas@technologyonecorp.com

Abstract— As more and more sophisticated artificial decision-making tools are developed, we see a natural progression from something a human may use, to engaging with virtual partners collaboratively. In this paper we define a computer game architecture that enables engagement of human and virtual partners in collaborative decision-making processes. The architecture of such a computer game is then demonstrated by engaging human and virtual partners in a Tender Assessment process.

Keywords—component; Collaboration, Decision-Making, Equal Partners, Layered Architecture.

I. INTRODUCTION

Humans have demonstrated a strong ability to collaborate throughout history to achieve staggering results. For humans, collaboration is a natural and beneficial medium with which to solve problems. Combining sophisticated tools and collaboration to create intelligent virtual beings that are equal partners with human beings in collaborative problem solving situations could be considered as a natural progression in furthering virtual collaborative decision-making settings.

In this paper, we describe an approach to engage virtual decision-making partners in collaborative problem solving with other partners (human or virtual) in a computer game environment. The architectural principles as well as the framework itself can be implemented in software agents as well as embodied agents (physical robots) for use in different applications ranging from collaborative evaluation to coordination and planning. For the purposes of this work however, we shall focus upon collaborative decision-making within a computer game framework.

II. FULLY EQUAL PARTNERS

Human and virtual beings that engage collaboratively as equal participants in a collaborative computer game are referred to as Fully Equal Partners or FEPs for short. When FEPs participate in a computer game, being of equal capability, it is not necessary for other partners to know whether a given FEP is human or virtual. Therefore, FEPs exhibit the ability to replace or substitute with another as necessary (Figure 1). Conceptually, human and virtual beings as FEPs can be considered autonomous agents [1]. From this frame, it is

possible to extend the concept to include both human and virtual entities as equal partners [2]. That is:

- Work cooperatively towards a defined set of objectives;
- An equivalence in capability in terms of sensors and effectors (not necessarily cognitive equivalence) within the domain of collaboration (i.e. the Game World)
- The ability to substitute or replace an equivalent entity

In addition, FEPs interact at a level of equality, meaning that they do not necessarily know (or deem relevant) the true nature of other entities as humans or virtual beings.

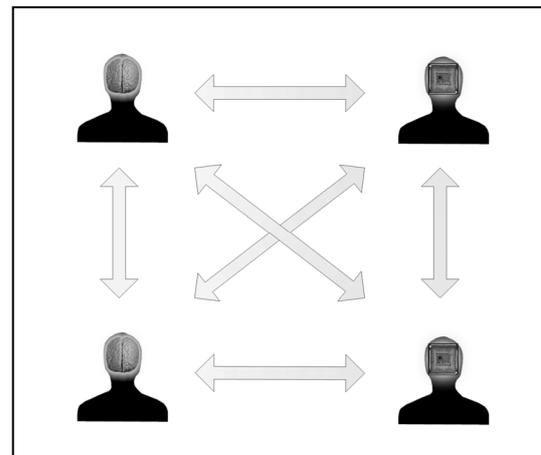


Figure 1. Human and virtual beings as Fully Equal Partners

Multiplayer games provide entertainment for millions of people every day. These games engage humans as adversaries, partners (or combinations of both) within a virtual game world. There are a myriad of different game genres that offer multiplayer capabilities, of which the Massively Multiplayer Online (MMO) game type is an example of large scale game play where humans can engage with others collaboratively via various social interactions.

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 [3].

There are many opportunities to develop this area in terms of content generation (that is, play scenario) [4, 5] and virtual actors [3]. Our contribution to developing this area is to consider a multiplayer computer game as a collaborative world within which virtual beings engage with human players as equals. This means that the virtual beings are no longer simple artifacts of the computer game world but are rather "playing" the game as human would: participating as FEPs within a rich interactive game world with their own goals and objectives.

Introducing FEPs as a complete replacement for a human would undermine a lot of the social appeal of a computer game. However, the inclusion of FEPs to supplement the gaming experience for human participants by introducing undirected emergent interactions adds additional depth and richness that many players of MMO role-playing games would find compelling [6]. The use of FEPs is considered complementary to purely human to human social interactivity and collaboration [7].

While inclusion of virtual FEPs in commercial entertainment games may be some time away, there are many avenues to explore their utility within education, training and research. In particular, FEP oriented games provide an attractive approach to brainstorming, candidate interviewing and testing situations where humans are being assessed on their approaches to various situations. Interest in novel approaches to collaboration in the context of software engineering [8] may also provide opportunities for FEPs in areas such as change control, build management and testing.

Human and virtual beings participating together as FEPs provide an opportunity to design new types of games that may offer creation of a more dynamic (causal) atmosphere for entertainment and training.

The collaborative computer game presented here utilizes the above mentioned principles of equality and substitutability of FEPs and assists in the consideration and evaluation of software tenders. Earlier versions of this development were tested in conjunction with the selection of holiday destinations [9] as well as project risk assessment [2] game scenarios.

III. TECHNICAL ARCHITECTURE

1) *A Layered Collaborative Architecture*

To facilitate collaboration amongst human and virtual FEPs a Layered architecture consisting of Communication, Physical and Cognitive layers was created [9]. 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 (TABLE I).

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.

TABLE I. ARCHITECTURAL LAYERS OF A COLLABORATIVE COMPUTER GAME UTILIZING FEPs

Architectural Layer	
Communication Layer:	Consisting of low-level transmission protocols, marshalling and information exchange
Physical Layer:	Encapsulates the sensors and effectors available to each partner, acting as an abstraction layer above the technical implementation of the communication layer
Cognitive Layer:	Interprets, assesses, stores and acts upon the information received via the sensors, enacting responses via the effectors of the physical layer

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[10], concepts of time [11], experimental support as well as many practical features that allow the environment to be worked with effectively [12].

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.

2) *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 2. shows, human and virtual beings are situated within the electronic boardroom. A collaborative computer game 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 2.):

- 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.

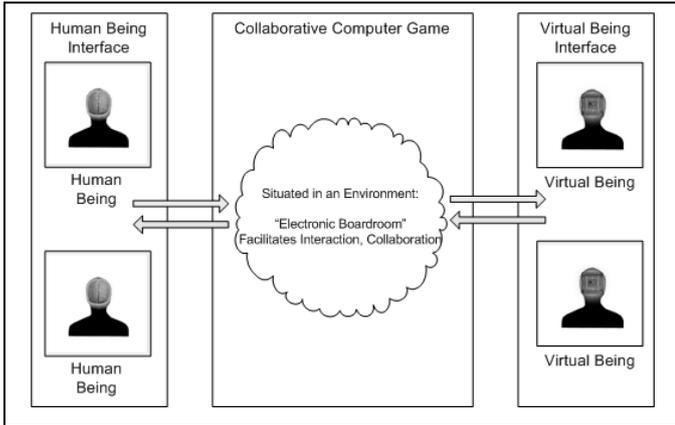


Figure 2. Human and virtual beings are situated within the Electronic Boardroom

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) Game Play Environment

Fully equal partners are situated within their environment and interact with this environment through a well-defined interface [1]. 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.

a) Communication Layer

The electronic boardroom game itself forms the backbone of the communication layer. As fully 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 fully 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 fully equal partners. By maintaining a discrete interface between the layers, it was possible to make this replacement with minimal effort.

b) 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:

- Different causal structures
- Differing concepts of time
- 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.

c) 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.

One of the simpler, yet vitally important aspects of the cognitive layer is the structured process of interaction amongst FEPs. Known as the Collaborative Process [2], this structure ensures that FEPs of varying cognitive capability are able to collaborate to a degree within the game. Consider that a group of FEPs engaged in a collaborative process have a defined set of goals. The result of this process is a set of outcomes (1),

$$O = c(P, G) \quad (1)$$

where P is the set of engaged partners, G is the set of goals, c is the collaborative engagement and O is the set of outcomes. It is important to note that there is not necessarily a 1:1 ratio between goals and outcomes since a goal may not be met, or a set of goals contribute to a single outcome.

The collaborative process is a structure by which human and virtual FEPs can engage in interactions that provide knowledge to the group as a whole, allowing them to make decisions based upon the information presented. At a high level, the process consists of [2]:

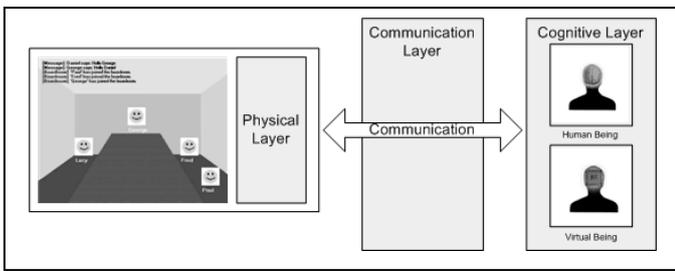


Figure 3. Electronic Boardroom Computer Game Composition

- Prerequisite collection, which includes invitation and attendance, and may also include collection of requisite material and/or knowledge.
- The initiation of a collaborative engagement, including the Statement of Goals,
- Conversations amongst the engaged partners which include questions, responses, actions and determination of trust
- Group decision making where the partners determine outcomes as a group.
- Negotiations that may arise as part of the decision making process, and;
- Conclusion of the engagement

4) 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.

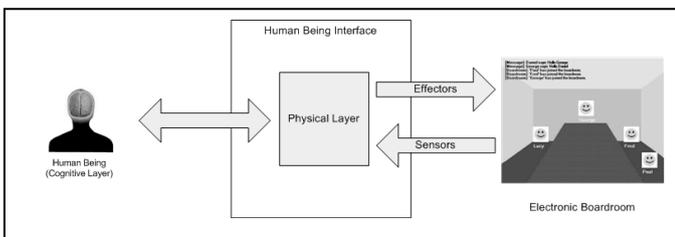


Figure 4. Human Being Interface structure

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.

a) 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.

b) 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.

c) HBI Cognitive Layer

When working with the human being interface, it is apparent (Figure 4.) 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.

5) 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 5.). 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 fully equal partner. The VBI:

- Contains features that allow the virtual being to be situated within the electronic boardroom game.
- Is autonomous; Interaction with the computer game is through a well-defined interface.
- Provides the necessary Social Ability elements such that the virtual being may interact and cooperate with other FEPs.
- Is able to act reactively based on the information provided by sensors
- 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.

a) 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.

b) 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.

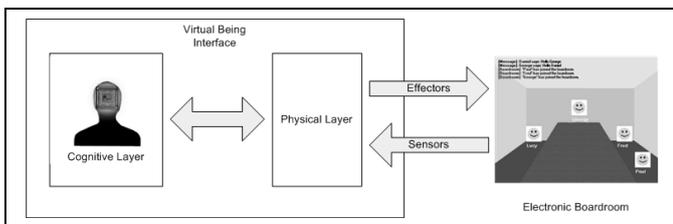


Figure 5. Virtual Being Interface structure

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.

c) 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 [13] 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.

IV. A COLLABORATIVE DECISION MODEL

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 [14]. It is therefore important that a formal method for collaborative decision making underpins the outcomes of the collaborative computer game.

In our previous work, the collaborative process involved a neutral party which would aggregate the decisions of the involved partners [2]. 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, a topic beyond the scope of this paper.

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 [15]. This is achieved by adding modifiers to the membership function to promote over-achievement and demote under-achievement [14]. In addition, weighting coefficients can be utilized to assist in determining the trade-offs that can be applied.

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.

V. CASE STUDY: TENDER SELECTION PROCESS

Generically speaking, the purpose of engaging a group of partners in a collaborative decision making process is to obtain and disseminate information within the group as well as make decisions based upon the information available. There are many factors that can contribute to the outcome of a group of decision makers such as influence, trust and the process by which the decision is reached. While the concepts of influence and trust are beyond the scope of this paper, we can observe how a collaborative FEP architecture facilitates a tender selection process within the context of a collaborative computer game.

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 [16].

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 II).

TABLE II. TENDER ATTRIBUTES AS PRODUCED BY THE SOURCE ORGANIZATIONS

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

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 III).

TABLE III. TENDER ATTRIBUTES TO BE OBTAINED DURING THE GAME

Attribute	Sub-Attribute
Profit	Staff Costs Training Costs Hire Costs Revenue
Time	Lead Time (Time between vendor announcement and start of the project) Time to Hire Staff Time to Train Staff
Resources	Utilization
Business Area	Tender Business Area Vendor Business Area

Therefore, the collaborative engagement undertaken within the computer game has two goals:

- The derivation of tender attributes relevant to the vendor and;
- 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 IV.). 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 analysts and developers required to provide this information back to the Financial FEP as the Staff Costs sub-attribute.

TABLE IV. ATTRIBUTES AND SUB-ATTRIBUTES PROVIDED BY THE DIFFERENT DEPARTMENTS

FEP Representing Department	Attribute	Sub-Attribute
Finance	Profit	
Human Resources	Resources	Utilization Staff Costs Hiring Costs Time to Hire Staff
Training		Training Costs Time to Train Staff
Project Management	Time	Lead Time
Executive	Business Area	Vendor Business Area

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.

VI. TENDER EVALUATION COMPUTER GAME IMPLEMENTATION

In this play scenario, a number of partners representing various departments in a business software organization have been asked to give an assessment on a number of large development projects that have gone to tender. The group must assess each project based upon the suitability of the project in terms of the responsibilities of each partner's department (Table 3). The computer game defines two outcomes for the collaborative FEPs:

- The determination of Tender attributes for assessment based upon sub-attributes obtained from the source tender information, and business information particular to the departments of the involved FEPs
- The assessment of the presented tenders based upon the obtained attributes, and the aspiration/reservation levels of the participating partners

For the game to operate, three constituent elements are required: A layered collaborative software architecture consisting of three distinct layers (TABLE I.); a collaborative process (electronic mediator) and the FEPs themselves (TABLE V.).

While each of the partners engaged in the collaborative process represents a different department within the vendor organization, an additional role is required for the collaborative

process: that of chairperson (generically referred to as the leader role). The chairperson is responsible for controlling the flow of the collaborative process, operating the electronic mediator and presenting the outcomes of the computer game.

TABLE V. PARTNERS ENGAGED IN THE COLLABORATIVE COMPUTER GAME

Partner	Role(s)
Martyn	Executive Representative Chairperson
Ljubo	Training Representative
Daniel	Project Management Representative
Kara	Human Resources Representative
William	Financials Representative

TABLE VI. STATEMENT OF GOALS

Partner	Communication
Martyn:	The goals of this meeting are as follows. The purpose of the Tender Projects Assessment group is to review incoming requests for tender and determine whether our company should pursue one or more of these tenders. Task 1 requires us to perform an Assessment of the following tender documents to determine Profit, Time, Resources and Business Area. Task 2 requires us to select the most suitable tender.

The game uses the collaborative process as the structure by which information is exchanged amongst each of the engaged partners. Once all partners are in attendance (Figure 7.), the process begins with the chairperson stating the two goals.

The first goal is to obtain the assessment attributes of each of the presented tenders based on the sub-attributes known to the group. It is acceptable for a partner to choose to not give an assessment if a particular attribute is not related to their area of expertise, or seek additional information from other partners for required sub-attributes.

TABLE VII. A CONVERSATION TAKING PLACE TO OBTAIN TENDER ATTRIBUTE INFORMATION

Partner	Communication
Martyn:	Ljubo, can you determine a Profit Rating?
Ljubo:	I Cannot
Martyn:	William, can you determine a Profit Rating?
William:	I require a Staff Cost from Human Resources
Martyn:	Kara, can we have further information on staff cost?
Kara:	The estimated staff cost for this project is \$960000.00
Martyn:	William, can you determine a Profit Rating?
William:	I require a Training Cost from Corporate Training
Martyn:	Ljubo, can we have further information on training cost?
Ljubo:	Training cost is \$5000
Martyn:	William, can you determine a Profit Rating?
William:	I require a Recruitment Cost from Human Resources
Martyn:	Kara, can we have further information on recruitment cost?
Kara:	The estimated recruitment cost for this project is \$0.00
Martyn:	William, can you determine a Profit Rating?
William:	This project has an estimated profit of \$285000.00

Once all tenders have been assessed, the chairperson will announce to the group the results of the first task

TABLE VIII. CHAIRPERSON ANNOUNCING THE ATTRIBUTES DETERMINED FOR THE TENDERS

Partner	Communication
Martyn:	We have established the following attributes: Northern Council - Profit: 285000.00, Planning Rating: 8.45, Resources: 5.2, Business Area Match: 10 Consolidated Logistics - Profit: 1030000.00, Planning Rating: 1.304, Resources: 8, Business Area Match: 4 Granite Belt Exploration - Profit: 125000.00, Planning Rating: 6.923, Resources: 2.8, Business Area Match: 3

At this point, the second defined goal of the collaborative engagement can commence. Each partner is given the opportunity to contribute to the decision making process by submitting decision cards to the chairperson. Each partner's decision card allows the partner to specify their tolerances towards a particular attribute. In this way, each partner is contributing their aspiration and reservation levels as input information for the electronic mediator. Once all decision cards are received, the chairperson provides the cards to the electronic mediator. The mediator then initiates the achievement function for each of the tenders and their attributes. The chairperson then announces the results provided by the mediator.

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 IX. CHAIRPERSON ANNOUNCING THE OUTCOME OF THE COLLABORATIVE DECISION

Partner	Communication
Martyn:	Our final collaborative decision scores are as follows: Northern Council: 4.948 Consolidated Logistics: -6.39 Granite Belt Exploration: -1.71 Therefore, our final decision with a score of 4.948 is Northern Council



Figure 6. FEPs engaged in a collaborative process in an electronic boardroom

VII. CONCLUSION

There are many compelling opportunities to engage human and virtual beings as fully equal partners across a wide variety of application areas. We see many opportunities to utilize FEPs across a range of computer games ranging from entertainment games such as MMOs to training and assessment games oriented towards business processes.

To facilitate this engagement between human and virtual beings the tender evaluation decision-making process requires a layered collaborative architecture that allows FEPs to interact with equal capability within the computer game. This engagement is facilitated by the collaborative process which provides the framework for FEP interaction.

To demonstrate this architecture, FEPs are engaged in a Tender Evaluation computer game. The game required the partners to assess tender information provided, couple this information with knowledge of specific business areas and collaborate to obtain a collective group decision.

The FEPs involved in the game demonstrated group decision-making with all partners contributing to decisions via a neutral electronic mediator which applied an order-consistent achievement function to cater for partner tolerances as well as compensating for over and underachievement when assessing tenders.

The FEPs concept provides a useful contribution by way of exploring an avenue of collaborative engagement between human and virtual beings situated in the same computer game setting. Work currently being undertaken is exploring this in terms of the cognitive layer and the decision-making techniques required by virtual partners. Beyond this work, collaboration between human and virtual partners opens opportunities beyond the computer game world in embodied real-world physical systems that engage with humans as more than mere intelligent tools.

VIII. REFERENCES

- [1] N. R. Jennings and M. Wooldridge, "Intelligent Agents: Theory and Practice," In *Knowledge Engineering Review*, vol. 10, pp. 115-152, 1995.
- [2] D. I. Thomas and L. B. Vlacic, "Collaborative Decision Making Amongst Human and Artificial Beings," In *Intelligent Decision-Making: An AI Based Approach*, pp. 97-133, 2008.
- [3] A. Nareyek, "Game AI is Dead. Long Live Game AI!," In *IEEE Intelligent Systems*, vol. 22, no. 1, pp. 9-11, 2007.
- [4] Trion World Network. (2009, May) Trion World Network, Inc. [Online]. <http://www.trionworld.com/news18.php>
- [5] B. Magerko, J. E. Laird, M. Assanie, and D. Stokes, "AI Characters and Directors for Interactive Computer Games," In *Proceedings of The 16th Innovative Applications of Artificial Intelligence Conference*, 2004, pp. 877-883.
- [6] D. Choi, H. Kim, and J. Kim, "Toward the Construction of Fun Computer Games: Differences in the Views of Developers and Players," In *Personal Technologies*, vol. 3, pp. 92-104, 1999.
- [7] B. Nardi and J. Harris, "Strangers and friends: collaborative play in world of warcraft," In *Proceedings of CSCW '06: Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*, 2006, pp. 149-158.
- [8] J. Whitehead, "Collaboration in Software Engineering: A Roadmap," In *Proceedings of FOSE '07: 2007 Future of Software Engineering*, 2007, pp. 214-225.
- [9] D. I. Thomas and L. B. Vlacic, "TeamMATE: Computer Game Environment for Collaboration and Social Interaction," In *Proceedings of IEEE Workshop on Advanced Robotics and its Social Impacts (ARSO'05)*, 2005, pp. 60-65.
- [10] M. E. Pollack, S. Hanks, and P. R. Cohen, "Benchmarks, Testbeds, Controlled Experimentation, and the Design of Agent Architectures," In *AI Magazine*, vol. 14, pp. 17-42, 1993.
- [11] R. Vincent, B. Horling, and V. Lesser, "Experiences in Simulating Multi-Agent Systems Using TAEMS," In *Proceedings of The Fourth International Conference on MultiAgent Systems (ICMAS 2000)*, 2000.
- [12] D. I. Thomas and L. B. Vlacic, "Selecting an Environment for Cooperative Autonomous Robot Research," In *Intelligent Robots: Vision, Learning and Interaction.*: KAIST Press, 2003, pp. 187-198.
- [13] J. Yan, M. Ryan, and J. Power, "Using Fuzzy Logic," , 1994.
- [14] A. P. Wierzbicki, "Negotiation and Mediation in Conflicts, II: Plural Rationality and Interactive Decision Processes," In *Proceedings of Sopron 1984, 1985*, pp. 114-131.
- [15] A. P. Wierzbicki, "A Mathematical Basis for Satisficing Decision Making," In *Mathematical Modelling*, vol. 3, pp. 391-405, 1982.
- [16] B. Whittaker, "What went wrong? Unsuccessful information technology projects," In *Information Management & Computer Technology*, vol. 7, no. 1, pp. 23-29, 1999.