COMPUTER ANIMATION AND VIRTUAL WORLDS
Comp. Anim. Virtual Worlds 2013; **24**:335–343
Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/cav.1517

SPECIAL ISSUE PAPER

Towards polite virtual agents using social reasoning techniques

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ABSTRACT

The use of polite agents is a new approach in order to improve efficiency and naturalism in navigation for player characters in crowded virtual worlds. This paper aims to model the politeness of virtual humans using logic-based approaches, subject to theory of politeness decomposed of conventional and interpersonal politeness. To do so, we propose a high-level agent architecture combined with normative framework to model and reason about 'polite' behaviours in social situations. With this architecture, we demonstrate (i) specifying polite behaviours as a form of social norms; (ii) generating polite behaviours using social reasoning technique; (iii) deliberation with such norms in belief–desire–intention agents; and (iv) realising physical actions based on the decision. Implementation for social reasoning is achieved by Inst*AL*, based on the semantics of answer set programming. Using experiments with simple collision avoidance model, we show the effectiveness of polite behaviour in navigation designed by such architecture, as well as the adequacy of this architecture for modelling theory of politeness in all circumstances. Copyright © 2013 John Wiley & Sons, Ltd.

KEYWORDS
polite agents; social agents; autonomous virtual human; intelligent virtual agents

Supporting information may be found in the online version of this article.

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1. INTRODUCTION

Navigation in virtual environments (VEs) is an essential task for virtual humans, but it remains challenging for several reasons. A significant contributing factor is that VEs are getting more sophisticated, dynamic and crowded because of the outstanding advances in recent years resulting in changes in form, scope and purpose [1]. In addition, the awkwardness of many user input devices severely impacts ease of navigation of player characters (PCs).

These circumstances lead to a poor interaction experience for users, with both satisfaction and believability likely to be decreased [2] in consequence. In this context, the use of politeness in virtual agents is proposed as an approach for a resolution of such tensions. Allen *et al.* [3] put forward the idea that polite behaviours of non-PCs (NPCs) may promise a more pleasant navigation experience for PCs in virtual worlds. Allen uses a predictive model to understand a PC's intention, which allows virtual humans to behave politely (collision avoidance in this case) and so improves the interaction in dense crowds.

Presumably, politeness looks like an aspect of social intelligence because such polite behaviours are brought about by prediction, accompanied by recognition of other's behaviour in social relationships. This view is supported by the literature on the theory of politeness.

The recent but also popular theory of politeness is presented in [4]. Traditionally, the notion of politeness has been discussed in the context of linguistic theory [5], but Arndt *et al.* extend the discussion in terms of verbal and non-verbal communications. They decompose politeness into *conventional* politeness and *interpersonal* politeness. The former refers to compliance with social conventions (or etiquette) that maintains order in society. The latter, interpersonal politeness, refers to the considerations of others and their feelings in social interactions. This implies that more comprehensive awareness in social situations (beyond conversational situations) ought to be required to be polite in some personal situations. Accordingly, it is clear that politeness seems to be a part of or closely related to social intelligence, which enhances the adequacy of human behaviour to society or its members in public and (or) private social situations.

The use of normative frameworks is one potentially effective approach to satisfy the aforementioned theory. In effect, normative frameworks provide a repository of knowledge of social conventions, particularly about correct behaviours, by capturing human social structures [6]. In addition, such a framework may also infer expected behaviours, subject to specific situations, by means of logic-based reasoning processes. It seeks to identify the connections between observations in the external world and potentially correct behaviours that are only meaningful within given social situations [7]. This can be viewed as a sort of prediction about rational decisions corresponding to the specific interpersonal context.

Hence, it seems clear that modelling behaviour, subject to the theory of politeness, is feasible with assistance from normative frameworks. Virtual humans may be able to behave adequately under the governance of social rules–conventional politeness but may also take actions as a result of recognising situation-specific actions from observing the activities of others associated with personal interactions—interpersonal politeness.

Within this context, this paper aims to demonstrate the enhancement of politeness using the combination of normative frameworks and virtual agents. Beyond the individual world view of virtual agents, this mechanism allows the analysis of social situations in which each virtual agent is situated and thus leads them to 'rational' decision making with assistance from adding social norms and social reasoning: The former, social norms, may enlighten virtual agents to be capable of being conventionally polite in a society, whereas the latter may promise a better understanding of current social situations, so that it becomes a source of prediction about 'when' and 'what' to do in order to be interpersonally polite as perceived by other participants.

The main contribution of this paper is a mechanism to cope with politeness in general rather than in a small specific aspect of daily activities. In reality, humans are likely to be engaged in many complicated social interactions so various kinds of polite activities are required corresponding to those situations. Likewise, virtual agents are also situated in similar circumstances because of major advances in virtual worlds, thus they need a higher level of autonomy to deal with a wider range of situations in which to be more polite.

With this aim in mind, the main objective of this paper is to (i) introduce a high-level agent architecture combined with normative frameworks, which is capable of modelling, reasoning and deliberation about polite behaviours in social situations; (ii) demonstrate the interpretation of high-level behaviour into sequence of physical atomic actions formed in animations in VEs; and (iii) show the evaluation of this approach.

The remainder of this paper is organised as follows. Section 2 presents an outline of normative frameworks and its main functionalities. In Section 3, we describe the high-level agent architecture and its mental model to achieve a formulation of high-level politeness. This is followed by an illustration of a practical implementation of polite behaviour in terms of actions and animations in VEs. The result are shown in Section 5 composed of experiment, evaluation and discussion. This is followed by a survey of related works in Section 6 and conclusions and future work in Section 7.

2. THE NORMATIVE FRAMEWORKS

The use of social norms has the potential to contribute to advances in the social intelligence of virtual agents, as indicated by a number of papers in the literature [8–11]. Not only do norms offer guidance about correct behaviour in specific situations but also provide better understanding about a current situation. Hence, it might be seen that the addition of normative reasoning to virtual agents can be regarded as a way in which to improve agent reasoning and response capabilities and in particular to enhance response in social settings.

Normative frameworks—also known as institutional models—are a kind of external source of knowledge delivering norms to virtual agents. It is a set of rules being able to govern the agent society. These rules can be seen as situation-specific norms resulting from reasoning about the current social context, rather than just a hard-coded repertoire of reactions such as those in the static expert systems. It describes not only correct and incorrect actions but also norms such as obligations, while maintaining a record through its internal state, that evolves according to events captured from the external world.

We adopt Cliffe's institutional framework [12], which provides the function of regulatory governance of agents through its capacity for social reasoning. The regulation takes the form of permissions and obligations that an agent is free to follow or ignore, but the latter may have social consequences, such as ostracism [13], for example—although we do not explore this issue further here. The framework provides a formal action language Inst*AL* to specify norms describing social interactions between agents and (or) environments in the context of the institutions. Then, the formal framework is translated to a computational framework based on answer set programming (ASP) [14], which enables the reasoning about the current social context described in the institution.

The institutional model is composed of a set of *institutional states*, evolving over time triggered by the occurrence of *events*. An institutional state is a set of *fluents*, which may hold positive or negative at certain time. In addition, such institutional fluents may be separated into *domain* and *normative fluents*, which comprises of the following subsets: (i) *power* ($\mathcal{W}$) which indicates that events are empowered to bring about institutional change; (ii) *permission* ($\mathcal{P}$) which indicates that events can be performed without violation; and (iii) *obligations* ($\mathcal{O}$) which specifies that events are obliged to happen before the occurrence of deadline (e.g. a timeout), otherwise, violation is generated. These normative fluents represent the normative consequences of particular behaviours that should be achieved by virtual agents at a certain social context.

DOI: 10.1002/cav

For example, the form of the normative information is represented as `obl(act, deadline, violation)` or `perm(act)`, which means an agent X is obliged to carry out action *act*, or an agent X is permitted to perform action *act*, respectively.

As described earlier, these normative fluents are brought about by the events, which can be classified into (i) *external events* (ε_{ex}) that capture the events occurred in VEs; and (ii) *institutional events* (ε_{inst}) that are interpretation of external events in the institutional context.

By observing the occurrence of a series of external events, the institutional state in VEs evolves over time according to the given social context by the *institutional rules*. These rules can be divided into (i) generation rules ($\mathcal{G}$) that generates institutional events from the occurrence of external/institutional events subject to conditions on the state; and (ii) consequence rules ($\mathcal{C}$) that updates institutional states by initiation/termination of fluents, subject to the occurrence of some events and conditions. These two rules identify the construction of normative consequences at the particular moment triggered by events.

All these elements are specified in the institution by Inst*AL*. The actual operation of the reasoning about normative consequences, subject to an observed but incomplete trace of ε_{ex}, is accomplished by answer set solver, just after the translation of formal institution model to a corresponding computational model using ASP. In the reasoning process, answer set solver performs traversing all cases with descriptions and constraints derived from $\mathcal{G}$ and $\mathcal{C}$ and find the most adequate answer in all answer sets afterwards. For more details, refer to [12].

3. HIGH-LEVEL AGENT ARCHITECTURE

As discussed in the preceding section, the normative frameworks serve a general mechanism for the recognition of specific social situation and somehow prediction of correct behaviours to be polite, which is expected by others at that moment. These are assumed as additional context information for virtual agents, so agents have to do the decision making using their own knowledge and normative guidance. To do so, we use a lightweight and distributed high-level architecture as proposed in [15], which supports the combination of the deliberation with the normative frameworks to accomplish social reasoning with belief–desire–intention (BDI) agents [16] supporting individual reasoning.

A high-level architecture for agent decision making is shown in Figure 1. This system is composed of three software components as follows: (i) the normative framework, which formulates and delivers norms corresponding to environmental events delivered by agents; (ii) the virtual character situated in the VE and being capable of sensing and acting; and (iii) the BDI reasoning agent receiving percepts from the virtual character and generating plans delivered to the virtual character.

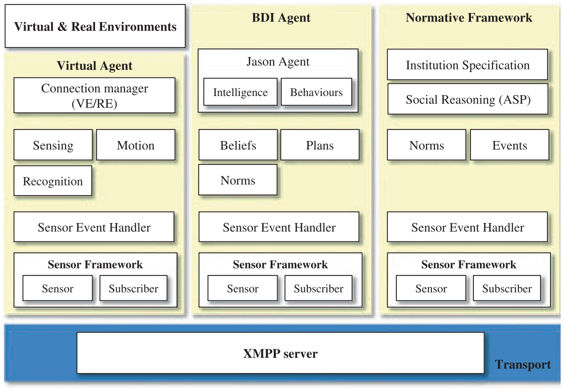

Figure 1. High-level agent architecture.

The perceived data from the virtual character is usually raw, so it must be converted into a symbolic representation to be used in the BDI agent. Likewise, the action plans from BDI reasoning agent are high-level abstract behaviours that need to be decomposed in atomic virtual character actions, similarly. Percepts transferred from the virtual agent build up the belief set of the BDI reasoning agent, along with normative consequences from the normative framework. As part of the belief set in the BDI reasoning agent, those normative consequences also contribute to the agent's decision-making process. All decision making is performed by the BDI reasoning agent, and each one of them is directly mapped to a virtual character. When we refer to 'virtual agent', we mean this pair of entities: the BDI reasoning agent and the virtual character.

Delivery of normative consequences to the individual BDI reasoning agent is accomplished by run-time reasoning mechanism like that illustrated in [17]. Once the belief set in the BDI reasoning agent is updated by percepts (denoted as ε_{ex}, information about the environments) collected by the virtual character, then ε_{ex} is delivered to the normative framework, and the normative state ($\mathcal{P}$ or $\mathcal{O}$) is updated. When queries are made by the BDI reasoning agent to the normative framework, it gives rise to a social reasoning process and replies with new normative consequences ($\mathcal{P}$ or $\mathcal{O}$) to the BDI reasoning agent. The mental state of BDI agent is updated by this social normative information, denoted as $\mathcal{N}(\varepsilon_n^{iva_i})$.

As a complementary information about the current social situation, the normative information, $\mathcal{N}(\varepsilon_n^{iva_i})$, is typically incorporated in the belief base or as subgoal to the main goal in the BDI reasoning agent. With this information, the BDI reasoning agent performs individual reasoning, in conjunction with its own contextual knowledge and then high-level behaviours are passed to the virtual character in order to achieve tasks composed in a sequence of animations.

4. MODELLING POLITE VIRTUAL AGENTS

In this section, we show a simple illustrative example of how politeness is achieved by the combination of high-level agent architecture and virtual characters. This demonstration consists of (i) specifying the polite behaviour as a form of social norms in the institutional model; (ii) social reasoning technique for the generation of social norms representing polite behaviour; (iii) deliberation with such norms in the BDI reasoning agent; and (iv) realisation of the polite behaviour by atomic physical actions inside the virtual character.

We present a collision avoidance model, which is triggered when PCs are detected by virtual agents. This is a modelling of the theory of politeness composed of (i) a formulation of a social norm representing an obligation, '*avoid collision*', and its related decision making in high-level agent architecture, for conventional politeness; and (ii) a resolution of collision and a prediction of the future situation by the recognition of others' activities, which represents interpersonal politeness.

4.1. High-Level Modelling

Specifying polite behaviours. As introduced in Section 2, we employ the declarative action language Inst*AL* to construct the formal model of institution, which specifies the social norms in the collision avoidance scenario.

We define three domain fluents denoting the friendship between an agent and a PC `friends(Ag, P)` and two kinds of interpersonal distance (IPD) associating them: `lowIPD(Ag, P)` and `highIPD(Ag, P)` subject to the closeness of the friendship. When an intimate character is moving towards a virtual agent, then `lowIPD(Ag, P)` should be initiated to maintain a lower personal distance between them, otherwise `highIPD(Ag, P)` is initiated.

```
lowIPD(Ag, P) when friends(Ag, P);
highIPD(Ag, P) when not lowIPD(Ag, P);
```

An exogenous event is defined to indicate the physical event that a PC is detected, which then generates the corresponding institutional event

A set of consequence rules are also provided to specify the norms that should be initiated subject to the condition of the IPD as follows: (i) when a high IPD is required, the agent is obliged and permitted to avoid collision with the player; (ii) when a low IPD is required, the agent is obliged and permitted to greet the player.

```
exogenous event detected(P);
inst event intDetected(P);
arrived(P) generates intArrived(P);
```

```
intArrived(P) initiates
    perm(avoidCollision(Ag, P)),
    obl(avoidCollision(Ag, P), deadline,
        violpoliteness(Ag))
    if highIPD(Agt, P);

intArrived(P) initiates
    perm(greet(Ag, P)),
    obl(greet(Ag, P), deadline,
        violpoliteness(Ag))
    if lowIPD(Agt, P);
```

Social reasoning using ASP. Once polite behaviours are specified using Inst*AL*, it can be then translated automatically into the a computational model in ASP, which sets the stage for the normative reasoning performed by the answer set solver, *Clingo*. What follows is a fragment of ASP code for the initiation of the obligation norms translated from the Inst*AL* formal model.

```
initiated(obl(greet(Ag,P),
    deadline,violpoliteness(Ag)),I) :-
    occurred(intArrived(P),I),
    holdsat(live(ipd),I),
    holdsat(lowIPD(Ag,P),I),
    player(P), agent(Ag),instant(I).
initiated(obl(avoidCollision(Ag,P),
    deadline,violpoliteness(Ag)),I) :-
    occurred(intArrived(P),I),
    holdsat(live(ipd),I),
    holdsat(highIPD(Ag,P),I),
    player(P), agent(Ag),instant(I).
```

The process of social reasoning consists of (i) translation of specifications from Inst*AL* into ASP code; (ii) generation of all possible answer sets using observed events, the rules of the specification and the constraints on answer set generation; and (iii) querying the resulting answer sets for behavioural actions for the agents.

The query should result in the identification of 'correct' (somehow polite) behaviour as a form of social norms. A fragment of an answer set representing social norms is shown in the succeeding text. It shows the normative consequences of a query following the observation of an external event that a player is detected

Provided with the friendship information that *jason2* is a friend of the player *p1*, whereas *jason1* is not, the normative consequences generated for agent *jason1* and *jason2* are shown earlier. The agent *jason1* is obliged to perform

```
Answer: 1
observed(detected(player1), t0).
holdsat(obl(avoidCollision(jason1,p1),
        deadline,
        violpoliteness(jason1)),t1)
```

```
holdsat(obl(greet(jason2,p1),
        deadline,
        violpoliteness(jason2)),t1)
SATISFIABLE
```

action *avoidCollision* before the *deadline*, otherwise, a violation event *violpoliteness* is produced. For *jason2*, the obligation is to greet the player.

Decision making with norms in BDI agents. As mentioned in Section 3, such normative consequences sometimes become a part of belief set or subgoals presented as follows. At the same time, the BDI reasoning engine then carries out the decision making and sends a sequence of action plans to the virtual character to perform motor actions.

```
% Norms as a Belief
+!polite : obl(avoidCollision) & ~lowIPD
    <- change(speed, low);
       change(orientation, orthogonal).
% Norms as a Sub-Goal
+!greeting : lowIPD & ~highIPD
    <- greeting(say);
       greeting(bow).
+obl(greeting) : true %sub-goal!
    <-  move(close);
        greeting.
```

4.2. Low-Level Modelling

Prediction of potential collisions. The simple approach for the prediction of potential collisions is inspired by the social force model [18]. Both characters are modelled as cylinders, which are r_p in radius for PCs and r_v for NPCs, respectively. Physical collisions occur when the distance between PCs and NPCs is less than $r_p + r_v$. Likewise, the scanning range is modelled as a cylinder, with a radius of R_s in order to verify the proximity between PC and NPC.

Once PC comes inside the scanning range R_s, then the NPC investigates and predicts using the following information: (i) vectors representing the direction of characters, determine whether collisions will occur or not (see Figure 2); and (ii) the intimacy determined by the IPD [19], which allows an NPC to approach closer to a PC. The velocity is not considered because all agents have the same speed in this VE, but it would be straightforward to take this additional factor into account.

Resolution of physical collisions. Once the collision avoidance is decided, subject to the IPD between PC and NPC, then the new position of an NPC is updated by the same model proposed in [3]. Given the current location of the NPC at l_v, the new location l'_v is determined by

$$l'_v = l_v + \frac{l_p - l_v}{\|l_p - l_v\|}((r_p + r_v) - \|l_p - l_v\|) \quad (1)$$

where r_p and r_v are the radii of PC and NPC, respectively.

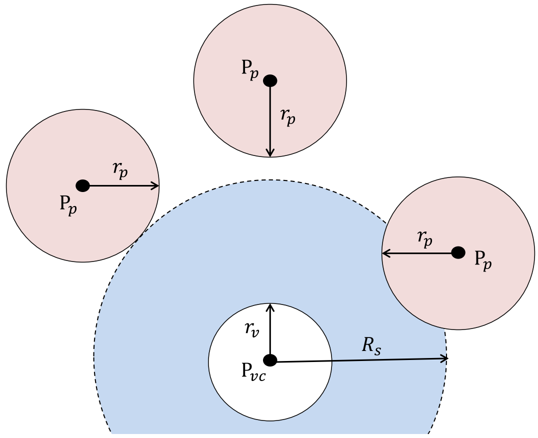

Figure 2. Prediction of potential collisions.

5. EVALUATION

5.1. Experiments

We conduct a brief experiment chosen from [3] to evaluate the effectiveness of using polite behaviours for navigation in VEs. Two simple navigation scenarios are designed, navigation on the open road and in a doorway, seen in Figures 3 and 4, respectively. The main task of PCs is to reach the destination by passing through the group of avatars, which are moving in the opposite direction to the players. We assume that there may be moderate space between avatars, which ensures players to walk between them without much effort.

The experiments are carried out in the *Second Life (SL)* [20] virtual world. Players directly log in to the main server using its client programme. These PCs are manipulated by an ordinary keyboard as usual for most human users. The virtual agents are created by libOMV [21] and are controlled by BDI reasoning agents. A total of 10 virtual agents are used for a formation of a group in both scenarios. Each scenario is played out for 40 trials, split equally into 20 for polite agents and 20 for otherwise.

The collision detection is achieved programmatically by (i) capturing collision notifications from the *SL* server; and (ii) measuring distance at the same time between PCs and virtual agents. Both are perceived by virtual agents internally. Note that we only take account of collisions between PCs and virtual agents in these experiments: PC–PC and NPC–NPC collisions are not considered.

5.2. Results

Overall statistics for collisions are shown in Table 1, where μ and σ are the mean and standard deviation, respectively.

These results suggest that polite agents provide quicker and easier navigation in crowded VEs. In both scenarios, we can say that passing through a group of polite agents is smoother and collision-free than that within a group of ordinary agents.

Figures 5 and 6 also illustrate the effectiveness of the politeness of virtual agents using social reasoning technique. In the first scenario, a high density group of agents provides enough space for the PC to be able to pass through with little or no change of direction. Similarly, the player is rarely observed being obstructed by polite virtual characters despite the doorway being somewhat narrow and that many agents are still moving around in that space.

It may be appropriate to emphasise that all the virtual agents participating in this experiment are fully autonomous. There is no training process or learning process involved, so each run will see different individual action sequences: the agents are not automata that do the same thing each time, hence the necessity for multiple runs. In our model, the agent autonomy is developed on the basis of temporal reasoning with sequence of event occurrences, which provides a degree of flexibility making it applicable for a range of circumstances. In addition, thanks to the use of autonomous and deliberative BDI agents, more rich behaviours may be presented with the combination of social and individual reasonings at any time in any places.

5.3. Limitation

Notwithstanding the aforementioned positive results of the collision avoidance model that are achieved by social reasoning, there are some issues to discuss regarding the matter of taking measurements from experiments in SL.

The unusual definition of collision in SL weakens the reliability of the statistics of collision detection. In the SL server, collisions are only detected when one avatar's position is changed by being pushed by another. Only in this case is the collision actually detected and communicated to the client side. So, some cases that do not satisfy those condition may not be counted as collisions, even though they may be clearly observed by human eyes.

The client–server architecture is another factor interfering with the immediate detection of collisions. In the SL system, the metrics (such as position, orientation, velocity and so on) of avatars come from the server to update client-local information, which might be used for monitoring the movement of others. However, packet loss, transmission delay and status update failure can all contribute to inaccuracy in movement detection. As a result, again, not all collisions may be counted.

Lastly, if an avatar keeps moving all the time, sometimes, this avatar cannot detect any event or the movement of other. This is serious because not all collisions can be reported, even if everything is witnessed.

Figure 3. Road scenario.

Figure 4. Doorway scenario.

For more precise and accurate measurement, it seems that manual counting of collisions using recorded video sequences [3] is the only reliable method. An alternative solution is to change to a different VE.

6. RELATED WORKS

There has been relatively little work published on the topic of politeness and virtual characters. So, we intend to extend this from the discuss about modelling politeness for virtual characters and also some basic techniques affecting virtual agent's behaviour, such as the use of norms in virtual agents and its society, or behaviour prediction systems with intention/activity recognition.

Polite agents. Allen *et al.* [3] propose the pioneering work about the politeness in interactions between PCs and virtual characters. On the basis of an asymmetric relationship, virtual characters predict the next few movements of PCs using a Hidden Markov Model and react politely such as changing velocity and path around PCs to avoid collisions. The result with regard to the number of collisions and completion time of navigation is remarkable, so the ease in navigation is achieved despite using low precision user input devices. However, off-line learning is always required with a training data representing spatial information and its related reactive behaviours in this system.

As discussed in Section 5.2, our model has more generality to be applied for all circumstances without training data. In addition, we use autonomous and deliberative agents so more rich behaviours may be presented with the combination of social reasoning and individual reasoning at any time in any places.

Table 1. Statistics of collisions.

Road				Doorway			
	Type	μ	σ		Type	μ	σ
Collisions	Polite	0.40	0.50	Collisions	Polite	0.55	0.60
	Impolite	3.05	1.64		Impolite	2.10	0.97

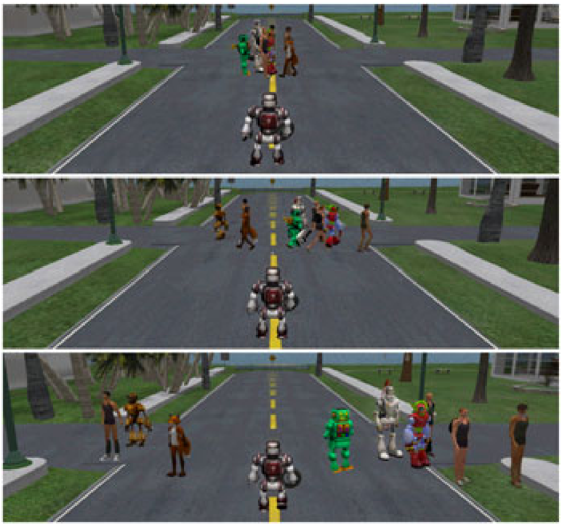

Figure 5. Polite behaviour on the road.

Figure 6. Polite behaviour in doorway.

Virtual agents with norms. Bogdanovych *et al.* propose virtual institutions [22], which they also call a 3D electronic institutions (EI), through the integration of EI—an alternative approach to institutional modelling—and Second Life virtual world. The social norms are explicitly included in a set of physical places, such as 3D object, rooms or buildings, which is regarded as a separated 'EI' in the 3D VEs. Each agent is able to take a role specified in the social norms and carry out activities permitted for that role in the EI.

A different approach to the use of norms is seen in Thespian, proposed by Si *et al.* [23]. With the partially observable Markov decision processes offering an interesting alternative to the explicit representation of norms, they defined a set of social norms, which may improve the agent social behaviours particularly in a conversational context. Those norms are entered into the mental state of virtual agents as an explicit goal that must be achieved, rather than a goal that the agent may choose to achieve or not.

Although those systems seek the advances of the social intelligence for virtual agents, sometimes, the existence of social norms limits the agent autonomy by regimentation due to obviously hard-coded norms in the agent mind or environments. Our approach is different in that the system supports the regulation approach: the social norms are not obvious goals that should be always achieved but can be accepted, violated or ignored by agents depending on their context. In addition, those norms are not fixed but evolve over time corresponding to changes in environments. These features ensure that the virtual agent not only has a higher level of its own autonomy but also performs right and adequate actions, such as polite behaviours, at anytime, anywhere.

Prediction systems by intention recognition. Traditionally, the prediction of intention depends on a 'search and hit' mechanism between observed actions and plan libraries (or recipes) in the agent's mind [24]. Using predefined relational functions or utilities between atomic actions and its properties, agents try to find intentions (or motivations) for achieving a certain goal from an observed sequence of actions. A good example is 'Mindreading skills' introduced by Breazeal *el al.* [25].

Another approach is inspired by rule-based systems using a logic background. Mental abduction [26] is a well-known technique to read and predict agents' mind. By observing the action sequence of other agents, it infers the mental state of other BDI agents in accordance with its beliefs, goals and intentions, using plan–goal rules. This is promising to have a possibility of the incorporation of attributed mental states and the decision making of the self-agent.

Our approach also supports a sort of prediction using our logic-based approach. 'Correct' or 'expected' behaviours can be inferred by social reasoning capability of the institutional model, through both consequence and generation rules describing relationships between observed event sequence and those behaviours. Thanks to ASP, the prediction may be performed with incomplete set of events.

7. CONCLUSION AND FUTURE WORKS

As we suggested at the outset, polite behaviour in virtual agents is promising for the efficiency and naturalism in navigation in dynamic VEs. To support this, we propose a high-level agent architecture combined with normative frameworks, which is capable of modelling, reasoning and decision making about polite behaviour under social situations. Using this architecture, a collision avoidance model between PCs and virtual agents subject to IPD is demonstrated as a simple example in a real-world 3D VE. PCs are able to pass through a group of virtual agents and navigate around them with relative ease.

Our approach is more flexible than the literature we cite because it can be applied in different scenarios. This is because it depends upon rule-based, temporal reasoning with a sequence of event occurrences, rather than a spatial reasoning systems that needs suitable training data. Also, all forms of polite behaviours can be created subject to the theory of politeness thanks to the main functionalities in normative frameworks.

We hope that future research may enable more delicate polite behaviours through the extended IPD model and also the politeness a common trait for virtual characters, beyond the asymmetric relationship in players and virtual agents. Politeness is inherently a qualitative judgement on behaviour, which would suggest the need for quite challenging—from a science and psychology perspective, as well as cost, time and repeatability—human-based studies. Consequently, we seek a lighter weight quantitative mechanism as a proxy for the qualitative study, for which factors such as number of changes of direction and the angular change involved in passing through the crowd might be some suitable indicators of the quality of the avoidance mechanism. From an architectural perspective, multiple institutional models and related decision-making mechanism in BDI agents will be explored with the aim of providing a similar circumstance with real human society.

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