A logical model of Theory of Mind for virtual agents in the context of job interview simulation

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ABSTRACT
Job interview simulation with a virtual agent aims at improving people’s social skills and supporting professional inclusion. In such simulators, the virtual agent must be capable of representing and reasoning about the user’s mental state based on social cues that inform the system about his/her affects and social attitude. In this paper, we propose a formal model of Theory of Mind (ToM) for virtual agent in the context of human-agent interaction that focuses on the affective dimension. It relies on a hybrid ToM that combines the two major paradigms of the domain. Our framework is based on modal logic and inference rules about the mental states, emotions and social relations of both actors. Finally, we present preliminary results regarding the impact of such a model on natural interaction in the context of job interviews simulation.

Categories and Subject Descriptors
I.2.11 [Distributed Artificial Intelligence]: Intelligent agents

General Terms
Theory, Experimentation

Keywords
Theory of Mind, Cognitive Models, Logic-Based Approaches, Human-Agent Interaction, Affective Computing, Serious Games for Inclusion

1. INTRODUCTION AND POSITIONING
During the last decade, several projects have proposed to use intelligent virtual agents in digital games for user empowerment [19] [22] [23]. The work presented in this paper considers the use of virtual agents in job interview simulation games for young unemployed peoples, a.k.a NEETs. Current research reveals that NEETs often lack self-confidence.

1NEET is a government acronym for young people not in employment, education or training. According to Eurostat, and the essential social skills needed to seek and secure employment [9]. Training with a virtual agent can help them acquire self-confidence and improve their social skills. Indeed, it has already been proven that training at job interviews with a virtual agent could improve the performance [17].

The role of the virtual agent in such training games is to be able to react in a coherent manner: based on the non-verbal inputs (smiles, emotion expressions, body movements), the agent must select relevant verbal and non-verbal responses. In this context, several work illustrated the role of emotion regulation in the context of job interviews. For instance, in [29], a study shows that people who tried to suppress or hide negative emotions during a job interview are considered more competent by evaluators. Similarly, Tiedens [30] shows that anger and sadness play an important role in job interviews. For this reason, credible simulation of emotions appears as a key issue when it comes to using virtual agents in job interview simulations.

Most existing models for virtual agents rely on a reactive approach, in which the system does not manipulate or reason on the mental states of the interlocutor [17] [22] [23]. However, in human psychology, Theory of Mind (ToM) refers to the ability of human beings and primates to interpret, predict and even influence others’ behavior [4]. Such an ability is a key feature in the development of intelligent virtual agents in the context of tutoring and training systems. In this paper, we propose a new model of ToM for virtual agent in the context of job interview simulation.

The next section briefly discusses existing research that serves as a basis to our work. Sections 3 and 4 present the general architecture and the logical framework for our ToM. Section 5 describes our implementation of this model in the context of job interviews simulation. An outline of the preliminary evaluation we conducted is given in Section 6. Finally, results and perspectives are discussed in Section 6.3.

2. RELATED WORK
In order to be able to reason on the affective dimension of the interaction, conveyed by the non-verbal behaviour of both in march 2012, 5.5 million of European youngster (16 to 25 years old) were unemployed meaning that 22.6% of the youngster global population in European union is unemployed. This unemployment percentage is 10 points superior to the whole population showing that the employment of NEETs is a real problem in Europe.
interlocutors, several models rely on the cognitive structure of emotions and appraisal theories such as CPM [27] or OCC [21]. These theories provide domain-independent descriptions of triggering conditions of emotions, that are required for the development of the affective aspect of the ToM reasoner. For instance, [11] are BDI-based implementation of the OCC theory. Fatima’s double appraisal model [3], although not implemented using a BDI framework, also encodes the OCC model. However, in these models, the inference mechanism itself encodes the chosen Appraisal Theory. On the contrary, in our model, we propose a theory-independent ToM reasoner. While our experiments were conducted using an OCC-based model, the corresponding rules (described in equation [20]) could be easily replaced by another theory.

To support such adaptability, we propose to rely on the BDI model. Several computational models of emotions have already been proposed (e.g. [16, 11]) that show that BDI is a good basis to represent and to reason about the interlocutor’s mental state. Our aim is thus to define a logical model of emotions and ToM in BDI.

From the philosophical point of view, a debate about how ToM is processed by human adults opposes two theories. The theory-theory (TT) argues for a folk-psychology reasoning, i.e. a set of rules one acquires regarding human mind functioning. [8]. The simulation-theory (ST) [13] defends a mirroring or projection process allowing for taking someone else’s perspective. Various research demonstrated that neither pure TT nor pure ST were realistic [31] and both theorists and simulationists turn toward more hybrid models [8, 13].

Existing computational ToM models either imply a choice between the TT and ST theories (e.g. [3] that relies on a ST approach, or [7] and [25] that position in the TT) or implement them separately as in [15]. In our work, we propose a hybrid approach that relies on theory-theory to model the agent’s mental states and commonsense rules, but also on simulation-theory to others’ perspective by projecting attributed mental states on its own inference engine. Both models are integrated in the same reasoner.

3. ARCHITECTURE OVERVIEW
Our ToM reasoning architecture consists of two main components, as presented on Figure 1.

The agent’s mental states contains beliefs, attitudes, goals and intentions. Beliefs represent knowledge about general facts, rules of the world (i.e. commonsense knowledge from the theory-theory) and mental states of self or other’s (i.e. attributed mental states). Attitudes represent appreciations of the current state of affairs and, by extension, desires (what the agent wants to be true in the future) and ideals (what the agents would like to be always true). Goals and intentions form the deliberative aspect, limited to immediate actions.

The agent’s inference engine contains three parts. The folk-psychology deliberative reasoner is responsible for intention generation (according to the agent’s beliefs and attitudes) and updating mental state. The Commonsense reasoner’s role it to enrich the agent’s beliefs base using commonsense rules and facts. Finally, the emotional inference engine computes emotion based on the appraisal theory.

Our hybrid ToM modeling relies on: 1) a TT approach based on folk-psychology and commonsense to reason about others, and 2) a ST approach consisting in projecting their attributed mental states on the agent’s own inference engine. The following section details this logical model.

4. LOGICAL FRAMEWORK
In the following, $\equiv$ and $\overset{\text{def}}{=} \Rightarrow$ respectively mean equals by definition and implies by definition. The former is used to define new operators as functions of others and the latter to express inference rules.

4.1 Syntax
Assume finite sets of atomic propositions $ATM$, physical actions $ACT$, illocutionary (speech) acts $ILL$, agents $AGT$, emotions $EMO$ (which is a subset of the twenty two OCC emotions in our model), and the intervals of real numbers $DEG = [-1, 1]$ and $DEG^+ = [0, 1]$. $ATM$ describes facts or assertions (e.g. salary is bad, picnic is fun) or external events such as rain starts falling. $ACT$ describes actions that the agents or humans ($AGT$) may perform, e.g. introduce itself or have a picnic.

Our model defines events as acts in which at least one of the actors of the interaction take part. Elements in $EVT$ are tuples in $AGT \times AGT \times (ACT \cup ILL(\text{ATM}))$ where the first element is the actor that performs the action, the second is a passive agent and the act can be either an actions ($ACT$) or a speech act ($ILL$). This representation is similar to the one in [20] except we associate a subjective degree of plausibility as is usually done in BDI models and we do not distinguish actions from communication. Illocutionary speech acts have the form $\chi(\varphi)$ and mean “actor utters $\varphi$ to recipient through the illocutionary act $\chi$”.

The language we define is the set of formulas described by the following BNF (Backus-Naur-Form):

\begin{align*}
EVT : \epsilon & := \langle a, (a \emptyset), a \rangle | \langle a, a, \text{Spk}(\varsigma, \varphi) \rangle \\
Prp : \pi & := p | \epsilon | \text{Like}_{a,b}^k | \text{Dom}_{a,b}^k \\
Fml : \varphi & := \pi | \text{Bel}_{a,b}^k(\varphi) | \text{Attr}_{a,b}^k(\varphi) | \text{Int}_{a}(\varphi) | \text{Emo}_{a,b}(\epsilon, \varphi) | N(\varphi) | U(\varphi, \varphi) | \neg \varphi | \varphi \land \varphi
\end{align*}

(1)
where \(a, b \in \text{AGT}\), \(\alpha \in \text{ACT}\), \(p \in \text{ATM}\), \(\epsilon \in \text{EVT}\), \(\varepsilon \in \text{EMO}\), \(l, i \in \text{DEG}\), \(k \in \text{DEG}\). Like, Dom, Bel, Att and Int are modal operators and \(N\), and \(U\) are temporal operators Next and Until from LTL and CTL*. The other temporal operators \(F\) and \(G\) and boolean conditions \(\top, \bot, \lor\) and \(\Rightarrow\) are defined in the standard way. Moreover, in the events' representation, we use “−” as the any operator.

For the representation of social relation \(\text{Like}\). Like\(_a^b\) determines the level of liking agent \(a\) has for agent \(b\), while Dom\(_a^b\) represents the degree of dominance.

Bel\(_a^b(\varphi)\) is a graded belief, in a similar manner to \(\text{Bel}\), and has to be read “\(a\) believes that \(\varphi\) with certainty \(l\)”. For instance, Bel\(_a^b(\phi)\) means “\(a\) is sure that \(\varphi\)” and Bel\(_a^b(\phi)\) can be read “For \(a\), \(\varphi\) is not plausible at all”.

Similarly, Att\(_a^b(\varphi)\) is a graded attitude that has to be read “\(a\) appreciates/values the fact that \(\varphi\) with a degree \(l\)” in our context, this operator will be used to cover various notions, such as Desires, Ideals and Goals that are represented with different modal operators in other work such as \([1]\) and \([14]\). We define desires as a positive attitude toward future facts and ideals as what the agents would like to always be true:

\[
\text{Des}_a^b(\varphi) \overset{\text{def}}{=} \text{Att}_a^b(F(\varphi))
\]

\[
\text{Ideal}_a^{k>0}(\varphi) \overset{\text{def}}{=} \text{Att}_a^{k>0}(G(\varphi)) = \text{Des}_a^{-k<0}(\neg\varphi)
\]

The definition of goals through attitudes will be presented in the next subsection.

Note that in our model, the subject of an attitude can as well be preserving_forest, being_nice_to_others, hiring_new_employee or Bel\(_a^b((a,c,\text{give_sandwich}))\), eventually encapsulated in temporal operators.

As in classical BDI, Int\(_a(\varphi)\) represents an agent’s plan \([26]\) and has to be read “\(a\) intends to make \(\varphi\) true” (with \(\varphi\) being an event in the general case).

Emo\(_a^{(b)l}(\varphi)\) represent emotions. Following classical literature \([12]\), our emotions are related to facts and can be directed toward an agent. Emo\(_a^{(b)l}(\varphi)\) has to be read “\(a\) feels \(\varepsilon\), eventually for/towards \(b\), with intensity \(i\), regarding the fact that \(\varphi\)” with \(\varepsilon \in \text{EMO}\). In the following sections, it will be simplified into \(\varepsilon\)\(_a^{(b)l}(\varphi)\).

For the sake of readability, we introduce new operators to represent agents’ involvement in an event. Resp\(_a\) expresses a direct responsibility. Unlike \([1][14]\), we do not consider an agent responsible for a situation it could have avoided. Wit\(_a\) means that the agent witnessed the occurrence of the event:

\[
\text{Resp}_a(\epsilon) \overset{\text{def}}{=} (\epsilon = (a, -, -))
\]

\[
\text{Wit}_a(\epsilon) \overset{\text{def}}{=} (\epsilon = (a, -, -)) \lor (\epsilon = (-, a, -))
\]

4.2 Semantics

Based on possible world semantics, we define a frame \(\mathcal{F} = (W, B, \mathcal{D}, \mathcal{I}, \mathcal{E})\) as a tuple where:

- \(W\) is a nonempty set of possible worlds,
- \(B\) : \(\text{AGT} \rightarrow (W \rightarrow 2^W)\) is the function that associates each agent \(a \in \text{AGT}\) and possible world \(w \in W\) to the set of belief-accessible worlds \(B_a(w)\),
- \(D : \text{AGT} \rightarrow (W \times \text{DEG}^+ \rightarrow 2^W)\) is the function that associates each agent \(a \in \text{AGT}\) and possible world \(w \in W\) with a level of desirability \(l \in \text{DEG}^+\) to the set of desire-accessible worlds \(D_a(w, l)\),
- \(\mathcal{I} : \text{AGT} \rightarrow (W \rightarrow 2^W)\) is the function that associates each event \(\epsilon \in \text{EVT}\) to the resulting possible world.

Then, a model \(M = (\mathcal{F}, \mathcal{V})\) is a couple where \(\mathcal{F}\) is a frame and \(\mathcal{V} : W \rightarrow \text{ATM}\) a valuation function.

Given a model \(M\) we note \(M, w \models \varphi\) a formula \(\varphi\) that is true in a world \(w\). Truth conditions of formulas are defined by induction in the classical way:

\[
M, w \models p \iff p \in V(w);
\]
\[
M, w \models \neg\varphi \iff \not M, w \models \varphi;
\]
\[
M, w \models \varphi \land \psi \iff M, w \models \varphi \text{ and } M, w \models \psi;
\]
\[
M, w \models \text{Bel}_a^l(\varphi) \iff \text{card}(\mathcal{GB}_a(w)) = l
\]
where \(\mathcal{GB}_a(w) = \{ v \in B_a(w) : M, v \models \varphi \};
\]
\[
M, w \models \text{Des}_a^l(\varphi) \iff M, v \models \varphi \forall v \in D_a(w, l);
\]
\[
M, w \models \text{Int}_a(\varphi) \iff M, v \models \varphi \forall v \in I_a(w);
\]
\[
M, w \models \epsilon \iff M, v \models \top \forall v \in E(\epsilon);
\]

The truth condition of \(\text{Bel}_a^l(\varphi)\) states that the level of plausibility of \(\varphi\) is the proportion of belief-accessible worlds where \(\varphi\) is true. The next subsections describe the rules for the inference engines presented in section 3. When required, the computation of believability, desirability and intensity degrees will be represented by a \(f\) function that is part of the implementation and will not be detailed in this section (see section 3 instead).

4.3 Folk-psychology reasoner

4.3.1 Graded beliefs

Following \([11]\) and \([1]\), all accessibility relations \(B\) are transitive and euclidean, which ensures that the agent is aware of its own belief:

\[
\text{Bel}_a^l(\varphi) \overset{\text{def}}{=} \text{Bel}_a^l(\text{Bel}_a^l(\varphi))
\]

We generalize \([1]\) so that agents are aware of their own mental states, social relations and involvement.

However, unlike other models \([1]\), \(B\) is not serial\(^3\) Only \(\mathcal{GB}\) is. This represents the fact that the agent generally has uncertainty about states of affairs. Intuitively:

\[
\text{Bel}_a^l(\varphi) \overset{\text{def}}{=} \text{Bel}_a^{-1}(-\varphi)
\]

\(^2\)If \(wRv\) and \(vRu\), then successively by transitivity, euclideality and transitivity again: \(wRu\) and \(vRu\).

\(^3\)A relation \(R\) is serial iff \(\forall w, \exists v\) so that \(wRv\).
For convenience, we define two thresholds $mod\_th$ and $str\_th$ with $0.5 < mod\_th < str\_th$. They correspond to situations where the agent moderately ($Bel^{(\geq mod\_th)}_a(\varphi)$) and strongly ($Bel^{(\geq str\_th)}_a(\varphi)$) believes something.

Finally, if an agent believes a state of affairs to possibly cause another, it will deduce a belief about it:

$$Bel^l_a(\psi) \land Bel^l_a(\varphi \Rightarrow \psi) \overset{def}{=} Bel^l(l,l')(\varphi) \quad (6)$$

4.3.2 Graded attitudes

Attitudes can be positive or negative and we assume that goals hold consistent desires:

$$\forall \varphi, \psi (\varphi \land \psi) \Rightarrow Bel^l_a(\varphi) \land Bel^l_a(\psi) \Rightarrow Bel^l_a(\psi)$$

We leave it to the implementation phase (section 5) to decide how intentions are ordered when several possible known $\psi$ can be used to achieve a goal.

4.3.3 Goals

Goals are then turned into intentions either because the agent strongly believes it might lead to an undesirable $\psi$ and

$$Bel^{(\geq str\_th)}_a(\psi) \Rightarrow Bel^{(\geq str\_th)}_a(\varphi) \Rightarrow F(\varphi) \land \neg IncDes^k_a(\psi) \overset{def}{=} N(Des^k_a(\psi)) \quad (8)$$

with $IncDes^k_a(\varphi)$ representing inconsistent desires:

$$IncDes^k_a(\varphi) \overset{def}{=} (Bel^{(\geq str\_th)}_a(\varphi) \Rightarrow \neg \psi) \land Des^k_a(\neg \psi) \quad (9)$$

This means that desiring $\varphi$ is inconsistent when the agent strongly believes it might lead to an undesirable $\psi$. We allow for adopting indirectly inconsistent desires only when the agent only believes moderately that there can be a certain incompatibility with existing ones.

We also define a weaker case of inconsistency where $\varphi$ leads to an undesirable state of affairs of a higher level:

$$WIncDes^k_a(\varphi) \overset{def}{=} Bel^{(\geq str\_th)}_a(\varphi) \Rightarrow \neg \psi \land Des^k_a(\neg \psi) \quad (10)$$

4.3.5 Updating attitudes

Beliefs are updated as new events occur (except for ideals that are constant and hold globally). In order for the agent to react to situation change, attitudes about new states of affairs have to be triggered. In our model, following [29][10][3], the attitude is influenced not only by new beliefs, but also by the attitude of others and the social relation. Formally:

$$Bel^{(\geq str\_th)}_a(\varphi) \land Bel^l_a(F(\varphi)) \land Bel^l_a(Atk^l(\varphi)) \land Like^k_{a,b} \land Dom^k_{a,b} \overset{def}{=} Atk^{f(k,k,k)}(\varphi) \quad (11)$$

Finally, as far as accessibility relations $\mathcal{E}$ are concerned, we consider any witness believes with degree 1 that the event happened and that the other witness also believes it. Note that when an event occurs, the belief that it happened remains true afterwards.

4.3.6 Speech acts and social interaction

Beliefs can be also updated through communication. Although our work mostly focus on non-verbal communication, we consider a limited set of illocutionary acts $\mathcal{ILL} = \{\text{Assert, Request, Commit, Express}\}$. Based on similar work in speech acts formalization [16][13], we define triggering rules for our speech acts. For instance:

$$\neg Bel^l_a(\varphi) \land Bel^l_a(\varphi) \overset{def}{=} Request_{a,b}(\varphi) \quad (12)$$

In turn, these events will lead to new mental states for the recipient agent, similarly to classical FIPA semantics and existing work on social interaction modeling [16][10]. For
4.4 Emotional inference engine

The emotional inference engine consists of a set of appraisal rules for emotion categories EMO. In this implementation, we have used an OCC-based model, highly inspired by [14] [11]. Here are some examples of triggering conditions for each group of emotions.

\[
\begin{align*}
\text{Bel}^b_a(\gamma) &\land \text{Att}^{k>0}_a(\gamma) \overset{\text{def}}{=} N(\text{Joy}^i_{a,b}(f(l,k,i))(\gamma)) \\
\text{Bel}^b_a(F(\gamma)) &\land \text{Des}^{k<0}_a(\gamma) \overset{\text{def}}{=} N(\text{Fear}^i_{a,b}(f(l,k,i))(\gamma)) \\
\text{Bel}^b_a(\gamma) &\land \text{Bel}^b_a(\text{Att}^{k<0}_a(\gamma)) \land \text{Lik}^{k'<0}_{a,b} \\
\text{Bel}^b_a(\gamma) &\land \text{Ideal}^b_a(\gamma) \land \text{Bel}^b_a(Rsp_b(\gamma)) \\
\text{Bel}^b_a(\gamma) &\land \text{Ideal}^b_a(\gamma) \land \text{Bel}^b_a(Rsp_b(\gamma)) \land \text{Goal}^b_a(\gamma) \\
\text{Bel}^b_a(\gamma) &\land \text{Bel}^b_a(Rsp_b(\gamma)) \land \text{Goal}^b_a(\gamma) \\
&\overset{\text{def}}{=} N(\text{Gratitude}^i_{a,b}(f(l,k,i,k'))(\gamma)) \\
&\overset{\text{def}}{=} N(\text{Int}_a(\gamma)) \\
\end{align*}
\]

(19)

4.5 Commonsense reasoner

The commonsense reasoner allows the agent to acquire new beliefs based on a set of commonsense rules. It is mostly domain-dependent. Section 5 describes how we used it to implement a job interview simulation scenario. Here is a simple example of how this reasoner can combine with the folk-psychology inference engines presented above.

4.5.1 Example

Consider two friends John (J) and Mary (M) having a conversation about their holidays. Mary is going to her home-town (ht). The fact that she is going to visit her father is a detail she could either mention or not:

\[
\begin{align*}
\text{Des}^{75}_M(\text{talking_about_holidays}) &\quad (\text{input}) \\
\text{Bel}^{75}_M(M,\text{visiting_ht_and_dad}) &\Rightarrow F(\text{talking_about_holidays}) &\quad (\text{input}) \\
\text{Bel}^{75}_M(M,\text{visiting_ht}) &\Rightarrow F(\text{talking_about_holidays}) &\quad (\text{input}) \\
\end{align*}
\]

Nevertheless Mary remembers John recently lost his father and thus supposes it is a sensitive topic:

\[
\begin{align*}
\text{Bel}^{75}_M(J,\text{lost_his_dad}) &\quad (\text{input}) \\
\text{Bel}^{75}_M(J,\text{lost_his_dad}) &\Rightarrow \text{Ideal}^8_J(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\text{J},\text{dad})\text{))))))))))) &\quad (\text{input}) \\
&\Rightarrow \text{Bel}^i_M(\text{Ideal}^8_J(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\text{J},\text{dad})\text{))))))))))) \\
\end{align*}
\]

Of course, Mary knows that saying she is going to visit her father implies actually talking about her father:

\[
\begin{align*}
\text{Bel}^{75}_M(M,\neg,\text{visiting_ht_and_dad}) &\Rightarrow (M,\neg,\text{dad}) &\quad (\text{input}) \\
\end{align*}
\]

And, knowing that John wants to avoid this topic, she does too. Hence, she is will not mention the fact that she is visiting her father when talking about her holidays:

\[
\begin{align*}
(\Rightarrow)\text{Ideal}^8_J(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\text{J},\text{dad})\text{)))))))))) &\Rightarrow (\Rightarrow)\text{Ideal}^8_J(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\neg(\text{J},\text{dad})\text{)))))))))) \\
\end{align*}
\]

5. IMPLEMENTATION

The theoretical model we presented in previous sections is aimed to be domain-independent. Yet, the purpose of our current work in the TARDIS project [2] is to develop a training game in order to facilitate NEETs’ access to employment. Therefore, we propose to implement it in the context of job interview simulation. Indeed, this sort of application appears as a promising way to increase applicant’s self-confidence [17]. Additionally, job interviews are a good example of semi-structured dyadic interactions where recruiters have several opportunities to reason about candidates’ mental and affective states. Nevertheless, to our knowledge, existing models do not include a Theory of Mind.

Our implementation was done in SWI-Prolog for the inference engine and the logical framework. This reasoner was embedded in a C++ program that handles the reasoning loop and the communication between the modules.

Reasoning loop

Following the classical BDI interpreter, at every cycle, the agent interpret external events to generate a list of potential actions, deliberate to select one of them, update its intentions and then execute them:

Thresholds and level functions

The implementation of the model requires to instantiate all thresholds (th) and combination function (f) for degrees of believability and desirability of new mental state or the intensity of emotions.

In our implementation, mod_th = 0.5, str_th = 0.75 and des_th = 0.7.

The combination function cannot be given in detail in this paper but we consider two families:
Algorithm 1 ToM Reasoning loop

loop
  Execute_intentions()
  Simulate_others_emotions()
  Update_beliefs_and_attitudes()
    Update_beliefs_with_new_SoA()
    Handle_operators_equivalence()
  Adapt_new_desires()
  Order_goals()
  Adapt_new_intentions()
  Adapt_new_intentions_from_goals()
  Adapt_new_intentions_from_intentions()
end loop

For attitude dynamics and credibility (e.g. equation 17), we use simple average functions on the relevant interval:

\[ f(k, k') = \frac{(k + k')}{4} + 0.5 \]

For emotions (see equation 20), we combine the linear influence from attitude (for instance, joy has been chosen to be linearly correlated to the attitude toward the fact) with a logarithmic influence of the degree of certainty. This way, we get to trigger more salient emotions even with relatively weak beliefs. Nevertheless, let us remind here that we only consider beliefs which levels are greater than a certain threshold (mod. thld = 0.5 in our implementation).

\[ f(l, k) = \frac{k}{2} \times \frac{\log(2l - 1) - \min}{\min} + 0.5 \]

where \( \min \) represents the smallest value coded by the machine (i.e. the value of \( \log(x) \) when \( x \to 0 \)). The \( 2l - 1 \) factor is used to adjust the value in \([0,1]\) before we compute the intensity, which is then readjusted in \([0.5,1]\) to get significant values.

### Job interview simulation

The course of the job interview is handled in the commonsense module: we define a series of topics that must be adressed by the agent through speech acts (e.g. questions about the salary, the experience...). Moreover, each topic is associated with some expectations about the impact of the question. Based on the current goals (in terms of affective state for the interlocutor), the agent will select a question (a speech act) or another.

Moreover, the agent computes beliefs about the interlocutor’s self-confidence, motivation and qualification, based on its reaction to the questions and simple TT-rules. For instance, hesitating in the job description topic can indicate they are not qualified enough while being focused when introducing themselves denotes a good self-confidence level. The perception of “hesitation” and “focused” is done by another module of the TARDIS platform which is not part of this paper (see [2]).

### 6. PRELIMINARY EVALUATION

In this section, we describe a preliminary evaluation aiming to assess the functioning of our model and its possible contribution in the context of job interview simulation.

Subjects play the role of an unemployed youngster lacking work experience and applying for the job of sales department secretary. The virtual recruiter utterances are predefined for each possible speech act and situation in the model. No constraint were given about a supposed personality, level of education of professional background of the role-played interviewee.

#### 6.1 Method

We recruited 30 volunteers – 11 females and 19 males –, 19 of them working or having an internship at our university. All the subjects were aged over 24, had gone to university and were familiar with computers. 18 of the participants are native speakers and the remaining have at least an intermediate level. Since we are not interested in verbal communication, this is sufficient so that the participants understand what the recruiter says.

The recruiter’s utterances were given in a very simple Graphical User Interface (GUI). The valence of the agent’s affective state and its runtime evaluation of the candidate’s self-confidence, motivation and qualification (values in \([-1,1]\]) were represented by slide-bars. A text field allows the subject to type his/her answer to the virtual recruiter’s questions. Besides, a series of 8 sliders (values in \([0,1]\]) gives them the possibility to express their affective states to the recruiter as combinations of the following affects: relieved (REL), embarrassed (EMB), hesitating (HES), stressed (STR), ill at ease (IAE), focused (FOC), aggressive (AGG) and bored (BOR).

Subjects faced one agent out of 3 possible recruiter profiles: one that tries to make the candidates feel at ease (PROFILE_A), one asking regular questions, with no specific goal on the user’s mental state (PROFILE_B) and one that, asks embarrassing questions (PROFILE_C). This is simply done by varying their goals regarding the emotional reaction they want to elicit in our model. All three agents use the same ToM reasoner described in previous sections.

#### Hypothesis: The profile variation will have an impact on the participants’ emotional states as expressed through the slidebars.

#### Measures: In this paper, we focus on measures extracted from the interaction history. They refer to the average intensity of relief, embarrassment, hesitation, stress, uneasiness, concentration, aggressiveness and boredom expressed by the participants as well as the total emotional expressiveness (TOT). More specifically, we measure the mean amount of information the candidates gave about their affective states.

#### 6.2 Results

Shapiro-Wilk test shows that none of our measures follows a normal distribution. Besides, Kruskal-Wallis test reveals a main effect of PROFILE on TOT \( (\text{Chi}^2(2, 629) = 11.435; p < 0.01) \) and particularly EMB \( (\text{Chi}^2(2, 629) = 6.231; p < 0.05) \) and FOC \( (\text{Chi}^2(2, 629) = 9.218; p < 0.01) \).

This means that the profile of the recruiter (comprehensive,
neutral or challenging) has an effect on the affects assessed (and possibly expressed) by the user, and that this effect is particularly important for embarrassment and concentration.

A Mann-Whitney test then shows that participants that interact with PROFILE_A (comprehensive recruiter) express more affects in general ($U = 20; p < 0.05$), more embarrassment ($U = 20; p < 0.05$) and more concentration ($U = 21; p < 0.05$) than those who interact with PROFILE_B. Likewise, PROFILE_C (challenging recruiter) elicits more affects ($U = 6; p < 0.01$) and in particular stress ($U = 18; p < 0.05$), uneasiness ($U = 24; p < 0.05$) and concentration ($U = 10; p < 0.01$) than PROFILE_B. We also note that in this case, no effect appears regarding embarrassment ($U = 26; p = 0.069$). Finally, no significant effect is revealed between PROFILE_A and PROFILE_C. See Figure 2.

![Figure 2: Effect of PROFILE factor. This figure shows the average affects intensity expressed by the participants. The error bars represent the standard error. Significant effect appears on the embarrassment, stress, uneasiness, concentration and the total emotional intensity.](image)

6.3 Discussion

Theory of Mind is a complex process that relies on various other cognitive and perceptual processes. It is not only hard to model but also to assess. Thus, a simple protocol such as the one we used in this study is not sufficient to fully evaluate the impact of our ToM model on the quality of the training. First, the GUI we used is not user-friendly and does not allow for user’s immersion in the scenario. We assume that using the full TARDIS project’s setting would enhance the interaction credibility and help highlight the virtual agent’s reasoning and reactivity. Besides, the evaluation process should be based on richer measures (e.g. thorough post-hoc questionnaire) in order to evaluate the effect of our model. Yet, such a specific evaluation protocol for affective and interaction-oriented ToM still has to be defined.

In the literature, there are validated methods to evaluate whether subjects – generally children – have ToM abilities and use it. Nevertheless, there is no such test that integrates a strong interactional aspect to our knowledge. From the computational point of view, points out the issue of evaluating a ToM model. In this work, the course of events and the agent’s actions and explanations are specified in advance for different scenarios. Thus, the ToM models are evaluated based on whether they match these specifications. Similarly, builds expectations about user’s actions – based on formal models in the specific context of wartime negotiations – in order to model a simplified theory of mind and then compare them with the actual user’s behavior. These two approaches are not applicable in our human/agent interaction situation, because they rely on a model of the task which is difficult to describe when it comes to affective non-verbal behaviour.

Nevertheless, the study we present in this paper shows promising results regarding the contribution of our ToM model in the context of a training game. Although all recruiters’ profiles benefit from the ToM reasoner, only PROFILE_A and PROFILE_C use it to select questions according to a reasoning about the mental and emotional states they could induce. The more recruiters ask such questions, the more mindreading they perform. The study shows that this kind of ToM-based behavior indeed has an impact on the users’ reactions. It also demonstrates the benefit of implementing several profiles in the enrichment of the coaching scenarios.

7. CONCLUSION & PERSPECTIVES

In this paper, we proposed an affective and interaction-oriented Theory of Mind model to support the development of intelligent agents that are able to represent and reason about their human interlocutors’ mental states. It relies on a hybrid mindreading approach mixing theory-theory and simulation-theory paradigms. This model is domain-independent, which means it can potentially be used in different context of application, including social coaching.

It has been implemented and evaluated in the context of job interview simulation in which the virtual recruiter both evaluates the human candidates based on their affective reactions, and reacts emotionally according to its desires and ideals. This study demonstrates the influence of the implementation of various recruiter profiles on the enrichment of the system’s efficiency. In addition, the explanatory capability of our reasoning model is a key feature for the users to benefit from a rich post-interview feedback. While evaluating such a complex cognitive process as ToM remains a difficult task, we are currently working on the integration of this model in the TARDIS platform in order to perform mental states evaluation using signal processing. We plan to evaluate the impact of such a ToM model on the credibility of the virtual recruiter.

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