Decision Model for a Virtual Agent that can Touch and be Touched

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ABSTRACT

Touch is an essential sense to the social development and well-being of individuals, acting as a communicative channel for emotions and empathy. Our overall objective is to enhance the ability of embodied conversational agents (ECAs) to bond with humans. To reach such an objective, we have endowed an ECA with the capacity to touch and be touched in a social interaction with a human in an immersive environment. By drawing inspiration from literature on human-human social touch and related works on human-agent tactile interactions, we have developed a framework for a touching ECA able to perceive when and how a user touches it and decide when and how to respond accordingly. This paper focuses on going beyond a simple bi-directional touch interaction through a decision model that actually adapts its behaviour to the content of the interaction, the level of rapport and the human's touch avoidance sensibility. This enables an actual interactive loop between the agent and the human.

KEYWORDS

Social Touch; Embodied Conversational Agent; Computational Model of Emotion; Immersive Environment; Interactive Loop

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1 INTRODUCTION

Touch has been shown to be a very effective channel for the communication of emotions [22] and to facilitate social bonding [9] between toucher and touchee. In the field of virtual reality, haptics are an increasingly important field of research, further improving the feeling of presence and immersion in virtual environments [17].

Embodied conversational agents (ECAs), on the other hand, are being given the abilities to display more and more verbal and non-verbal behaviours and to adopt strategies to bond and interact socially with humans or other agents. They can thus communicate through speech, prosody, gestures, facial expressions,... Putting all those abilities to good use, ECAs have been able to elicit short-term bonding in the form of rapport [2] and self disclosure behaviours in human interactants [32]. However, touch is a modality that is still missing in the ECAs' panel of expressive displays. While immersive environment and haptics enable the use of bi-directional touch with virtual agents (Figure 1) [30], modeling an ECA that would be able to adapt to and use touch requires to think in terms of interactive loop. Furthermore, as touch is a very intimate sense, the agent should take the notion of the acceptability of a touch into account to monitor for what the human might be comfortable with. Thus the agent must not only be able to touch and perceive touch (bi-directionality), it also needs to be able to determine, based on the context and the human's reactions, when a touch is useful and acceptable: when to use it and when to opt for other modalities of interaction, in order to keep the interaction going.

Figure 1: Human user interacting with an ECA in an immersive room

We aim to investigate if giving the ability to touch and be touched by an ECA would improve their ability to build rapport [51] and express emotions to a human [3]. Building a system allowing a virtual ECA to use touch will participate in evaluating whether this is indeed a useful and needed ability for its human interlocutors. We propose a decision model allowing an ECA to decide when to touch and with which touch type. This decision model is part of an overall framework for a touching and touchable ECA in an immersive virtual environment.

2 RELATED WORKS

2.1 Human-Human Social Touch Interactions

Social Touch designates all the instances of interpersonal touch in a social context. From the handshake to seal a deal to the encouraging tap on the shoulder between athletes, social touch can take many forms and express both emotions and communicative intentions. Work by Hertenstein and his colleagues [22] showed how being touched without seeing the touch could still lead people to identify specific emotions correctly, even when the touch was performed by strangers. Following on these findings, other works have nuanced

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those results by putting into light that the accuracy of the recognition of the emotion was improved when the two persons knew each other to some extent (close friends, romantic relationship,...) [35]. Similar types of touch are valenced and interpreted differently based on the situation: a touch performed by an opponent in a competitive setting will be interpreted entirely differently when performed by a partner in a collaborative setting [7, 26]. Touch can thus be categorized by its multiple meanings. For individuals, touch is a sensitive matter. Culture [41] and level of relationship as well as gender influence the way we accept or feel attacked when we receive a touch. The topography of acceptance of touch has indeed been shown to be highly dependent on the level of relationship [49] and somewhat on the gender of both the person receiving and the one performing touch. The notion of touch avoidance has been built to evaluate, through a questionnaire, an individual's level of acceptance of interpersonal touch [34].

2.2 Human-Agent Tactile Interactions

Research works that focus on human-agent touch interaction can be separated in two broad fields: the sensing part of the interaction (how to perceive and recognize a touch performed on the agent), and the generation of haptic feedback (giving a sensation of touch to the human via technology).

Most of the works regarding sensing and recognizing touch use tangible textiles that act as an artificial skin [47]. They can reach levels of accurate recognition/interpretation of touch similar to those of humans and are often used to equip robots. When it comes to virtual agents however, the sensing of touch is much less studied, as tangible interfaces are rarer, for now, because of the difficulty to integrate them to immersive environments. An exception is the work by [37] that covers an agent's virtual body (in an immersive room) with shapes able to determine when a human body part intersects one of these shapes. These shapes, which act as colliders, make for a virtual skin of the agent and are used to determine where and for how long the agent is touched. A similar collider-based approach is used in more recent works involving multiple users using mediated touch in a VR environment [50]. The approach of [37] is however more complete in terms of the specifics of the touch detection.

On the other hand, when it comes to the haptic sensation generation, researches aiming at making virtual agents able to touch the human are slowly becoming more common. They often feature a humanoid agent able to perform unidirectional touch, as in [52] where agents are engaged in dialog interactions with humans, may it be in the context of a collaborative or competitive game [24, 26], or in a conversation regarding health prevention [3]. To simulate an agent touching a human, different haptic devices placed on humans have been used such as vibrotactile sleeves [25, 44] or inflating devices simulating hand grabbing [3]. Combined with virtual or augmented reality technologies, those devices produce interesting sensations of co-presence when being touched [24].

As for the decision model itself and how an agent should use touch, there are still very few works on human-agent interaction that currently focus on going beyond bi-directional touch with a complete interactive loop. When exploring this area of research, one of the first questions that comes to mind is: can an ECA use social touch in a human-understandable way at all? And do humans react to an agent using touch similarly as they do in human-human interactions? Through a reviewing of the social touch literature, Van Erp and Toet [14] have shown how we can indeed expect similar reactions and behaviours from humans when they interact with a touching agent. However, in mediated interactions, social touch practices have already led to different situations of harassment in VR setups [4]. It is therefore especially important to take into account the human's comfort with touch (such as touch avoidance, location of the touch, etc.) during the interaction. We thus believe that ECAs should consider social norms when interacting via touch and that this should be taken into account as early in the design of the agent as possible.

3 TOWARD A DECISION MODEL

As mentioned in [24] and [14], the main abilities that are required for an agent to interact seamlessly with a human are: an ability to perceive the environment and what the human is doing; an ability to adapt and decide, based on what was perceived and interpreted, what behaviour to adopt in return; an ability to actually perform that behaviour. When it comes to social touch, this means that a touching agent should be able to perceive a touch coming from the human; it should have the ability to interpret this touch and decide how to adequately answer, with a touch or not; it should have the ability to actually perform the chosen behaviour with its correct modality in a way that the human can perceive.

As seen in section 2.1, touch and emotional expressions are closely related. To be able to take the emotional side of the interaction into account, and have the ECA react in a believable manner to touch, computational models of emotion [33] [38] seem like prime candidates for the decision model of a touching agent. Computational models of emotion (CME) implemented from appraisal theories [31] are decision models that evaluate the perceived inputs in cognitive terms to generate emotions for the agent. The inputs coming from the perception modules are considered as events that are appraised (i.e. cognitively evaluated) [43], based on the agent's personality as well as how much these events score on certain scales like valence or desirability for others, and finally how the events impact the agent's current beliefs and goals.

Touch is related to bonding [9] and the relationship between toucher and touchee affects the acceptance of a touch. The agent should take its relationship with its human interlocutor into account. We consider the notion of rapport [51], which can be defined as "mutual attentiveness, positivity and coordination", with attentiveness and positivity being especially important in the first interactions, and coordination becoming more important when a bond has already been created. While our decision model for a touching agent does not intend to propose a very detailed way of measuring rapport, having a touching agent adopt a rapport building strategy and have a basic estimation of its level of rapport with its human interlocutor should allow it to better determine when a touch would be acceptable.

3.1 Proposed Framework

The model is designed as a computational model of emotions with an appraisal of the inputs that is based on an internal representation

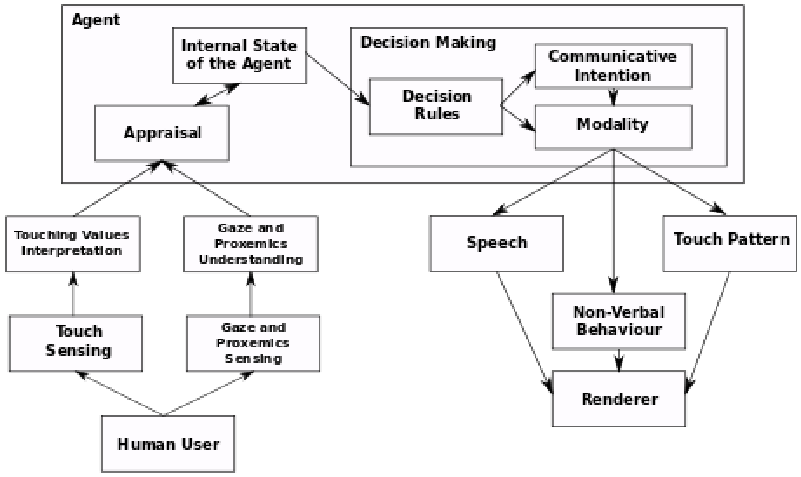

Figure 2: Schematic overview of the framework and process order of our decision model in an interactive loop with a human.

of the states of the interaction and of the human user, and that will trigger emotions and mood in the agent. The emotional state of the agent and its beliefs regarding the perceived level of rapport and the perceived emotional state of the human are fed to the decision model, which allows it to select the adequate decision rules. This process produces a communicative intention, which is then used to determine an adequate modality such as speech, non-verbal behaviour and/or touch. Finally, the chosen behaviour is rendered by the corresponding devices.

3.2 Types of Inputs

Touch can be characterized by different parameters. We rely on those defined in the literature from social touch and social touch gestures recognition [21] [13]. We identify six touch parameters but only focus on four of them for our touch perception for now: *intensity*, body *location*, presence of *movement* and its *velocity of movement*. *Intensity* is the kinematic velocity that the gesture has at the time of first contact; body *location* is the part of the body that is being touched; *movement* indicates whether the touch is static or dynamic, moving along the agent's body; *velocity of movement* is the velocity of the human's hand on the agent's body, while caressing for example. *Duration* and *pressure* are the two additional parameters of touch that we do not include in our representation so far. *Pressure* is indeed difficult to estimate in a VR context without tangible interfaces, and *duration* of touches is a work-in-progress.

Other non-verbal behaviours of interest are the proxemics which give information on the distance between the agent and the human, and gaze direction that indicates where the human is gazing at. This last parameter is also used to compute how attentive the human is to the interaction. Proxemics information is based on the work by Hall [20], with four spaces around the agent and the human, from intimate space to public space. Those proxemics values have been shown to still hold true in virtual environments [6]. Gaze direction is discriminated between: is the human looking at the agent, at an object from the environment that has a relationship to the topic of the interaction, or at something else entirely?

Finally, all the actions of the human which directly relate to the progression of the interactive scenario, such as choices prompted by the agent or interaction with an object of the environment are necessary inputs.

3.3 Agent's Internal States and Fixed Values

The agent's internal states are divided between its emotional state and its beliefs.

The emotional state of the agent is dynamically adjusted as time passes and events happen in the interaction. The appraisal process of the model generates the mood and emotions experienced by the agent based on a cognitive assessment of each event. The way an event is evaluated is defined via appraisal rules, which take into account the agent's goals and the current state of its beliefs.

The beliefs, which are stored in a knowledge base, constitute all the information that the ECA knows (or believes) about the environment, the human and the state of the situation. Those beliefs are dynamically adjusted during the interaction, for example the attention level of the human or the step of the scenario they are at. However, some values are fixed, such as absolute truths (location of some objects in the environment for example) or values that are not expected to change over time. One of those values is the baseline touch avoidance of the human. To build a touch-based interaction that will not make the human uncomfortable or feel invaded, the agent ought to have an idea of the human's overall comfort with touch. To determine it, for sake of simplicity for the moment, a validated touch avoidance questionnaire is given to participants to determine their usual level of touch avoidance. This value is then set in the agent's beliefs prior to the beginning of the interaction in order to improve the decision making of the agent.

In other words, we can define different individual agents with different attitudes and priorities by fixing values such as the agent's goals. During an interaction with a human user, the agent's beliefs (e.g. the perceived level of human attention) and the emotional state of the agent are constantly updated during the interaction, based on what happens and what is done by the human. The updated agent's mind is continuously fed to the decision module.

3.4 Processing of the Inputs

Once the inputs of the interaction are extracted, they are interpreted and used to update the ECA's emotional state and its beliefs about the current situation, about the human's perceived emotional state and about the perceived level of rapport between them.

First comes the estimation of the attentiveness of the human based on proxemics and gaze direction values, as those are known to relate to attention and engagement [46]. Then, touch values and actions of the human are processed to estimate his/her emotional state. To measure its variation over time, we chose to use a dimensional model, based on the emotional cues displayed by the human. As the relationship between touch and dominance is still unclear and studies report different results [12, 48], we couldn't use the Pleasure-Arousal-Dominance scale of emotions [36]. We thus decided to instead use the cirumplex model of emotion that determines emotions based on a scale of Valence-Arousal [40]. More details on how the values are computed in terms of attention and emotional state of the human can be found in [5].

Both the updates of the human's estimated emotional state and the estimated human's attentiveness are then processed to evaluate the level of rapport, as they correspond respectively to the positivity and the attentiveness that constitute two of the three main components of rapport [51], and the most important ones in first interactions. Once all internal states have been updated, the event is appraised: based on the goals of the agent, new emotions are generated. For example, if the level of rapport goes down, the agent might appraise this as an undesirable event which will set a negative mood and incentivize it to adjust its behaviour to improve the level of rapport.

For our model, level of rapport, current state of the interaction, human's perceived emotional state and the agent's own emotional state are the most important internal states for the decision making process of whether to touch or not.

3.5 Decision

As evidenced by the literature on social touch between humans, touch in social settings can take many different meanings [16, 19, 22, 28]. We designed the rules of our decision model based on those studies and specifically selected the following functions of touch: 'attention-getting' touch, 'turn giving or taking' touch, 'emotional emphasis' and 'supporting' touch. However, we believe that the notion of a 'supporting' touch might not be completely unambiguous, and we chose to further divide and clarify it into the notions of 'comforting' touch [8, 45], 'encouraging' touch [18], 'calming' touch and a general notion of touching for 'maintaining rapport'.

Here, it is important to keep in mind that while touch appears to be an appropriate communicative channel for those functions, it is not the only one, and all of those functions can also be achieved through other modalities, as evidenced by all the works related to endowing conversational agents with gestural and speaking abilities. Furthermore, since touch can be a rather invasive modality in terms of intimacy, it is not as easily suited for every context and every kind of relationship [49]. The agent should therefore be able to first determine what communicative intention it wants to convey and then determine what modality to use for this specific intention considering the context of interaction, its interlocutors and especially the current estimated level of rapport. The decision making itself thus happens in two steps.

To detail this further, the decision making process first takes as input the current step of the scenario to determine all the actions objectively available to the agent at this point. Based on the agent's beliefs regarding the level of rapport with its interlocutor and its own emotional state, it selects a specific communicative intention. For example, if the level of rapport is estimated as low and the internal beliefs of the agent indicate an apparent lack of attentiveness from the human, the agent will decide to try to get the human's attention. If the emotional state of the human is evaluated as agitated (high arousal), the agent could instead adopt a calming behaviour.

It is in the second step of the decision making that the communicative intention will be instantiated into an actual multimodal behaviour. The agent can use speech, non-verbal behaviour such as gaze direction, gestures, facial expression, and/or touch. Our rules specify which modality is available for each communicative intention, and what are the specific conditions under which each of those modalities should specifically be used. Among those conditions, the level of rapport and the value of the human's touch avoidance are first used to determine if touch should happen at all, and then the physical conditions that make a touch possible are examined (is the agent in range to perform the touch?). The decision model thus outputs a communicative intention and its instantiated behaviours specifying the modalities to use and the utterance or content to perform. This gets transmitted to the concerned renderers (text-to-speech, animation module, and tactile sleeve).

4 IMPLEMENTATION

In this section we present the perception module, the actual implementation of the decision process and the haptic feedback. Even though speech is a very important modality of interaction, for the sake of simplicity we do not include human speech as an input modality. Speech could however be added to the implementation in future works without having to alter the framework. We focus here on touch and how the agent updates its internal beliefs about the environment, its human interlocutor and the interaction.

4.1 Immersive Apparatus and Perception of Touch

Making sure that the human can feel his/her own body immersed in a 1:1 scale environment is central when working on touch. One of the best immersive setups for this is the $CAVE^{TM}$ [10], an immersive room where the environment is projected in stereoscopic 3D on the walls and the floor at 1:1 room-scale. Contrarily to what happens with head-mounted displays (HMD), such immersive rooms allow the user to keep vision of his/her own body and gestures, as only stereoscopic glasses are required to see the environment. This makes it particularly appropriate to an interaction based on touch (see Figure 1). On the other hand, it is much more costly than the commercially available HMD solutions, and, unlike those, a $CAVE^{TM}$ makes it much more difficult to bring tangible equipment inside the room, as it can damage the quality of the immersion by obstructing vision of the screens.

However, and despite those advantages of the VR HMDs, using such VR devices rather than a $CAVE^{TM}$, would require studying the sense of embodiment and the effects of touch when one is not seeing one's own body but a virtual avatar instead. As recent works have shown, this constitutes a research topic on its own [15, 50]. Instead, our work is more specifically focused on coherent decision making regarding bidirectional touch interactions. We thus chose to use a $CAVE^{TM}$-like immersive room, which is ideal for our situation, while making sure to develop a generic software framework that would not rely on a specific VR/AR or haptic setup.

Following the works of Nguyen, Wachsmuth and Kopp [37], we built a virtual sense of touch for our agent by placing invisible boxes and cylinders acting as tactile cells on the agent's virtual body. When the coordinates of the human's hand overlap with those of the cells it is considered as a collision and is used to determine the physical values of the touch. One of the problems with the implementation by [37] was that accuracy of the localisation of the touch depended on the resolution of the grid of virtual skin receptors (their number). To avoid this drawback and make the detection of movements and of the precise location of touch more reliable, we use large tactile cells corresponding to a whole part of the body: arm, torso, shoulders, head,... Inside those cells, a system of local coordinates allows us to determine *where* exactly the touch happens and if it's moving along time.

This setup allows us to know *when* and *where* on the body of the agent a touch happens and for *how long* (timing, *location* and *duration*). The initial kinematic velocity of the touching gesture is also be recorded as a measure of the touch *intensity*. If the touch is detected as moving along the body of the agent, then the *velocity of movement* is also recorded. However, since the agent is intangible and physical objects can go through it, measuring the *pressure* of the human's hand on the agent's body is difficult in the current state of our work.

Based on the coordinates of the agent and of the human, we can measure their interpersonal distance. An estimation of the human gaze direction is obtained by tracking the glasses and their forward direction. This is only an estimation of the gaze direction; it estimates the head direction but does not allow us to precisely track where the eyes of the user are looking at.

4.2 Instantiating the Decision Model

To make our work as easily available and reproducible as possible, we wanted to have a generic software framework, especially for the decision model. We also wanted to use a model that would have an appraisal theory of emotion as a basis. There were many candidates [23] but in the end our choice was to use the FAtiMA model, which relies on the Ortony, Clore and Collins (OCC) model of emotions [39], has a modular architecture making it easy to modify for our needs, is in open access, easily plugged in an Unity3D environment and has already been validated and used in the literature [11]. The model's inputs can come from various sources as long as a module translates them in FAtiMA-understandable format. Similarly, with an off-the-shelf touch device, it would only be required to translate the model's decisions into valid signals for the specific device. This guarantees the adaptability of our work with different technological setups.

The FAtiMA model [11] functions with parallel appraisals and updating of the internal beliefs of the agent, with the latter being based on a world model. Within the knowledge base of the agent, we have implemented five main beliefs for our touching agent: human's estimated *attentiveness* and *emotional state*, *estimated level of rapport*, *current state of the scenario*, and *static touch avoidance of the human*. *Attentiveness of the human* is currently implemented as a discrete scale ranging from 1 to 7, where 1 stands for low and 7 for high: $Attentiveness(Human) = [1, 7]$. The human's estimated *emotional state* is divided into two beliefs implemented as discrete scales for valence and arousal: $MoodValence(Human) = [1, 5]$, $MoodArousal(Human) = [1, 5]$. We want to be able to adapt the measurement of rapport based on what we value more in our specific situation between attentiveness, arousal or valence. Certain scenarios may require emphasis on the human's attentiveness, while others require it on the level of the human's experienced valence. It is thus calculated as a function of the values taken by the human's estimated *attentiveness* and the *emotional state* over time:

$$\begin{aligned} Rapport(Human) &= Attentiveness(Human) * x \\ &+ (MoodArousal(Human) * y + MoodValence(Human) * z) \\ &+ ThresholdValues \end{aligned} \tag{1}$$

In this equation, x, y and z are weights that represent, respectively, the amount of *attentiveness* or *emotional state* (arousal and valence) that influence *rapport*. Those weights can be set differently in order to alter the calculation depending on the situation. In our case, we want attentiveness to have the same overall importance as arousal and valence combined, and arousal and valence to have equivalent importance.

$$AttentivenessMax * x = ArousalMax * y + ValenceMax * z \tag{2}$$

$$ArousalMax * y = ValenceMax * z \tag{3}$$

We also want our agent to avoid using touch in an invasive manner and thus we need to emphasize the distinction between low and high values of rapport, while keeping a continuous spectrum of values so that the model can make varied decisions even within low and high values. The value of rapport thus ranges between 1 (lowest) and 100 (highest). The *ThresholdValues* are added values when *attentiveness*, *arousal* and *valence* reach higher levels. The actual values are to be empirically adjusted based on further evaluations. This means that *rapport* is low (resp. high) if either *attentiveness* of the human is low (resp. high) or the *human's estimated emotional state* is expressing a negative (resp. positive) mood. Finally, the *static touch avoidance* of the human is a discrete measure which can take the values of low (tactile person), medium (average touch acceptability) and high (overall averse to touch). The *static touch avoidance* is determined before the interaction starts via a questionnaire and is inputted as a fixed value which will modulate the level of rapport required for a touching action to be chosen.

Besides its beliefs, the agent's internal states also include its own emotional state, generated by the appraisal process. This is represented inside of FAtiMA by a continuous scale acting as mood, which can be negative or positive, and labeled emotions with different intensities. In FAtiMA, two different sets of rules are defined: the appraisal rules that determine how the agent evaluates an event (that is, how the agent's emotional state is calculated) and the decision rules. The appraisal rules determine how each type of occurring event scores in terms of appraisal variables. There are five appraisal variables taken into account in FAtiMA: desirability, desirability for others, praiseworthiness, goal success probability and liking. Any action performed by the agent or the participant is considered as an event from the point of view of the agent, as long as the agent is in a position to observe it. For each kind of event, such as the human getting closer to the agent or starting to look at something else in the environment, a specific rule needs to be designed depending on the interactive scenario and the goals given to the agent. In our case, 'looking elsewhere in the environment' is appraised as undesirable because it is interpreted as a sign of inattention. This updates the level of the agent's mood and generates emotions or modifies their intensity.

We define a touch event in FAtiMA as a tuple composed as follows: *TouchEvent(Location, Intensity, Movement, MovementVelocity)* where *Location* designates the body part being touched, *Intensity* designates the initial kinematic velocity of the touch and *Movement* indicates whether the touch is static or not. For example, when appraising a touch event we define an appraisal rule that consider two variables: desirability and liking. A touch event detected by the agent will thus be considered as desirable when occurring on an acceptable body part (arms, hands) and undesirable when occurring on a less accepted body part (shoulders, torso, head, legs), generating respectively positive or negative feelings for the agent. However, a touch on the shoulders and the back can become desirable if the level of estimated *rapport* is considered as high, as relationships impact the acceptability of a touch.

The decision algorithm relies on logic programming, with each rule being determined by a set of conditions expressed as logical or mathematical statements, with a system of substitution of values and variables. Our decision rules are thus further divided into two types of actions the agent can chose to perform: dialog actions that can be selected exclusively when the agent has the talking floor, and generic actions (such as walking around, grasping an object) which can always be selected.

Dialog actions. are defined inside a *dialog manager*, working as a sort of state machine where each entry has a current state and next state, which allows taking the sequential nature of the interactive scenario into account. Each action has an initiator (the one that performs the action) and can have a target. In our case of social interaction, the target will most of the time be the human participant. We define a dialog action as a 4-tuple consisting of: *Speak(CurrentState, NextState, CommunicativeIntention, Modality)* and a set of conditions that regulates when a specific dialog action should be selected. The communicative intention designates the function that this action serves in the scenario (attention-getting for example, among the functions enumerated in section 3.5), and modality determines which set of non-verbal behaviours should accompany the action. For now, there are only two available modalities: gestures (which involves both body gestures and facial expressions) and touch (which involves hand and arm movement adding touch). Different rules exist for each combination of communicative intention and modality.

Here is an example of a rule for the communicative intention of getting the attention of the human available at the start of the interaction. This is not a decisive action in terms of the overall progress of the scenario, so it doesn't modify the state of the interaction. The modality of this rule is touch, its conditions determine whether it is appropriate to perform the communicative intention of getting attention through a touch. The last condition indicates that when, both, the estimated attentiveness and emotional state of the human are low, the priority goes on being mindful of the emotional state of the human.

```
Speak(Step1, Step1, GetAttention, Touch)
Conditions:
1. Has(Floor) = SELF
2. Rapport(Human) < 50
3. Attentiveness(Human) < 4
4. StaticTouchAvoidance(Human) != High
5. Mood(Human) >= 3
```

A second example considers a different communicative intention: comfort. This allows seeing the difference in the activating conditions of those two rules. The intention comfort is triggered when the level of rapport is low, the perceived emotion level of the human is negative and the touch avoidance of the human is not high.

```
Speak(Step1, Step1, Comfort, Touch)
Conditions:
1. Has(Floor) = SELF
2. Rapport(Human) < 50
3. Mood(Human) <= 2
4. StaticTouchAvoidance(Human) != High
```

We observe that a first condition always determines whether the level of rapport is either high enough to perform a touch, or if it is so low that it requires the agent to perform an action to improve it. In a case where the level of *rapport* is low, the next conditions determine whether it is the perceived emotional level of the human that is at fault or the perceived attentiveness level of the human. Finally, we look at the level of the *static touch avoidance* to determine whether the current conditions are enough to activate the rule. Duplicate versions of those rules exist with different conditions depending on values of touch avoidance. This implies that there could be multiple decision rules with conditions validated at the same time. To make the final choice between multiple possible candidates we assign a level of priority to each rule and the highest priority rule is selected.

Generic action. encompasses any actions the agent can perform apart dialog actions. They are encoded in the same format as dialog actions with conditions that determine when to select them. It could be, for example, *Smile(Duration)* which can happen regardless of whether the agent has the talking turn or not, and provokes the agent to smile for the indicated duration. The conditions of this action include *Mood(Agent)* and *StrongestEmotion(Agent)*.

Once a final decision has been reached, it is sent to the concerned renderers (haptic device for the touch and the animation engine for the other modalities), as seen in figure 2.

4.3 Haptic and Audiovisual Feedback

We use the GRETA platform [42] to render the animation of the agent. This agent platform follows the SAIBA model [29] and computes synchronized verbal and nonverbal behaviors. The GRETA platform is integrated into a Unity3D application that renders the whole environment with the stereoscopic 3D and manages the physics of the virtual environment and the perception module.

As for the haptic feedback, the choice of the immersive room limits the kind of equipment that can be brought inside, with massive and static installations being undesirable in order to preserve the 3D projection. Since we need something wearable of a reasonable size that does not tire the user out, we opt for the creation of a vibrotactile sleeve, SOFTLY. It is designed in accordance with the literature, especially for the tactile brush algorithm [27] allowing the use of the apparent motion illusion to give the sensation of receiving a stroke on the arm. While vibrations are not the most realistic sensations when it comes to touch, they are still able to communicate affective information and be recognized accordingly by humans [25, 44]. We choose to use voice coils as actuators that allow us to precisely set the frequency at which the actuators vibrate, thus improving the quality of the vibrotactile rendering.

When it comes to the touch patterns themselves, we looked back to the literature of social touch between humans to determine the most interesting patterns to simulate. As vibrotactile sleeves are less adequate to represent types of touch involving pressure, such as grasping, we didn't chose to use those kinds of touch. Based on [1] [21] we selected a hit, a caress, a tap and a "neutral" sustained touch to be the most versatile in terms of the emotions and communicative intents they can express. Vibrotactile patterns (meaning signals such as pink/white/brown noise and custom wave shapes) emulating those touch patterns were created. Still basing ourselves on the literature, we then assigned each haptic pattern to a specific function of touch considered in our model [1] [21]. Attention getting is represented by a tap, comforting touch is expressed through a caress, etc. When the decision regarding the behaviour to perform is made, SOFTLY automatically performs the signal associated to the communicative intention that it receives.

A preliminary validation with about ten human participants allowed us to empirically test these patterns. The experiment involved receiving these patterns via SOFTLY in a randomized order in a free of context scenario (that is, only the touch patterns are provided to the users). Participants evaluated each stimulus through a questionnaire on valence and arousal. Both valence and arousal were rated consistently with our expectations for each pattern, but the very small pool of participants doesn't allow us to determine any significant effects. Further validation of the device in context is planned as soon as the national pandemic context allows it.

5 USE CASE SIMULATION

To validate our model, and in order to have supplementary inputs for our model, we designed a task-oriented scenario (in the form of a game) for an experiment. Since the COVID-19 pandemic situation does not allow us to have human users experimentally validate nor use our interfaces for the perception and generation of touch, we choose to use simulated participants instead, and focus on evaluating the decision making process and especially the decision of touching or not for the agent. Switching to an online setup was not possible for this specific protocol as it does not take perceptual differences between VR and desktop monitor into account. We simulate all the inputs of the participant and try different base values of attentiveness, emotional state and static touch avoidance. In the scenario, the simulated participant P must reproduce a sequence of colours and input the colours in the order the agent A gives them. P faces a screen with five numbered and colour-filled boxes; A stands next to them. To complete the task, P must remember which box is filled with which colour, and then A indicates in which order each box must be filled. This task is performed twice, with a different random sequence of colours each time. In this scenario, the goals of A are to build an above-average level of rapport and help P to accomplish the task.

We model A so that it believes that the emotional state of P becomes more negative when failing to perform the task; A also believes that this failure is an indication of a low attentiveness from P. That is, we hypothesize that P is emotionally affected when making mistakes and that it is a mark of her lack of attentiveness. We set the influence of the game success rate on P's state of mind as follows. The task can either be perfectly done with the right colours in the right boxes and the right input order (with the consequence of an increase in the perceived emotional state, and in the estimated attention), done correctly in terms of colours but not in terms of input order (which A does not comment about, but evaluates as improving P's emotional state and attention), done with one error in terms of colours (decrease in P's estimated emotional state and attention) or completely failed (decrease in P's estimated emotional state and an even larger decrease in attention). Before the beginning of the interaction, the static touch avoidance estimated for P is set directly in A's beliefs. For this simulation, this is also done for the initial level of attentiveness and emotional state. To simulate different types of participants, we present three simulations where the participants differ in those initial levels of attentiveness, touch avoidance and emotional state.

In our first simulation, the initial inputs are the following: *Attentiveness(P) = 6*, *Mood(P) = 1* and *StaticTouchAvoidance(P) = High*, which indicates a high level of attentiveness, a very negative emotional state but little appreciation for touch in general. The results of this simulation are as follows:

(1) The equation 1 presented in section 4.2 is used to compute the level of rapport, which is estimated as: *Rapport(P) < 50*. Since *Mood(P) = 1*, the decision model outputs: *Speak(Step1, Step1, Comfort, Gesture)*, with no touch considering the high level of touch avoidance. A second decision is made to make the scenario progress: *Speak(Step1, Task1, Inform, Gesture)*. The model decides to give the information regarding the task, again with no touch modality.

(2) Result of the task: P succeeds, only making a mistake about the input order: as a consequence, A's belief regarding P's mood has become more positive; since P has performed well in the task, P may have been attentive; the agent thus perceives an increase in its rapport with the participant: *Mood(P) = 2, Attentiveness(P) = 7, Rapport(P) = 60*

(3) This is positively appraised by A, which generates a positive improvement of its own mood. Based on those values, the

decision model outputs: *Speak(Task1, Step2, Congratulate, Gesture)*, with no touch since rapport is not high enough to counterbalance the high touch avoidance.

(4) Even though the estimated emotional state of P is still quite low, the high level of attentiveness and the fact that P succeeded in the task make up for it, and A chooses to directly give the next information regarding the second task, instead of comforting again, without using the touch modality.

The second simulation uses the following variables: *Attentiveness(P) = 2, Mood(P) = 5, StaticTouchAvoidance(P) = Medium*, which indicates a low level of attentiveness, a positive emotional state and no strong feelings against the use of social touch in general.

(1) *Rapport(P) = 60* prompts the following output from the decision model: *Speak(Step1, Task1, Inform, Gesture)*, with no touch since the level of rapport is average and this is not a communicative intention where touch has priority.
(2) Task: P has made a mistake on one colour, leading to a drop in the estimated variables. *Mood(P) = 4, Attentiveness(P) = 1, Rapport(P) < 50*
(3) This is negatively appraised by A. Based on those values, the decision model outputs: *Speak(Fail1, Fail1, GetAttention, Touch)*, with touch since it is an appropriate modality for this communicative intention, rapport is not too low and the static touch avoidance is not high. P reacts to the touch by looking at A, which improves the attentiveness. Then A invites the participant to try again. This time P manages to find the right sequence, but not the right input order: *Attentiveness(P) = 4, Mood(P) = 5, Rapport(P) = 75.*
(4) Since rapport is now high, the decision model first outputs a congratulation with the gesture modality, and then decides to directly give the information regarding the last task: *Speak(Step2, Task2, Inform, Touch)* where touch is used for its function of maintaining rapport.

For the third simulation, we use the following variables: *Attentiveness(P) = 3, Mood(Human) = 1, StaticTouchAvoidance(P) = Low.* This indicates a low-medium level of attentiveness, a very negative emotional state but a general appreciation for tactile interactions.

(1) *Rapport(P) < 25* prompts the following output from the decision model: *Speak(Step1, Step1, Comfort, Touch)*. Despite low rapport, touch is selected because the touch avoidance is low and touch is considered very adequate for comforting.
(2) Task: P completely fails, which brings all variables to lowest values. *Mood(P) = 1, Attentiveness(P) = 1.*
(3) This is negatively appraised by the agent. Based on those values, the decision model outputs: *Speak(Fail1, Fail1, Comfort, Gesture)*. This time touch is not selected because touch had already been attempted before and was immediately followed by a negative result. A invites P to try again with a gesture, which leads to a partial success.
(4) *Attentiveness(P) = 2, Mood(P) = 2.* The decision process outputs congratulations without touch, because rapport is still far below the mean value. Then, it outputs: *Speak (Step2, Step2, Comfort, Touch)*. Here, a comforting touch is attempted again because of the low static touch avoidance. Finally, A informs P of the last task without touch.

Overall, the outputs of the model are mostly coherent with what we expected based on the literature. The selected communicative intentions fit the interaction context, and rapport and touch avoidance are taken into account in the selection of the modality. In the third simulation, the agent decides not to touch the human as it believes the human could have failed the task because of the agent's touch. Since long-term temporality of actions is not yet considered in our decision model, the agent touches the human later in the interaction. These decisions of touching or not the human may appear incoherent. However, this needs to be validated through human perceptive study. Temporality of continuous actions, such as a long lasting touch, are also not yet implemented, which somewhat limits the interaction possibilities.

While those results are encouraging, only an evaluation with actual human participants can allow us to determine whether those rules are believable and acceptable in context. To evaluate the perception of the interaction by human participants, we will use objective measures such as the position of the human in the environment during the interaction, their gaze direction, as well as questionnaires to determine how the participants have felt during the interaction, both regarding the touches they received and their sentiment toward the agent. Furthermore, questions about the coherence of the touch decisions and the human's own estimated level of rapport and acceptability of the touches will be used.

6 CONCLUSION

We have described a model to design a complete interactive loop between a human and an ECA involving social touch as a communicative modality inside an immersive environment. A perception module allows the agent to perceive when its interlocutor touches it and how s/he acts in the environment. The ECA is then able to use this perception to estimate its level of rapport with the human and to generate emotions. This allows a decision model, based on a computational model of emotion, to decide when and how to perform a touch. The final decision is instantiated thanks to a haptic device and animations of the agent. The challenges of such an implementation are to reach satisfactory levels of perception, decision making and haptic and graphic rendering at the same time. Our framework does not yet allow very high levels of satisfaction on all those points, as temporality some types of touch are still hard to perceive or simulate. We nonetheless believe that even with simple inputs such as the ones presented here, a believable interaction can happen. Our next step is to evaluate the model with human participants in a situation of interactive storytelling.

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REFERENCES

[1] Nadia Bianchi-Berthouze and Ana Tajadura-Jiménez. 2014. It's not just what we touch but also how we touch it.. In *Workshop on Tactile User and touching objects of different shapes as a way to Experience Evaluation Methods.* 4.
[2] Timothy Bickmore and Justine Cassell. 2001. Relational Agents: A Model and Implementation of Building User Trust. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '01).* ACM, New York, NY, USA, 396–403. https://doi.org/10.1145/365024.365304 event-place: Seattle, Washington, USA.

- [3] T. W. Bickmore, R. Fernando, L. Ring, and D. Schulman. 2010. Empathic Touch by Relational Agents. *IEEE Transactions on Affective Computing* 1, 1 (Jan. 2010), 60–71. https://doi.org/10.1109/T-AFFC.2010.4
- [4] L. Blackwell, N. Ellison, N. Elliott-Deflo, and R. Schwartz. 2019. Harassment in Social VR: Implications for Design. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 854–855. https://doi.org/10.1109/VR.2019.8798165 ISSN: 2642-5254.
- [5] Fabien Boucaud, Indira Thouvenin, and Catherine Pelachaud. 2020. Quand et Comment Toucher un Humain ? Un Modèle de Décision pour un Agent Touchant. In *Workshop sur les Affects, Compagnons artificiels et Interactions (WACAI 2020)*. CNRS, Université Toulouse Jean Jaurès, Université de Bordeaux, Saint Pierre d'Oléron, France. https://hal.inria.fr/hal-02933486
- [6] Angelo Cafaro, Brian Ravenet, Magalie Ochs, Hannes Högni Vilhjálmsson, and Catherine Pelachaud. 2016. The Effects of Interpersonal Attitude of a Group of Agents on User's Presence and Proxemics Behavior. *ACM Trans. Interact. Intell. Syst.* 6, 2 (Aug. 2016), 1–33. https://doi.org/10.1145/2914796
- [7] Jeroen Camps, Chloé Tuteleers, Jeroen Stouten, and Jill Nelissen. 2013. A situational touch: How touch affects people's decision behavior. *Social Influence* 8, 4 (Oct. 2013), 237–250. https://doi.org/10.1080/15534510.2012.719479
- [8] Asta Cekaite and Malva Kvist Holm. 2017. The Comforting Touch: Tactile Intimacy and Talk in Managing Children's Distress. *Research on Language and Social Interaction* 50, 2 (April 2017), 109–127. https://doi.org/10.1080/08351813.2017.1301293
- [9] Jonas Chatel-Goldman, Marco Congedo, Christian Jutten, and Jean-Luc Schwartz. 2014. Touch increases autonomic coupling between romantic partners. *Front. Behav. Neurosci.* 8 (2014). https://doi.org/10.3389/fnbeh.2014.00095
- [10] Carolina Cruz-Neira, Daniel J. Sandin, and Thomas A. DeFanti. 1993. Surround-screen Projection-based Virtual Reality: The Design and Implementation of the CAVE. In *Proceedings of the 20th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '93)*. ACM, New York, NY, USA, 135–142. https://doi.org/10.1145/166117.166134 event-place: Anaheim, CA.
- [11] João Dias, Samuel Mascarenhas, and Ana Paiva. 2014. FAtiMA Modular: Towards an Agent Architecture with a Generic Appraisal Framework. In *Emotion Modeling: Towards Pragmatic Computational Models of Affective Processes*, Tibor Bosse, Joost Broekens, João Dias, and Janneke van der Zwaan (Eds.). Springer International Publishing, Cham, 44–56. https://doi.org/10.1007/978-3-319-12973-0_3
- [12] Rosemarie Dibiase and Jaime Gunnoe. 2004. Gender and Culture Differences in Touching Behavior. *The Journal of Social Psychology* 144, 1 (Feb. 2004), 49–62. https://doi.org/10.3200/SOCP.144.1.49-62
- [13] Wail Elbani. 2019. Social touch: stimuli-imitation protocol and automated recognition. In *2019 8th International Conference on Affective Computing and Intelligent Interaction Workshops and Demos (ACIIW)*. IEEE, Cambridge, United Kingdom, 11–15. https://doi.org/10.1109/ACIIW.2019.8925025
- [14] J. B. F. V. Erp and A. Toet. 2013. How to Touch Humans: Guidelines for Social Agents and Robots That Can Touch. In *2013 Humaine Association Conference on Affective Computing and Intelligent Interaction*. 780–785. https://doi.org/10.1109/ACII.2013.145
- [15] Rebecca Fribourg, Ferran Argelaguet, Anatole Lécuyer, and Ludovic Hoyet. 2020. Avatar and sense of embodiment: Studying the relative preference between appearance, control and point of view. *IEEE transactions on visualization and computer graphics* 26, 5 (2020), 2062–2072.
- [16] Alberto Gallace and Charles Spence. 2010. The science of interpersonal touch: An overview. *Neuroscience & Biobehavioral Reviews* 34, 2 (Feb. 2010), 246–259. https://doi.org/10.1016/j.neubiorev.2008.10.004
- [17] Gonzalo Garcia-Valle, Manuel Ferre, Jose Brenosa, and David Vargas. 2018. Evaluation of Presence in Virtual Environments: Haptic Vest and User's Haptic Skills. *IEEE Access* 6 (2018), 7224–7233. https://doi.org/10.1109/ACCESS.2017.2782254
- [18] Nicolas Guéguen. 2004. Nonverbal Encouragement of Participation in a Course: the Effect of Touching. *Social Psychology of Education* 7, 1 (March 2004), 89–98. https://doi.org/10.1023/B:SPOE.0000010691.30834.14
- [19] Antal Haans, Renske de Bruijn, and Wijnand A. IJsselsteijn. 2014. A Virtual Midas Touch? Touch, Compliance, and Confederate Bias in Mediated Communication. *J Nonverbal Behav* 38, 3 (Sept. 2014), 301–311. https://doi.org/10.1007/s10919-014-0184-2
- [20] Edward T. Hall. 1990. *The hidden dimension.* Anchor Books, New York.
- [21] Steven Hauser, Sarah McIntyre, Ali Israr, Håkan Olausson, and Gregory Gerling. 2019. Uncovering Human-to-Human Physical Interactions that Underlie Emotional and Affective Touch Communication. https://doi.org/10.1109/WHC.2019.8816169
- [22] Matthew J. Hertenstein, Rachel Holmes, Margaret McCullough, and Dacher Keltner. 2009. The communication of emotion via touch. *Emotion* 9, 4 (2009), 566–573. https://doi.org/10.1037/a0016108
- [23] Eva Hudlicka. 2011. Guidelines for Designing Computational Models of Emotions. *IJSE* 2 (Jan. 2011), 26–79. https://doi.org/10.4018/jse.2011010103
- [24] Gijs Huisman, Merijn Bruijnes, Jan Kolkmeier, Merel Jung, Aduén Darriba Frederiks, and Yves Rybarczyk. 2014. Touching Virtual Agents: Embodiment and Mind. In *Innovative and Creative Developments in Multimodal Interaction Systems (IFIP Advances in Information and Communication Technology)*, Yves Rybarczyk, Tiago Cardoso, João Rosas, and Luis M. Camarinha-Matos (Eds.). Springer Berlin Heidelberg, 114–138.
- [25] G. Huisman, A. Darriba Frederiks, B. Van Dijk, D. Hevlen, and B. Kröse. 2013. The TaSSt: Tactile sleeve for social touch. In *2013 World Haptics Conference (WHC)*. 211–216. https://doi.org/10.1109/WHC.2013.6548410
- [26] Gijs Huisman, Jan Kolkmeier, and Dirk Heylen. 2014. With Us or Against Us: Simulated Social Touch by Virtual Agents in a Cooperative or Competitive Setting. In *Intelligent Virtual Agents (Lecture Notes in Computer Science)*, Timothy Bickmore, Stacy Marsella, and Candace Sidner (Eds.). Springer International Publishing, 204–213.
- [27] Ali Israr and Ivan Poupyrev. 2011. Tactile Brush: Drawing on Skin with a Tactile Grid Display. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 2019–2028. https://doi.org/10.1145/1978942.1979235 event-place: Vancouver, BC, Canada.
- [28] Stanley E. Jones and A. Elaine Yarbrough. 1985. A naturalistic study of the meanings of touch. *Communication Monographs* 52, 1 (March 1985), 19–56. https://doi.org/10.1080/03637758509376094
- [29] Stefan Kopp, Brigitte Krenn, Stacy Marsella, Andrew N. Marshall, Catherine Pelachaud, Hannes Pirker, Kristinn R. Thórisson, and Hannes Vilhjálmsson. 2006. Towards a Common Framework for Multimodal Generation: The Behavior Markup Language. In *Intelligent Virtual Agents (Lecture Notes in Computer Science)*, Jonathan Gratch, Michael Young, Ruth Aylett, Daniel Ballin, and Patrick Olivier (Eds.). Springer Berlin Heidelberg, 205–217.
- [30] A. Kotranza, B. Lok, C. M. Pugh, and D. S. Lind. 2009. Virtual Humans That Touch Back: Enhancing Nonverbal Communication with Virtual Humans through Bidirectional Touch. In *2009 IEEE Virtual Reality Conference*. 175–178. https://doi.org/10.1109/VR.2009.4811019
- [31] Richard S. Lazarus. 1991. *Emotion and adaptation.* Oxford Univ. Press, New York. OCLC: 23252739.
- [32] Gale M. Lucas, Albert Rizzo, Jonathan Gratch, Stefan Scherer, Giota Stratou, Jill Boberg, and Louis-Philippe Morency. 2017. Reporting Mental Health Symptoms: Breaking Down Barriers to Care with Virtual Human Interviewers. *Front. Robot. AI* 4 (2017). https://doi.org/10.3389/frobt.2017.00051
- [33] Stacy Marsella and Jonathan Gratch. 2014. Computationally Modeling Human Emotion. *Commun. ACM* 57, 12 (Nov. 2014), 56–67. https://doi.org/10.1145/2631912
- [34] Matthew M. Martin and Carolyn M. Anderson. 1993. Psychological and biological differences in touch avoidance. *Communication Research Reports* 10, 2 (Dec. 1993), 141–147. https://doi.org/10.1080/08824099309359927
- [35] Sarah McIntyre, Athanasia Moungou, Rebecca Boehme, Peder Mortvedt Isager, Frances Lau, Ali Israr, Ellen A. Lumpkin, Freddy Abnousi, and Haakan Olausson. 2019. Affective touch communication in close adult relationships. https://doi.org/10.17605/OSF.IO/7XRWC
- [36] Albert Mehrabian and James A. Russell. 1974. *An approach to environmental psychology.* MIT Press, Cambridge, Mass. OCLC: 714320.
- [37] Nhung Nguyen, Ipke Wachsmuth, and Stefan Kopp. 2007. Touch perception and emotional appraisal for a virtual agent.
- [38] Desmond C. Ong, Jamil Zaki, and Noah D. Goodman. 2019. Computational Models of Emotion Inference in Theory of Mind: A Review and Roadmap. *Topics in Cognitive Science* 11, 2 (2019), 338–357. https://doi.org/10.1111/tops.12371
- [39] Andrew Ortony, Gerald L. Clore, and Allan Collins. 1988. *The Cognitive Structure of Emotions.* Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511571299
- [40] Jonathan Posner, James A. Russell, and Bradley S. Peterson. 2005. The circumplex model of affect: An integrative approach to affective neuroscience, cognitive development, and psychopathology. *Develop. Psychopathol.* 17, 03 (Sept. 2005). https://doi.org/10.1017/S0954579405050340
- [41] Martin S. Remland, Tricia S. Jones, and Heidi Brinkman. 1995. Interpersonal Distance, Body Orientation, and Touch: Effects of Culture, Gender, and Age. *The Journal of Social Psychology* 135, 3 (June 1995), 281–297. https://doi.org/10.1080/00224545.1995.9713958
- [42] Fiorella de Rosis, Catherine Pelachaud, Isabella Poggi, Valeria Carofiglio, and Berardina De Carolis. 2003. From Greta's mind to her face: modelling the dynamics of affective states in a conversational embodied agent. *International Journal of Human-Computer Studies* 59, 1 (July 2003), 81–118. https://doi.org/10.1016/S1071-5819(03)00020-X
- [43] Klaus R. Scherer. 2009. The dynamic architecture of emotion: Evidence for the component process model. *Cognition and Emotion* 23, 7 (Nov. 2009), 1307–1351. https://doi.org/10.1080/02699930902928969
- [44] H. Seifi and K. E. MacLean. 2013. A first look at individuals' affective ratings of vibrations. In *2013 World Haptics Conference (WHC)*. IEEE, Daejeon, 605–610. https://doi.org/10.1109/WHC.2013.6548477
- [45] Hossam A. Shaltout, Janet A. Tooze, Erica Rosenberger, and Kathi J. Kemper. 2012. Time, Touch, and Compassion: Effects on Autonomic Nervous System and Well-Being. *EXPLORE* 8, 3 (May 2012), 177–184. https://doi.org/10.1016/j.explore.2012.02.001
- [46] Candace L. Sidner, Christopher Lee, and Neal Lesh. 2003. Engagement by Looking: Behaviors for Robots when Collaborating with People. In *In Kruiff-Korbayova and*

Kosny (eds.), Diabruck: The Proceedings of the Seventh Workshop on the Semantics and Pragmatics of Dialogue. University of Saarland. 123–130.

[47] David Silvera-Tawil, David Rye, and Mari Velonaki. 2014. Interpretation of Social Touch on an Artificial Arm Covered with an EIT-based Sensitive Skin. *Int J of Soc Robotics* 6, 4 (Nov. 2014), 489–505. https://doi.org/10.1007/s12369-013-0223-x

[48] Diana L. Summerhayes and Robert W. Suchner. 1978. Power implications of touch in male—Female relationships. *Sex Roles* 4, 1 (Feb. 1978), 103–110. https://doi.org/10.1007/BF00288381

[49] Juulia T. Suvilehto, Enrico Glerean, Robin I. M. Dunbar, Riitta Hari, and Lauri Nummenmaa. 2015. Topography of social touching depends on emotional bonds between humans. *Proc Natl Acad Sci USA* 112, 45 (Nov. 2015), 13811–13816. https://doi.org/10.1073/pnas.1519231112

[50] Philipp Sykownik and Maic Masuch. 2020. The Experience of Social Touch in Multi-User Virtual Reality. In *26th ACM Symposium on Virtual Reality Software and Technology (VRST '20)*. Association for Computing Machinery, New York, NY, USA, 1–11. https://doi.org/10.1145/3385956.3418944

[51] Linda Tickle-Degnen and Robert Rosenthal. 1990. The Nature of Rapport and Its Nonverbal Correlates. *Psychological Inquiry* 1, 4 (Oct. 1990), 285–293. https://doi.org/10.1207/s15327965pli0104_1

[52] Jan B. F. van Erp and Alexander Toet. 2015. Social Touch in Human–Computer Interaction. *Front. Digit. Humanit.* 2 (2015). https://doi.org/10.3389/fdigh.2015.00002