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# Affective computing with primary and secondary emotions in a virtual human

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**Abstract** We introduce the WASABI ([W]ASABI [A]ffect [S]imulation for [A]gents with [B]elievable [I]nteractivity) Affect Simulation Architecture, in which a virtual human's cognitive reasoning capabilities are combined with simulated embodiment to achieve the simulation of primary and secondary emotions. In modeling primary emotions we follow the idea of "Core Affect" in combination with a continuous progression of bodily feeling in three-dimensional emotion space (PAD space), that is subsequently categorized into discrete emotions. In humans, primary emotions are understood as onto-genetically earlier emotions, which directly in uence facial expressions. Secondary emotions, in contrast, afford the ability to reason about current events in the light of experiences and expectations. By technically representing aspects of each secondary emotion's connotative meaning in PAD space, we not only assure their mood-congruent elicitation, but also combine them with facial expressions, that are concurrently driven by primary emotions. Results of an empirical study suggest that human players in a card game scenario judge our virtual human MAX significantly older when secondary emotions are simulated in addition to primary ones.

**Keywords** Affective computing · Emotion modeling · Primary and secondary emotions · Aware emotions · Emotion expression · Embodied agent · Virtual human · Affect simulation architecture · PAD emotion space · Emotion dynamics · BDI-based architecture · Virtual reality · Affective gaming

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This article is an extended version of Becker-Asano and Wachsmuth [8].

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## 1 Introduction

Researchers in the  eld of embodied agents [10,36] build anthropomorphic systems, which are employed in different interaction scenarios that afford communicative abilities of different style and complexity. As these agents comprise an increasing number of sensors as well as actuators together with an increase in expressive capabilities, they need to be able to process social cues in face-to-face communication in order to ful ll a human attendee's expectations.

One factor in social interaction is the ability to deal with the affective dimension appropriately. Therefore researchers in the growing  eld of "Affective Computing" [34] discuss ways to derive human affective states from various intrusive and non-intrusive sensors. With regard to the expressive capabilities of embodied agents the integration of emotional factors in uencing bodily expressions is argued for. These bodily expressions include, e.g., facial expression, body posture, and voice in ection and all of them must be modulated in concert to synthesize coherent emotional behavior.

In this work, scienti c inquiry and engineering are closely interwoven, by taking a cognitive modeling approach (building on both symbolic and dynamic system paradigms). Creating an arti cial system that reproduces certain aspects of a natural system can help us understand internal mechanisms that lead to particular effects. With the WASABI architecture we present our attempt to exploit different  ndings and conceptions of emotion psychology, neurobiology, and developmental psychology in a fully-implemented computational system. It is based on the simulation of an emotion dynamics in three-dimensional emotion space, which has proven bene cial to increase the lifelikeness and believability of our virtual human MAX in two different interaction scenarios [4]. With this emotion dynamics simulation, however, we were limited to a class of rather simple emotions, that are similar to Damasio's conception of primary emotions. In the WASABI architecture we additionally use our agent's cognitive reasoning abilities to model the mood-congruent elicitation of secondary emotions as well.

In the following section the psychological as well as neurobiological background is described with respect to the distinction of primary and secondary emotions. Subsequently we give an overview of related work in the  eld of Affective Computing. The WASABI architecture is presented in Sect. 3. We explain how nine primary emotions together with three secondary emotions—namely the prospect-based emotions hopes, fears-conÞrmed, and relief—were integrated in such a way that their mood-congruent elicitation can be guaranteed. We conclude by discussing results of a  rst empirical study on the effect of secondary emotion simulation in a card game scenario.

## 2 Background and related work

We will  rst introduce the psychological and neurobiological background before an overview of related work in affective computing is given.

### 2.1 Psychological and neurobiological background

Following the work of Scherer [40] the psychological construct labeled emotion can be broken up into the component of cognitive appraisal, the physiological component of activation and Arousal, the component of motor expression, the motivational component, and the component of subjective feeling state. We follow the distinction of a cognitive appraisal component and a physiological component in our computational simulation of affect.[1] We also account for the motivational component, because our agent’s reasoning capabilities are modeled according to the belief-desire-intention approach to modeling rational behavior [37]. We further believe that modeling the dynamic interaction between a cognitive and a physiological component is a promising first step toward the goal of computationally realizing subjective feelings.

Recently, psychologists started to investigate “unconscious processes in emotions” [42] and Ortony et al. [31] discuss levels of processing in “effective functioning” by introducing a distinction between “emotions” and “feelings”. They understand feelings as “readouts of the brain’s registration of bodily conditions and changes” whereas “emotions are interpreted feelings” [31, p. 174] and propose three different levels of information processing, which are compatible with Scherer’s three modes of representation [42].

According to Ortony and colleagues [31, p. 197], lower levels have to contribute in order to experience “hot” emotions such that “cold, rational anger” could be solely the product of the cognitive component “without the concomitant feeling components from lower levels.” A purely primitive feeling of fear, on the contrary, also lacks the necessary cognitive elaboration to become a hot emotion. These psychological considerations are compatible with LeDoux’s distinction of a low and a high road of fear elicitation in the brain [23] and Damasio’s assumption of bodily responses causing an “emotional body state” [11, p. 138] that is subsequently analyzed in the thought process.

Damasio [11] distinguishes at least two classes of emotions, namely, primary and secondary emotions, on the basis of his neurobiological findings. They are central to our simulation of affect and, thus, introduced next.

The class of “primary emotions” [11] is supposed to be innate. According to Damasio primary emotions developed during phylogeny to support fast and reactive response behavior in case of immediate danger, i.e. they trigger basic behavioral response tendencies like “flight-or-fight” behaviors. In humans, however, the perception of the changed bodily state is combined with the object that initiated it resulting in a “feeling of the emotion” with respect to that particular object [11, p. 132]. Primary emotions are also understood as prototypical emotion types which can already be ascribed to one-year-old children [12]. Furthermore, they are comparable to the concept of “Core Affect” [17,38], which is based on the assumption that emotions cannot be identified by distinct categories from the start. “Core Affect”, however, is represented in two-dimensional emotion space of Pleasure/Valence and Arousal, which is sometimes extended by a third dimension [20,39] labeled “Control/Dominance/Power” of connotative meaning [32] (as empirically shown by Mehrabian [27], each PAD component can be related to personality traits). Originally, Wundt claimed that any emotion can be characterized as a continuous progression in such three-dimensional emotion space [44]. The three-dimensional abstract emotion space is commonly referred to as PAD space.

Secondary emotions like “relief” or “hope” are assumed to arise from higher cognitive processes, based on an ability to evaluate preferences over outcomes and expectations. Accordingly, secondary emotions are acquired during onto-genesis through learning processes in the social context. Damasio uses the adjective “secondary” to refer to “adult” emotions, which “utilize the machinery of primary emotions” [11, p. 137] by influencing the acquisition of “dispositional representations”, which are necessary for the elicitation of secondary emotions. These acquired dispositional representations, however, are believed to be different from the “innate dispositional representations” underlying primary emotions. Furthermore, secondary emotions influence bodily expressions through the same mechanisms as do primary emotions.

[1] The motor expression component has been realized as well, but is not discussed here (cf. [4] for details).

### 2.2 Related work

El-Nasr et al. [16] present FLAME as a formalization of the dynamics of 14 emotions based on fuzzy logic rules. It includes a mood value, which is continuously calculated as the average of all emotion intensities to provide a solution to the problem of conflicting emotions being activated at the same time. The idea of expectations is realized in FLAME by means of learning algorithms based on rewards and punishments. Although it was not integrated into the simulation of a virtual human, the mutual influence of emotion and mood is quite similar to the conception of emotion dynamics in the WASABI architecture.

Marsella and Gratch [26] focus with their EMA model on the dynamics of emotional appraisal. They also argue for a mood value as an addend in the calculation of otherwise equally activated emotional states following the idea of mood-congruent emotions. Their framework for modeling emotions is considered to be the first fully implemented, domain-independent architecture for emotional conversational agents.

Marinier and Laird [24] aim to combine the work of Marsella and Gratch [26] with the findings of Damasio [11]. In [25], however, Damasio's work is less central and they follow the ideas of Scherer [41]. Their central idea of "appraisal frames" is based on the EMA model [26] and eleven of Scherer's sixteen appraisal dimensions are modeled for integration in the Soar cognitive architecture. They distinguish an "Active Appraisal Frame", which is the result of a momentary appraisal of a given event, from a "Perceived Appraisal Frame", which results from the combination of the actual mood and emotion frames. Thereby, they take Damasio's distinction between emotion and feeling into account—similarly to the conception underlying the WASABI architecture.

With their development of "Greta" Pelachaud and Bilvi [33] are mainly concerned with believability of conversational agents. To guarantee that Greta's facial expressions are always consistent with the situational context, de Rosis et al. [13] model Greta's "mind" based on the BDI-approach. This architecture's emotion model builds upon a "Dynamic Belief Network", which integrates the time dimension in the representation of uncertainty of beliefs. Ochs et al. [29] present another BDI-based approach to implement OCC-based appraisal for Greta taking into account the socio-cultural context and integrating a computational model of emotion blending for facial expressions. All of these approaches to simulate emotions by means of BDI-based reasoning, however, have difficulties to deal with temporal aspects of the dynamics of emotions, which is central to our work.

Although André et al. [1] start by distinguishing primary and secondary emotions, this idea is not taken up in their later publications (e.g. [19]). Gebhard [18], recently, uses PAD space to derive a mood value from emotions resulting from OCC-based appraisal. Three-dimensional emotion spaces similar to PAD space are also used to drive the sociable robot "Kismet" [9] and the humanoid robot WE-4RII [22].

## 3 The WASABI architecture

The WASABI architecture conceptualized here builds upon previous work on the simulation of emotion dynamics for the virtual human MAX [3] that has proven to support the agent's believability in two different interaction scenarios [4,7]. It was, however, limited to the simulation of primary emotions.

Accordingly, the WASABI architecture [6] combines bodily emotion dynamics with cognitive appraisal in order to simulate infant-like primary emotions as well as cognitively elaborated (more adult) secondary emotions. In the following a technically suitable specifi-

Fig. 1 The nine primary emotions of Table 1 as points together with the three secondary emotions of Table 2 as weighted areas in PAD space

cation of the different concepts *emotion* and *mood* is derived from the theoretical background presented above.

*Emotions* are understood as current states with a specific quality and intensity, which are the outcome of complex neurophysiological processes for communication. These processes include neural activity of the brain as well as physiological responses of the body. One gets aware of one's emotions in two cases: (1) if their awareness likelihood $\omega$ exceeds a certain threshold (cf. Sect. 3.3) or (2) if one concentrates on the underlying processes by means of introspection.

Emotions can be classified into primary and secondary ones, but every emotion has either positive or negative valence of a certain value and compared to mood an emotion lasts significantly less long. The differences between primary and secondary emotions are conceptualized as follows:

- Secondary emotions are based on more complex data structures than primary ones. Accordingly, only some general aspects of secondary emotions (such as their respective valence components) are represented in PAD space.
- The appraisal of secondary emotions depends much more on the situational context and an agent's memory than that of primary emotions. Thus, secondary emotions are more dependent on the agent's cognitive reasoning abilities.
- The releasers of secondary emotions might be learned based on the history of primary emotions in connection with memories of events, agents, and objects.
- The agent's facial expressions of primary emotions (cf. Fig. 1) may accompany secondary emotions such that they do not necessarily need to be expressed by their own set of facial expressions.
- Secondary emotions also modulate the agent's simulated embodiment, such as its general level of Arousal.
- The agent expresses its awareness of secondary emotions verbally.

Table 1 Primary emotions in PAD space

| | Primary emotion | Facial expr. (Ekman) | PAD values | Base intensity $i_{pe}$ |
|---|---|---|---|---|
| 1 | Angry | Anger (anger) | (80, 80, 100) | 0.75 |
| 2 | Annoyed | Sad (sadness) | (−50, 0, 100) | 0.75 |
| 3 | Bored | Bored (none) | (0, −80, 100) | 0.75 |
| 4 | Concentrated | Neutral (none) | (0, 0, ± 100) | 0.75 |
| 5 | Depressed | Sad (sadness) | (0, −80, −100) | 0.75 |
| 6 | Fearful | Fear (fear) | (−80, 80, 100) | 0.25 |
| 7 | Happy | Happy (happiness) | (80, 80, ± 100) | 0.75 |
| | | | (50, 0, ± 100) | 0.75 |
| 8 | Sad | Sad (sadness) | (−50, 0, −100) | 0.75 |
| 9 | Surprised | Surprised (surprise) | (10, 80, ± 100) | 0.0 |

The five “basic emotions” of Ekman [14] are assigned to the corresponding facial expressions modeled in Becker et al. [3] whenever such a mapping is possible (cf. Fig. 1) and additionally an individual base intensity $i_{pe}$ is set for each primary emotion (see also Sect. 3.3)

*Mood* is modeled as a background state with a much simpler affective quality than emotions. In contrast to the model of Gebhard [18] mood is not derived from PAD space, but modeled as an agent's overall feeling of well-being on a bipolar scale of positive versus negative valence already before a mapping into PAD space is achieved. Any non-neutral mood is slowly regulated back to a neutral state of mood—much slower than it is the case for emotional valence. Accordingly, a mood's duration is in general longer than that of any emotion.

The described interconnectivity of mood and emotions results in an “emotion dynamics” (described in more detail in [4]), in which mood influences the elicitation of emotions in such a way that mood-congruency of emotions is achieved. This idea is empirically supported by Neumann et al. [28], who found that individuals in a positive mood are less likely to experience negative emotions and vice versa.

## 3.1 Nine primary emotions

According to the above discussion, primary emotions are inborn affective states, which are triggered by reflexes in case of potentially harmful stimuli. They result in fast, reactive behavioral responses and, thus, are quite similar to the concept of proto-affect proposed by Ortony et al. [31]. According to developmental psychology, young children express their (primary) emotions directly, because they did not yet internalize this process as in the case of adults [21].

In our previous realization of emotion dynamics [3] this direct expression of primary emotions is achieved by implementing five of Ekman's six “basic emotions” [15]. In addition, the emotions “bored”, “annoyed”, and “depressed” as well as the non-emotional state “concentrated” are simulated. Each of the primary emotions is located in PAD space according to Table 1, for which the coordinates are derived from some of the values given in Russell and Mehrabian [39, p. 286ff].[2] Based on a distance metric in this emotion space they are dynam-

[2] Although Russell and Mehrabian [39] locate the emotion “bored” at a different point in PAD space, we are confident that we might label an emotional state of very low arousal and neutral valence with “bored” as well, because together with “depressed” it remains the only one modeled to consist of low arousal.

ically elicited concurrently to the agent's cognition, which is also responsible for triggering these emotions in such a way that their respective base intensities $i_{pe}$ are temporarily set to 1.0 (see Sect. 3.3 for further details).

The seven facial expressions of MAX corresponding to the eight primary emotions and the neutral state "concentrated" are shown in Fig. 1. In case of high Pleasure Ekman's set of basic emotions only contains one obviously positive emotion, namely happiness. Thus, in the WASABI architecture [6] this primary emotion covers the whole area of positive Pleasure regardless of Arousal or Dominance as it is located in PAD space four times altogether.

### 3.2 Three secondary emotions

According to Damasio, the elicitation of secondary emotions involves a "thought process", in which the actual stimulus is evaluated against previously acquired experiences and online generated expectations.

The "prospect-based emotions" cluster of the OCC model of emotions [30] is considered here to belong to the class of secondary emotions, because their appraisal process includes the evaluation of events against experiences and expectations. This OCC cluster consists of six emotions (namely fear, hope, relief, disappointment, satisfaction, and fears-confirmed), of which *hope*, *fears-confirmed*, and *relief* are simulated in the WASABI architecture. The two secondary emotions *disappointment* and *satisfaction* could be implemented similarly, but have not yet been implemented in our demonstrator system due to time limitations.

The prospect-based emotion *fear* is obviously similar to the previously introduced primary emotion *fearful* (cf. Table 1). This similarity is accounted for by assigning a rather low base intensity of $i_6 = 0.25$ to the emotion *fearful*, such that MAX is less likely to get aware of this primary emotion, if it has not been *triggered* by the agent's cognition, making *fearful* a more cognition-dependent primary emotion (see also Sect. 4.1 for an example).

#### 3.2.1 Hope

Ortony et al. [30] describe *hope* as resulting from the appraisal of a prospective event. If the potential event is considered desirable for oneself, one is likely to be "pleased about the prospect of a desirable event" [30, p. 110]. The calculation of this emotion's awareness likelihood, however, is rather independent from these cognitive processes (see Sect. 3.3.2). This analysis provides the rationale for representing *hope* in PAD space in the following way:

- *Pleasure*: An agent is more likely to get aware of *hope* the more pleasurable he feels.
- *Arousal*: With respect to an agent's Arousal, *hope* is more likely elicited the higher the agent's Arousal value.
- *Dominance*: The awareness likelihood of *hope* is modeled to be independent of the agent's general level of Dominance.

To realize this distribution of awareness likelihood in case of hope two areas are introduced in Fig. 1: one in the high Dominance plane and the other in the low Dominance plane. In Table 2 the exact values of the four corners of each of the two areas together with the respective base intensities in each corner are given for *hope*.

#### 3.2.2 Fears-confirmed

According to Ortony et al., *fears-confirmed* is elicited when being "displeased about the confirmation of the prospect of an undesirable event" [30, p. 110]. With respect to its rep-

Table 2 The parameters of the secondary emotions *hope*, *fears-conÞrmed*, and *relief* for representation as weighted areas in PAD space (cf. Fig. 1)

| Area | (PAD values), intensity |
| --- | --- |
| Hope | |
| High Dominance | (100, 0, 100), 0.6; (100, 100, 100), 1.0; |
| | (Š100, 100, 100), 0.5; (Š100, 0, 100), 0.1 |
| Low Dominance | (100, 0, Š100), 0.6; (100, 100, Š100), 1.0; |
| | (Š100, 100, Š100), 0.5; (Š100, 0, Š100), 0.1 |
| Fears-conÞrmed | |
| Low Dominance | (Š100, 100, Š100), 1.0; (0, 100, Š100), 0.0; |
| | (0, Š100, Š100), 0.0; (Š100, Š100, Š100), 1.0 |
| Relief | |
| High Dominance | (100, 0, 100), 1.0; (100, 50, 100), 1.0; |
| | (Š100, 50, 100), 0.2; (Š100, 0, 100), 0.2 |
| Low Dominance | (100, 0, Š100), 1.0; (100, 50, Š100), 1.0; |
| | (Š100, 50, Š100), 0.2; (Š100, 0, Š100), 0.2 |

resentation in PAD space the similarity to the primary emotion *fearful* is taken into account and the following decisions are taken:

- Pleasure: The awareness likelihood of *fears-conÞrmed* increases the less pleasurable the agent feels.
- Arousal: *fears-conÞrmed* is assumed to be independent of the agent's Arousal value.
- Dominance: *fears-conÞrmed* can only be perceived by the agent, when he feels submissive as in the case of *fearful*.

This distribution of awareness likelihood is realized in PAD space (cf. Fig. 1) by introducing an area in the low Dominance plane (cf. Table 2 for the exact coordinates and intensities).

#### 3.2.3 Relief

The secondary emotion *relief* is described as being experienced whenever one is "pleased about the discon rmation of the prospect of an undesirable event" [30, p. 110]. Taking the similarity with Gehm and Scherer's "content" cluster into account [20], *relief* is represented in PAD space according to the following considerations:

- Pleasure: *relief* is more likely to become aware the more pleasurable the agent feels.
- Arousal: Only in case of relatively low Arousal levels the agent is assumed to get aware of the emotion *relief*.
- Dominance: The awareness likelihood of *relief* is considered to be independent from the agent's state of Dominance.

The awareness likelihood is represented in Fig. 1 by two areas: one located in the high Dominance plane and the other in the low Dominance plane (cf. Table 2).

### 3.3 Emotion dynamics and awareness likelihood

The implementation of emotion dynamics is based on the assumption that an organisms natural, homeostatic state is characterized by emotional balance, which accompanies an agent's normal level of cognitive processing [43]. Whenever an emotionally relevant internal or external stimulus is detected, however, its valence component serves as an emotional impulse, which disturbs the homeostasis causing certain levels of Pleasure and Arousal in the emotion module. Furthermore, a dynamic process is started by which these values are continuously driven back to the state of balance (cf. [4] for details).

The two valences are mathematically mapped into PAD space (cf. Fig. 1) and combined with the actual level of Dominance, which is derived from the situational context in the cognition of the architecture. This process results in a course of a reference point in PAD space representing the continuously changing, bodily feeling state from which the awareness likelihoods of primary and secondary emotions are incessantly derived (see also [7]).

#### 3.3.1 Awareness likelihood of primary emotions

The awareness likelihood of any of the nine primary emotions $pe$ (cf. Table 1) depends on the distance between the actual PAD values and each primary emotion's PAD values (i.e. $d_{pe}$ in Eq. 1) with a smaller distance resulting in a higher awareness likelihood. When $d_{pe}$ falls below $\Phi_{pe}$ units for a particular primary emotion $pe$, the calculation of its awareness likelihood $w_{pe}$ is started according to Eq. 1 until $d_{pe}$ falls below $\Delta_{pe}$ units in which case the likelihood $w_{pe}$ equals the primary emotion's base intensity $i_{pe}$.

$$w_{pe} = \left(1 - \frac{d_{pe} - \Delta_{pe}}{\Phi_{pe} - \Delta_{pe}}\right) \cdot i_{pe}, \quad \text{with} \quad \Phi_{pe} > \Delta_{pe} \quad pe \in \{pe_1, \ldots, pe_9\} \qquad (1)$$

In Eq. 1, $\Phi_{pe}$ can be interpreted as the activation threshold and $\Delta_{pe}$ as the saturation threshold, which can be adjusted for every primary emotion $pe_n \in \{pe_1, \ldots, pe_9\}$ independently.[3] By setting a primary emotion's base intensity $i_{pe}$ to 0.0 (as in the case of *surprised*, cf. Table 1) it needs to be *triggered* by the cognition before it might gain a non-zero awareness likelihood $w_{pe}$.

In case of primary emotions that are represented in PAD space more than once (i.e. concentrated, happy, and surprised; cf. Table 1) the representation with the minimum distance to the reference point is considered in Eq. 1 for calculation of its awareness likelihood.

#### 3.3.2 Awareness likelihood of secondary emotions

With representing the three secondary emotions in PAD space their mood-congruent elicitation can be assured, because the actual PAD values are also relevant for calculating every secondary emotion's awareness likelihood. In contrast to most primary emotions, all secondary emotions' *base intensities* are set to zero by default (as in case of *surprised*, cf. Table 1). Accordingly, every secondary emotion needs to be triggered by a cognitive process, before it gains the potential to get aware to the agent. Furthermore, a secondary emotion's *lifetime* parameter (set to 10.0 by default) together with its *decay function* (set to linear by default) are used to decrease its intensity over time until its *base intensity* of zero is reached again. As secondary emotions are represented in PAD space by four sided polygons (cf. Table 2) with separate intensities per vertex (i.e. corner), linear interpolation is used to calculate a secondary emotion's awareness likelihood (cf. [6] for details).

[3] The nine primary emotions are indexed according to Table 1.

Fig. 2 The conceptual distinction of cognition and embodiment in the WASABI architecture. Any perceived stimulus is appraised by conscious and non-conscious processes in parallel leading to the elicitation of “emotional impulses”. These drive the “emotion dynamics”, which is part of the agent’s virtual embodiment and from which mood, Pleasure, and Arousal are continuously derived. PAD space is used (1) to directly elicit primary emotions with a certain intensity and (2) to act as an “awareness filter”, which ensures mood-congruency of both primary and secondary emotions. The resulting set of “aware emotions” is finally reappraised in the cognition before giving rise to deliberative actions.

### 3.4 Connecting cognition and embodiment

In Fig. 2 the conceptual distinction of an agent’s simulated embodiment and its cognition is presented and the different modules and components of the WASABI architecture are assigned to the corresponding layers.

To the left of Fig. 2 the virtual human MAX perceives some (internal or external) stimulus. Non-conscious appraisal is realized by directly sending an emotional impulse to the *Emotion dynamics*. This establishes the “low road” [23] of primary emotion elicitation. For example, the presence of visitors in the museum [3] is interpreted as intrinsically pleasant following the ideas of Scherer [41].

Another path resulting in emotional impulses begins with conscious appraisal of the perceived stimulus (cf. Fig. 2, top left). This process resides in the *Cognition*, because it is based on the evaluation of goal-conduciveness of an event [41] and can be considered the “high road” of emotion elicitation [23]. Therefore, MAX exploits his BDI-based cognitive reasoning abilities to update his *memory* and generate *expectations*. These deliberative processes not only enable MAX to derive his subjective level of *Dominance* from the situational and social context, but also propose cognitively plausible *secondary emotions*.

These *secondary emotions* are, however, first filtered in PAD space, before MAX might get *aware* of them (cf. Fig. 2, middle). Independent of this “awareness filter”, every cognitively plausible *secondary emotion* influences the *Emotion dynamics* component of the WASABI architecture, thereby modulating MAX’s *Pleasure* and *Arousal* values, i.e. his simulated *Embodiment*. This influence is achieved by interpreting the valence component of any *secondary emotion* as an *emotional impulse* (cf. Fig. 2, left). This way, *secondary emotions* "utilize the machinery of primary emotions" [11, p. 137], because they might result in the elicitation of mood-congruent *primary emotions*, which—in the WASABI architecture—drive MAX's facial expressions *involuntarily*. Furthermore, as the *Pleasure* and *Arousal* values are incessantly modulating MAX's *involuntary behaviors* (i.e. breathing and eye blinking) as well, even "unaware" *secondary emotions* have an effect on MAX's bodily state, which is expressed by these behaviors.

In combination with the actual level of *Dominance*, *primary emotions* are elicited by means of a distance metric in *PAD space*. As mentioned before, these primary emotions are directly driving MAX's facial expressions. Although this automatism might be considered unnatural for an adult, it has proven applicable and believable in the situational contexts in which MAX was integrated so far.

After the awareness filter has been applied, the resulting set of *aware emotions* consists of primary and secondary emotions, which have positive awareness likelihoods in that moment of the interaction. They are finally subject to further deliberation and reappraisal resulting in different coping behaviors (cf. [4]).

## 4 Application in the Skip-Bo scenario and first empirical evidence

The WASABI architecture was successfully used to extend the cognitive capabilities of MAX in the previously implemented Skip-Bo card game scenario [5,35]. In this section its technical realization along an exemplary interaction are described and details of an empirical study are given, which yields promising results with regard to the effect of secondary emotion simulation.

### 4.1 Technical realization and example of an interaction

The virtual human MAX is based an a multi-agent system that enables us to encapsulate his cognitive abilities by devising specialized software agents (see Fig. 3). They communicate with each other by passing messages.

The emotion dynamics simulation system is implemented as a so-called *Emotion-Agent* and acts in concert with a number of other agents (see Fig. 3; cf. [2,6] for details). In the Skip-Bo scenario the *Emotion-Agent* receives emotional impulses from the *BDI-Agent*, which is continuously being updated with awareness likelihoods of primary and secondary emotions. The reasoning processes within the *BDI-Agent* also derive the actual state of Dominance from the context of the card game, such that MAX feels dominant whenever it is his turn and non-dominant, i.e. submissive, otherwise. Thus, whenever the human opponent fails to follow the rules of the game, MAX takes the turn to correct her and accordingly feels dominant until giving the turn back to the human. Concurrently, the *BDI-Agent* keeps the *Visualization-Agent* updated about the actual primary emotions and PAD values.

The sequence diagram in Fig. 4 illustrates an example information flow within the WASABI architecture. The three agents *BDI-Agent*, *Emotion-Agent*, and *Visualization-Agent* ("Vis.-Agent") are represented as boxes in the top of Fig. 4. In the top-left box, labeled *BDI-Agent*, the three plans *generate-expectation* ("gen. exp."), *check expectations* ("check exp."), and *react-to-secondary-emotion* ("react sec.") are rendered as three white rectangles to show their

Fig. 3 The three most important software agents in the Skip-Bo scenario and their interconnection by means of message passing. Conceptually, the BDI-Agent realizes the cognition of MAX whereas his embodiment is simulated by two other software agents (cf. Fig. 2)

Fig. 4 Sequence diagram of an information flow between the software agents with the time-line from top to bottom

activity below.[4] The same rectangles are used to depict the PAD space as well as the emotions fearful and Fears-Confirmed ("Fears-Conf.") which all reside in the Emotion-Agent. The internal realization of the Visualization-Agent is not detailed here. In this example it only receives messages from the other agents, although in reality it also distributes information about the human player's interaction with the game interface by sending messages to the BDI-Agent (see Fig. 3).

An exemplary sequence of message communication of these agents is shown in Fig. 4 with the time-line from top to bottom. At first, the generate-expectation plan is called, e.g., after MAX played his last card. This plan, first, sends a negative impulse ("`send impulse neg.`") to the Emotion-Agent, thereby indirectly changing MAX's emotional state in PAD space (cf. Sect. 3.3). Subsequently, while following the same plan, the primary emotion fearful is being triggered ("`trigger fearful`") by the BDI-Agent, because MAX expects the human player to play an important card.

[4] Pseudo-code representations as well as detailed descriptions of all BDI-plans can be found in Becker-Asano [6].

Fig. 5 MAX first fearing the human player to play a card and then seeing his fears confirmed: a MAX fears that the human might play his stock pile card next and displays a fearful facial expression. b MAX realizes that his fears just got confirmed and utters “Das hatte ich schon befürchtet!” (I was afraid of that!)

In the Emotion-Agent, however, the negative emotional impulse pushed the reference point in PAD space already close enough to the (not yet triggered) emotion fearful to let MAX experience fear with low intensity, because fearful has a slightly positive base intensity of 0.25 (cf. Table 1). In Fig. 4 this non-zero standard intensity of fearful is indicated by a small double line along the dashed, vertical lifeline of fearful. Accordingly, “slightly fearful” is sent to the Visualization-Agent even before the BDI-Agent triggers the emotion fearful. Because the intensity of fearful in the Emotion-Agent abruptly changes with the incoming trigger fearful message, MAX’s emotional state changes from slightly fearful to very fearful. This sudden change in intensity is reproduced in Fig. 4 by the two gray triangles drawn along each emotion’s lifelines and leads to a clear expression of fear in MAX’s face as shown in Fig. 5a.

The intensity of fearful decreases within the next 10 s and the reference point changes its location in PAD space due to the implemented emotion dynamics. Thus, very fearful automatically changes to fearful (see right side of Fig. 4) without any further impulse or trigger messages.

Next, the check expectations plan is activated in the BDI-Agent to check, if a human player’s action meets the previously generated expectations. In this example, the BDI-Agent, first, sends a negative impulse to the Emotion-Agent, thereby changing the reference point’s location in PAD space such that MAX gets very fearful again. This sequence of different emotion intensities (slightly fearful, very fearful, fearful, very fearful) is possible for every primary or secondary emotion, although it is exemplified only for fearful in Fig. 4. It results from the dynamic interplay of lower-level emotional impulses and higher-level (cognitively triggered) changes of an emotion’s base intensity.

The check expectations plan then triggers the secondary emotion Fears-Confirmed (“`trigger Fears-Conf.`”) in the Emotion-Agent, thereby maximizing its base intensity. Together with the negatively valenced mood, fears-confirmed acquires a non-zero awareness likelihood, which is sent back to the BDI-Agent (“`send Fears-Conf.`”). The plan react-to-secondary-emotion is then executed to process the incoming message and results in an “`utter Fears-Conf.`” message, which is sent to the Visualization-Agent letting MAX produce an appropriate utterance (cf. Fig. 5b).

A human opponent would possibly give the following description of this sequence:[5]

> After MAX ended his turn with playing a hand card to one of his stock piles, he seemed to realize within 1 or 2 s that I could now directly play one of my four stock pile cards, because his facial expression changed to fearful and he seemed to inhale sharply, which produced the characteristic sound of someone being afraid. When I then actually played that stock card, MAX admitted that he had been afraid of that before.

Similar dynamic interplays between conscious appraisals and bodily feelings are realized within the Skip-Bo scenario for the secondary emotions *relief* and *hope* as well (cf. [6]).

### 4.2 Empirical evidence on the effect of secondary emotion simulation

Although our approach has not been subject to extended evaluation, some empirical evidence on the effect of secondary emotion simulation could already be gathered.[6] We derived the following hypothesis from the psychological findings presented in Sect. 2.1.

> *Hypothesis* MAX expressing primary and secondary emotions is judged older than MAX expressing only primary emotions.

As discussed in Sect. 2.1, secondary emotions are understood to be the product of ontogenetical development and children are less able to suppress their emotional expressions than adults. Accordingly, humans playing Skip-Bo against MAX with secondary emotions (i.e., driven by the WASABI architecture) should be expected to judge him older than those humans that play against a version of MAX which only simulates and directly expresses primary emotions (i.e., driven by the original emotion dynamics system of Becker [2], cf. [3]).

#### 4.2.1 Design

To test the above hypothesis the following two conditions[7] were designed:

(1) *Only primary emotions* condition: The emotion simulation is constrained to primary emotions and MAX expresses them directly by means of facial expressions and "affective sounds". He acknowledges a human player's actions verbally and appraises them negatively. In constrast, he appraises his own progress in the game positively. During his turn and while correcting a human's mistake he feels *dominant*, otherwise *submissive* (i.e. non-dominant).

(2) *Primary and secondary emotions* condition: Secondary emotions are simulated in addition to the setup of condition (1) and MAX expresses them verbally in case of positive awareness likelihood (cf. Sect. 4.1).

In order to model condition (1) the WASABI architecture is initialized such that:

– The three secondary emotions *hope*, *fears-confirmed*, and *relief* are not included.

[5] A video of this and similar interactions is available for download at http://www.becker-asano.de/WASABI_MaxInCave_Page.avi

[6] We can only present a summary of the empirical study here, but a detailed description can be found in Becker-Asano [6].

[7] Notably, the number of verbal utterances performed by MAX is likely to be higher in condition (2) than in condition (1). This difference, however, adds to the impression of MAX as a less child-like interaction partner in condition (2), because young children are also less good at expressing their feelings verbally.

– Every primary emotion has the same saturation threshold $\Delta_{pe}$ (0.2), activation threshold $\Phi_{pe}$ (0.64), and base intensity (1.0).

In effect, the simpler emotion simulation system of Becker [2] is reproduced within the WASABI architecture for condition (1).

To realize condition (2) the emotion module is initialized according to Tables 1 and 2 (cf. Sect. 3.1, page 8ff.). Furthermore, for *surprised* the saturation threshold $\Delta_9$ is set to 0.3 in order to increase the probability of MAX getting aware of his surprise, after this primary emotion was *triggered* by the cognition (cf. [6] for details).[8]

#### 4.2.2 Participants

Fourteen male and nine female university students voluntarily took part in the study and all but one of them were German. Their age ranged from 13 to 36 years and the average age was 23 years. Participants were randomly assigned to the conditions resulting in a total of 11 participants (six male and five female) for condition (1) and 12 participants (eight male and four female) for condition (2).

#### 4.2.3 Procedure

Participants received written instructions of the card game (in German) with a screenshot of the starting condition and got the chance to ask clarifying questions about the gameplay before they entered a room with a three-sided large-screen projection system. Participants entered the room individually and were equipped with goggles for 3D viewing and a marker for the right hand. They were briefed about the experiment, in particular that they would play a competitive game. Then, the participants played a short introductory game against a non-emotional MAX, which allowed them to get used to the interface, and also gave them the chance to ask clarifying questions about the game. Each participant won this first game easily.

From now on, the experimenter remained visually separated from the participant only to supervise the experiment. After the game was reset manually, MAX welcomed the participant verbally and asked him or her to play the first card. After the game was completed, participants were asked to fill in a questionnaire in German presented on the screen of another computer in a room next door.

This questionnaire contained a total of 26 questions, of which 25 had already been asked in Japanese to the participants of a similar study in Japan [35]. To falsify our hypothesis we additionally asked the following question:

If MAX were a real human, how old would you judge him to be?

The participants were asked to fill in MAX's suspected age in years in a blank behind this question.

[8] *Surprised* is the only primary emotion with a base intensity of 0.0 (cf. Table 1) such that it can only get aware to the agent after being triggered by the cognition. This is based on the assumption that surprised is only expressed in reaction to unexpected events and expectedness of events is checked within the BDI-Agent, i.e. the agent's cognition.

Fig. 6 Mean values and standard deviations of the answers to question number 17b "If MAX were a real human, how old would you judge him to be?" a Between primary emotions only condition (1) and primary and secondary emotions condition (2) a significant difference occurred. b No gender-related effects were observed with regard to question 17b

### 4.2.4 Results

The two mean values and standard deviations of the participants' answers to the above question are presented in Fig. 6a. In the *primary emotions only* condition (1) MAX was judged to be significantly younger (mean value 19.8 years, standard deviation 7.7) than in condition (2), in which secondary emotions were simulated as well (mean value 27.5, standard deviation 7.5). A two-tailed t-test assuming unequal variances results in $p = 0.025$.

Because male and female participants were not evenly distributed among the two conditions (cf. Sect. 4.2.2), the answers of all nine female participants were compared to the answers of all 14 male participants regardless of the experimental condition. The mean values of these two groups did not differ significantly (cf. Fig. 6b) letting us assume that no gender effects occurred. This result strengthens the supposition that the between-conditions difference can be interpreted to confirm the initial hypothesis.

## 5 Discussion and conclusion

We presented the WASABI architecture for mood-congruent simulation of primary and secondary emotions as it is integrated in, and makes use of, the overall cognitive architecture of the virtual human MAX. The simulation and direct expression of primary emotions is based on the idea to capture an agent's bodily feeling as a continuous progression in three-dimensional emotion space (i.e. PAD space), which is subsequently translated into weighted, primary emotions. Secondary emotions, in contrast, are understood as a class of emotions that require higher cognitive reasoning abilities and a certain sense of time, in that an agent has to be able to take experiences and expectations into account to generate prospect-based, secondary emotions. To also assure mood-congruency of secondary emotions, we capture aspects of their connotative meanings in PAD space as well by introducing weighted areas. Furthermore, to account for the decisive influence of cognitive processes in the elicitation of secondary emotions, they can gain a certain awareness likelihood in PAD space of the agent's virtual embodiment, only after having been triggered by cognitive processes.

The simulation of secondary emotions was exemplified by integrating three prospect-based emotions into the WASABI architecture. We believe, however, that other high-level, secondary emotions could be simulated similarly.

Finally, we reported on an empirical study conducted to answer a question derived from developmental psychology, namely, if the additional simulation of secondary emotions lets our virtual human MAX appear older within a playful interaction. Although the results of this study can be interpreted af rmatively, we acknowledge that the difference in MAX's use of spoken language between conditions may have compromised the results. Independent thereof, the practical applicability of the WASABI architecture to a well-de ned, playful interaction scenario was demonstrated successfully.

In conclusion, we believe that the WASABI architecture is a helpful model to understand how the dynamic interplay of body and mind together with past experiences and future expectations sometimes turns "cold" cognitions into "hot" affective states.

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