# WASABI for affect simulation in human-computer interaction

## Architecture description and example applications

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**Abstract.** This paper describes the WASABI affect simulation architecture, which was developed and used to simulate dynamically changing emotions for virtual and robotic agents. It is argued that the unique feature of WASABI as compared to the many alternative computational models of emotion is its simple interface that makes it particularly easy to integrate into agent architectures. This is demonstrated by several applications that made use of WASABI as a core ingredient.

**Keywords:** computational modeling of emotions, human-computer interaction, social robotics

## 1 Introduction

Anthropomorphizing the interface has been argued the best approach for letting humans effectively and intuitively interact with the computer [1]. Although we still do not instruct computers using natural (body) language and most machines lack both human-like appearance and response capabilities, a number of research projects have been [2] and are addressing open questions concerning this research goal [3–5]. It is widely accepted that, as soon as machines are given a human-like appearance, they should also be able to use it appropriately not only to convey nonverbal but also emotional signals [6]. Actually, many computational emotion simulation architectures have been devised to focus on different aspects of HCI as is detailed below.

The WASABI architecture [7] is especially simple to integrate into agent architectures and it has even proven able to generate predictions about a human's course of emotions during interaction with a computer [8]. Although some challenges and opportunities remain to be addressed [9], the architecture is mature enough to be used as a flexible emotion simulation component.

The remainder of this paper is structured as follows: Section 2 introduces related work covering the fields human-computer interaction, social robotics, and emotion psychology. In Section 3 the basic functionality of WASABI's core are laid out before its integration into general cognitive agent architectures is detailed. Applications of WASABI are presented in Section 4 and, finally, general conclusions are drawn.

## 2 Related work

As early as in 1992 the question of how a computer could possibly reason about emotions has been thoroughly investigated [10]. Based on a structural theory of emotions (OCC, [11]) the "Affective Reasoner" [12] has been straightforwardly applied to tutoring agents and interactive story-telling [13]. However, the OCC model itself has been criticized for lacking features that seem mandatory for achieving believable behavior of animated agents [14]. Despite this insufficiency it has become very prominent in computational emotion modeling (e.g. [15, 16]). A different approach has been taken in the development of "EMA" [17], which is deeply rooted in symbolic reasoning as well, but follows a different theoretical model. Thereby, the authors avoid being subject to the same criticism but they also stick to the rather traditional reasoning approach as it is at the core of many appraisal theories of emotions [18]. The PhD thesis by Stefan Rank contains a detailed analysis of the advantages and drawbacks concerning these different approaches [19]. Surprisingly, the thesis fails to provide an alternative approach to achieve a more sophisticated architecture. In [20] a detailed discussion presents the drawbacks and advantages of following any combination of the available theoretical emotion models when trying to capture the richness of emotional experience computationally.

In contrast to this rational approach of emotion modeling, several projects followed the idea of dimensional emotion theories. Most prominently, variants of the pleasure-arousal-dominance space (PAD space, [21]) formed the basis of emotion simulation systems in social robotics [22, 23]. By representing a relevant set of emotions within this space it is straightforward to identify an agent's emotional state with one particular point in this space at any given moment in time. The core of WASABI makes use of this idea as well.

## 3 The WASABI architecture

This section first introduces the basic functionality of the WASABI Affect Simulation Architecture for Believable Interactivity. Then its integration into general agent architectures is explained.

### 3.1 Basic functionality

At the core of WASABI is the idea that emotions and mood influence each other over time [24]. Thus, whenever something positive is happening to the agent—may it be a virtual or robotic agent, or even simply a software agent within a disembodied multi-agent system—its mood will rise, which, in turn, results in a predisposition to experience positive rather than negative emotions. The opposite is happening whenever some negative event occurs giving rise to negative

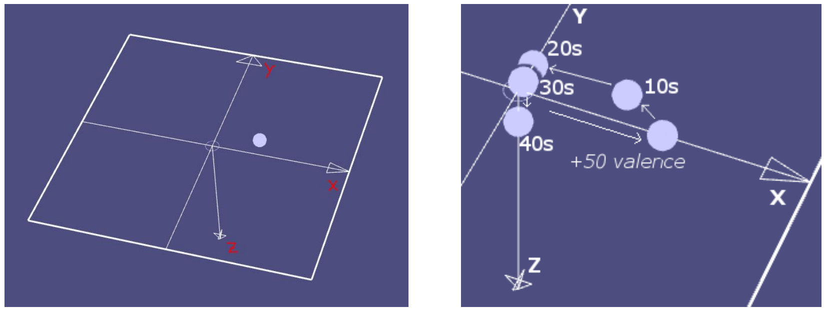


**Fig. 1.** The complete dynamic space (left) and an example of a course of valence (X), mood (Y), and boredom (Z) over time (right)

valence. The agent's mood is dampened making positive emotions less likely to be enacted. Concurrently, the two intensities of valence and mood are driven back to zero by two independently simulated mass-spring systems, a stronger one for valence and a weaker one for mood.

This idea of an emotion dynamics is realized within the two-dimensional space of "valence" (X) and "mood" (Y) as depicted in Fig. 1, left. Additionally, a third Z-axis is used to realize boredom in the absence of any emotionally relevant events. For example, after a positive event led to a one time valenced impulse of 50 (cf. Fig. 1, right), the x-value will instantaneously be increased by 50 points. Ten seconds later, this positive valence will have led to a slightly positive mood (Y) and at the same time the valence (X) itself will have started to diminish. When 20 seconds have passed without anything emotionally relevant happening, the "valence" has returned to zero, but the "mood" will still be slightly positive. After 30 seconds the mood is nearly neutral again and a linear increase of boredom (Z) will begin, which reaches a slight level after a total of 40 seconds have passed.

These three values are internally updated with frequency of 50 Hz and continuously mapped onto "pleasure" (P) and "arousal" (A) values according to the following equations:

$$p(x_t, y_t) = \frac{1}{2} \cdot (x_t + y_t)$$
$$a(x_t, z_t) = |x_t| + z_t \text{ (with } z_t \text{ being negatively signed)}$$

Thus, the above example course of "pleasure" and "mood" results in the course of pleasure and arousal as depicted in Fig. 2, right. The locations of emotions indicated in Fig. 2 (left) with two circles around each one are customizable. For example, in most applications described below two additional locations for *happy* are included, one at $(50, 0, 100)$ and the second one at $(50, 0, -100)$. All of them are understood as primary emotions [25] that do not require higher cognitive reasoning capabilities to be elicited. For them to become active in the WASABI architecture it suffices for the reference point in PAD space to enter

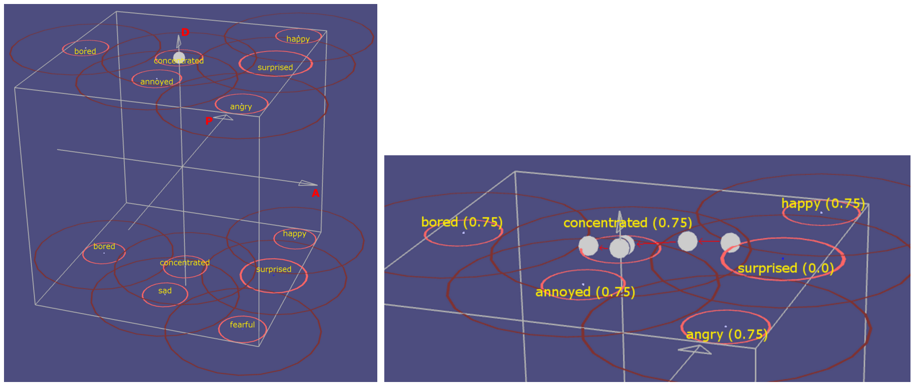


**Fig. 2.** The complete PAD space (left) and the same example as in Fig. 2, right, with its course over time in PAD space. The values in parentheses

the outer circle of any of them with the exception of surprise. Surprise needs to be "triggered" in the emotion module in order to get a chance to be activated, because this emotion affords a certain unexpectedness of an emotionally relevant event.

Accordingly, in the above example of a single positive event happening only once the sequence of primary emotions resulting from the emotion dynamics would be: *concentrated* → *concentrated/happy* → *concentrated* → *concentrated/annoyed*. The emotional state *boredom* would be reached another 10 seconds later and be mixed with *concentrated/annoyed*, first, and then only with *concentrated*, because their resp. "activation regions" (as indicated by the bigger circles around each emotion in Fig. 2) overlap. Only the "saturation region" (smaller circles) of *concentrated* is passed such that only this emotion is activated with its full "base intensity" of 0.75.

The values for these two regions around each (primary) emotions can be adjusted individually per emotion. Similarly, all parameters of the emotion dynamics simulation can be changed at runtime by means of the graphical user interface provided with the open source WASABI architecture [26]; cf. Fig. 3.

Secondary emotions such as *Hope* or *Relief* are classified as to afford higher cognitive reasoning, esp. regarding expectations about outcomes of possible future events [25]. Nevertheless, they are also understood as to influence primary emotions. In effect, three exemplary secondary emotions—namely *Fears-confirmed*, *Hope*, and *Relief*, which were chosen on the basis of OCC [11]—are implemented in WASABI as well. In their case, however, it seems implausible to rely on the rather reactive and uncontrolled elicitation mechanism described above. Consequently, the same "triggering" mechanism as used for "surprise" is also applied to these secondary emotions and they are represented in PAD space in terms of regions rather than distinct points (see [27] for a detailed description). *Hope* is more intense in case of both positive pleasure and high arousal and less intense with displeasure and neutral arousal. *Hope* together with *Relief*

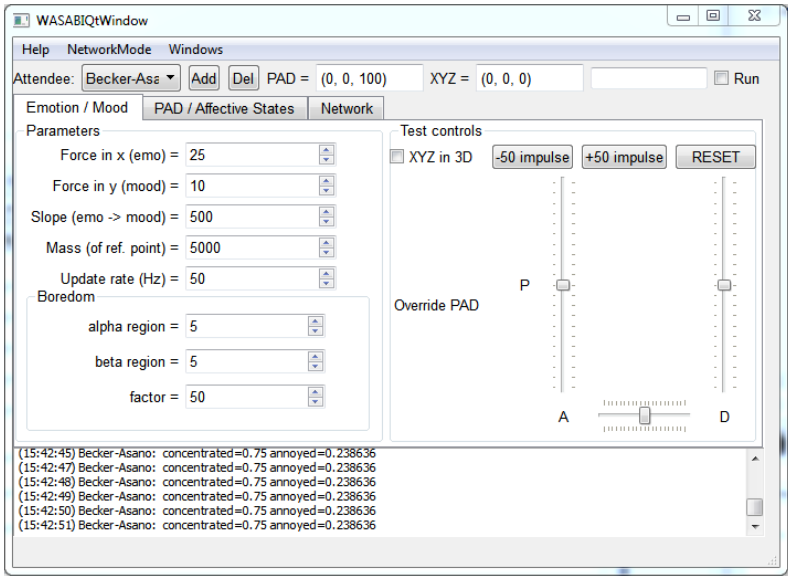


**Fig. 3.** The graphical user interface provided by the WASABI architecture

are both independent of dominance and the latter is most intense with positive pleasure and only moderate arousal. *Fears-confirmed* is only activated when the agent is non-dominant (i.e. submissive) and very displeased.

### 3.2 Integration

Figure 4 presents a sketch of how the WASABI architecture can be integrated into an agent framework that consists of four separate modules:

1. A main module receives and handles the raw input data from the environment (1).
2. A cognition module performs the reasoning based on the continuously updated situation descriptions it receives from the main module (2). So far, this module has been realized following the Belief-Desire-Intention (BDI) philosophy [24, 29] and, recently, by employing parts of the ACT-R (Adaptive Control of Thought—Rational) cognitive architecture [28]. This module provides the main module with a single action or a sequence thereof to be performed by the agent (3).
3. The emotion module receives and processes both valenced impulses and the aforementioned emotion triggers from the main module (2) and the cognition module (3). The latter is also responsible for changing the agent's dominance based on the appraisal of coping potential, social status, and the like. Concurrently, it updates the main module with "emotion vectors" (3/4) that contain the current emotions together with their resp. intensities.

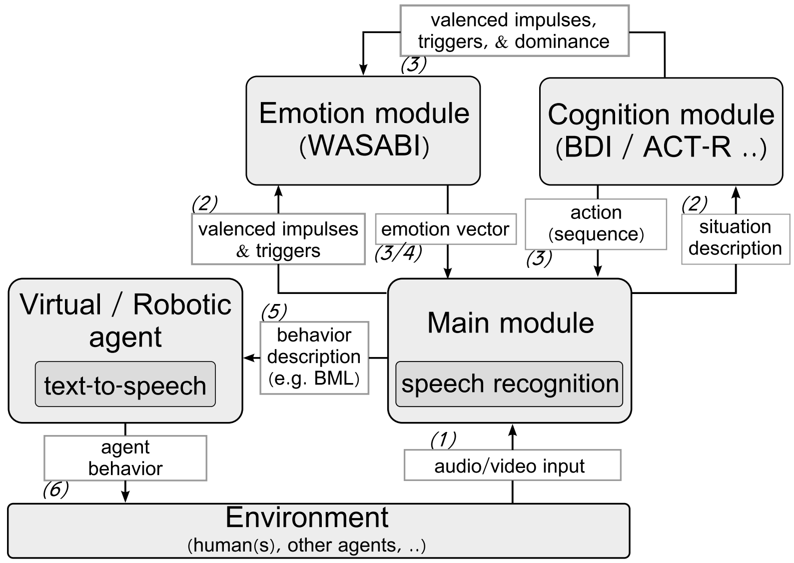


**Fig. 4.** An outline of how the WASABI architecture can be integrated into an agent framework that is supposed to be used for direct human-computer interaction; e.g. [28]

4. The virtual or robotic agent uses the behavior description (5), which might be encoded according to the behavior markup language (BML) standard [6], to be instructed by the main module about how to animate the agent (6).

Notably, the emotion module can directly receive valenced impulses and emotion triggers from the main module (2), by which a reactive processing level is established. Concurrently it can be driven by the cognition module (3) realizing a deliberate processing level of emotions. Both levels of emotion processing result in a combined effect within the emotion module, which, in turn, continuously updates the main module with the emotion vectors.

This parallel processing capability of the WASABI-based emotion module can be considered the key advantage of implementing a concurrent simulation of emotion dynamics in PAD space.

## 4 Applications of WASABI

During its development the WASABI architecture has been integrated, tested, and used for empirical research in the context of building the Virtual Human MAX [24]. Recently, it was combined with the MARC character animation system [30, 28]. In addition, the robotic platform Scitos-G5 is being used as interaction medium [31].

### 4.1 The virtual agents MAX and Simon

**Chatting with and playing against agent Max.** With regard to its believability the agent MAX was tested in a "chat bot"-like conversational scenario [24, 32, 33] and as an opponent in a card game [34, 35]. In the conversational agent scenario a main module receives keyboard as well as video input. The former is analyzed by a BDI-based reasoning component for, e.g., praises and insults to generate emotional, ELIZA-like [36] responses. Concurrently, the camera input is analyzed for facial colored regions and certain gestures performed by the human in front of MAX, e.g. waving. The emotion module, realized by WASABI, contains only primary emotions with all of them being set to 1.0 base intensity, such that no trigger commands are needed to elicit the emotions. This constitutes the simplest way to use WASABI as a component in human-computer interaction.

In order to simulate prospect-based emotions [11] an agent must be able to derive expectations regarding future events from what is currently known. A conversational scenario seemed too complex and unpredictable in this respect. Thus, we decided to change to an even more playful interaction that consists of a limited number of precisely describable actions. Choosing the card game Skip-Bo [34] enables us to distinguish private from public knowledge and the agent MAX can be programmed (using the BDI-approach again) to form expectations about the human player's next moves. Whenever any of her options have positive consequences for MAX, the secondary emotion Hope is triggered and a positive impulse is send from the cognition module to the emotion module (cp. Fig. 4). If this results in Hope being the emotion with the highest intensity as encoded in an emotion vector, the agent will make a statement such as "Couldn't you play the card X next?" while looking at the human player. The secondary emotions Relief and Fears-confirmed were modeled similarly for this scenario [7].

In summary, results of a number of empirical studies [35, 8, 33] showed that the subjective impression and behavior of a human being confronted with MAX can be modified in a coherent manner simply by changing WASABI's simulation parameters.

**Learning with agent Simon.** Despite the positive results gained with WASABI in concert with the agent MAX, it remained an open question, if the rather admittedly complex simulation of emotions also impacts a human's task performance in a significant way. In order to address this question, WASABI was combined with the agent Simon as supplied by the MARC framework [30] and a specific memory retrieval function of the ACT-R cognitive architecture [37]. An interactive desktop setup was realized to investigate the effect of an agent as the interface for presenting a sequence of association pairs to a human, who has to recall these pairs later on [28]. The results of the between-groups study, however, indicate no effect of the agent presenting the task in a non-emotional as compared to an emotional fashion as derived from the human learner's performance. In this setup the predictions of human recall probabilities calculated by the ACT-R function were checked against the actual recall performance during the learning task. Any discrepancies between these two values were then used to change the sign and intensity of the “valenced impulse” send to the emotion module. This procedure can be seen as an online calculation of expectation deviation, which is crucial for an agent to appear (emotionally) intelligent. Whether the task is too special to allow for an effect and/or the dynamically changing expressions of the agent are not believable enough remains unclear.

### 4.2 The robot Scitos-G5

The mutual influence of “valence” and “mood” realized in the emotion dynamics of WASABI (cp. Section 3.1) allows for easy simulation of different personalities as was shown by a study employing the robot Scitos-G5 [31]. This robot consists of a mobile platform with a number of sensors and a transparent sphere on its top, in which two “eyes” give the slight impression of human-likeness. Nevertheless, the emotion display is achieved by an animated talking head displayed on a touchscreen attached to the robot. The emotion dynamics is solely driven valenced impulses that are derived from the robot’s average CPU load and the location of the robot with certain rooms having positive or negative effects.

The three personalities “neutral”, “happy”, and “unhappy” are modeled (1) by adjusting the location-dependent impulses and (2) by changing the standard “mood” value, to which the emotion dynamics is driven back, from 0 to either a positive (happy) or a negative (unhappy) value. Also, the robot’s verbal expressions are defined to convey the change in personality. A first empirical study let to convincing albeit limited results.

## 5 Conclusions and future work

WASABI has proven flexible enough to be integrated into frameworks for cognitive agents that interact with humans in a variety of situational contexts such as smalltalk, gaming, learning, and tour-guiding. Currently, its set of emotions is being extended to include social emotions, e.g., guilt, shame, and embarrassment. This goal can only be achieved based on sophisticated reasoning capabilities that might afford the integration of dynamic epistemic logic [38]. Additionally, for capturing social norms and standards deontic logic is currently being considered relevant as well.

## Acknowledgments

The author would like to thank Julien Hué for insightful discussions and his helpful feedback on the paper.

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