Connecting Feelings and Thoughts - Modeling the Interaction of Emotion and Cognition in Embodied Agents

Christian Becker, Nadine Lessmann, Stefan Kopp, Ipke Wachsmuth
Faculty of Technology
University of Bielefeld
33594 Bielefeld
Germany
{cbecker,nlessman,skopp,ipke}@techfak.uni-bielelefeld.de

Abstract

The integration of emotion and cognition in cognitive architectures for embodied agents is a problem of increasing importance. In this paper, we describe how two separate modules for these tasks, as we employ them in our virtual human Max, can influence each other in such an architecture. In the first direction, from cognition to emotion, we present domain-specific as well as more general *appraisal* mechanisms, as employed in three different interaction scenarios. For domain-independent appraisal the belief-desire-intention model is exploited to derive emotional impulses during the decision process. In the opposite direction, we discuss how emotions can influence cognition either as self-beliefs or as modulators to the decision-making process itself. For the latter, extensions to the BDI-interpreter are proposed.

Introduction and Motivation

With the growing interest in socially intelligent agents, the integration of simulated emotions into an agent's cognitive architecture becomes increasingly important. The resultant architecture may comprise dedicated modules for deliberative reasoning as well as emotions, or a more integrated approach can be taken, deriving and managing emotions within the deliberative module itself. In any case, the interplay of cognitive and emotional processes takes place via two main kinds of mechanisms. The first is *appraisal*, the evaluation of sensory or cognitive events for their impact on the emotions of the agent. The second is concerned with the influences of emotions on the agent's deliberative module, and is much harder to be treated in similarly clear-cut ways.

In this paper, we present our work toward the integration of cognitive and emotional processes in the architecture of the virtual human Max. Max's internal modular structure has been built up, tested, and extended in a row of different scenarios, including a collaborator in Virtual Reality assembly tasks [9], an empathic opponent in a cards game [4], or a conversational museum guide in a public computer museum [8]. Across these scenarios with their different characteristics and requirements, we have addressed the question how the thoughts and feelings of Max can be interconnected in increasingly comprehensive models, and how this can be utilized for more believable behavior in the respective domains.

In the next section, we will start with an overview of related work along the lines of two major emotion research trends in psychology. In Section 3, we introduce our virtual agent's modular architecture along with an outline of the three main interaction scenarios. In Section 4, we introduce a system for simulating the agent's emotions and present different solutions for how it can be driven by the agent's cognitive processes. More precisely, we will describe implementations and results of domain-specific appraisal, as exemplified and applied in the three task-oriented interaction scenarios, as well as more general mechanisms of how the influence of goal-directed deliberation on emotions can be modeled. Section 5 addresses the opposite direction of influencing, namely, how the effect of emotions on cognitive processes can be modeled for embodied agents. We will differentiate between emotions that are fed back into cognition as a form of belief about oneself and the role of emotions as modulators of the overall deliberative processing.

Related Work

We start with discussing the approaches that have been taken to simulate emotions for artificial agents, and how they interact with the agent's cognitive reasoning processes. According to [1] at least two main viewpoints can be distinguished in modeling emotions: cognitive theories of emotions and dimensional theories of emotions.

One cognitive theory has become the standard model for emotion synthesis and is commonly known as the OCC [16] model of emotions. It was carefully designed as a computational model of emotions and builds upon the assumption that 22 discrete emotion categories can be derived as valenced reactions to situational contexts, based on deliberative reasoning. Appraisal is the basis of every computational emotion theory, but in the OCC model it is indistinguishably intertwined with the cognitive processing of an agent. This approach is conceptually close to the methodologies applied in symbolic A.I., and it has been frequently applied to integrate emotions into agent architectures, e.g. [20]. Despite its comprehensiveness and explanatory power, this model was frequently criticized, e.g., for not taking into account the mutual interaction of emotion categories and for not keeping track of their development in time. Many implementations have tried to circumvent these drawbacks (e.g. [7], [19]), but these attempts have only been moderately successful. Ortony himself [15] has proposed that it might be sufficient to integrate only ten emotion categories into an agent's architecture, five positive and five negative ones. He also argued that it might be adequate to start with an agent that can only differentiate positive from negative, letting it evolve richer emotional experience by means of machine learning techniques. To our knowledge, no one has followed this idea consequently in an implemented system.

Initially Wundt [22] has claimed that any emotion can be characterized as a continuous progression in a three-dimensional space of connotative meaning. Several researchers (e.g. [13]) have provided statistical evidence for this assumption. Using principle component analysis they found that three dimensions are sufficient to represent the connotative meaning of emotional categories. These dimensions are commonly labeled *Pleasure/Valence (P)*, representing the overall valence information, *Arousal (A)*, accounting for the degree of activeness of an emotion, and *Dominance/Power (D)*, describing the experienced "control" over the emotion itself or the situational context it originated from (PAD-space, in short). For emotion recognition, this space is often reduced to the first two dimensions *Pleasure/Valence* and *Arousal (A)* [10]. For example, Prendinger et al. [17] derive the human's emotional state from physiological data, assuming that skin conductance is positively correlated with arousal and that muscle tension is an indicator of negative valence. The derived values are then classified in the two dimensional emotion space according to [10]. The restriction to two dimensions is mainly due to the fact that *Dominance* can not be derived from such sensor data, as it depends on an actor's subjective feeling of control over a situation. Embodied agents, in contrast, are embedded in a (virtual or physical) situational context, therefore enabling them to derive this sense of control analytically. The emotion system of the sociable robot "Kismet" [5], for example, is based on a three-dimensional emotion space similar to the one explained above.

The Virtual Human Max

The virtual human Max, under development at Bielefeld University's A.I. group, is a testbed for studying and modeling human-like communicative behavior in natural face-to-face interactions [9]. We started out from the idea of having an anthropomorphic agent as the embodiment of the artificial intelligence to interact with, and of using its simulated physis to provide a bodily grounding in situational context. In interactions, Max should be able to use the modalities of speech, gestures, facial expressions, gaze, or posture in combination, as humans do when communicating with each other. To this end, we equipped the agent with a physis and provided him with the motor capabilities needed for synthesizing nonverbal communicative behavior. The skeleton provides human-like maneuverability and delivers simulated proprioceptive feedback about the current body posture or motion; 21 simulated face muscles allow for animation of lip-sync speech and a variety of facial expressions.

Max internal architecture consists of a reactive module, a cognition module, and an emotion module ([11]). The reactive module is generally in charge of realizing all behaviors that are requested by the other components. On the one hand, this includes feedback-driven reactive behaviors like tracking the current interlocutor by gaze based on incoming positioning events. Other behaviors concern the agent's secondary behaviors like eye blink and breathing. On the other hand, the reactive module accomplishes behavior generation for all intentional actions Max is to make, in particular his multimodal utterances.

The cognitive module builds on the belief-desire-intention model (BDI, in short) of rational behavior, i.e. it incessantly pursues multiple plans (intentions) to achieve persistent goals (desires) in the context of up-to-date knowledge about the world (beliefs). Desires, which are differentiated from instantiated subgoals, can emerge from internal processing but also through interactions with the environment or the human interlocutor. Intended courses of action are represented as plans with preconditions, context conditions, effects, and a utility function. The BDI-interpreter continually pursues the plan with the highest utility value as an intention. Plans in execution can either directly trigger specific behaviors and motor programs to act, but may also invoke other self-contained planners that construct context-dependent plans. Thus, complex plans can be expanded on demand by instantiating lower-level plans.

The emotion module of Max's architecture follows the simulation-based approach. In contrast to communication-driven approaches where expressions of emotions are deliberatively used as a means of communication, we focus on a simulation that allows for a coherent evolvement of emotions over time. Two major assumptions underly our realization, as supported by psychology literature (e.g. see [14]):

1. Every elicited emotion has a fortifying or alleviating effect on the *mood* of an individual. An emotion can usually be associated with its eliciting stimulus and is a short-lived psychological phenomenon. A mood, in contrast, is a more diffuse and longer lasting, valenced state. The predisposition to experience emotions changes together with the mood, e.g. humans in a positive mood are thought to be more susceptible to positive than negative emotions, and vice versa.

2. Every basic emotion category can be positioned in the emotion space introduced above and a distance metric can be applied to map the dynamically simulated emotional state onto one of these categories.

Based on these two assumptions, we implemented an emotion dynamics simulation system that runs concurrently with the BDI module and processes valenced impulses together with the actual degree of dominance as input signals. These signals are driving the internal dynamics of a dimensional emotion representation by, first, changing the emotional valence, secondly, influencing the agent's mood and finally mapping these values into the PAD-space (see Figure 1) for classifying the emotion (see [3] for details). The emotion system provides the agent's overall architecture with the currently active categorical emotion, the actual level of pleasure and arousal, and the actual mood value. At the physis of the agent, the values of pleasure and arousal are directly expressed through his body (rates of breathing and eye blink) and his prosody (pitch and speech rate of the voice). Likewise, the agent's facial expressions are directly driven by the emotion categories based on [6] (see Figure 1).

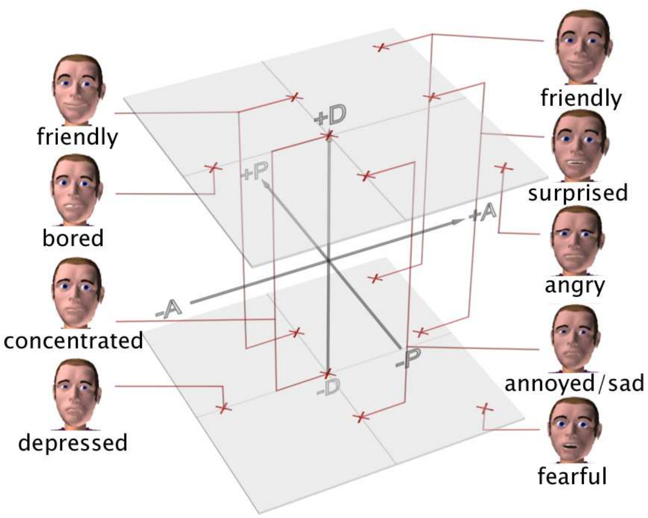

Figure 1: The ten emotion categories in PAD-space together with the seven attributed facial expressions

We investigated the interplay of the reactive, deliberative, and emotion modules, including the mutual influence of cognition and emotion as described in the following sections, in the context of three interaction scenarios:

Museum Guide Scenario In the first scenario our agent Max is employed as a conversational guide in a public computer museum [8]. By means of a video camera Max can perceive the presence of museum visitors, and he engages them in conversations in which he provides information about the museum, the exhibition, and other topics. The visitors can talk to Max by entering text input via a keyboard in front of the agent.

Cards Game Scenario We implemented a cards game called "Skip-Bo" as a face-to-face interaction scenario between a human player and Max [4]. In this game, both players have the goal of getting rid of their cards either following an offensive or defensive strategy. In such a playful interaction, we were interested in the effect that affective and/or empathic agent behavior has on human players. To let Max show positive or negative empathy, we measured physiological indicators for the emotions of the human players, e.g. their skin conductance. By evaluating this data as well as results from a questionnaire we could analyze for the observer's emotional experience, solely depending on Max's emotional appraisal and display.

Assembly Scenario Finally, Max has been employed in a collaborative assembly task, where he meets a human face-to-face in a VR environment [9]. Combining deliberative and reactive conversational behaviors with the capability to initiate assembly actions, the agent guides the interlocutor through interactive construction procedures. In our current work, emotions are associated with goal achievement or failure.

How Cognition Influences Emotions

Two main approaches can be differentiated in modeling how emotional effects arise out of cognitive processes, domain-specific and domain-independent emotion simulation. As Gratch and Marsella [7] point out, in domain-specific emotion simulations researchers use task-oriented algorithms to implement appraisal routines specifically designed for the current task of the agent. Fewer approaches are domain-independent in that they bring emotional appraisal to a conceptually higher level, thereby not relying on special aspects of the agent's concrete task. In the modeling of our system, we have applied and combined both ways.

Domain-specific Emotion Simulation

Within fixed domains, one way to let emotions originate from cognition pertains to cognitively appraising incoming events and then sending appropriate impulses to the emotion system. We have followed and tested this approach in two different scenarios.

In the *museum guide scenario* Max uses a rule-based analysis of the typed input to respond multimodally by means of synthesized gestures and voice. Part of this is an appraisal of incoming events, such that Max is emotionally influenced by insults or praising remarks by a human interactant. This appraisal has been scripted as domain-dependent rules and added to the agent's module for event interpretation. This module employs keyword spotting in a context-sensitive way to evaluate the language input and then sends a positive or negative *impulse* to Max's emotion system. Regarding the nature of this interaction scenario, where Max is supposed to provide the visitor with presumably new information, it was not necessary to implement a heuristics to determine the possible dynamics of the "dominance" relationship between the interlocutors. The agent is thus always feeling dominant in this scenario. As one consequence he gets angry instead of fearful when being insulted, as in the emotion system anger and fear are only distinguished by their respective *Dominance* values (cf. Figure 1).

In the *cards game scenario* the cognitive appraisal is likewise driven directly by the situational context. Every move of the human player leads to a negative impulse sent to the agent's emotion system, as it is contrary to the agent's overall goal of winning the game. When Max can play a card himself, however, a positive impulse is sent to the emotion system. The intensities of the impulses are dependent on the importance of the move in the overall situation, of which we distinguished *negative empathic* and *positive empathic.* In the *negative empathic* condition the moves of the human player are appraised as very negative, e.g. causing an emotional impulse of -25, whereas in the *positive empathic* condition the same event is appraised only slightly negative. Furthermore, adequate *empathic behaviors* are triggered to let the agent react to a change of the human player's emotional state. Just by shifting the intensities of the impulses and supportingly triggering adequate *empathic behaviors*, we could show that the agent's emotional behavior is changed significantly enough to create the impression of negative or positive empathy (see [4]).

Domain-independent Emotion Simulation

Building upon the experiences with domain-dependent appraisal, we wanted to further the architecture towards a more general interplay of cognition and emotion. Our goal was to model the mechanisms that cause an agent to experience emotions in the context of his reasoning processes, independently of the particular scenario.

Oatley and Johnson-Laird [14] present an approach in which the evocation of emotions stands in a close relationship with general plan success and failure. They propose the following elicitors: subgoals being achieved, failure of major plan or loss of active goal, threatened self-preservation goals, active plan frustrated (e.g. blocked), and gustatory goal violated; leading to the emotions of happiness, sadness, anxiety, anger, and disgust, respectively. In addition, Bechara et al. [2] argue for emotions being evoked directly at deliberation time from the decision process itself. They state that *somatic markers* occur as values assessing the emotional quality of outcomes of possible actions. These markers constrain the decision-making space, making it manageable for logics-based and cost-benefit analysis.

To model these mechanisms of emotion evocation, several requirements must be met. Gratch and Marsella [7] point out that in order to enable an agent to experience emotions, amongst other requirements, an explicit representation of intermediate knowledge states is needed for further inferences and appraisal. For example, to reason about the desirability of states and courses of action, the agent must represent preferences over outcomes. We thus extended Max's cognitive architecture in several ways.

The representation of preferences over outcomes enables the agent to reason about which plan to commit to. A desired state of the world is characterized by the number of satisfied and unsatisfied goals and their priorities, respectively. To decide which plan to pursue, the agent not only needs to take the preferred state into account, but also the means to achieve it. We therefore extended the plan representation to account for resources required for the execution of the plan and the effort it takes to carry it out. Resources cover both objects in the world as well as e.g. certain body parts of the agent. The effort values are determined either by assuming a default value for the plan's average effort, or by calculating a context-specific sum of the estimated effort values of its subgoals. This calculation can further be broken down to simple plans that directly trigger behaviors and motor programs, i.e. are rooted in the agent's physis and situational context.

With the extended architecture, we can introduce mechanisms for the automatic triggering of emotional impulses. As proposed by Oatley and Johnson-Laird [14], we concentrate on significant junctures of plans: a positive impulse is sent to the emotion module in cases of goal/subgoal achievement, and a negative impulse is used in case of goal failure. The strength of the impulse is deduced from the goal's priority value. Beyond these direct consequences of goal achievement/failure, emotions arise in a close relationship to the *expectations* connected to a plan. Expectations can occur toward the interaction partner, e.g., in the assembly scenario, Max expects his interlocutor to react to a request by either signaling refusal or by carrying out the action asked for. If the interlocutor does not respond at all, Max will try to encourage her. Failing this goal, and thus experiencing negative impulses, he gets in a bad mood. On a lower level, the agent's beliefs about his own capabilities serve as a source of expectations. For example, to account for the frustration of a plan, we can build on the expected effort values of plans (see above). These effort expectations are calculated at the time the agent commits to a plan. In regular intervals, they are updated and compared with the actually investigated effort. If a plan gets more effortful than expected, negative impulses will be deposited to the emotion system. By this means, the agent recognizes not only cases of plan failure but also currently ineffective plans.

How Emotions Influence Cognition

In the previous sections we have concentrated on how emotions arise in the context of cognitive processes. Now we turn to the opposite phenomena and discuss which impact emotions can have on cognition. That is, we are getting at a closed-loop interaction between cognition and emotion, in which the current emotional state is even able to influence the basic cognitive mechanisms. As Marsella and Gratch [12] point out, "by providing an explicit and rich reasoning infrastructure, plan-based approaches facilitate models of how emotions impact decision-making. Emotional state can act as search control, focusing cognitive resources on specific goals or threads. It can also alter the overall character of problem solving." Another view is advocated by Oatley and Johnson-Laird [14], according to which emotions act as a specific system of internal communication to coordinate multiple plans and goals under the constraints of time and limited resources. For example, emotions can change the relative priorities of goals in a parallel system of planning, thus serving as an indicator for the evolving success of plans and the overall performance of the agent. We differentiate here between these two basic roles that emotions can play as beliefs and modulators.

Emotions as Beliefs

The straight-forward way to model the influence of emotions on cognition is to incorporate them as variables in the deliberative processes. To this end, in Max's architecture, the actual emotion category as well as the mood value, incessantly provided by the emotion system, are asserted as beliefs on the cognitive layer of the agent. That is, the agent becomes cognitively "aware" of every emotional state of himself that is decisive enough to be classified in terms of his emotional categories. These beliefs influence the agent's goal and plan selection process on a symbolic level. On the one hand, these beliefs can rule out plans when formulated as part of a plan's preconditions. On the other hand, emotions can that way directly trigger behaviors, thus evoking a mechanism to to cope with the emotional state or the situation in which it arose. For example, getting to know about his own bad mood allows the agent to invoke certain behaviors, or possibly raise certain goals, he would not invoke in a different, more relaxed emotional condition.

In the museum setting, for instance, this mechanism is utilized to allow the agent to de-escalate rude visitor behavior: repeated insults by visitors will incrementally put his emotional system in a bad mood (via domain-dependent appraisal), which will eventually lead to anger of an increasing intensity. When first becoming "angry" the agent says warningly "Now I'm getting angry", accompanied by physical indicators like a low pitch and rate of his voice as well as by the facial expression of angriness. Further negative impulses result in a more intense anger. Cognitively "realizing" this state, the agent's deliberation decides – again in a domain-dependent manner – to cope with this emotional state by leaving the scene, and staying away until the state has returned to a normal, balanced level. The period of absence can either be shortened by complimenting Max or extended by insulting him again.

Such behavior strategies for coping with strong feelings were defined beforehand and added to the plan library of the agent. However, they are of special importance for the agent, and they are invoked in any context as soon as a decisively strong feeling arises. To this end, specific *reactive plans* are incorporated in the agent's deliberative module, watching out for certain relations describing the agent's emotion category. If the emotion exceeds a specified threshold, the plan fires with a high priority, leading to the instantiation of a goal to cope with the emotion.

Emotions as Modulators

The second important way of how emotions can influence cognitive processes is by modulating their basic functioning. That is, the strategies of planning and decision-making themselves can be affected by the current emotional state. For example, negative affect can bias problem-solving strategies in humans towards local, bottom-up processing, whereas positive affect can lead to global, top-down approaches.

To pinpoint where emotions can take effect in the cognitive processing, the BDI-interpreter algorithm [18] is presented in Algorithm 1. In Max's architecture emotions can modulate the interpreter's processes at the following points. In line 4, where possible options of future action are generated, emotions can directly restrict this collecting, such that only those actions are taken into account which fit with the agent's emotional state. E.g. if the agent is angry, he won't ask his interaction partner for help. Additionally, the process which calculates the utility values of plans can be either coarse and optimistic (e.g. with respect to the expected effort) in case of a positive emotional state, or more exact and pessimistic when the agent is in a negative emotional state.

Algorithm 1 BDI-interpreter [18]

```
 1: procedure THINK
 2:     initialize-state()
 3:     loop
 4:         options ← option-generator(event-queue)
 5:         selected_options ← deliberate(options)
 6:         update-intentions(selected-options)
 7:         execute()
 8:         get-new-external-events()
 9:         drop-successful-attitudes()
10:         drop-impossible-attitudes()
11:     end loop
12: end procedure
```

In line 5, the choice which option to adopt as next intention can be influenced by the emotional state of the agent, too. When pursuing multiple goals simultaneously, the agent can reason about negative interactions between them, such as resource conflicts or one plan's effect prohibiting another plan's execution. Likewise, positive interactions such as the fulfillment of two goals by executing only one plan, or the performance of one plan making another plan applicable can be taken into account. But, as these processes tend to be time-consuming, the agent should not apply them in arbitrary depth and should not always consider them. We hence propose to let the application of these mechanisms in line 5 depend on the agent's emotional state: negative emotions seem to lead to a narrowed problem-solving, while positive emotions lead to broader problem-solving attempts to achieve multiple goals simultaneously [21]. We can model this effect by investigating the extra effort of considering positive interactions between goals and plans only when the agent is in a positive emotional state. If in a bad mood, the agent will then not consider positive interactions but would narrowly focus on his most important goal, becoming more "narrow-minded".

In line 10 of the agorithm, the process of dropping impossible goals can be extended to account for plans that perform badly. This decision process, whether to abandon the plan and on which level, can thereby be influenced by the emotional state. If the agent is in a negative emotional state, he will abandon the complete plan and try to re-plan again, otherwise if in a good mood, the agent can be more patient and retry to achieve the subgoal.

Conclusion and Future Work

In this paper, we have presented ongoing work on the mutual interaction between emotion and cognition in the architecture of our embodied agent Max. Based on our experiences with domain-specific emotion evocation, we have presented approaches toward a higher-level, domain-independent connection of the separate modules for emotion simulation and deliberative reasoning. Along these lines, one particularly promising approach is to ground the appraisal processes of the embodied agent on his physis, based on the concept of *effort*. One issue for our future work will thus be to generally extend motor behaviors to an estimation of their expected effort, taking account of the forces and energy needed to move the body in the appropriate way. In addition, the modeling of how the emotion dynamics can influence and fine-tune decision-making beyond the inclusion of feelings as self-realized facts, is still in its beginning. We have proposed how a classical BDI-interpreter can be extended to simulate how cognitive processing itself can be influenced by the emotional state of the agent, notably, during the creation and selection of options, as well as the dropping of unsuccesful plans. While certainly to be proven empirically, we believe that the proposed steps toward modeling the interaction of emotion and cognition will yield to a more consistent and believable behavior of embodied agents.

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