

# Human-Robot Collaboration: Affect-Driven Functional Coexistence

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## Abstract

The capability of functional coexistence is critical in the design of symbiotic cognitive systems. To obtain this capability, a cognitive system should possess evaluative and communicative processes. Emotions and their underlying processes provide such functions in social and collaborative environments. We investigate the mutual influence of affective and collaboration processes in a cognitive theory to support the interaction between humans and robots or virtual agents. We develop new algorithms for these processes, as well as a new overall computational model for implementing collaborative robots and agents. We build primarily on the *cognitive appraisal* theory of emotions and the *SharedPlans* theory of collaboration to investigate the structure, fundamental processes and functions of emotions in a collaboration context.

Intelligence is a set of mental abilities that enables a human to comprehend, reason and adapt in the environment, and as a result, act effectively and purposefully in that environment. Emotions play a crucial role in humans' explanation of intelligent behaviors. Emotions affect not only what people do, but also the way they do it (Cowie, Sussman, and Ben-Ze'ev 2011). Ronald De Sousa in *The Rationality of Emotion* (Sousa 1990) makes a good case for the claim that humans are capable of rationality largely because they are creatures with emotions. Emotions significantly impact the procedures of action generation, execution, control, and interpretation (Zhu and Thagard 2002) in different environments.

Emotions are conceptualized as ongoing processes rooted in dynamic social contexts, which can shape both implicit and explicit emotional responses (Marinetti et al. 2011). Emotions are dynamic episodes that not only makes changes in cognitive states, but also produce a sequence of response patterns on body movements, posture, voice and face (Scherer and Elgring 2007). Emotions typically occur in response to an event, usually a social event, real, remembered, anticipated, or imagined. They are associated with distinctive relational meanings (Parkinson 2009). These relations can be with the individual's past experience, the individual's

surrounding objects and environment, or the other individuals with or without mutual beliefs in a dyadic or a group setting. Emotions are evaluative and responsive patterns that serve the function of providing appraisal about whether the ongoing event is harmful, threatening or beneficial for the well-being of an individual (Zhu and Thagard 2002). Consequently, reasoning and emotional processes have an integral and a supportive relationship, rather than an antagonistic and a conflicting one.

The idea of having robots or other intelligent agents living in a human environment has been a persistent dream from science fiction books to artificial intelligence and robotics laboratories. However, there are many challenges in achieving collaboration between robots and humans in the same environment. Some of these challenges involve physical requirements, some involve cognitive requirements, and some involve social requirements. Thus far, there has been an emphasis on the design of robots to deal with the physical requirements. Many researchers are also working on the cognitive requirements, inspired by a diverse set of disciplines. As time passes, there is an increasing recognition of the importance of the social requirements, and how cognitive systems can include the influence of the others.

## Social Functions of Emotions

Humans are able to communicate their emotions in a social context. The social functions of emotions are the reason behind why humans try to communicate their emotions. Emotions describe interpersonal dynamics in a way that they can constitute individuals' relationships (Parkinson 1996; Tiedens and Leach 2004). One aspect of expressing and communicating emotion in a social context is to express one's social motives and intentions (Hess and Thibault 2009). Another aspect of communicating emotions is to reveal the underlying mental states of an individual (Parkinson 2005). In (2009) Van Kleef has discussed the idea of inferential processes with which individuals can infer information about others' feelings, relational orientations and behavioral intentions based on their emotional expressions. He also argues that emotional expressions can impact social interactions by eliciting others' affective responses.

## Motivation

Functional coexistence is an important aspect of the symbiotic cognitive systems in social environments. Collaboration requires coexistence with the others and describes how a cognitive agent can function in such environment. Therefore, the ability of collaborating with humans in the same environment is crucial for cognitive agents. In fact, a cognitive agent's ability to understand the collaborative environment impact the effectiveness of a collaboration. Examples of cognitive capabilities that support the effectiveness of collaboration include: a) perceiving one's own internal states and b) communicating them, c) coordinating personal and group behaviors, d) identifying self and mutual interests, e) recognizing the accountability of private and shared goals, f) selecting appropriate actions with respect to events, and g) engaging others in collaboration.

We are investigating the cognitive processes involved in a collaboration in the context of a cognitive architecture. There are several well-developed cognitive architectures, e.g., Soar (Laird 2012) and ACT-R (John Robert Anderson 1998), each with different approaches to defining the basic cognitive and perceptual operations. There have also been efforts to integrate affect into these architectures (Dancy 2013; Marinier III, Laird, and Lewis 2009). In general, however, these cognitive architectures do not focus on processes to specifically produce emotion-regulated goal-driven collaborative behaviors. At the same time, existing collaboration theories, e.g., SharedPlans theory (Grosz and Sidner 1990), focus on describing the structure of a collaboration in terms of fundamental mental states, e.g., mutual beliefs or intentions. However, they do not describe the associated processes, their relationships, and their influences on each other. In contrast, *Affective Motivational Collaboration Theory* deals with the major processes, including affective and motivational processes, having an impact on the collaboration structure. This theory is informed by research in psychology and artificial intelligence. Our contribution, generally speaking, will be to synthesize prior work on motivation, appraisal and collaboration, and thus to provide a new theory which describes the prominent emotion-regulated goal-driven phenomena in a dyadic collaboration.

## Affect and Collaboration

Collaboration is a coordinated activity in which the participants work jointly to satisfy a shared goal (Grosz and Sidner 1990). There are many important unanswered questions about the involvement of an individual's cognitive abilities during collaboration. Some of these questions are related to the dynamics of collaboration, as well as the underlying mechanisms and processes. For instance, a general mechanism has yet to be developed that allows an agent to initiate proactive collaborative behaviors when it faces a blocked task. There is also a lack of a general mechanism that, in the event of a task failure, allows an agent to consider the collaborator's anticipated mental states and emotions, while managing its own internal goals and the collaboration's shared goal. There are also other questions about the components involved in these processes at the cognitive level, such as

the processes that are involved for evaluative, regulatory or motivative purposes. There has also not been enough attention on the processes that are involved to maintain the social aspects of a collaboration.

Emotions have a key role in influencing the cognitive processes involved in social interaction and collaboration. Emotion processing and decision-making are integral aspects of daily life and maintain their prominence during social interaction and collaboration. However, researchers' understanding of the interaction between emotions and collaborative behaviors is limited. We believe that the evaluative role of emotions, as a part of cognitive processes, helps an agent to perform appropriate behaviors during a collaboration. To work jointly in a coordinated activity, participants (collaborators) act based on their own understanding of the world and the anticipated mental states of the counterpart; this understanding is reflected in their collaborative behaviors. Emotions are pivotal in the collaboration context, since their regulatory and motivational roles enhance an individual's autonomy and adaptation as well as his/her coordination and communication competencies in a dynamic, uncertain and resource-limited environment.

## Affective Motivational Collaboration Theory

We are building Affective Motivational Collaboration Theory on the foundations of the *SharedPlans* theory of collaboration (Grosz and Sidner 1990) and the *cognitive appraisal* theory of emotions (Gratch and Marsella 2004). Affective Motivational Collaboration Theory is about the interpretation and prediction of observable behaviors in a dyadic collaborative interaction. The theory focuses on the processes regulated by emotional states. The observable behaviors represent the outcome of reactive and deliberative processes related to the interpretation of the self's relationship to the collaborative environment.

Affective Motivational Collaboration Theory aims to explain both rapid emotional reactions to events as well as slower, more deliberative responses. The reactive and deliberative processes are triggered by two types of events: *external* events, such as the other's *utterances* and *primitive actions*, and *internal* events, comprising changes in the self's mental states, such as belief formation and emotional changes. Affective Motivational Collaboration Theory explains how emotions regulate the underlying processes when these events occur during collaboration. This theory elucidates the role of motives as goal-driven emotion-regulated constructs with which an agent can form new intentions to cope with internal and external events. Affective Motivational Collaboration Theory explains the functions of emotions in a dyadic collaboration and show how affective mechanisms can coordinate social interactions by enabling one to anticipate other's emotions, beliefs and intentions.

Our focus is on the mechanisms depicted as mental processes in Figure 1 along with the mental states. The *Mental States* includes self's (robot's) beliefs, intentions, motives, goals and emotion instances as well as the anticipated Mental States of the other (human). *Beliefs* are a crucial part of the Mental States. Beliefs can be generated based on whether they are shared or not between the collaborators.

The SharedPlans (Grosz and Sidner 1990) theory is the foundation of this view on beliefs in which for any given proposition the agent may have: a) private beliefs (the agent believes the human does not know these), b) the inferred beliefs of the human (the agent believes the human collaborator has these beliefs), and c) mutual beliefs (the agent believes both the self and the human have these same beliefs and both of them believe that). Beliefs also can be generated based on who or what they are about, i.e., beliefs can be about the self, the other, or they can be about the environment. *Intentions* are mental constructs directed at future actions. They play an essential role in taking actions according to the collaboration plan, and behavior selection in the Coping mechanism. *Motives* are mental constructs which can initiate, direct and maintain goal-directed behaviors. They are created by the emotion-regulated Motivation mechanism. Motives can cause the formation of a new intention for the agent according to: a) its own emotional states (how the agent feels about something), b) its own private goal (how an action helps the agent to make progress), c) the collaboration goal (how an action helps to achieve the shared goal), and d) other's anticipated beliefs (how an action helps the other). *Goals* help the agent to create and update its collaboration plan according to the current private and shared goal content and structure. Goals direct the formation of intentions to take appropriate corresponding actions during collaboration. Goals also drive the Motivation mechanism to generate required motive(s) in uncertain or ambiguous situations, e.g., to minimize the risk of impasse or to reprioritize goals. *Emotions* in Mental States are emotion instances that are elicited by the Appraisal mechanism.

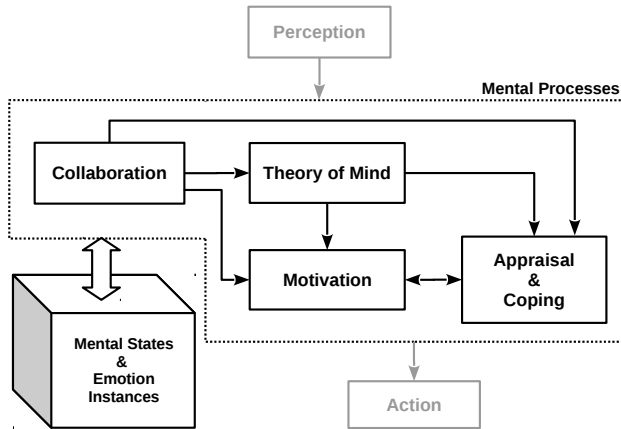


Figure 1: Computational framework based on Affective Motivational Collaboration Theory (arrows indicate primary influences between mechanisms).

The *Collaboration* mechanism maintains constraints on actions, including task states and the ordering of tasks. The Collaboration mechanism constructs a hierarchy of tasks and also manage and maintain the constraints and other details of the collaboration specified by the plan. These details include the *inputs* and *outputs* of individual tasks, the *preconditions* specifying whether it is appropriate to perform a task, and

the *postconditions* specifying whether a just-completed task was successful (which can be used as an indication of an impasse or failure). Collaboration also keeps track of the focus of attention, which determines the salient objects, properties and relations at each point of the collaboration. Moreover, Collaboration mechanism has the ability to shift the focus of attention during the collaboration. The Collaboration mechanism also provides processes to update and monitor the shared plan.

*Appraisal* is a subjective evaluation mechanism based on individual processes each of which computes the value of the appraisal variables used in our computational model. The Appraisal mechanism is responsible for evaluating changes in the self's Mental States, the anticipated Mental States of the other, and the state of the collaboration environment. The Collaboration mechanism needs the evaluative assistance of the Appraisal mechanism for various reasons. The course of a collaboration is based on a full or a partial plan which needs to be updated as time passes and collaborators achieve, fail at or abandon a task assigned to them. The failure of a task should not destroy the entire collaboration. Appraising the environment and the current events helps the agent to update the collaboration plan and avoid further critical failures during collaboration. Appraisal also helps the agent to have a better understanding of the human's behavior by making inferences based on appraisal variables. Furthermore, in order to collaborate successfully, a collaborator cannot simply use the plan and reach to the shared goal; there should be an adaptation mechanism not only for updating the plan but also the underlying Mental States.

The *Coping* mechanism is responsible for interpreting ongoing changes in the Mental States and adopting the appropriate behavior with respect to these changes. The Coping mechanism provides the self with different coping strategies associated with changes in the self's mental states with respect to the state of the collaboration.

The *Motivation* mechanism closely work with the Appraisal mechanism. The purpose of this component is to generate new motives. These motives are generated based on what the agent believes about the environment including self and the other collaborator and the corresponding appraisals. The agent uses these motives to achieve a private or shared goal according to new conditions, to interact better with a human who needs social interactions, or to evaluate the success of task performances. The Motivation mechanism operates whenever the self a) requires and intends to take a new action, b) requires a new motive to overcome an internal impasse in an ongoing task, or c) wants to provide an external motive to the other based on other's model when the other faces a problem in a task.

The agent uses the *Theory of Mind* mechanism to infer and attribute beliefs, intentions, motives and goals to its collaborator based on the user model it creates and maintains during the course of the collaboration. In other words, the Theory of Mind mechanism is the mechanism that infers a model of the other's anticipated mental state. The self progressively updates this model during the collaboration.

## Conclusion

The capability of functional coexistence is crucial in symbiotic cognitive systems. The nature of coexistence requires the ability to work together, in the same environment. To successfully work together symbiotic cognitive systems need to be able to a) communicate and understand social communication, and b) collaborate and maintain a collaborative structure. Therefore, the integration of emotion-regulated processes, e.g., appraisal, and collaboration structure and its underlying processes can lead us to a more functionally capable symbiotic cognitive system.

Emotions have a crucial role in communicating one's mental state, motivating one's actions, and evaluating and interpreting one's internal states and the environment. Emotions generally speaking provide a set of intra- and interpersonal functions which regulate internal processes and the self's relationship to the other during the collaboration. Emotions have meanings in a social context which can be interpreted by an observer. Emotion functions are important because they provide social characteristics that the self needs to manifest in its collaborative behavior.

Collaborative behaviors enable individuals to work together in a shared environment. These behaviors help an observer to distinguish between collaboration and other social or group activities. In order to generate collaborative behaviors, we are developing a new computational theory, called Affective Motivational Collaboration Theory, that combines emotion-based processes, such as appraisal and coping, with collaboration processes, such as planning, in a single unified framework. Affective Motivational Collaboration Theory provides emotion-regulated goal-driven mechanisms by which a robot will be able to show collaborative behaviors.

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