

Human-Robot Collaboration: Affect-Driven Functional Coexistence

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Abstract

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 will 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 (Gratch and Marsella 2004) and the *SharedPlans* theory (Grosz and Sidner 1990) of collaboration to investigate the structure, fundamental processes and functions of emotions in a collaboration context. As part of this work, we also address a deficiency in existing cognitive models by accounting for the influence of motivation on collaborative behaviors, such as overcoming an impasse. This motivation mechanism uses the results of cognitive appraisal to dynamically form new intentions related to the collaboration structure.

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 episode that not only makes changes in cognitive states, but also produces a sequence of response patterns on body movements, posture, voice and face (Scherer and Elgiring 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 involve the influence of the others.

Motivation

Functional coexistence is an important aspect of the symbiotic cognitive systems in social environments. Collaboration requires coexistence with the others and it also describes how a cognitive agent can function in such environment. Therefore, the ability of collaborating with humans in the same environment is crucial for agents using such cognitive systems. One'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, uncer-

tain 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). The *Collaboration* mechanism maintains constraints on actions, including task states and the ordering of tasks. The *Collaboration* mechanism also provides processes to update and monitor the shared plan. 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 *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 operates whenever the self a) requires a new motive to overcome an internal impasse in an ongoing task, or b) wants to provide an external motive to the other when the other faces a problem in a task. 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.

Functions of Emotions

Emotions have a crucial role in communicating one's mental state, motivating one's actions, and evaluating and interpreting their internal states and the environment. Emotions generally speaking provide a set of intra- and interpersonal functions which regulate internal processes and the self's re-

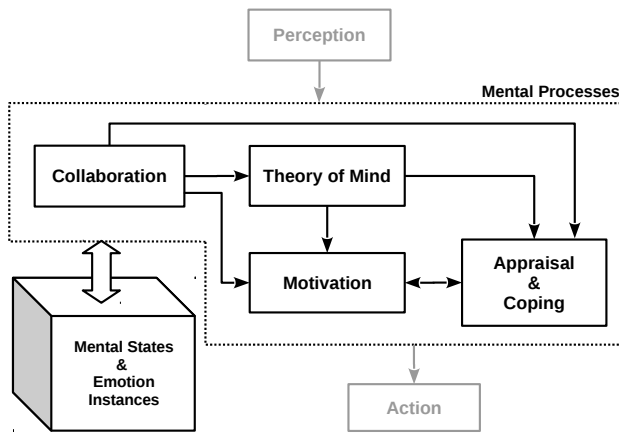


Figure 1: Computational framework based on Affective Motivational Collaboration Theory (arrows indicate primary influences between mechanisms).

lationship to the other during the collaboration. An emotion instance, e.g., *anger*, occurring during collaboration, can lead to different emotion functions, e.g., *Alarm Mechanism* and *Action Selection*. 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 in Symbiotic Environments

Collaboration is a coordinated social activity in which participants work together to perform tasks achieving a shared goal. 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. For instance, collaborators need to be able to synchronize themselves with their partner and collaborative environment with respect to the state of the shared goal. To generate collaborative behaviors one requires to include certain computational mechanisms. Affective Motivational Collaboration Theory provides affect-regulated goal-driven mechanisms (see Figure 1) by which a robot will be able to show collaborative behaviors. In the followings, we briefly describe eight different social characteristics of collaboration and how they are related to emotion functions.

- **Awareness**
- **Motivation**
- **Self-synchronization**
- **Participation**
- **Mediation**
- **Reciprocity**
- **Reflection**
- **Engagement**

Awareness

Awareness is the self's ability to manage and understand its own emotions and those of the other, and the ability to express emotions accordingly. Managing emotions refers to the self's capacity to regulate its internal emotions and to direct them towards constructive activities. Emotions, as a crucial evaluative substance of the cognition, can increase the accessibility and significance of discrepancies between Mental States, leading to higher awareness of one's sense of self and one's collaborator. In my theory, beliefs about the outcome of the appraisal and reverse appraisal (de Melo et al. 2012) provide an internal and social understanding of the world. Ultimately, the self and social awareness helps our agent to become part of a collaboration process, while adopting and maintaining a shared goal.

Motivation

Motivation as a social characteristics of collaboration is goal-driven and concerned with self's actions and what determines those actions. There are several motivation theories describing various functional aspects of motivations. These theories can be categorized into two different groups, the *self-regulatory* and the *purposive* motivations (Graham and Weiner 1996). As a regulatory process, motivation restores internal cognitive equilibrium of the self as well as self's social stance during collaboration. From a purposive perspective, the motivation process emphasizes the goal-directed nature of behaviors by anticipating the utility of self's individual actions or series of actions reaching to the private or the shared goal. In both self-regulatory and purposive perspectives, emotions serve the Motivation mechanism, offering their evaluative nature to assess the internal and external events. This process drives our agent to gain consensus in problem solving or development during collaboration.

Self-synchronization

Self-synchronization represents the temporal and spatial relationship of the self with the collaboration environment (Manso and Moffat 2011). Adaptation as a function of emotions (see Section ??) play a crucial role in short and long-term behavior changes in our agent enabling self-synchronization. Furthermore, the sensory integration function of emotions can impact the synchronization procedure in the sensory level by filtering or blocking of the input data. For instance, the self can perceive the other's anger and consequently infers that the other will not totally pay attention to what the self says. The prominent role of emotions in the synchronization process during collaboration extends to their other functions in different levels of cognition including action selection, not only based on a plan but according to the self's emotional states; goal management, whenever a new goal or a sub-goal is required to be created or reprioritized; alarm mechanisms for informing the self by interrupting other cognitive processes; attentional focus, by changing the self's focus of attention between different existing salencies in the collaboration environment; and strategic processing, by influencing the actual decision making processes of the self. As a result, our agent decides when things need to happen during the course of a collaboration.

Participation

It is suggested that the benefits of the collaboration arise from active participation in interaction and verbal communication with a partner who has a different perspective, either due to more knowledge, or a different viewpoint (?). Active participation in doing tasks and communicating during the collaboration is directly related to the evaluative factors of one's cognitive processes. These evaluative factors are intertwined with different aspects of performance assessment hinged on the core concept of the collaboration, the shared goal. In order to achieve the shared goal, the self employs the evaluative nature of the appraisal process to be able to assess and participate in the ongoing collaboration. Emotion instances provide appropriate, accountable and communicative signals (verbal and non-verbal behaviors) both for the self, through the manipulation of the Appraisal and Belief Formation mechanisms, and for the other, through the multimodal emotional expressions which make the other socially aware of the self's internal states. Consequently, our agent participates in collaboration while expecting the other to participate to achieve the shared goal together.

Mediation

Collaborations can include disputes needed to be intervened and solved by the collaborators. Negotiation is the bargaining process between parties seeking to discover a common ground and reach an agreement to settle a matter of mutual concern or resolve a conflict. Collaborative negotiation is an interest-based, constructive negotiation (as oppose to competitive negotiation) in which the self and the other are seeking a fair and equitable agreement without having an always-conceding approach. During the collaborative negotiation the collaboration parties openly discuss their needs and try to create as much mutual value as they can. Therefore, the collaborators try to use and understand the feelings, deeper interests and motives of their collaboration partner as well as their own. Emotions, once again, become important for the self in assessing the other's offers and counter offers. Additionally, the self can communicate the result of this internal assessment through the expression of emotion instances. In the inverse of the same procedure, the reverse appraisal assists the self to perceive and interpret the other's emotional expressions and observable behaviors. Hence, our agent would be able to assess the negotiation events and to communicate its internal states during negotiation and therefore, find a middle ground according to the mutual interests and agreements.

Reciprocity

Reciprocity is an adaptation process by which individuals monitor their contributions in light of their partner's contributions and make adjustments accordingly (Cole and Teboul 2004). Reciprocity is fundamental for creating mutually beneficial and non-zero-sum outcomes through social exchange of resources and coordination of joint activities. In fact, the adaptations associated with coordination using mutual beliefs and the shared goal concepts create a different, yet another important aspect of the reciprocity in collaboration. It leads to punishment or avoidance of collaborators

with detrimental actions and to reward in contrasting situations.

There are several underlying mechanisms helping the self to perform reciprocal behaviors (Cole and Teboul 2004). First, a tacit *resource monitoring mechanism* is required for the self to monitor its own as well as the other's resources contributions over the course of the collaboration. This monitoring process essentially requires the existence of an assessment process on collaborators' behaviors. The Appraisal mechanism provides this required evaluative functionality. This notion of evaluation process helps the self to a) perceive other's affective responses, and b) communicate its own. Second, a *reciprocal behavior failure detection mechanism* is needed to detect the other's failure in vital reciprocal situations (which can be met with the guidance of the Appraisal mechanism). Third, a *resource adjustment mechanism* is crucial for a collaborative agent to adjust its own social exchange behavior and also to influence the other's reciprocal behavior. The self can apply the emotion instances, e.g., guilt and gratitude, as inducements to get the other to return favors. The same mechanism, e.g., anger and sadness, can be applied by the self to punish or avoid the other based on his behavior. As a result, our agent will share resources and thoughts, and will expect sharing in return through reciprocity.

Reflection

Reflection is an attempt to make the implicit, explicit in order to learn from experience. There are two different types of reflection (Schon 1987). The first, *reflecting on action*, helps the self to think back on behaviors of the other occurring because of the self's last action. This process uses the Appraisal mechanism to evaluate the other's response, and serves the self by reshaping what the self does, by modification of the underlying beliefs and intentions. Additionally, reflection helps the self to learn the consequences of each action, using the content of its own Mental States, including beliefs about the other's Mental States. Consequently, the outcome of this evaluation enables the self to update its user model of the other. These processes represent the deliberative side of the emotion functions. The second type of reflection, *reflecting in action*, helps the self when a familiar routine produces an unexpected result; an error stubbornly resists correction; or, the meaning of an event has changed because of changes in the self's evaluative and/or interpretive processes. All these changes produce pleasant or unpleasant results for the self leading to different emotion instances, e.g., surprise, during collaboration. The self can intentionally ignore the events signaling these emotions and not attempt to change its own focus of attention, or in contrast, can show a quick emotional reaction, for instance because of the occurrence of an unexpected event, in which the latter represents the reflexive function of emotions. Subsequently our agent can process the collaboration status and consider alternative actions at each point in time, when required.

Engagement

There are three different forms of engagement: *behavioral*, *emotional* and *cognitive* engagements (Appleton, Christenson, and Furlong 2008). The *behavioral engagement* is associated with self's sustained behavioral involvement by taking actions during collaboration. The self's behaviors that can be indicative of behavioral engagement include persistence in taking actions, maintaining the focus of attention during collaboration, asking questions from the other whenever it is required in the current state of the world, and contributing to achieving the shared goal. The *emotional engagement* is associated with self's emotional reactions to its collaborator. These reactions are aimed at showing empathy to the other in different cases, for instance, the occurrence of the failure or disruption in one of the collaborators' tasks, e.g., anger or frustration. In general, the self can empathize with the other in the event of the appearance of any anticipated negative emotion. The emotional engagement can also help the self to evaluate the level of satisfaction based on the performance of the individual tasks from its own and the other's point of view. This evaluative process will help the Motivation mechanism to form the most appropriate intention to maximize the performance of the collaboration according to the shared plan. The *cognitive engagement* is associated with whether the self is willing to get involved in solving problems occurred during the collaboration. The Appraisal and the Motivation mechanisms serve the self to evaluate the status of the collaboration and form new intentions for actions. The Intention Formation process helps the self to find the proper solution for an ongoing issue even if the action is a part of the other's task. Consequently, our agent will proactively engage in cases when an unexpected problem occurs during collaboration, rather than just waiting to see what the other's demand is.

Conclusion

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