An Overview of Affective Motivational Collaboration Theory

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Abstract

The capability of collaboration is critical in the design of symbiotic cognitive systems. To obtain this functional 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 have developed 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). Sousa in The Rationality of Emotion (1990) makes a case for claiming that humans are capable of rationality largely because they are creatures with emotions. Emotions significantly impact different procedures of goal management, and action generation, execution, control, and interpretation (Zhu and Thagard 2002). Emotions are dynamic episodes that not only make changes in cognitive states, but also produce a sequence of response patterns on one's verbal and nonverbal behaviors (Scherer and Eligring 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 with the individual's experiences and environment (Parkinson 2009). Emotions are evaluative and responsive patterns that serve the function of providing appraisal about whether the ongoing event is harmful or beneficial for the well-being of an individual (Zhu and Thagard 2002). Therefore, reasoning and emotional processes have an integral and a supportive relationship, rather than 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 (Laird 2012; Scheutz, Harris, and Schermerhorn 2013; Hemion 2013). As time passes, there is an increasing recognition of the importance of the social requirements, and how cognitive systems can include the influence of others.

Social Functions of Emotions

Emotions describe interpersonal dynamics in a way that they can constitute individuals' relationships (Parkinson 1996; Tiedens and Leach 2004). 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. 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 to collaborate with humans in the same environment is crucial for cognitive agents. In fact, a cognitive agent's ability to understand the collaborative environment impacts 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.

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 Kraus 1998; 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. *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. Therefore, *motives* as an additional mental construct are required. 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). *Emotions* in Mental States are emotion instances that are elicited by the Appraisal mechanism.

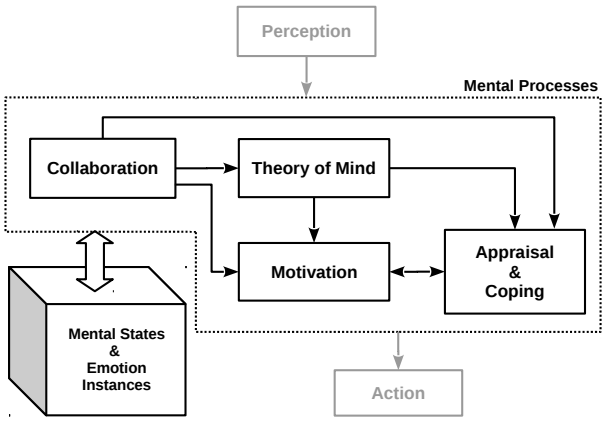

Figure 1: Computational framework based on Affective Motivational Collaboration Theory (arrows indicate primary influences between mechanisms).

Mechanisms

We provide some examples through out the desciption of each mechanism. The example scenario is part of a much larger interaction we are implementing to test our theory. The examples show the involvement of different mechanisms during the collaboration between a robot and an astronaut. Their mission is to finish installing a few solar panels together. However, the astronaut encounters a measurement tool problem, and expresses her worry about their mission.

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 manages and maintains 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). For example, malfunction in the astronaut's measurement tool causes failure of the postcondition of the current goal indicating an impasse in collaboration. Collaboration mechanism 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, 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 and collaboration structure have reciprocal influences on each other. We use collaboration structure to compute appraisal variables, i.e. relevance, desirability, expectedness, and controllability, for every event (Shayganfar, Rich, and Sidner 2016a). For example, the impasse occurring for the current goal will be appraised as a *relevant, undesirable, unexpected* and *controllable* one by the robot. Mutually, we use appraisals to regulate the goal management process during collaboration (Shayganfar, Rich, and Sidner 2016b). By using reverse appraisal (de Melo et al. 2012) of the human collaborator's emotion, and its own appraisal of individual goals, the robot is able to successfully shift the focus of attention from the blocked goal (causing to elicit negative emotions, e.g., worry) to an appropriate one to maintain the collaboration. Goal management is one of the crucial reciprocal influences of appraisal on a collaboration structure. We also investigate how appraisal impacts forming new motives as well as the action selection process. Therefore, in order to collaborate successfully, a collaborative robot should possess an adaptation mechanism to update the shared plan, and adopt affect-regulated goal-driven motives while being able to choose appropriate actions.

The *Coping* mechanism is responsible for interpreting ongoing changes in the Mental States and adopting the appropriate behavior with respect to these changes. For example, the robot first acknowledges the astronaut's perceived emotion (i.e., worry) to mitigate her negative emotinal state, then chooses the best action based on the most appropriate goal influenced by the appraisal mechanism to overcome the impasse. 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 coordinates 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. For example, the robot's motive before the asronaut's task failure was "hold-the-panel", and the robot's new motive is to "acknowledge-astronaut's-emotion" after perceiving astronaut's emotion.

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. For example, if the robot perceives astronaut's worry, the robot will infer the event as *undesirable* from astronaut's perspective. The self progressively updates this model during the collaboration.

Conclusion

The capability of collaboration 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. 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. Emotion functions are important because they not only regulate one's internal processes, but also provide social characteristics that the self needs to manifest its collaborative behavior. Therefore, the integration of emotion-regulated processes, e.g., appraisal, with collaboration structure and its underlying processes can lead to a more functionally capable symbiotic cognitive system. Affective Motivational Collaboration Theory is a computational theory which provides emotion-regulated goal-driven mechanisms for a collaborative robot. This theory combines emotion-based processes, such as appraisal and coping, with collaboration processes, such as planning, in a single unified framework.

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References

Cowie, R.; Sussman, N.; and Ben-Ze'ev, A. 2011. Emotion: Concepts and definitions. In *Emotion-Oriented Systems*, Cognitive Technologies. London, New York: Springer-Verlag Berlin Heidelberg. 9–30.

Dancy, C. L. 2013. ACT-Rϕ: A cognitive architecture with physiology and affect. *Biologically Inspired Cognitive Architectures* 6:40–45.

de Melo, C. M.; Gratch, J.; Carnevale, P.; and Read, S. J. 2012. Reverse appraisal: The importance of appraisals for the effect of emotion displays on people's decision-making in social dilemma. In *Proceedings of the 34th Annual Meeting of the Cognitive Science Society (CogSci)*.

Gratch, J., and Marsella, S. C. 2004. A domain-independent framework for modeling emotion. *Cognitive Systems Research* 5(4):269–306.

Grosz, B., and Kraus, S. 1998. The evolution of shared plans. In *Foundations and Theories of Rational Agency*, 227–262.

Grosz, B. J., and Sidner, C. L. 1990. Plans for discourse. In Cohen, P. R.; Morgan, J.; and Pollack, M. E., eds., *Intentions in Communication*. Cambridge, MA: MIT Press. 417–444.

Hemion, N. 2013. *Building Blocks for Cognitive Robots: Embodied Simulation and Schemata in a Cognitive Architecture*. Ph.D. Dissertation, Bielefeld University.

Hess, U., and Thibault, P. 2009. Darwin and emotion expression. *American Psychologist* 64(2):120–128.

John Robert Anderson, C. L. 1998. *The Atomic Components of Thought*. Lawrence Erlbaum Associates.

Kleef, G. A. V. 2009. How emotions regulate social life: The emotions as social information (EASI) model. *Current Directions in Psychological Science* 18(3):184–188.

Laird, J. 2012. *The Soar Cognitive Architecture*. MIT Press.

Marinier III, R. P.; Laird, J. E.; and Lewis, R. L. 2009. A computational unification of cognitive behavior and emotion. *Cognitive System Research* 10(1):48–69.

Parkinson, B. 1996. Emotions are social. *British Journal of Psychology* 87(4):663–683.

Parkinson, B. 2005. Do facial movements express emotions or communicate motives? *Personality and Social Psychology Review* 9(4):278–311.

Parkinson, B. 2009. What holds emotions together? meaning and response coordination. *Cognitive System Research* 10(1):31–47.

Scherer, K. R., and Eligring, H. 2007. Are facial expressions of emotion produced by categorical affect programs or dynamically driven by appraisal? *Emotion* 7(1):113–130.

Scheutz, M.; Harris, J.; and Schermerhorn, P. 2013. Systematic integration of cognitive and robotic architectures. *Advances in Cognitive Systems* 2:277–296.

Shayganfar, M.; Rich, C.; and Sidner, C. L. 2016a. Appraisal in human-robot collaboration. In *Under Review*.

Shayganfar, M.; Rich, C.; and Sidner, C. L. 2016b. Impact of affective appraisal on collaborative goal management: My robot shares my worries. In *Under Review*.

Sousa, R. D. 1990. *The Rationality of Emotion*. MIT Press.

Tiedens, L. Z., and Leach, C. W. 2004. *The Social Life of Emotions (Studies in Emotion and Social Interaction)*. Cambridge University Press.

Zhu, J., and Thagard, P. 2002. Emotion and action. *Journal of Philosophical Psychology* 15(1):19–36.