

# CHAPTER 1

## INTRODUCTION

### 1.1 Motivation

The idea of robots or other intelligent agents living in a human environment has been a persistent dream from science fiction books to artificial intelligence and robotic laboratories. Collaborative robots are expected to become an integral part of humans' environment to accomplish their industrial and household tasks. In these environments, humans will be involved in robots' operations and decision-making processes. The involvement of humans influences the efficiency of robots' interaction and performance, and makes the robots sensitive to humans' cognitive abilities and behaviors.

A key aspect of the sociability of robots is their ability to collaborate with humans in the same environment. Collaboration is a coordinated activity in which the participants work jointly to satisfy a shared goal [7]. There are many challenges in achieving a successful collaboration between robots and humans. To meet these challenges, it is crucial to understand what makes a collaboration not only successful, but also efficient. Existing computational models of collaboration explain some of the important concepts underlying collaboration; such as the presence of a reason for collaborators' commitment, and the necessity of communicating about mental states in order to maintain progress over the course of a collaboration. The most prominent collaboration theories are based on plans and intentions [3] [7] [10], and are derived from Bratman's BDI architecture [1]. Two theories, Joint Intentions

[3] and SharedPlans [5, 6, 7], have been used to support teamwork and collaboration between humans and robots or virtual agents [2] [13] [15] [16]. However, these theories explain only the structure of a collaboration. For instance, in SharedPlans theory collaborators build a shared plan containing a collection of beliefs and intentions about the actions in the plan. Collaborators communicate these beliefs and intentions via utterances about actions that contribute to the shared plan. This communication leads to the incremental construction of a shared plan, and ultimately successful completion of the collaboration. In contrast, in Joint Intentions theory, the notion of joint intention is viewed as a persistent commitment of the team members to a shared goal. In this theory, once an agent enters into a joint commitment with other agents, it should communicate its private beliefs to other team members.

Although existing collaboration theories explain the important elements of a collaboration structure, the underlying processes required to dynamically create, use, and maintain the elements of this structure are largely unexplained. For instance, a general mechanism has yet to be developed that allows an agent to effectively integrate the influence of its collaborator’s perceived or anticipated emotions into its own cognitive mechanisms to prevent shared task failures while maintaining collaborative behavior. Therefore, a process view of collaboration must include certain key elements. It should inherently involve social interactions since all collaborations occur between social agents, and it should essentially constitute a means of modifying the content of social interaction as the collaboration unfolds. The underlying processes of emotions possess these two properties, and social functions of emotions explain some aspects of the underlying processes in collaboration. This thesis makes the case for emotion-driven processes within collaboration and demonstrates how it furthers collaboration between humans and robots.

## 1.2 Thesis Statement and Scope

In this thesis, we develop and validate a framework based on *Affective Motivational Collaboration Theory* which can improve the effectiveness of collaboration between agents/robots and humans. This thesis is established based on the reciprocal influence of collaboration structure and the appraisal processes in a dyadic collaboration. We focus only on two-participant collaboration; teamwork collaboration is out of our scope. Furthermore, this work focuses on a) the influence of emotion-regulated processes on the collaboration structure, and b) prediction of the observable behaviors of the other during a collaborative interaction.

We describe the cognitive processes involved in a collaboration in the context of a cognitive architecture. There are several well-developed cognitive architectures, e.g., Soar [9] and ACT-R [8], each with different approaches to defining the basic cognitive and perceptual operations. There have also been efforts to integrate affect into these architectures [4, 11]. 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 [7] theory, focus on describing the structure of a collaboration in terms of fundamental mental states, e.g., mutual beliefs or joint intentions. However, they do not describe the associated processes, their relationships, and influences on each other. *Affective Motivational Collaboration Theory* deals with some of the major affect-driven processes having an impact on the collaboration structure. This theory is informed by research in psychology and artificial intelligence which is reviewed in Chapter 2. Our contribution, generally speaking, is to synthesize prior work on appraisal and collaboration, and motivation to provide a new theory which describes some of the prominent emotion-regulated goal-driven phenomena in a dyadic collaboration.

### 1.3 Contributions

Throughout this work we aim to show how a robot can leverage emotion-driven processes using appraisal algorithms to improve collaboration with humans. As such, in this thesis work, we introduce a novel framework, called Affective Motivational Collaboration (AMC) framework, which allows a robotic agent to collaborate with a human while incorporating the underlying emotion-driven processes and the expressed emotion of the human collaborator. Such a framework is built based on computational models of collaboration and appraisal allowing for task-driven interaction with robots or other agents. The theoretical foundation, computational models and algorithms as well as the overall framework, and the end-to-end evaluation of the framework make the following contributions:

1. **Introducing *Affective Motivational Collaboration Theory*:**

(Chapter 3) As mentioned earlier, since the theoretical foundation of AMC framework is built on the combination of SharedPlans theory of collaboration [7] and cognitive appraisal theory of emotions [12] [14], one of the contributions of our work is to introduce theoretical concepts incorporating key notions of both theories in a dyadic collaboration context. Applying cognitive appraisal theory in the collaboration context is novel. Other models of the appraisal theory have not paid attention to the dynamics of the collaboration.

2. **Developing new computational models and algorithms for *Affective Motivational Collaboration Framework*:**

(Chapter 4) Another contribution of our work is to create computational models and algorithms to compute the value of appraisal variables in a dyadic collaboration. We use the collaboration structure to compute appraisal variables. Reciprocally, we use the evaluative nature of the appraisal to make changes to the collaboration structure as required. We have also developed

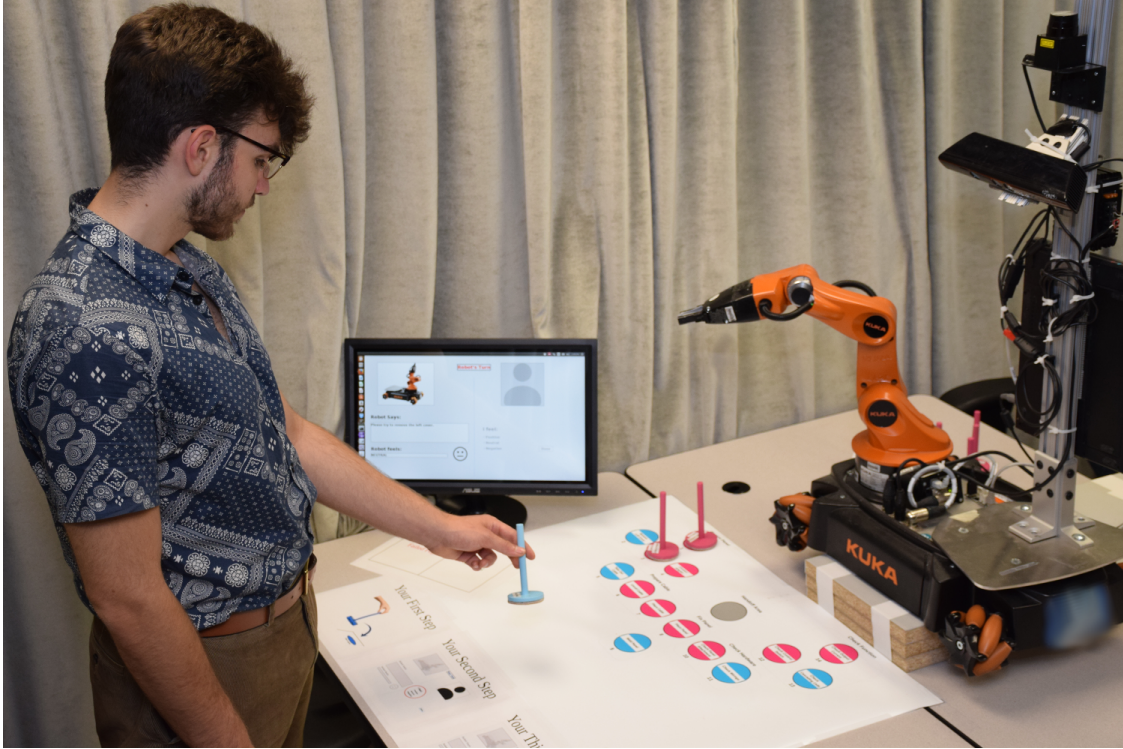


Figure 1.1: A robotic arm collaborating with a human to achieve a shared goal using *Affective Motivational Collaboration Framework*.

a new algorithm for emotion-driven goal management in the context of collaboration. Goal management is one of the important functions of emotions during collaboration. Existing models and implementations of emotions focus only on how emotions regulate and control internal processes and sometimes behaviors. This part of our work shows how appraisal components of the self and the human collaborator contributes to goal management as an emotion function.

### 3. Developing a computational framework based on *Affective Motivational Collaboration Theory*:

(Chapter 5) In order to evaluate our computational models and algorithms within an interaction with human collaborators, we have developed a computational framework based on our theoretical foundations in *Affective Motiva-*

*tional Collaboration Theory*. Our computational framework implements the key concepts related to *Affective Motivational Collaboration Theory* as well as minimal implementation of other processes which are required for validation of the model but are not part of this thesis' contributions. The emphasis of the model is on the underlying cognitive processes of collaboration and appraisal concepts, rather than the Perception and the Action mechanisms.

#### 4. Validating *Affective Motivational Collaboration Theory*:

(Chapters 4 and 6) We have conducted two user studies a) to validate our appraisal algorithms before further development of our framework, and b) to investigate the overall functionality of our framework within an end-to-end system evaluation with human subjects and a robot. The second user study was also conducted to evaluate the benefit of using our computational framework in human-robot collaboration. In the first user study, we crowd sourced our questionnaires to test our hypothesis that humans and our algorithms will provide similar answers to questions related to different factors within our appraisal algorithms. In the second user study, we investigated the importance of emotional awareness in human-robot collaboration, and the overall functionality of the AMC framework with the participants in our study environment.