CHAPTER 1
INTRODUCTION

1.1 Motivation

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

Current computational theories of collaboration are too task-driven. These theories explain many of the important concepts underlying collaboration, focusing on tasks, their constraints and their requirements, including the collaborators' commitments, and the necessity of communicating about mental state in order to maintain progress over the course of a collaboration. However, a key aspect of collaborative robots missing from those theories is being able to show behaviors that make them more likable, trustworthy, and understanding of human's feelings and goals. These aspects of collaborative behaviors can greatly influence the performance of a collaboration. Therefore, collaborative robots need to take into account human collaborator's affective state, and not only focus on executing different actions with respect to their plan to maintain the collaboration process.

Accoring to [103] collaboration is a coordinated activity in which the participants work jointly to satisfy a shared goal. We believe that in addition to the status of the shared plan, mutual beliefs and intentions, or other task-driven details of the collaboration, human's decisions are also influenced by affect-driven functions. Humans perceive, assess, and interpret their collaborator's activities in order to coordinate their own acts. Therefore, collaborators need mechanisms to a) perceive their counterpart's affective states (and perhaps their meanings), and b) communicate their own understanding of these perceptions. This aspect of reasoning is missing in the existing computational collaboration theories and their applications.

From a different point of view the most prominent computational collaboration theories, i.e., SharedPlans [101, 103] and Joint Intentions [54], explain only the structure of a collaboration. For example, in SharedPlans theory collaborators build a shared plan containing a collection of beliefs and intentions about the tasks in the shared plan. Collaborators communicate these beliefs and intentions. This communication leads to the incremental construction of a complete shared plan, and successful completion of the collaboration. Although these 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. In particular, a general mechanism has yet to be developed that allows an agent to effectively integrate the influence of its collaborator's perceived or anticipated affective state into its own cognitive mechanisms to prevent shared task failures. Therefore, a process view of collaboration should inherently involve social interactions, since all collaborations occur between social agents, and it should contain a means of modifying the content of social interaction as the collaboration unfolds. The social functions of emotions explain some aspects of the underlying processes in collaboration. This thesis makes the case for affect-driven processes within collaboration and demonstrates how they further collaboration between humans and robots.

1.2 Thesis Statement and Scope

In this thesis, we develop and evaluate a framework called *Affective Motivational Collaboration* (AMC) which can improve the effectiveness of collaboration between agents/robots and humans. We address only two-participant collaboration; larger team collaboration is out of our scope. This thesis focuses on the reciprocal influence of the collaboration structure and the appraisal processes in a dyadic collaboration, spesifically: a) the influence of affect-regulated processes on the collaboration structure, and b) the prediction and interpretation of the observable affective behaviors of the other during a collaborative interaction.

The AMC framework relies theoretically on the collaboration structure described by SharedPlans theory, and its implementation uses the collaboration manager, Disco. Disco is the open-source successor to COLLAGEN [203, 204] which incorporates algorithms based on SharedPlans theory for discourse generation and interpretation. AMC theory deals with the major affect-driven processes having an impact on the collaboration structure and ultimately a collaborative robot's behavior. This theory is informed by research in psychology and artificial intelligence, which is reviewed in Chapter 2. Our contribution, generally speaking, has been to synthesize prior work on appraisal[1], SharedPlans theory's description of collaboration, and motivation to provide a new computational theory of affect-regulated dyadic collaboration.

1.3 Contributions

Throughout this work we aim to show how a robot can leverage affect-driven processes, specifically appraisal algorithms, to improve collaboration with humans. As such, we first introduce our foundational theoretical concepts under the title Affective Motivational Collaboration theory, and then we introduce a novel computational

[1] We have chosen appraisal-based modeling of emotions among several theories of emotions.

framework, based on this theory, which allows an agent to collaborate with a human incorporating underlying affect-driven processes and the affective expression of the human. The following summarize our contributions:

1. ***Affective Motivational Collaboration (AMC)* theory:**

   (Chapter 3) The theoretical foundations of AMC framework are SharedPlans theory of collaboration [101, 103] and the cognitive appraisal theory of emotions [162] [223]. Applying cognitive appraisal theory in the collaboration context described by the SharedPlans theory is novel. AMC theory accounts for several key functions of affect in collaboration: *goal management, motivation, social regulation*, and *attentional focus.*

2. **New appraisal algorithms based on collaboration structure:**

   (Chapter 4) We use SharedPlans description of the collaboration structure in four appraisal algorithms. i.e., *relevance, desirability, expectedness* and *controllability*, to compute the value of appraisal variables in a dyadic collaboration. These algorithms are inspired by [162], and as a novel approach these algorithms are designed based on different elements of mental state and human collaborator's affective state.

3. **New algorithms to influence collaboration structure:**

   (Chapter 4) We use the evaluative nature of the appraisal to make reciprocal changes to the collaboration structure as required. We have developed new algorithms for different functions of emotions such as affect-driven goal management in the context of collaboration.

4. **Implemention of a computational system based on *Affective Motivational Collaboration* theory:**

   We implemented a computational system which employs our models and algorithms in *Affective Motivational Collaboration* framework. Our computational

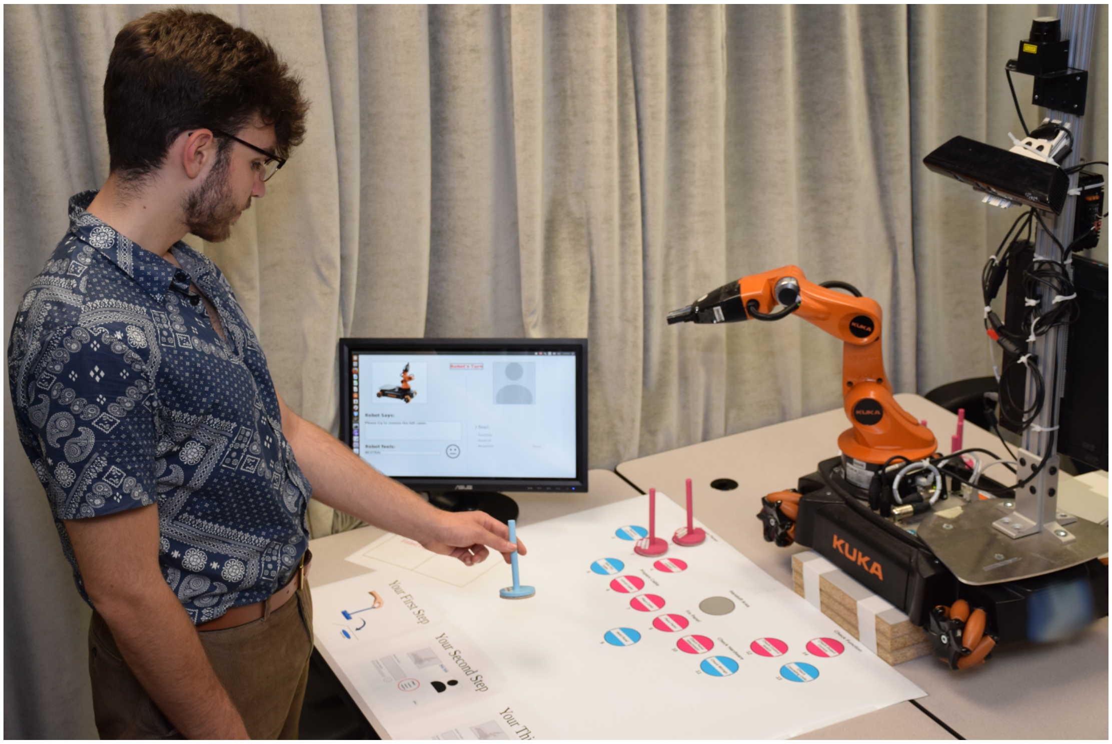

Figure 1.1: A robotic arm collaborating with a human (in our end-to-end system evaluation) to achieve a shared goal using *Affective Motivational Collaboration* framework.

system 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. We use Disco as our collaboration manager to receive and maintain the collaboration structure. The emphasis of the implementation is on the underlying cognitive processes of collaboration and appraisal, however the implementation also includes the Perception and the Action mechanisms.

5. **Evaluation of *Affective Motivational Collaboration* theory:**

   (Chapter 5) We conducted two user studies to a) evaluate our appraisal algorithms before further development of our framework, and b) investigate the overall functionality of our framework within an end-to-end system evaluation with participants and a robot (see Figure 1.1). In the first user study, we crowd-sourced questionnaires to test our hypothesis that our algorithms will resonate with humans' decisions by providing answers similar to humans' responses to questions related to different factors within our appraisal algorithms. In the second user study, we investigated the importance of affect-awareness in human-robot collaboration, and the overall functionality of the AMC framework with the participants in our study environment.