Expectedness in Human-Robot Collaboration

(Extended Abstract)

Mahni Shayganfar, Charles Rich, Candace L. Sidner
Worcester Polytechnic Institute
100 Institute Road
Worcester, Massachusetts
mshayganfar, rich, sidner@wpi.edu

ABSTRACT

We have investigated the mutual influences of affective and collaborative processes in a cognitive theory to support interaction between humans and robots or virtual 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. We have developed the *expectedness* appraisal algorithm as part of a new overall computational model. We have evaluated our implemented algorithm by conducting an online user study.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Intelligent agents*

General Terms

Algorithms, Design, Human Factors, Experimentation

Keywords

Algorithms; Appraisal; Human-Robot Collaboration

1. INTRODUCTION

This work is implemented as part of a larger effort to build robots capable of generating and recognizing emotions in order to be better collaborators. Our contribution is to ground general appraisal concepts in the specific context of collaboration. In this paper, we report on the specific problem of appraising the expectedness of events within a collaboration (see Figure 1). This work is part of the development of *Affective Motivational Collaboration Theory* [3] which is built on the foundations of the *SharedPlans* theory of collaboration [2] and the *cognitive appraisal* theory of emotions [1]. We believe appraisal plays a key role in collaboration due to its regulatory and evaluative nature. Also, collaboration induces some changes to underlying appraisal processes due to its unique nature. Yet, collaboration and emotion theories have never been combined, as they are in our work. Therefore, a systematic integration of collaboration theories and appraisal theory can help explain the underlying processes of collaboration structure.
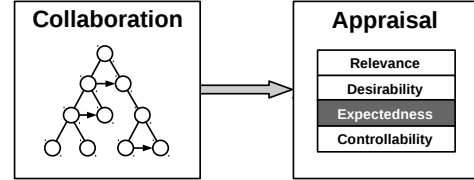
Figure 1: Influence of Collaboration on Appraisal (mechanisms in our framework).

2. COLLABORATION

The Collaboration mechanism constructs a hierarchy of goals associated with tasks in a hierarchical task network (see Figure 2), and maintains the constraints and other required details of the collaboration including the inputs and outputs of individual tasks, the preconditions, and the postconditions. Collaboration also monitors the focus of attention, which determines the salient objects at each point, and shifts the focus of attention during the interaction.

- *recognizeGoal(ε_t)* returns the unique goal to which the given event (e.g., action) directly contributes; it is only one goal since the robot can only do one primitive action at a time in our collaboration model. [1]

- *getTopLevelGoal(g_t)* returns g_t's top level goal.

- *isLive(g_t)* returns *true* if all the predecessors of g_t are ACHIEVED and all the preconditions are SATISFIED, i.e., PENDING or IN PROGRESS goals; otherwise returns *false*.

- *isFocusShift(g_t)* returns *true* if the given goal is not the previous focus (top of the stack); otherwise returns *false*.

- *isNecessaryFocusShift(g_t)* returns *true* if the status of the previous focus was ACHIEVED; otherwise returns *false*.

- *isPath(g_1, g_2)* returns *true* if there is a path between g_1 and g_2 in a plan tree structure; otherwise returns *false*.

3. EXPECTEDNESS IN COLLABORATION

Expectedness is the extent to which the truth value of a state could have been predicted from causal interpretation of an event. In the collaboration context the expectedness of an event evaluates the congruency of the event with respect to the existing knowledge about the shared goal. Thus, expectedness underlies a collaborative robot's attention. The collaboration mechanism uses expectedness to maintain the robot's attention and subsequently its mental state with respect to the shared goal. Reciprocally, the appraisal mechanism uses the underlying information of the collaboration structure to evaluate the expectedness of an event.

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[1]Ambiguity introduces some extra complexities which are beyond scope of this paper.
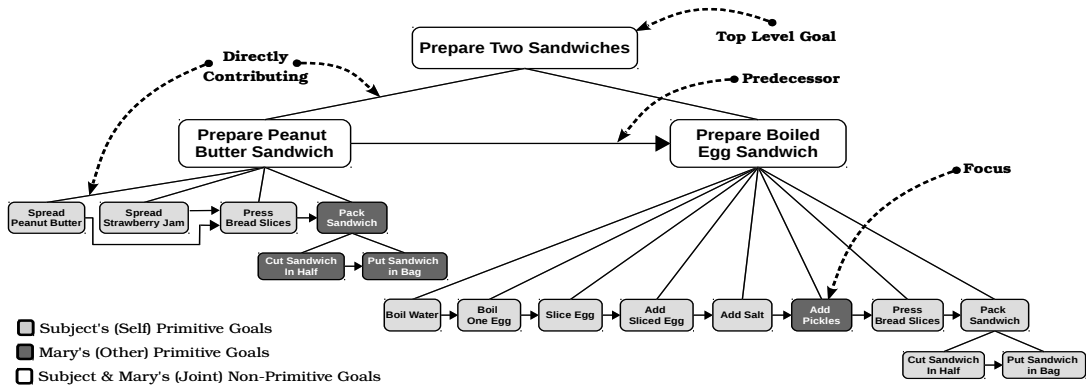
Figure 2: Example of collaboration structure (also used as task model for the evaluation).

In Algorithm 1 we provide the process of computing the expectedness based on the shared plan and status of the shared goal. The key point in this algorithm is the status of the current shared goal (g_t), which is associated with the event ε_t and its relationship with the top level goal (g_{top}).

The intuition captured here is that one expects the current goal to be finished before undertaking another activity, but the goals that can be the next focus of attention are also to be expected. Therefore, if the goal is live, the algorithm checks whether the goal has not changed, or whether the interpretation of the last event results in a necessary focus shift. Shifting the focus to a new goal is necessary when the former goal is achieved and a new goal is required. Consequently the new event is the MOST-EXPECTED one. However, even if the focus shift is not necessary, the new event can be considered as EXPECTED, since the corresponding goal is already live. For goals that have not yet been started (that is, are not live), the algorithm must determine how unexpected it would be to pursue one now; if the goal is at least in the plan, i.e., on the path to the top level goal, it is just UNEXPECTED while any others are MOST-UNEXPECTED.

Algorithm 1 (Expectedness)

1: **function** ISEVENTEXPECTED(Event ε_t)
2:　　$g_t \leftarrow recognizeGoal(\varepsilon_t)$
3:　　$g_{top} \leftarrow getTopLevelGoal(g_t)$
4:　　**if** ($isLive(g_t)$) **then**
5:　　　　**if** ($\neg isFocusShift(g_t)$ **or**
6:　　　　$isNeccessaryFocusShift(g_t)$) **then**
7:　　　　　　**return** MOST-EXPECTED
8:　　　　**else**
9:　　　　　　**return** EXPECTED
10:　　**else**
11:　　　　**if** ($isPath(g_t, g_{top})$) **then**
12:　　　　　　**return** UNEXPECTED
13:　　　　**else**
14:　　　　　　**return** MOST-UNEXPECTED

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4. EVALUATION

We conducted a between-subject user study using an online crowdsourcing website – CrowdFlower[2] – to test our hypothesis that humans will provide similar answers to questions related to our expectedness algorithm. There were originally 40 subjects. We had a questionnaire with 12 questions (including 2 test questions). Test questions were included to check the sanity of the answers. We eliminated subjects providing wrong answers to our sanity questions, and subjects with answering times less than 2 minutes.

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[2]http://www.crowdflower.com

To minimize the background knowledge necessary for our test subjects, we used a simple example of preparing a peanut butter and jelly sandwich, and a hard boiled egg sandwich. We provided textual and graphical instructions for the questionnaire; Figure 2 shows the corresponding task model which was also the input to our algorithm. The instructions presented a sequence of hypothetical collaborative tasks to be carried out by the test subject and an imaginary friend, Mary. We also provided a simple definition for the expectedness appraisal variable. The questions introduced specific situations related to the shared plan, which included blocked tasks and failure or achievement of a shared goal.

Each question had 3 answers; therefore, a random distribution would result in a ratio of 0.33 agreement with our algorithm's output. However, average results and standard deviation of the ratio of subjects answers agreeing with our algorithm's output was 0.785 and 0.120, respectively. Our results indicate that people largely performed as our hypothesis predicted. The p-value obtained based on a one-tailed z-test shows the probability of human subjects' answers being generated from a random set. The very small p-value (<0.001) indicates that the data set is not random; in fact, the high percentage of similarity confirms our hypothesis and shows that the algorithm can help us to model expectedness as an appraisal in collaboration.

5. CONCLUSION

According to the collaboration theories (e.g., SharedPlans), collaborators are required to commit to their shared plan or intentions to successfully collaborate and achieve a shared goal. This commitment requires them to appraise their environment based on the shared plan structure. In our next step, we want to test our appraisal algorithms and their influence on action selection during collaboration. This study will be conducted between a KUKA youbot and human subjects on a different task model.

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