Impact of Affective Appraisal on Collaborative Goal Management: How My Robot Shares My Worries

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***Abstract*—A collaborative robot needs to be able to regulate and manage shared goals during collaboration. Emotion has a crucial influence on the goal management process. In this paper, we provide a cost function that we use to choose the goal in the shared plan with the lowest cost value out of a set of alternative goals. This cost function provides the cost value a) based on the goal attributes we consider in our framework, b) with respect to the reverse appraisal of the percived emotion, and c) the appraisal of the collaborative environment.**

I. Introduction

Goals represent an important part of the context during collaboration. However, not all goals are appropriate to pursue, depending on conditions. In fact, it can be destructive for a collaboration to pursue a good goal in a wrong context. Therefore, a collaborative robot must be able to manage shared goals during collaboration. The goal management process provides a critical influence on a collaborative robot's behavior by maintaining or shifting the focus of attention to an appropriate goal based on the collaboration status.

Changes in a collaboration environment alter the balance of alternative goals. These changes can reflect the collaborators' internal changes, and the influence of their actions. In a collaboration environment, emotions represent the outcome of underlying mental processes of the collaborators. Emotions have different functions [1]. These functions, e.g., *goal management*, help one to communicate and/or regulate internal changes as well as changes in the environment. Goal-oriented emotions such as anger, frustration and worriedness, constitute the mental processes specifically influenced by one's internal goals. Therefore, reverse appraisal [2] of the collaborator's perceived emotion can impact regulation of the robot's active goals during collaboration. Furthermore, the appraisal of the individual alternative goals provides a context-dependent assessment of these goals.

II. Contribution

Here, we focus on a small part of a larger architecture framework built based on our *Affective Motivational Collaboration Theory* [3]. We introduce our goal management process based on a cost function including the influence of affective appraisal and reverse appraisal processes. Goal management is a crucial part of our investigation of the reciprocal influence of appraisal on a collaboration structure (see Figure 1).

We have investigated the influence of a collaboration structure on appraisal processes, and implemented distinct algorithms for different appraisal processes for a collaborative robot [4]. According to the appraisal theory, the outcome of these processes are separable antecedents of emotion with which the robot evaluates the environment. Our appraisal variables included: a) *relevance* used to measure the significance

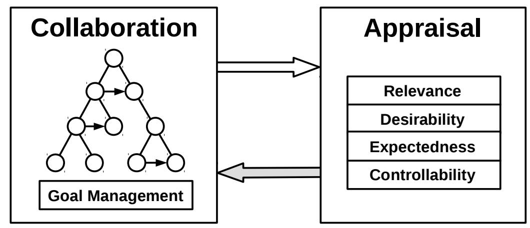

Fig. 1. Reciprocal influence of Collaboration and Appraisal mechanisms in our framework.

of an event for the robot, b) *desirability* to characterize the value of an event to the robot in terms of whether the event facilitates or thwarts the collaboration goal, c) *expectedness* and d) *controllability* (the last two appraisal variables are beyond the scope of this paper). The outcome of each appraisal process is a specific value for the corresponding appraisal variable. The vector containing these appraisal variables can be mapped to a particular emotion instance at each point in time. However, it is not the actual emotion instance that is important for us. In fact, it is a) the functions of emotions in a social setting, i.e., *goal management*, and b) the meaning of the collabrator's perceived emotion in collaboration context.

A collaboration structure provides a hierarchy and constraints of the shared goals in the form of a shared plan (Figure 2) which contains both the robot and the human collaborator's goals. The robot pursues the goals for which the robot is responsible in the shared plan. However, there can be several "live" goals available for the robot to pursue at each point in time during collaboration. A goal is live if all of its *predecessors* are achieved and all of its *preconditions* are satisfied. Therefore, a collaborative robot requires a mechanism to choose between a set of live goals. We believe appraisal processes are crucial to choose between the available live goals; since the appraisals are the immediate outcome of the robot's assessment of the collaboration environment.

For instance, Figure 2 shows a nonprimitive "Prepare Panels" goal decomposed into three primitive goals. Therefore, if "Prepare Panels" is live, its primitive goals can be pursued by the responsible agent. In our example, the astronaut is responsible for the "Check Connector" goal; the robot is responsible for the remaining two primitive goals. According to the collaboration mechanism in our overall framework, "Check Connector" is in focus, with the astronaut pursuing this goal. Suddenly, however the astronaut tells the robot that the connector is broken and she is *worried* about failure of the overall goal. The robot's response to this situation will be explored in-line as we discuss details of our cost function.

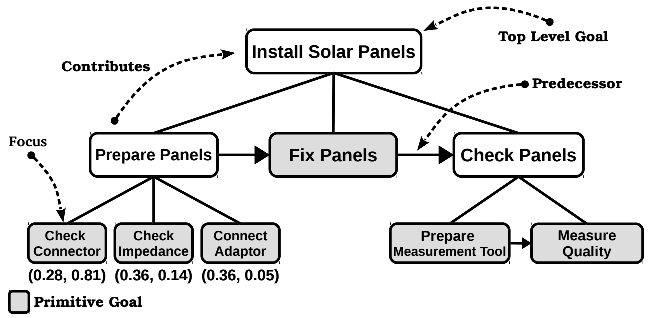

Fig. 2. Astronaut-robot collaboraiton structure (shared plan).

Equation 1 shows our general cost function we use to calculate the cost of each potential goal. The base in the equation calculates the cost of pursuing any given goal. There are three different functions used to calculate the cost: *proximity* $P(g)$, *difficulty* $D(g)$, and *specificity* $S(g)$ of a goal (see equations 3 to 5). The exponent part of our cost function (Equation 2) captures a) the influence of the human's emotional instance on the cost, and b) the influece of self appraisal of any given goal. $R_h \in [0,1]$ and $D_h \in [-1,1]$ are *relevance* and *desirability* values respectively, which will be attained based on the reverse appraisal of the human's perceived emotion. For instance, if the astronaut is *worried*, D_h is negative, e.g., -0.8 (depending on how undesirable the event is according to reverse appraisal), and R_h will be 1 for the active goal and its value descends to 0 for other live goals depending on their distance to the active goal in the shared plan (e.g., 0.6 and 0.5). $R_r \in [0,1]$ and $D_r \in [-1,1]$ are also *relevance* and *desirability* values, provided by the self appraisal functions for all of the live goals. For instance, for the active goal for which the astronuat was *worried*, D_r can be positive, e.g. 0.7 (depending on the self's desirability appraisal function); R_r can be 1, since the active goal is *relevant* for the robot. These values will change for the other live goals depending on how *relevant* they are with respect to the collaboration status (e.g., 0.9 and 0.8). Finally, $C \in [1,\infty)$ is a constant (e.g., 2) used to control the influence of affect on cost value. It is negative since *undesirablity* (negative values) should increase the cost. $\alpha \in [1,\infty)$ is another constant (e.g., 3) used to control the importance of reverse appraisal relative to self appraisal.

$$Cost(g) = \Big(\omega_0.P(g) + \omega_1.D(g) + \omega_2.S(g)\Big)^{\Gamma} \quad (1)$$

For simplicity, we assume equal values for the weights: ω_i=1.

$$\Gamma = -C[(R_r+1)D_r + \alpha(R_h+1)D_h] \quad (2)$$

The *proximity* of a goal indicates how far the goal is from the current active goal in the shared plan. It is calculated by the distance function (Equation 3) which returns the number of edges between the current active goal $g_{_{act}}$, and the given goal g in the shared plan. In our example, $P(g)$ is 2 for both "Check Impedance" and "Connect Adaptor" goals.

$$P(g) = max\{1, distance(g_{_{act}}, g)\} \quad (3)$$

The *difficulty* of a goal is a function of three parameters (Equation 4) which consider the difficulty based on a) topology of the shared plan tree (domain independent), and b) the amount of effort required to pursue a given goal (domain dependent). The $\sum pred_e(g)$ is the sum of efforts that all the *predecessors* of a given goal g require. The $\sum desc_e(g)$ is the sum of efforts that all the *descendants* of a given goal g require. The effort values represent the amount of effort for the goals with respect to the domain. In our example, we assume the values of all the goal efforts are 1 for simplicity. The $H(g)$ is the height of the given goal g. The heights of all primitives under "Prepare Panel" goal are 0 in our example.

$$D(g) = \Big(H(g)+1\Big) \times \left[\sum_{m=0}^{M} pred_e(g) + \sum_{n=0}^{N} desc_e(g)\right] \quad (4)$$

The *specificity* of a goal is the function of *depth* (distance from the root) and *degree* (number of children) of a given goal g. The first number primitive goal (root) is the least specific goal, and the primitives (leaves) are the most specific goals. As calculated based on Figure 2, the values of $S(g)$ for the three primitives under the "Prepare Panels" are 2.

$$S(g) = \frac{depth(g)}{degree(g)+1} \quad (5)$$

The tuples below the goals in Figure 2 indicate the cost value of each goal. The first number in each tuple is the normalized cost value without the influence of the affective part of the cost function, i.e., the exponent is equal to 1 in Equation 1. The second number of each tuple indicates the normalized value of the cost including the influence of affective appraisal and the astronaut's perceived emotion.

Based on our cost function, the cost of completing the primitive goal "Check Connector" is 0.81 (see Figure 2). As shown, when affect is not considered the cost is 0.28; the negative emotion of the astronaut (worriedness) significantly increases the cost of the current goal, and also impacts the other two primitive live goals under the same parent. Therefore, instead of insisting on pursuing the same blocked goal which has caused the astronaut's negative emotion, the robot can mitigate the astronaut's emotions by acknowledging her worriedness. The robot shifts the focus of attention to "Connect Adaptor" to mainatain progress and prevent failure of the collaboration. The details about the robot's behavior is beyond the scope of this paper.

III. Conclusion

We use our proposed cost function in our goal management algorithm to be able to integrate affective appraisal into the collaboration mechanism in our framework. We will evaluate our cost function through conducting a user study to compare our results with humans' responses. We will continue to implement other parts of our framework, including action selection and motivation processes.

References

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