Toward Improving Human-Robot Collaboration with Emotional Awareness

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Abstract . . .

1 Introduction

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2 Related Work

2.1 Emotions in Social Context

2.2 Social Functions of Emotions

2.3 Affect and Motives

2.4 Collaboration Theory

3 Example Scenario

3.1 The Backstory

The scenario transpires in a NASA's research center. Light, temperature and other environmental factors are simulated based on conditions on the surface of the moon. The mission is to finish installing the required solar panels to provide energy for the operation of NASA's science lab on the moon. Ninety percent of these panels have already been installed. However, the operation is now faced with low batteries which forces everyone to be cautious about consuming energy. The astronaut is inspecting the working conditions in the field and planning the installation of the remaining panels in collaboration with the robot. He determines that the sun will cast shadows over the installation structure, leading to potential difficulties. The astronaut asks control base to go through the final checks of the robot and prepare it for the operation.

3.2 Astronaut-Robot Interaction

The robot and the astronaut will collaborate with each other to achieve their shared goal, which is to install two solar panels. They will face various difficulties, ranging from the task being unpleasant and challenging to conflicts of their private and/or shared goals occurring because of a blocked or a protracted sub-task. The robot and the astronaut will go through a series of assessment processes to figure out a) how did the current blocking happen? b) why is the current task is blocked? and c) what is the next action they are going to take? The robot uses its cognitive abilities and its communication skills to overcome these problems and to motivate the astronaut to propose alternative tasks. The following is part of an interaction between the astronaut and the robot during their collaboration on installing solar panels.

3.3 Agreeing on Shared Goal (Emotion-Awareness)

This and the next hypothetical examples show that agreeing on a shared goal requires the robot to be aware of its collaborator's emotions (here it is frustration). In this example, the Astronaut's first turn (A1), shows her verbally

conveying her frustration with respect to the disfunctioning measurement tool for checking the quality of the installed panel. In return, the Robot's first turn (A2), as the crucial part of this interaction shows the Robot perceiving the Astronaut's frustration and acknowledging that verbally. Later on, in Section 6.1, we are going to show how the computational mechanisms, discussed in Section 4, are involved in this process. In other words, we are going to discuss how the emotion-driven goal-directed mechanisms can work together and lead the Robot's behavior to acknowledge perceived emotion of the Astronaut properly to avoid termination of the collaboration. Continuing in turn A3, the Astronaut's utterance shows the change of the underlying belief from termination of the collaboration to a belief showing the possibility of seeking instrumental support by asking the Robot whether it is possible to fix the measurement tool. Notice that the proper acknowledgement of the Astronaut's emotion helps to change her emotion from frustration to neutral. Now that the Astronaut does not express a negative emotion (i.e., frustration), and she is asking for instrumental support, the Robot can provide the alternative task as a potential solution. Here is another advantage of the emotion-awareness in this hypothetical example. Although, the robot, according to the shared plan (see Sections 2.4 and 4), could provide the same alternative task as solution to the Astronaut, instead, it procrastinated providing the potential solution based on the Astronaut's negative emotional state, i.e., frustration. Finally, since agreeing on a shared goal is a collaborative negotiation process, emotion-awareness plays an imperative role in providing a more fair offer to the collaborator during negotiation. As a result, the Astronaut's response in the last turn (A5) shows the acceptance of the Robot's potential solution to continue collaboration and agreeing on the shared goal. In the next example we are going to show what happens to the same hypothetical example when the Robot ignores the Astronaut's emotion and tries to save the collaboration process from failure.

> **A1. Astronaut:** Oh no! Finishing the quality check of our installation with this measurement problem is so frustrating. I think we should stop now!
> [*Astronaut is frustrated.*]

> **A2. Robot:** I see. This is frustrating. But, I can help you with the measurement tool and we can finish the task as originally planned.
> [*Robot perceives Astronaut's frustration and acknowledges that.*]

> **A3. Astronaut:** Can you fix the measurement tool?
> [*Astronaut's emotion is neutral.*]

> **A4. Robot:** The next task is fixing the panel and it needs you to prepare and attach the welding rod to your welding tool. To save our time, I will fetch another measurement tool while you are preparing your welding tool.
> [*Robot perceives Astronaut's neutral emotion, and tries to negotiate and provide a fair offer.*]

A5. Astronaut: That would be great!
[*Astronaut is content.*]

3.4 Agreeing on Shared Goal (Emotion-Ignorance)

This example shows the same process of agreeing on a shared goal as previous one except that it diverges from reaching to an agreement, despite the fact that it begins with the same utterance (B1) as it appears (A1) in previous example. As mentioned earlier in Section 3.3, the emotion-awareness is beneficial in collaboration by channeling the collaboration process towards the shared goal in the right direction. Without the emotion-awareness a collaborative robot will try to maintain the status of the shared goal and prevent it from failure without considering its collaborator's negative emotion which can be a direct result of a type of task failure during collaboration. First, the emotion-ignorant robot does not acknowledge the Astronaut's frustration (i.e., B2 in compare to A2 in Section 3.3), since it does not perceive that emotion. Then, while negotiating the shared goal the robot fails to offer a potential solution based on the Astronaut's emotional state, resulting in the failure of the negotiation during collaboration.

In this example, the Robot is not capable of perceiving the Astronaut's emotion, thus it does not apply this emotion (i.e., frustration) as an influential factor in its computational mechanisms (see Section 4). Hence, in the Robot's first response to the Astronaut's utterances (B2), first it does not acknowledge the Astronaut's emotion, and second, it immidiately conveys two available alternative actions according to the shared plan (see Section 2.4) and asks the Astronaut to select between these two actions. As it appears in the Astronaut's response, the Robot's immidiate proposal does not make any progress in collaboration. As a result, the Astronaut just repeats himself about the task status (B3) while still expresses frustration. The Astronaut's response does not change the Robot's mental state and this causes the Robot to try to repeat its own question (B4). The Robot's utterance creates an ambiguious assumption for the Astronaut on whether the Robot can fix the broken measurement tool for her. This ambiguity makes the Astronaut even more frustrated and causes her to ask a question to remove the ambiguity of the Robot's proposal (B5). In return, the Robot not only misses the Astronaut's intensified frustration, but it also nullifies the Astronaut's assumption about fixing the disfunctional measurement tool and proposes the potentioal solution of replacing the broken tool and seeing whether the Astronaut agrees on that (B6). In B7, the Astronaut modifies its assumption and announces the shortage of time as justification of expressing her anger. At this point, the Robot's response becomes more crucial since its wrong way of interaction and emotion-ignorance behavior shift the Astronaut's emotional and mental states into a noncollaborative status. Consequently, again, the Robot wants to revive the collaboration process, therefore it provides more information about the repercussions of terminating

the collaboration process and wants to see whether the Astronaut can pursue another task (B8). Finally, the incorrect interaction of the Robot caused by its emotion-ignorance behaviors which was developed since the Robot's very first response, leads to an unsuccessful termination of their collaboration (B9).

B1. Astronaut: Oh no! Finishing the quality check of our installation with this measurement problem is so frustrating. I think we should stop now!
[*Astronaut is frustrated.*]

B2. Robot: I can help you with the measurement tool, or we can terminate this task. What do you want me to do?
[*Robot does not perceive Astronaut's frustration.*]

B3. Astronaut: As I said the measurement tool does not work properly. We can not continue!
[*Astronaut is frustrated.*]

B4. Robot: Okay. Do you want me to fix this problem or terminate the task?
[*Robot does not perceive Astronaut's frustration.*]

B5. Astronaut: Can you fix my measurement tool?
[*Astronaut is frustrated, even more.*]

B6. Robot: I cannot fix your measurement tool, but I can fetch another one for you if you want?
[*Despite Astronaut's strong frustration, Robot tries to negotiate.*]

B7. Astronaut: No, I don't want another measurement tool! We don't have time for that!
[*Astronaut is angry.*]

B8. Robot: Okay. You want me to terminate this task. Terminating this task can influence the quality of installing this solar panel which can cause the mission to fail. Or, do you want us to work on another task? This can help us to install the panel using your welding tool, but I do not know whether the quality of our installation will be acceptable.
[*Not only the Robot does not perceive Astronaut's anger, but also continues to negotiate the next step based on the shared plan to select proper action.*]

B9. Astronaut: I told you we have this problem and we should terminate the mission! We cannot continue without the measurement tool!
[*Astronaut is angry.*]

3.5 Delegation of a Task (Emotion-Awareness)

This and the next hypothetical examples show how delegation of a task critically depends on understanding how worried the other collaborator is and the

necessity of having sufficient time, which play together. This example shows
when the robot is aware of the Astronaut's worriedness, it can use its own
motivation mechanism drived by emotions to come up with a way to alleviate
that. Its methods are to exactly postpone any questions until such time as they
are critical (effects are appeared in C2, C4). At the beginning of this example
(C1), Astronaut is worried because of the lack of time in achieving the shared
goal (finishing to install solar panels) for the overall task. She proposes the
Robot to begin installing the second panel, since the first one still has some
problems. The Robot in its first turn (C2), perceives the Astronaut's emotion
(i.e., worriedness) and using the same cognitive mechanisms (see Section 4)
acknowledges the Astronuat's emotion just as it did in first example in Section
3.3. As mentioned earlier, we are going to show step-by-step (see Sections 6.1
to 6.4) how different emotion-driven goal-directed mechanisms get invloved in
each turn of the collaboration process to appropriately respond to the Astro-
naut based on the *Affective Motivational Collaboration Theory* (see Section
4). Continuing in this example, after acknowledging the Astronaut's emotion,
the Robot infers that it needs to postpone asking questions about the missing
parts of the shared plan (see Section 2.4) since installing a panel is a collabo-
rative task and some of the primitive tasks need to be done by the Astronaut.
Then, the Astronaut perceives the Robot's response as a proper acceptance
of the task delegation and tries to communicate the status of her own, even
though she is still worried about finishing the overall task (C3). Now, the
Robot without asking the actual questions, declares the possibility of asking
some follow-up questions whenever the Astronaut's answers are required to
make progress in executing some primitive tasks while installing the second
panel (C4). Here, the Robot not only prevents overwhelming the Astronaut
with several questions related to executing the next steps in the future, but its
utterance implicitly reveals its knowledge of tasks' requirements to the Astro-
naut. As a result, the Robot's appraoch on acceptance of the delegated task
mitigates the Astronaut's negative emotion (i.e., worriedness) which makes
her to respond possitively to the Robot's proposal. The next example explains
the same hypothetical task delegation scenario except it shows the negative
impact of missing the Astronaut's emotion on task delegation process.

> **C1. Astronaut:** I still have some problems with attaching the first panel! We do not have
> enough time. You should begin to install the second panel.
> [*Astronaut is worried.*]

C2. Robot: Okay. Don't worry. I can handle that.
[*Robot perceives Astronaut's worriedness and acknowledges that. Also, it doesn't ask
the Astronaut (because of perceiving worriedness) if it is okay to leave the current task
which was helping the Astronaut to install the first panel.*]

[*Robot perceives the Astronaut's request as on open planning (as oppose to specific ex-
ecutive) task delegation.*]

> **C3. Astronaut:** I will try to fix it asap.

[*Astronaut's is still worried.*]

C4. Robot: I might need to ask some questions while I am installing the second panel.
[*Robot perceives Astronaut's worriedness.*]

[*Robot checks a) dependencies of the task (a sub-task might need to be done by both parties), b) preconditions, c) required resources, d) possible future conflicts.*]

[*Robot needs to ask several questions to remove uncertainties, but because of the Astronaut's emotion, Robot decided to postpone questions about the details to when the Astronaut's answers are necessary to make progress. Robot modifies its utterance in a proper way.*]

C5. Astronaut: That's fine. Just let me know.
[*Astronaut is neutral.*]

3.6 Delegation of a Task (Emotion-Ignorance)

This and the next examples show how delegation of a task critically depends on understanding how worried the other collaborator is and the necessity of having sufficient time, which play together. The emotion-ignorant robot is doing planning in its most efficient manner (efficient because time is short): asking a lot of questions (i.e., B2, B4, B6, B8, B10) so that it can work out the plan. But asking questions exacerbates the Astronaut's worry, whereas when the robot knows about the Astronaut's worriedness, it can use its own motivation mechanism to come up with a way to alleviate that. Its methods are to exactly postpone any questions until such time as they are critical (i.e., A2, A4).

D1. Astronaut: I still have some problems with attaching the first panel! We do not have enough time. You should begin to install the second panel.
[*Astronaut is worried.*]

D2. Robot: Okay. I can handle that. Is it okay if I leave the current task though?
[*Robot does not perceive Astronaut's worriedness.*]

[*Robot perceives the Astronaut's request as on open planning (as oppose to specific executive) task delegation.*]

D3. Astronaut: Yes, that's fine. I can finish it by my own.
[*Astronaut is still worried.*]

D4. Robot: Okay. But according to the plan, I need your help when we need to weld the panel. Will you be able to help me?
[*Robot does not perceive Astronaut's worriedness.*]

[*Robot checks a) dependencies of the task (a sub-task might need to be done by both parties), b) preconditions, c) required resources, d) possible future conflicts.*]

[*Robot needs to ask several questions to remove uncertainties, so it does, since it misses the Astronaut's negative emotion.*]

D5. Astronaut: Yes, I will.

[*Astronaut is more worried about finishing the first panel.*]

D6. Robot: We also need your welding tool and supplies as well as the measuring tool to install the second panel.

[*Robot does not perceive Astronaut's worriedness. So, it continues to ask question.*]

D7. Astronaut: Just let me know whenever you need something!

[*Astronaut becomes frustrated, since he thinks the Robot's questions are killing time.*]

D8. Robot: Thanks. I will. How about the conflict that might occur while I am trying to fix the second panel? You are going to need my help at the same time. Last time this issue terminated our mission.

[*Not only the Robot does not perceive Astronaut's frustration, but also asks about some possible future problems based on reflection of the same tasks in the past.*]

D9. Astronaut: Robot, I really don't understand what you are talking about!

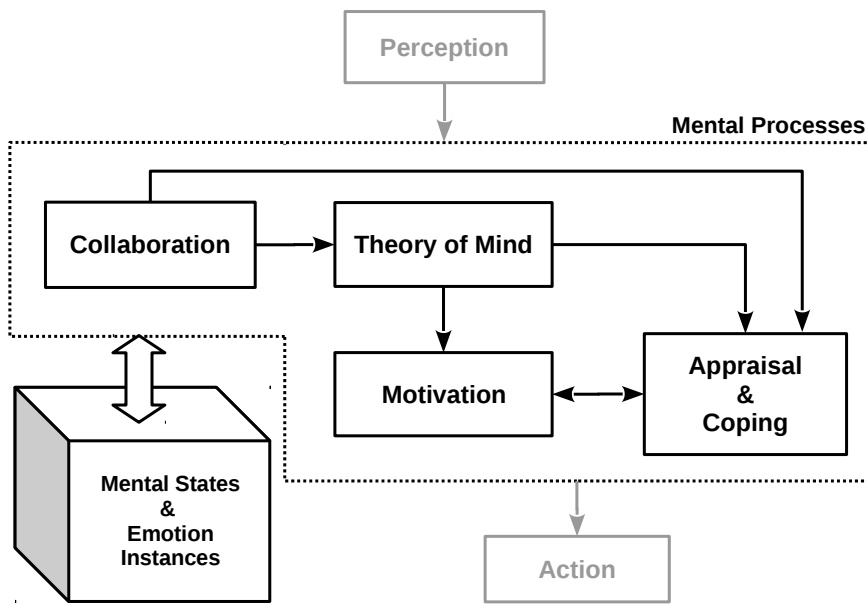[*Astronaut becomes more frustrated.*]

D10. Robot: Do you want me to provide some examples? [*Robot does not perceive Astronaut's strong frustration. So, it doesn't stop asking questions.*]

D11. Astronaut: We don't have time for this anymore!

[*Astronaut becomes angry.*]

Fig. 1 Roadmap of *Affective Motivational Collaboration Theory* showing primary influences between processes.

4 Affective Motivational Collaboration Theory

5 Computational Framework

6 Walk Through Computational Examples

6.1 Agreeing on Shared Goal (Emotion-Awareness)

6.2 Agreeing on Shared Goal (Emotion-Ignorance)

6.3 Delegation of a Task (Emotion-Awareness)

6.4 Delegation of a Task (Emotion-Ignorance)

7 Conclusion and Future Work

- Talking about other examples that I have.

References

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