Cybernetic Teams: Towards the Implementation of Team Heuristics in HRI

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Abstract. This paper examines a future embedded with "cybernetic teams": teams of physical, biological, social, cognitive, and technological components; namely, humans and robots that communicate, coordinate, and cooperate as teammates to perform work. For such teams to be realized, we submit that these robots must be physically embodied, autonomous, intelligent, and interactive. As such, we argue that use of increasingly social robots is essential for shifting the perception of robots as tools to robots as teammates and these robots are the type best suited for cybernetic teams. Building from these concepts, we attempt to articulate and adapt team heuristics from research in human teams to this context. In sum, research and technical efforts in this area are still quite novel and thus warranted to shape the teams of the future.

Keywords: Human-robot interaction, team heuristics, cybernetic teams, social robots.

1 Introduction

Human-robot interaction is a rapidly expanding multidisciplinary field that will evolve significantly over the course of the next half-century. In particular, there will not only be an increase in unmanned vehicle usage [1], both internationally and domestically, but also an increase in artificial intelligence (AI) leading to increasingly interactive and autonomous robotic systems. These advances may lead to a multitude of Human Factors issues, ranging from the "how and when" of implementing intelligent robotic systems, to the creation of dynamic human-robot (HR) teams. Previous work has demonstrated a need for adapting human team-training heuristics to HR teams [2]. Specifically, concepts such as supporting precise and accurate communication, diagnosing communication errors, providing practice opportunities, and building team orientation need to be realized in the context of HR teams. Though this is a demanding challenge, it leaves the area ripe for research. There is much to be done to understand the nature of HRI, when robots are no longer perceived as tools, but instead as team members. Therefore, this paper will focus on some of the aspects of human teams that may translate readily to HR teams. Specifically, team heuristics [3], such as those detailed above, will be examined as a strong foundational starting point.

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Specifically, this paper will review relevant team heuristics theories in light of how they may be applied to future HR teams.

However, prior to reviewing these team heuristics, we first define our reconceptualization of a team by elaborating on what we mean by cybernetic teams. Then, we set the stage for how robots can even begin to possess the capabilities and intelligence required for fulfilling the role of a teammate by comparing human-agent and human-robot teams. We next elaborate on the specific types of robots that have been argued to be most capable of performing as effective teammates; namely, social robots [e.g., 4].

Although robots with such capabilities are not a widespread technology that have been instantiated as team members in operational environments, it is pertinent to uncover the issues discussed in this paper now in order to aid in the guidance of design. We may be decades away from social robots as teammates, but by applying our current knowledge of human team cognition and behavior to what we believe these cybernetic teams will be like in the future can only lead to a fortuitous and better preconceptualized endeavor.

1.1 Cybernetic Teams

With this paper, we first aim to open a discussion for understanding these "cybernetic" teams long before they are realized as technological instantiations. By cybernetic teams, we mean that the physical, biological, cognitive, and social systems traditionally comprising human teams must be extended through the further consideration of the mechanical, electronic, and technological constituents of the cybernetic team system. We argue that only from this broader perspective and through the careful consideration of the interdependent relations of each facet of these teams can the state of the art in HR teaming truly be advanced. Specifically, this allows for the necessary reconceptualization of robots as not just tools essential for completing a given task, but rather as a teammate that can interact dynamically and autonomously under varying conditions. Though certain aspects of human teams are still quite relevant to cybernetic teams, there will undoubtedly be emergent changes when HR teams are integrated more thoroughly through increased AI capabilities. In order to better explicate the nature of cybernetic teams, in the section following we draw a distinction between human-agent teams and human-robot teams.

1.2 Comparing Human-Agent Teams with Human-Robot Teams

Human-agent team research is one area of the literature that likely has established the groundwork for HR teams. The difference between human-agent teams and HR teams likely depends on the physical embodiment or presence of the robot in the real-word as opposed to a virtual world. Relatedly, Sukthankar, Shumaker, and Lewis [5] distinguish between a software agent and an embodied agent. *Software agents* are artificially intelligent systems that serve as intelligent members of a team, but are not necessarily tangible. They carry out algorithmic functions with regard to digital information rather than physically manipulating the world. One common example of a software agent is Apple's Siri, which essentially is just a voice from which a tangible concept or even image of the software agent is difficult to extract. An *embodied* *agent*, on the other hand, refers to the tangible entity that is able to carry out physical tasks and algorithmically deduce the best methods to carry out those functions. Here, we acknowledge that some embodied agents inhabit a strictly virtual environment; however, for our purposes we consider embodied agents to be those who inhabit the same physical environment as humans do.

In the context of human-robot teams, most commonly, software agents are embedded within and facilitate the operation of unmanned vehicles; however, given a certain degree of autonomy, intelligence, and dynamic interactive capabilities such unmanned vehicles could be considered robotic teammates [6]. In support of this notion, Sukthankar, Shumaker, and Lewis [5] later point out that if the AI of an agent acts as an extension of the human operators (i.e. augmenting cognition), than the team does not qualify as a pure human-agent team. The key difference here between human-agent teams and human-robot teams can thus be said to reside in both the intelligence and the interactive capabilities of the agents. This, to some degree, is what we are referring to as a cybernetic team, in which, the defining criteria is the dynamic and interactive collaboration with an intelligent agent as opposed to a unidirectional utilization of the agent. That is, team decision making and other team processes become more conversational and bi-directionally interactive, rather than purely command based. Therefore, it appears as though, from a foundation of human-agent teams, emerges the key distinction of human-robot teams. That is, HR teams rely on the use of autonomous, interactive, and physically embodied intelligent robots. From here we use HR teams and cybernetic teams interchangeably. However, it would be misleading to leave our discussion of robot teammates at this point, as there is much to unpack in regards to what it means for a robot to be able to autonomously interact with human teammates. As such, our next section aims to address this very point, by detailing advances in social robotics, that aim to provide robots with precisely these capabilities.

1.3 Social Robots as the Enabling Factor for Human-Robot Teaming

For robots to be successful teammates, it is essential to consider the degree to which such entities will be embodied and embedded in an information rich and complex social environment [7]. By this, we mean that it is naïve to envision robotic teammates working with humans without any sort of social intelligence or interactive capabilities. Specifically, it has been argued that effective human-robot teaming may only be achieved when robots have gained the appropriate social intelligence that allows them to function both naturally and intuitively in social interactions with humans [8-9]. That is, only when given this type of capability will robot teammates be able to work with humans towards shared goals and dynamically adjust plans based on the observation of human actions and the inferred social implications [10]. As such, further description of such robots is warranted to explicate what is needed for robots to function as teammates.

Social robots have previously been defined as robots that are: (1) physically embodied agents that, (2) function with a least some degree of autonomy, and are (3) capable of interacting and communicating with humans by, (4) adhering to normative and expected social behaviors [11]. Elaborating on this, [12] describe socially interactive robots as those that are able to (1) express or perceive emotions, (2) use high-level dialogue for communication, (3) have the ability to learn and recognize other agents,

(4) establish and maintain social relationships, and (5) use and perceive natural cues such as gaze and gestures. Depending on the domain and task, some or all of the aforementioned characteristics of social and socially interactive robots may be necessary. In instances where, for example, a robot must collaborate in a complex and high-stakes environment such as on the international space station, the bi-directional and dynamic features of collaborative work necessitates that the robot possess these social skills [10]. Accordingly, our aim here is not to review in detail the impressive advances in social robotics over the past decade; rather, our aim is to emphasize that these efforts are essential to the design of robots that will in turn facilitate effective human-robot teaming. Next, we describe the specific team heuristics from extensive research in human-human teams and describe how these will be useful in the context of HR teams.

2 Teaming Heuristics

Many important aspects of human teams have been established by work explicating team heuristics or, in other words, guidelines for successful team work [3]. Specifically, applications of team heuristics that ensure the team is working cohesively have been shown to substantially benefit team outcomes [13]. Therefore, it is important, we argue, to apply team heuristics to the design of robotic systems that will serve as team members in order to enable such robots to communicate, coordinate, and cooperate *as if* they were human teammates. Future robotic systems will need to "understand" these heuristics, and be able to adapt to the needs of the team based on these principles. For example, a heuristic such as 'update the plan' becomes complicated with the addition of a robotic team member: Which modality of communication does the robot use? How often does it need to update the plan based on its programming? Which team members need to be made aware of the updates? This leads to further design implications: Which type of communication will robotic assets be able to use? Which types of communication should they use? On human-only teams, some of these issues are solved through implicit and explicit communication, so how can we best integrate HR teams to have effective implicit and explicit communication? As can be seen, there are many questions, yet research has not been provided much in the way of answers to these questions. Accordingly, throughout this section we provide details of the most relevant team heuristics and attempt to convey how they could be realized in cybernetic teams.

2.1 Use Closed-Loop Communication

The most effective form of team communication is via the method of closed-loop communication. This method of communication establishes a standard of verification in which team members (i.e. sender and receiver of information) are required to acknowledge receipt of information [3], [13]. This is integral to ensuring that the communicated message has reached its intended destination and that all parties acknowledge receipt of and understanding of the communicated information.

In the case of the current state of robotics, the modality that may be best suited for closed loop communication will likely emphasize redundancy in scenarios where noise is a primary factor of miscommunication [14]. Therefore, in fact, it may be multi modal communication (MMC) that is best suited for facilitating closed-loop communication. MMC has recently been defined in the context of HRI as the flexible selection and exchange of information through the blending of auditory, visual, and tactile modalities in either an explicit or implicit communication [15]. Further, "explicit communication is the purposeful conveyance of information through multiple modalities…that has a defined meaning"; whereas, "implicit communication is the inadvertent conveyance of information about emotional and contextual state that will affect interpretation, thoughts, and behaviors" [15, p. 462]. The distinction between explicit and implicit communication leads to the question of which types of communication will need to be closed loop.

It is conceivable that explicit communications given their deliberate nature are most easily adopted for closed-loop communications. However, implicit communications particularly those conveyed by humans (e.g., body language) are equally relevant for certain tasks. Accordingly, technological systems for closed-loop communications in cybernetic teams are still largely undeveloped although such a system may display text and other key features of a given task through, for example, a head-mounted augmented reality display system. Nonetheless, robot teammates will require the appropriate social intelligence to understand both explicit and implicit communication whether or not they are implemented through closed-loop communication; and further, more communication options will become increasing available to robots as the technologies advance ultimately leading to narratively structured communications analogous to human dialogue [12]. Though such advances in closed-loop communications would help to facilitate the communication operations of any cybernetic team, the consistent diagnosis of communication errors would help to ensure both natural and resilient team performance.

2.2 Diagnose Communication Errors

Due to the complex nature of cybernetic teams and the ever evolving design of robotic systems by humans, "communication errors may be at multiple levels, and may include bandwidth issues, equipment failures, as well as incongruities of robotic assets" [2]. Notably, the types of communication errors and breakdowns in cybernetic teams will likely be quite different than those in human teams. As such, it is important for robotic teammates to remain as transparent as possible when it comes to issues in communication. This is essential for two purposes. On the one hand, arising issues that could negatively affect communication during the execution of a given task need to be explicitly communicated to team members. In cases such as this, the difference between signal loss due to physical obstruction is a very different issue than signal loss due to over-burdened bandwidth. Both require entirely different solutions, yet without understanding of the system's error, human team members may easily become frustrated and distrustful of robotic teammates.

On the other hand, diagnosis of communication errors is a task that should be continually examined by the designers and engineers of these robotic systems to ensure an ongoing mitigation of these errors thus improving the overall performance of the cybernetic team. Traditional post-mission debriefs used in human teams may be a useful strategy for the improvement of communication issues. Specifically, after a given mission human teammates could collaborate with designers and engineers to reflect on the communication errors and identify opportunities for correcting such issues. Ultimately, as machine learning and cognitive architectures for robotic systems advance, these robotic teammates will become increasingly metacognitive and self-corrective on their own; though this is certainly far from being instantiated, efforts are underway to provide robots with such capabilities [e.g., 16].

2.3 Evenly Distribute Workload Proportionally to Expertise

Salas et al. [3] emphasize the importance of utilizing the skillsets of each team member regardless of their seniority. For the scope of this paper, we will consider the distribution of workload with regard to a cybernetic team, although some research in HRI has examined the results of team performance when robots are assigned a more senior role [see 17]. As autonomy increases the amount and type of work executable by robotic teammates will evolve. That is, the workload for robotic teammates will change from a monotonous and repetitive task role to an increasingly dynamic and open ended role. Thus, traditionally, robots and machines have been more suited to conduct tasks or functions such as working for long hours without rest or conducting mundane tasks; however, as the technologies advance careful attention will need to be paid in selection and designation of tasks and workload to either the human or the robotic teammate.

On the other hand, robots with the appropriate social intelligence are more likely to adaptively respond to the shifting needs of their human teammates. By this we mean that give appropriate social-cognitive mechanisms, these robotic teammates would be able to not only interpret but also predict the intentions and thus the actions of human teammates in order to interact dynamically and share the workload for a given task [9], [18]. Such mechanisms have shown to be essential for effective coordination between humans and teammates [18]. Quite to the contrast, most humans do not interact and are not familiar with robots, which leads us to our next team heuristic.

2.4 Frequent Practice Opportunities

The importance of practice remains constant across human teams and cybernetic teams. In fact, it may be particularly more relevant for cybernetic teams given the novelty of interaction with robots. Specifically, it has been argued that "practice for HR teams should be frequent and mandatory. Practicing communication, missions, etc. will only enhance team performance" [2]. Practice in this sense can serve as a bi-directional benefit to human and robot teammates. On the one hand, humans gain familiarity working with the robot and perceiving it as a teammate and in doing so begin to develop trust in the system and fluidity in the types of interaction, among other things. In the case of the robot, it may need an interaction period of a certain duration in which it can learn about the behaviors of the human in order to begin to coordinate as an effective teammate. Of course this depends on the types of intelligence it is programed with, but it is likely the benefit of practice remains constant. In short, practice provides an opportunity for missions and tasks to be rehearsed in contexts in which the stakes are not high such that, the chances of success in complex operations are improved. Practice and interaction more generally between human and robot teammates can also lead to benefits in the convergence of mental models.

2.5 Refine Shared Mental Models

Prior research on shared mental models, within the context of HR teams has examined the importance of the convergence of mental models for enhanced team performance [19]. If mental models converge with flawed content, team performance can be negatively affected, resulting in situation assessment errors and conflict within the team [20-22]. In light of this, it is suggested that future research examine ways to decrease flawed mental model convergence in order to enhance team performance. Specifically, in the context of HR teams, we must ensure that the human teammate's mental model is properly suited to the dynamics of the robotic teammate. In particular, efforts are also needed to further explore the ways in which the notion of mental models can be instantiated in such robot systems [see 23].

As detailed previously, HRI researchers have recognized the importance of explicit and implicit communication between humans and robots [2], [15]. That being said, integrating robots into human teams will require both types of communication, and could therefore, increased communications between humans could decrease errors in mental model convergence. Furthermore, through combination of closed-loop communication augmented with multi-modal communication systems as well as appropriate social intelligence, it is expected that adequate mental model convergence would ensue thus facilitating efficient teamwork. Of course efforts are needed to not only instantiate the notion of mental models in robots but to empirically examine the effects of such efforts and the variables that play a role in both their accurate and inaccurate convergence.

2.6 Manifest Deep Understanding of Tasks

Typically the emphasis here is on a deliberate intervention in which a designated team leader encourages team members to provide environmental assessments to better define the tasks and situation parameters leading to the creation of well-developed plans and the development of adaptive expertise in team members [3]. Thorough explication of these issues prior to practice sessions or missions can help to enable the coordination and success of the team. This provides each team member with more detailed and flexible understandings of the dynamic nature of their tasks. However, cybernetic teams will not only require such interventions for effective team performance, but also for understanding the capabilities of robotic teammates. Software updates will likely be relentless, of course, in pursuit of better robotic teammates, but nonetheless, often a game changer. Once robots reach a certain level of intelligence and interactivity the modifications of their software will be limitless and could also at some point become self-corrective. Thus, an adaptive expertise in terms of interaction with robotic teammates must be developed for the assimilation of new software and how that affects future team operations. This notion is related to our next team heuristic.

2.7 Build Team Orientation

Given the novelty of robotic teammates it is essential to "integrate robots early in team formation so that roles can be discovered and trust established" [2]. Trust in robotic teammates will not happen overnight; however, it essential for cooperation.

More so, if humans are untrusting or frustrated with the performance of their robotic teammates they will be less likely to cooperate and this could result in putting the team at risk of failure. Relatedly, depending on the intelligence and programming of the robot, instances could result in humans and robotic teammates that hold divergent viewpoints. Thus, through team orientation these cybernetic teams can become familiar with the varying perspectives and functions of each team member in relation to a given task. Early and frequent team orientation is thus recommended and can be instantiated through required practice and informal interactions. Benefits are likely to include improvements to team performance in the field by giving the team a chance to interact in a non-stressful environment when stakes are low. This will give the human team members time to understand the capabilities of their robotic teammate(s), as well as allow for the robotic asset to socially engage the team and build rapport.

3 Conclusions

In sum, we have first examined a reconceptualization of the traditional notion of a team of which we have termed *cybernetic teams*. We argue that this reconceptualization allows for greater consideration and treatment of the physical, biological, social, cognitive, mechanical, electronic, and technological components of such teams as a unified system. As these types of teams become increasingly prevalent, such a reconceptualization is necessary to foster better designs and ways of improving team processes and performance without neglecting any element of such a complex interdependent system. Next, we have drawn from human-agent teams to attempt a clear articulation at what is meant by a human-robot team. That is, a team in which robots are physically embodied, autonomous, interactive, and intelligent. However, one of the key contributions here is that for robots to ever be thought of as teammates, they must possess the appropriate social intelligence and interactive capabilities that allow them to function intuitively and naturally with human teammates. Building on this, we have reviewed and adapted some of the team heuristics that stem from the study of human teams and attempted to articulate how these might be realized in cybernetic teams. Of course, it is likely that as the state of the art advances in such teams, novel cybernetic team heuristics will emerge. Nonetheless, efforts such as this as well as empirical and technical efforts are warranted to instantiate and evaluate robots with the capabilities discussed herein and as a result, develop the teams of the future.

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