Fairness Properties for Collaborative Work Using Human-Computer Interactions and Human-Robot Interactions Based Environment: "Let Us Be Fair"

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Abstract. Fair human-computer interactions and human-robot interactions in distributed environments are inspected, and it is suggested that humans, computers and robots may have to achieve overlapping tasks. Permission-based and token-based algorithms are used to ensure fairness in interactions between humans, computers and robots. Results of simulation experiments are used to illustrate the impact of several environment properties including a variety of processes, sent messages, received messages, collaboration stratum, average waiting time, and the average execution time. Actual experiments efforts are discussed and the convenient properties involved in designing fair human-computer and human-robot interactions in distributed systems are considered.

Keywords: Human-Computer Interaction, Human-Robot Interaction, Collaboration, Fairness, Distributed Environment.

1 Introduction

Human beings environment has always been full of objects with which they had to interact. And over the years, technology has known a great development. Nowadays, the human is discovering new ways of interaction with his new surroundings among which computers and robots come on top. Since the advent of computers and robots technology, its use has progressed very rapidly. In fact, one can easily admit that our era is heavily based on man-machines interactions.

Through the past decades, Human-Computer Interaction (HCI) emerged as a focal area of computer science research, and has made great strides toward understanding and improving interactions with computer-based technologies. There betterments more than anything else have triggered this explosive development. Indeed, some of the reasons for its success are forthrightly interaction related, since HCI evoked many difficult problems and elegant solutions such as collaborative work.

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Now, advances in computer technology are leading to breakthroughs in robotic technology that offer significant implications for the Human-Robot Interaction (HRI) field. The latter has recently received considerable attention in research. Mainly HRI researchers are striving to develop systems that allow multiple robots and multiple humans to interact with each others.

In fact, how to ensure those interactions in the same environment has been a central issue for researchers. Nevertheless, rare are the works related to important theoretical common points and distinctions between HCI and HRI. In literature review, most of the studies deal with the applications of HCI and HRI separately in collaborative environments [1-2]. Indeed, an important remaining bottleneck is the need for computers as well as robots to interact efficiently with human team members. In the light of the development interactions has known, collaboration can be easily stated as the best option, however it is not as easy as it sounds. Coming together to work toward a common vision does not just happen on its own. We believe that by necessity, successful collaboration depends on developing relationships in which collaborators should be treated as equals. In fact, if fairness is found in a group, collaboration becomes an ideal concept, far more effective than an entity working alone.

It is well-known that one of the most significant concepts in collaborative environments in general [3], and in interactions in particular is that of fairness. In order to support the work on collaborative tasks within groups, the necessity for a fair collaborative environment arises. Within a given situation, there is usually a great deal of agreement as to how given humans, computers and robots ought to be treated identically, and what properties matter to the fairness. Indeed, the most difficult tasks can be accepted if collaborators are convinced to be treated fairly, inversely, gainful interactions may be rejected if they feel unfairly treated.

This leads to the questions of "given a group of humans, a group of computers, a group of robots, an environment, and a task, how should fair collaborative behavior arise?", and "what properties should be taken into account in order to ensure fair interactions?" The idea presented in this paper is how to amalgamate HCI and HRI in a fair way in order to collaborate in a distributed system. Our approach differs from other approaches in the way that our platform deals with distributed environment integrating both HCI and HRI and considers different interaction stratums. The practicality of our platform is proven by an implementation facilitating fair interactions.

The next section presents related work in the field of HCI compared to HRI as well as their relation to fairness. We analyze some significant similarities and differences that have been proposed to date by considering them to be a basis for finding a fair collaboration based solution. In section 3 we present our concept of interaction stratums and their connection with fair collaboration. Section 4 introduces the distributed Java platform upon which the prototype for a collaborative fair interaction is built. Before we conclude this paper in section 6, section 5 gives a summary and a brief discussion illustrating ideas for potential extensions of our work and future development of the collaborative platform.

2 HCI vs. HRI Merging towards Fairness

HRI is an interesting topic of research since it is strongly driven by innovation, characterized by enormous potential and growth opportunities. Hence, the question that will need to be discussed is therefore whether robots as a new interactive technology can grasp with traditional HCI assumptions, models and processes. Thus, this section introduces existing similarities and substantial differences to clarify the relationship between HCI and HRI, embellished by fairness properties and collaboration estates.

In fact, Kiesler and Hinds [4] noted that in HRI three new aspects appear. First, they maintain that the human perception of robots is different from other computer technologies. People tend to anthropomorphize robots taking them as peers and fellows. A second major point is that of mobility. They argue that robots are in multiple cases mobile, negotiating interactions in dynamic environments. Finally, robots are able to learn about themselves and their surroundings and act correspondingly.

Another vision was given by Thrun [5] advancing that the main difference between HCI and HRI is autonomy. He explains that robots are able to make their own decisions in a broad range of situations; yet it is not the case for computational devices.

Han et al. [6] addressed the difference between computer-based contents and robot-based contents. They believe that HCI is static and restrictive; whereas in HRI, robots are expected to offer dynamic interactions, to be more interactive with humans and more user-friendly than computers.

Breazeal [7] believes that HRI can be classified into four interaction paradigms. She argues that the robot can be perceived as a tool used to perform a task, a cyborg extension physically merged as a part of the human body, an avatar being a person projection or as a social partner discerned as an artificial being. These paradigms lead to a differentiation between HCI and HRI in terms of duration, interaction intensity, decision making, and adaptability to new challenges.

Fong, Thorpe and Bauer [8] addressed the existing differences between HCI and HRI. They believe that computers are always controlled by humans, but robots have a certain degree of autonomy. They also think that the major components of a HCI are a human and a computer, while HRI components are a man, a robot and an environment. They do believe that HCI is simple whereas HRI is complex. They assume that computers are in general fixed or portable such as Smartphones, while robots are able to move. Finally, they advance that on the one hand, HCI are mostly based on vision and audio, and on the other hand, HRI can provide different means of interactions.

Likewise, Scholtz and Bahrami [9] argue that HRI requires different relationships than those in HCI and propose five roles of interaction: supervisor who monitors robots, operator who helps the robot accomplish a particular task, mechanic or programmer who applies a software or hardware fix to the robot, peer or teammate who interacts with the robot at a task level and bystander who has no training but needs to co-exist in the same environment as the robot.

Feil-Seifer and Matarić [10] believe that the key difference between the two types of interactions is that HRI allows embodied systems to utilize physical context and mobility. They argue that unlike PDAs for example, robots do have the ability to take decision and they are mobile.

Table 1 summarizes the general views as introduced above. Indeed, a description of the relationship between HCI and HRI in all embracing and concluding argumentation currently seems inevitable.

Table 1. Summary of similarities and differences between HCI and HRI

Research Study	HCI	HRI
Kiesler and Hinds [4]	— Robots Perception (robot as a peer) — Robots Mobility — Robots Decisions Making	
Thrun [5]	The main difference between HCI and HRI is autonomy	
Han et al. [6]	— Static and Restrictive Interaction — Mostly Mouse and Keyboard Inputs — Output to Human : Audio, Animation, Moving	— Dynamic and User-Friendly Interaction — Voice, Face, Touch Screen, Gesture and Sensing Inputs — Output to Human : Audio, Video, Animation, Voice, Gesture, Facial Expression
Breazeal [7]	— Short/Medium Term Interaction — Restricted Environment — Interface layer/Control layer — Superficial Interaction with People — Less Possibilities of Learning	— Long Term Interaction — Survival in the Real Environment — Deeply Integrated “Interface” and “Control” — Intense Interaction with People — Learning in the Human Environment
Fong, Thorpe and Bauer [8]	— Controlled by Humans — 2 dimensions (human + computer) — Simple — Static User Model — Fixed or Portable — Mostly Vision and Audio	— Autonomy — 3 dimensions (human + robot + environment) — Complex — Dynamic User Model — Movable (mobility) — Vision, Audio and Tangibleness — Face to Face — Learning and Decision Making
Scholtz and Bahrami [9]	5 roles of interaction in HRI : supervisor, operator, mechanic, peer, bystander	
Feil-Seifer and Matarić [10]	The main differences are physical embodiment and mobility	

Most of the approaches presented above focus on simple differences between the two types of interactions but they do not consider how in their presence, entities could fairly collaborate. In our own conceit, we believe that surely some properties should be taken into account, to which, fairness should be added for the sake of establishing good collaboration. First of all, we deem that an important point is that of movement: computers are generally in fixed positions or may be portable, while robots are usually in movement. Another point is that of teams' creation, we think that both computers and robots could be part of homogenous or heterogeneous teams of different sizes. Moreover, the number of collaborators interacting may vary from one to many in both HCI and HRI. This final point will be discussed in details while talking about collaboration stratums in next section. The study of such systems is of great importance since they are different from other traditional distributed systems in terms of fairness requirements. Hence, the study of fairness algorithms for collaboration is paramount.

3 HCI vs. HRI within Interaction Stratums

In this section, the focus is on the type of interaction which should be chosen in order to ensure collaboration between several humans, several computational machines and several robots.

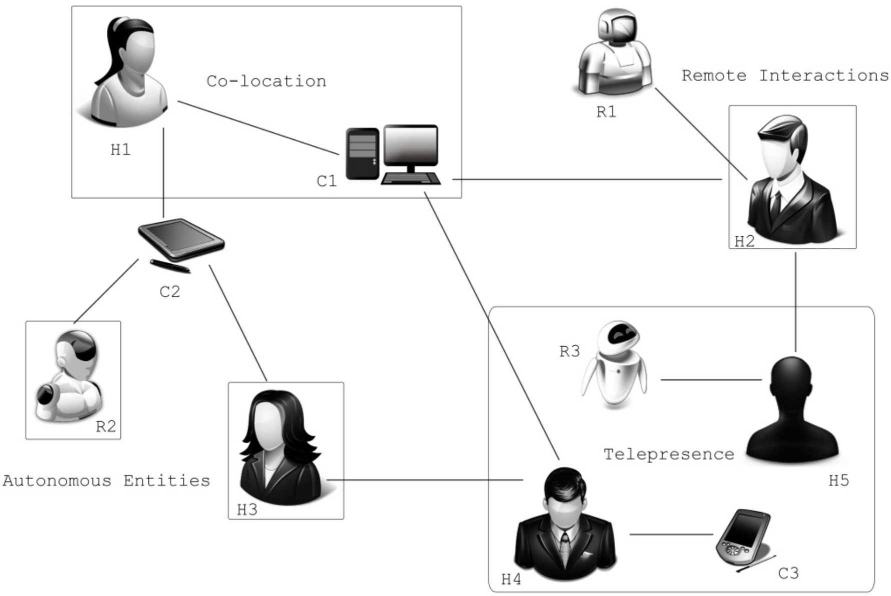

Fig. 1. Interaction stratums in collaborative environment

In [3] authors define collaboration as being a continuity of the collaborative workspace which is spread out over three dimensions going from coordination to collaboration while passing by cooperation. In order to ensure a good collaboration it is necessary to define and understand the different possibilities and situations that may occur during HCI and HRI. In fact, during collaboration the general topology of collaborators may change while moving in the environment. Thus, only one or a mixture of four interaction states could occur as illustrated in Fig. 1. We distinguish between “Co-location”, “Remote Interaction”, “Autonomous Entity”, and “Telepresence” stratums. It is a simplified illustration of the multi-stratum interaction environment. Other dimensions should also be taken into account, such as the roles that collaborators might have during an interaction and the communication modalities involved in it.

Co-location is one of the spatio-temporal conditions making spontaneous collaborative interactions possible [11], and is a recurrent theme in research concerning collaboration and fairness. Having two or more collaborators co-located in a physical environment is the most typical catalyst for interaction because where there is proximity there is often social engagement to interact. This closeness allows more interaction but also emphasizes requirements onto the communication and interaction ways.

In the situation of “Remote Interaction”, collaborators are separated by physical barriers but linked via telematic technologies, denoting a wide range of distances and thus panoply of interactions. Indeed, collaborators share the same visual perspective using a “what you see is what I see” interaction metaphor [12]. Yet, this distance has a great influence on fairness and collaboration strategies. Moreover, the plethora of mobility has led to a global trend for remote interaction and fair collaboration. An illustrating example is that of urban search and rescue robots, as discussed in [13].

While adding to this remote interaction a certain amount of autonomy, we then talk about “Autonomous Entity”. The word autonomy consists of the words “auto”, Greek word for “self”, and “nomos”, Greek word for “law”, which could be translated into “the one who gives oneself his/her own law”. It concerns systems capable of some degree of self-sufficiency, moving and acting without human interference. This interaction situation is shown in Fig. 1 where the human does not have any control on the robot and that the latter is operating on its own. An example of this case, is discussed in [14] emphasizing the importance of autonomy especially for air vehicle systems.

The last case of interaction as depicted is “Telepresence”, which refers to the application of complex video technologies to give geographically separated collaborators a sense of being together in the same location It gives the experience of “going there without being there”. This is represented by demonstrating that the primary collaborator is at a remote location and that the remote collaborator is collocated with the robot. It enables humans to interact with an environment that is spatially out of their reach. Often, this technology is proposed for applications involving environments that are hostile or unreachable for humans: outer space, deep recesses of the ocean, radioactive sites [15].

Considering the previous stratums, it can be concluded that humans, computers and robots must be endowed with fair mechanisms in order to ensure the aimed collaboration. In the next section, four algorithms are visited along the way taking into account two approaches: permission-based approach and token-based approach.

4 Simulation Results

The algorithms proposed by Lamport [16] and by Ricart and Agrawala [17] which fall into permission-based algorithms category, and the algorithms proposed by Naimi, et al. [18] and by Suzuki and Kasami [19] falling into token-based algorithms category are compared in this section, in order to choose the best approach for a fair collaboration. In this paper, humans, computers and robots are supposed co-located, thus we focus on the co-location interaction stratum. The simulation prototype is a Java programming language based platform, implementing algorithms using TCP sockets. During each experiment, all collaborators will have access once to the shared resource. To obtain statistically reliable results we made long-time simulations executing 100 collaborations. On each experiment we vary the total number of collaborators between 3 and 50. Figures 2 and 3 show the results of the simulations for the permission-based and token-based algorithms.

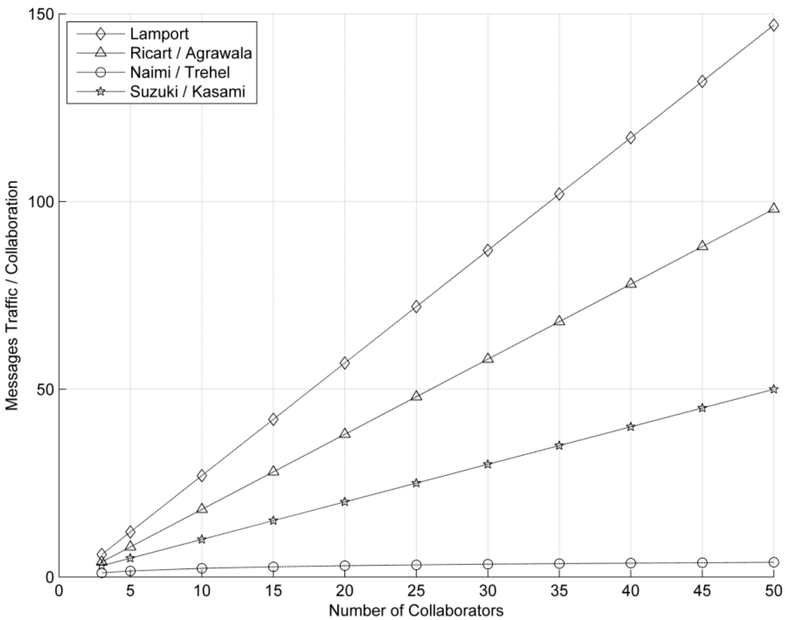

Fig. 2. Traffic intensity in accordance with the number of collaborators

To assess fairness performance of the collaborative algorithms, it is crucial to consider the impact of traffic intensity. Fairness performance making a comparison between permission-based and token-based algorithms in terms of messages traffic with a single sub-task per collaborator is critical. Fig. 2 shows messages traffic as a function of the number of collaborators. It is evident that the behavior of the four algorithms changes while the total number of collaborators increases. In fact, the token-based approach algorithms [18-19] outperform the permission-based approach algorithms [16-17] in fairness aspects according to the total number of collaborators. In other words, token-based algorithms guaranty fairness with a less traffic intensity.

Satisfying fairness, delay constraints are also important. Thus, we focus next, on the delay generated for different waiting times. The value of the collaboration delay should be small as much as possible in order to guarantee a fair collaborative environment. According to Fig. 3 the delay incurred represents different changes for different collaborative message propagation times. It shows delays in collaboration as a function of the message propagation time between any two collaborators. Under all values of the latter, permission-based algorithms showed better results and outperformed token-based algorithms.

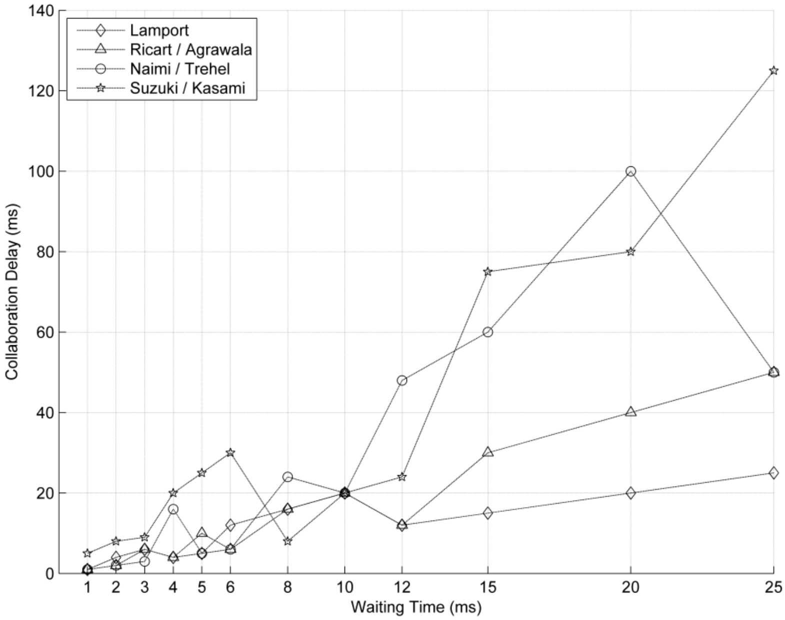

Fig. 3. Collaboration incurred delays in accordance to message transmission times

5 Discussion

In our research study, we support fairness in a distributed collaborative environment. In fact, we consider our work as a part of HCI and HRI and their relation to fair collaboration. Moreover, we identify fairness as the major performance criteria in evaluating the effectiveness of collaboration. Traffic intensity and delay are important fairness metrics but often contradicting. Further, fairness is a trade-off between traffic intensity, delays incurred and participation. Permission-based algorithms as presented, outmatched token-based ones in terms of collaboration delays performance. Yet, the latter outperformed permission-based algorithms in terms of traffic intensity. Moreover, token-based algorithms adapt to multiple topologies and offer extensibility possibilities. While permission-based algorithms are static, token-based ones are dynamic in terms of adding or removal of collaborators and the general topology and of the humans, computers and robots in the co-located collaborative HCI and HRI based environment. Thereby, we believe that token-based algorithms are more suitable to ensure fairness in our case of study. Nevertheless, a compromise in terms of collaboration delay should be assured. This result comes as a first step towards a quantitative verification of fairness properties. Thus, this study uncovered the need to incorporate a wide range of algorithms with the aim to choose the best for the HCI and HRI. For the future development of the platform, a number of extensions of the current prototype are planned. Indeed, there are several directions of further work possible from here. In fact, integrating the other interaction stratums is a highlight target and a challenging issue of our work.

6 Conclusion

In this paper, we present a comparative study between HCI and HRI emphasizing the similarities and differences between both interactions. We also tackle the way in which those interactions take place into a collaborative environment. A broad range of fair collaboration strategies were visited along the way. The goal of this work is not to propose new fairness algorithms and collaboration techniques but to adapt existing ones to this novel application domain. While many researchers have established the correlation between fairness and collaboration within distributed systems, no quantitative large studies have ever been attempted to consolidate the credibility of this theory within a HCI and HRI based environment. Moreover, to the author's knowledge, there have been few attempts to provide a formal classification of what fairness properties a HCI and HRI based collaborative environment requires. In this paper, we have shown how the fairness-based platform allows for enhanced interactions and better collaboration of distributed collaborators. The realization is based on the Java programming language as well as permission-based and token-based algorithms. This work represents the first steps towards an algorithmic vision of true fair team work between humans, computers and robots. The hope is that this work may provide a basis for a new algorithm responding to all of the already discussed problems. The ideas described in this paper are now facing the field reality through the experiments we are conducting. The preliminary results are encouraging, but the integration of other interaction stratums is still a great confrontation in our study.

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