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# Reimagining Trustworthy Robot Fleets with Animal Analogies

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**Abstract**: In the future, multi-agent robot fleets will be important for domains like agriculture, space exploration, and air combat. Trust of human-machine teams is needed to make the teams resilient to the faults of both human and robot teammates. Trust in multi-agent systems is often fragile: if any agent in the system is less reliable than the others, people will stop interacting with all of them. Studying relationships in human-animal systems can provide useful insights into designing human-robot systems. We present a method for gathering insight into how humans, working with animal systems think about the relationships between the individuals and the whole, and suggest how animal system models can be used as analogies and practical design features for the design of robot systems in order to increase trust. Using a more-than-human approach in design research phase of human-robot interaction, supports more secure collaboration between humans and robot systems.

**Keywords**: more-than-human design; human-robot interaction; animal analogies; systems

## 1. Introduction

In the future, multi-agent robot fleets will be prominent in domains like agriculture, space exploration, air combat, and space operations. For instance, in the field of agriculture mechanization, the need for machine capacity has increased significantly. Swarm robot tractors could replace their larger equivalents in different situations, such as planting, crop management or harvesting (Albiero, D. et al. 2022). Robot fleets could also assist in finding and collecting materials in space (Nguyen, L. A. et al. 2019). Thus, there will also be a need for a deeper understanding of the interaction between humans and robot fleets, which has primarily been studied in the field of Human Robot Interaction (HRI).

Trust in the "distributed intelligence" of human-robot teams is needed to make the teams resilient to the faults of both humans and robots. Prior work regarding the interaction of humans and robot fleets has found that trust in the aggregate of these systems is often fragile, and susceptible to the most unreliable system in the group (e.g. Schaefer et al. 2017; & Cameron et al. 2015). If any of the robot agents in the system are less reliable than the others, people will stop interacting with all of them (Rice at al., 2010). Justifiable trust then, is especially crucial when people work with robot fleets under pressure or in crisis situations, such as rescue missions or humanitarian work. Humans need to be able to rely on the fleet, in general, and in its ability to substitute individual machines who fall off even if the weakest link breaks.

Here, we investigate how animal system models, or animal analogies, serve as a practical method for designing multi-agent robotic systems to support fluent collaboration between humans and multiple robots and autonomous systems. We assess a method for gathering insight into how humans who work with these animal systems think about the relationships between the individuals and the whole. We present a case study, where we studied how beekeepers collaborate with bees and how they feel about their work.

The purpose of this article is not to present the full results of our study but to introduce the analogy and suggest a concept for gathering crucial information in the design research phase in order to increase trust between multi-agent robot system and human. We introduce preliminary results from our qualitative data, which consists of interviews with beekeepers focusing on cognitive science and emotion research perspectives. In addition, we suggest that this kind of approach provides practical insights for designing multi-agent robot fleets. We also argue that using a more-than-human approach in the design research phase of human-robot interaction is strongly needed for more secure and fluid future collaboration between humans and robot systems.

## 2. From human-centeredness to more-than-human design

Human centeredness (Human Centered Design, HCD) has long been a standard approach in technology design. Especially, the field of human-computer Interaction (HCI) has focused on ergonomics and cognitive features of design, specified by international standards (ISO 9241-210) (Coulton & Lindley 2019). Current studies suggest (Bodker 2006, Coulton & Lindley 2019) that HCI has evolved from understanding usability through focusing on growing efficiency and appropriateness, to studying technology in the various environments where it is used. The next step in this evolution process of design of technology could naturally be broadening the scope to studying the interaction of a larger environment and nature more broadly, that develops and survives around people. Currently, this is understood as a more-than-human design approach.

Previous work (e.g. Noyes 2001 & Bevan 1995) in the field of HCI has focused more on the human-centered approach, including human-human interactions, but mainly left the more-than-human approach out. However, the current times urge us to shift the focus from just humans to a larger scale (Fischer & Jameson 2023). In this study, by adopting a more-than-human design approach, we propose animal analogies as a way to consider explanations within ongoing relations of humans and multi-agent robot fleets, in which both people and robot agents are active participants in building mutual understanding.

The more-than-human design approach considers humans more than users, they are a part of an ecosystem. In an ecosystem, also non-human actors, such as plants and animals, are taken into account, and the effects of interactions are caused by many other actors than humans. The more-than-human design aims to find novel meanings and integrate this understanding of the existence and behavior of a larger environment and nature into designing objects (Giaccardi 2020). Furthermore, the more-than-human design will expand the scope to a planetary level: it touches the relationship humans have with the biosphere – directly or indirectly mediated by their tools. In other words, this design approach has the potential to shed light on how humans (with their tools) interact with nature at large, whether it is space, asteroids, weather on planet Earth, or forests and agriculture.

In addition, it is not always intuitive for humans to comprehend how complex technology works. Lukens & Disalvo (2011) argue that technological fluency is an important capability that requires a deeper understanding of how technology, information processing, and communication work. To reach this understanding of complex systems that advanced technology brings along, designers have to find novel approaches to aid human understanding. (Nicenboim, Giaccardi & Redström 2022). More-than-human design, and especially animal analogies, is one of those approaches.

## *2.1 Animal analogies in human-robot interaction*

Animal analogies may provide a fresh perspective for technology design since everything is not directly distinguishable by human observation or experience. Prior studies (e.g. Giaccardi 2020) suggest that this kind of approach offers designers a shift in perceptual scale and an ability to take into account insights that otherwise would not be seen as relevant. If this is applied to the field of human-robot interaction, human-animal interactions can serve as functional models for the design features. However, it seems animal analogies are still a quite rarely used method in the context of design research.

In the human-robot interaction literature, a growing number of researchers have argued that human-animal interactions can serve as useful models for human-robot interaction (de Visser et al., 2022; Krueger, Mitchell, Deshpande, & Katz, 2021; Lum & Phillips, 2023; Phillips, Schaefer, Billings, Jentsch, & Hancock, 2016). Specifically, researchers have examined how working animals (e.g., therapeutic animals, service animals, trained law enforcement and military animals) can be used to inform how interdependence and communication between humans and robots could be modeled to achieve similar levels of teamwork as functional human-animal working teams. Others have argued that modeling how bonded and attached relationships form between humans and animals, including through neural mechanisms, is also a good model for establishing human-robot attachment (Krueger, Mitchell, Deshpande,

& Katz, 2021). Still others have examined how animals can be used as a benchmark by which to judge the performance of autonomous machines (Lagerstedt & Thill, 2020).

However, this prior work has often focused on single-human-single-animal interactions and the majority have focused on reviewing the literature to gain insight into human-animal interactions. We extend this approach beyond single-human-single-animal interactions to human interactions with animal systems that resemble autonomous multi-agent robot fleet systems envisioned for the future. We also draw insights from domain experts in animal systems, namely beekeepers. We believe studying relationships in human-animal systems, like between beekeepers and bee colonies, can provide practical insights into how design can help humans to unite their thinking about multi-agent systems.

## 3. Methodology

The process was initiated by a human factors specialist, social psychologist specializing in cognitive science, and a human-centered designer (figure 1.). After establishing common ground, we were able to consider a wide range of perspectives while designing the study. Our interdisciplinary approach guaranteed that the human aspects were comprehensively considered and provided a steady base for broadening the scope to the direction of more-than-human design.

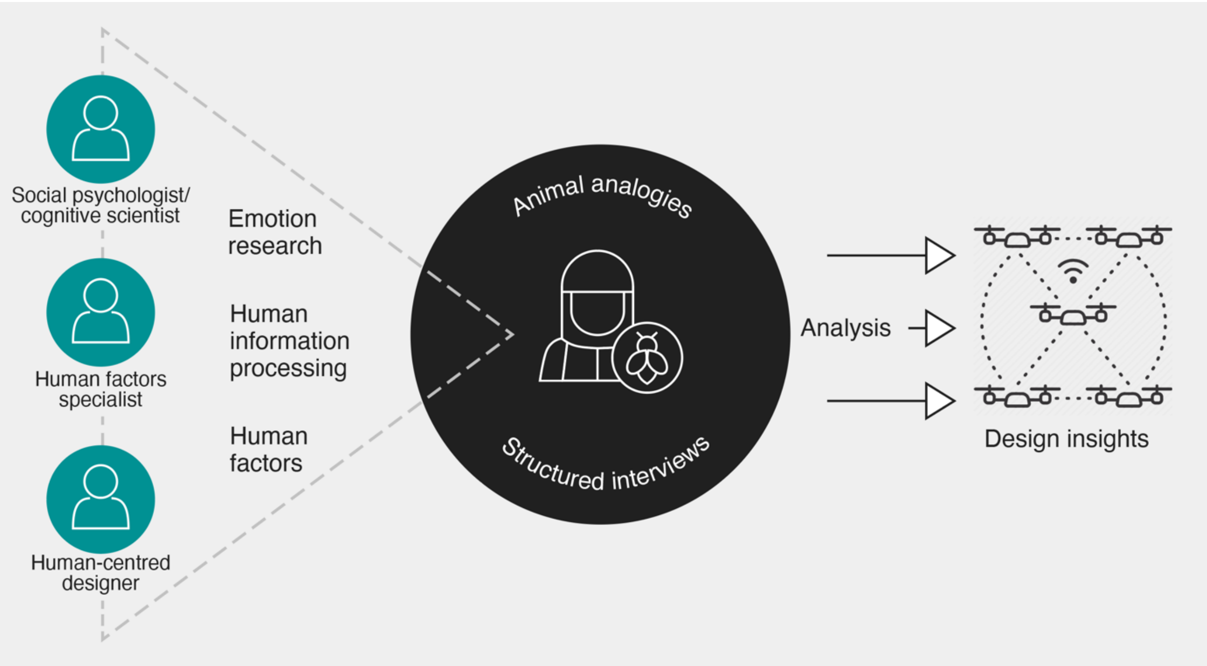


*Figure 1. The analytical process of our multidisciplinary approach visualized.*

Primarily, we wanted to explore the possibility to find design insights and features from the perspectives of trust, information processing, and social cognition when humans interact and work with non-human collaborators. Since our interest focused especially on multi-agent robot fleets, a suitable analogy was explored from animal colonies. As humans collaborate with bees in a consistent goal-oriented way, beekeepers were selected as target group and beehives as an analogy for multi-agent robot fleets.

## *3.1. Analytical framework*

As the larger intention of this project is to gain understanding of the boundary conditions on when people do not abandon a swarm of robots, it is crucial to recognize the process by which the beekeepers form their attachments with the bees. By doing this, we will potentially also understand what the cognitive mechanisms are that motivate humans to do so. This will help us to design future robot fleets in a way that facilitates human bonding with robots. This in turn will result in not losing expensive resources that have been used in developing new tools that have the potential to save lives.

We approached the phenomenon with semi-structured interviews since prior work from this perspective is limited. The interview structure was constructed collaboratively by using the information processing perspective as a metaframe for the interview questions. The questions were carefully designed in order to address the themes in our research questions.

Information processing is a fundamental feature of nature from the way our DNA functions all the way to the way our brain expresses emotions, and even to how our economies organize themselves (Mitchell, 2009). By taking this information processing stance (or cognitive stance), we will be able to construct the process by which the human-bee cooperative and cybernetic feedback loop is formed and maintained (see Dennett, 1985 for theories of intentional stance; Sayre, 1986 for intentionality and cognitive science and Newby, 1998 for Cognitive Stance).

Particularly, we wanted to encourage the beekeepers to use specific language to express their own experiences, thoughts, and feelings on decision-making, cooperation, and emotions regarding their work with the bee collectives. For instance, questions regarding the beekeepers' relationship with the hive, their perceptions of the bees as units and/or individuals, whether they experience trust in the hives, and what makes them motivated to work with the bees, were included in the interview structure.

During the interviews, we aimed to receive information on the different states where the bond between the beekeeper and the bees forms. We wanted to get the beekeepers talking and wished to fish for those phrases and expressions that elucidate how they form and constantly renew their attachments to the hive. We engaged with the beekeepers by implicitly treating the bee collectives and the beekeepers both as intentional agents.

## *3.2 Empirical procedures*

One pilot interview was conducted before starting the actual interviews. After that, the order of questions was slightly adjusted, and some wording and phrasing were specified.

We used purposeful sampling by contacting the research coordinator of the National Association of Beekeepers in Finland. Purposeful sampling means identifying and selecting participants with certain characteristics, knowledge or features (Palinkas et al. 2015). In our study, we wanted to interview people with a deep understanding of bees and beekeeping.

Every participant was carefully informed of the data management and privacy practices, voluntary nature of the study, and other necessary ethical practices before starting data collection. Interviews were conducted during two months in 2023 between August-September through video calls by using Microsoft Teams as a platform. They were recorded with the participant's consent. The recordings were transcribed immediately after the interview session, fully anonymized, and after that, the recording files were destroyed. All of the interviews (n=6) were conducted by the exact same protocol, which included six background questions and 16 main questions. The duration of each interview was approximately one hour.

Our intention is still to continue gathering data by interviewing a few more participants in Finland and collecting a similar sample in the U.S. in order to make cross-cultural comparisons between highly expressive and in-expressive cultures (Nishimura, Nevgi & Tella 2008).

### *3.3 Analyzing the data*

The analysis is still a work in progress. We will continue it with our multidisciplinary team of three researchers: a human factors specialist, a social psychologist specializing in cognitive science, and a human-centered designer. Preliminary analysis was conducted by using an affinity diagram, which is especially suitable for quick analysis and for discovering main themes and key insights from the data (Plain, C. 2007). Affinity diagramming is a common analysis method for organizing qualitative data visually in one place, and it is particularly effective when analysis is conducted collaboratively (Liu & Eagan 2021; Holtzblatt & Beyer 2016).

We will continue the analysis by systematically coding the transcribed and anonymized interview data by using the perspective that we described in section 3.1. As stated, the purpose in this paper is not to present the full results of our study but to assess the method and evaluate if there’s a need for interview structures in a more-than-human design research phase. The full results of the study will be presented in our future journal article.

## 4. Exploring the analogy: beekeeping

The participants were encouraged especially to elaborate on their own experiences and emotions of their work, not beekeeping in general. The participants were a heterogeneous group that consisted of people of different ages (from 30s to 70s), different educational levels, and sex. In addition, there was a considerable amount of variation regarding their experience with beekeeping (from a year to a few decades) and how many beehives they took care of (from a few hives to over a hundred).

The preliminary analysis was done by organizing the data in an affinity diagram, which revealed some initial main themes and key insights (figure 2.).

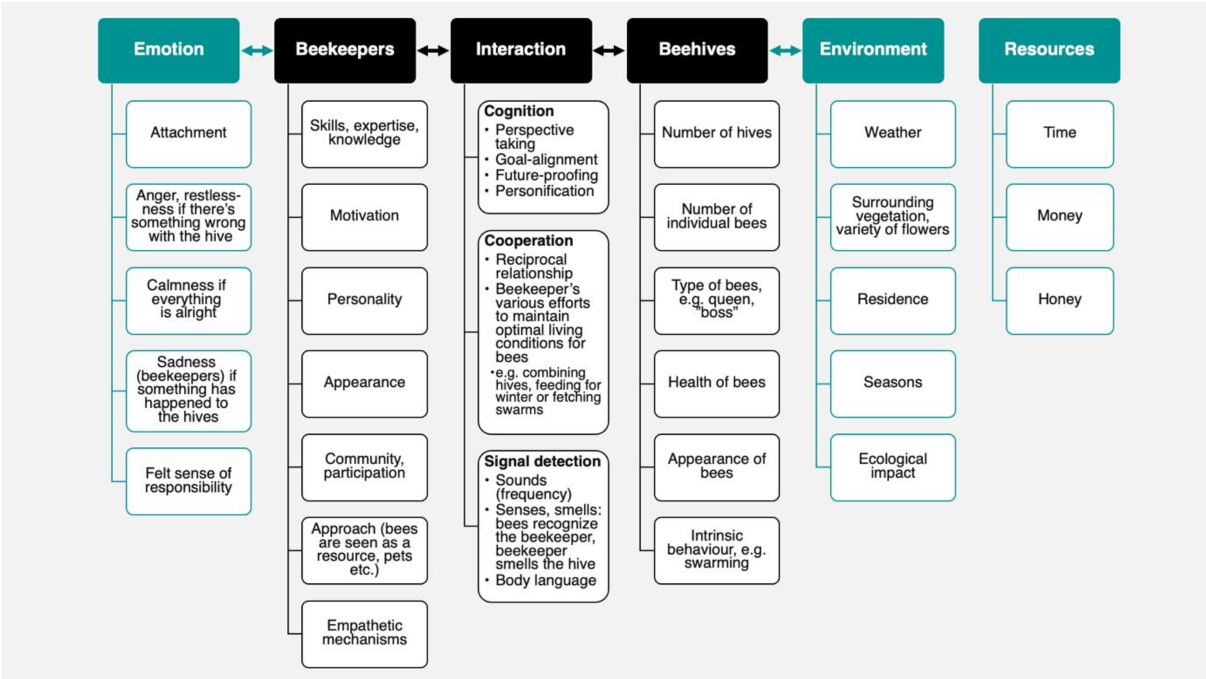


*Figure 2. The thematic categories of the data after analyzing it with an affinity diagram. A relationship between different categories was recognized.*

Overall, beekeepers seemed to enjoy their work with the bees, however, most of them considered it a hobby and practiced it in addition to their daily occupations. The beekeepers we interviewed seemed to invest considerable thought into how they tended the hives. They also engaged in self-reflective processing of their actions and their relationship with the hives.

## *4.1 Examples of the data*

The beekeepers we interviewed seem to understand quite profoundly that it is important to work in harmony with nature. Almost every beekeeper in some way was also mindful, either implicitly or explicitly, of their role as an intermediary in a larger system, or in an interactive cycle between themselves and the ecological factors that influenced this system. For instance, many of the participants described how they perceive surrounding vegetation more closely:

> I do pay more attention to when each type of flower blooms, but I'm not able to say in a week's accuracy when which plant starts its flowering. And where you'll get berries at a certain time, that is something I can say. And actually, how was the weather when those specific flowers bloomed in our surroundings, that I know. And, I'm not sure if I would have ever started to count bumble bees if I hadn't started to take care of bees. (P2, 55 yrs., five hives, ten years of experience).

Also, the beekeepers often mentioned that they were especially concerned about the well-being of the queen bee (or "boss," or "mother"). It seems they were able to interpret the state of the whole hive based on the condition of the queen bee. The beekeepers mentioned that they observed specifically the movements and behavior of the queen bee, and also how the hive reacted towards the queen bee. The existence of a queen is crucial to the hive, and it would not survive for long without it.

> They do need the mother bee, they clearly know it themselves because they start to grow new mothers quickly if the mother is removed. They clearly try to survive and try their best to get a new mother when they haven't agreed with us about the choice of mother bee. Especially, if there's something wrong with the mother, they don't want it. (P4, 43 yrs., four hives, four years of experience).

In addition, the beekeepers paid attention to the roles of the bees in general:

> They have differences in their characters, so that naturally the protector bees and care-taker bees, and the youngest bees are the most relaxed ones… I think it's because of the phase of their lives, and I believe all of them won't become protectors but they take care of the larvae, and then in the end they become nectar collectors, which might be the most important task of most of the bees. (P2, 55 yrs., five hives, ten years of experience)

The beekeepers were also oriented towards the general well-being of the bees because they recognized that at least a part of their income or livelihood was co-dependent on the survival of the hives over harsh Finnish winter conditions. They also felt they were working towards a mutual goal with the bees, for instance, successfully combining two hives into one in order to prevent swarming or repeatedly succeeding in surviving the winter conditions and collecting honey. Nonetheless, there was a seeming tension between the empathetic emotions towards the bees and a utilitarian stance (bees as farm animals, livestock, or as means of production).

> Of course, if you have a huge colony, their goal is to gather honey as much as the hive can fit. -- They probably would survive with lesser amounts, but it might be a biological need after all… -- There are also those beekeepers who just want a hive or two to their garden and just like to follow what they do. And do we have to take the honey away… Well, that's another question then. (P1, 60 yrs. four hives, 25 years of experience).

Similar themes arose from the data repeatedly when the beekeepers described in detail how they observed the scents, sounds, and motions of the bees. They seemed to interpret the hive's condition quite heavily based on their perceptions and senses. Emotion words such as "restlessness", "anger", "screaming" and "calm" were used to describe the communication between the beekeepers and the hives. For instance, participants described their interaction with the hive with the following words:

> If they [bees] are really aggressive, they'll sting you also on your overalls. There was something in that they were so grumpy and they wanted to show that they were not feeling well. And now when I fed them the other day, they [bees] were quite calm, I suppose they finally had gotten enough food to eat for the first time in the whole summer. After many feedings, it has seemed to be… I mean, now there's been a content hum from the hive when I feed them more. (P2, 55 yrs., five hives, ten years of experience).

> If you trust that the collaboration goes well, it goes, but there are situations when you know the bees get anxious, and especially if you're in a hurry already and stressed out, then it easily affects the bees. So, if you try too quickly to perform the care-taking tasks, the bees will get angry. (P3, 45 yrs., over hundred hives, 15 years of experience)

If beekeepers saw the bees solely as farm animals, machines, or means of production, they would not use so emotional expressions of them.

The respondents, in some cases, distanced themselves from the bees by "othering" the bees, and in other cases, almost entirely "proximated" themselves with the bees by describing their feelings of sadness and anxiety when, for instance, nobody had notified them about the destruction of the hives by bears. The failed attempts at "othering" the bees were also apparent in meticulous descriptions of the troubles the beekeepers went through when they had to, for instance, try to fetch run-a-way swarms. It was also evident in moments when the subjects reported their disapproval of "disturbing the peace" of the bees or lackluster treatment and accidental squashing of them in the middle of their care-taking routines.

Other themes that arose repeatedly from the interviews were the importance of beekeepers' community and participation in something larger than themselves.

## 5. From animal analogies to design insights

The preliminary analysis of our data suggests that applicable perspectives can be found when approaching animal analogies with structured interviews. Broadening the scope of the design research phase in HRI to a more-than-human approach allows us to explore and naturally notice elements that otherwise might not be considered relevant. Interpreting our findings into design insights included following established design processes, and also collaboratively exploring and systematically discussing the findings by utilizing our interdisciplinary expertise.

Based on our findings, we suggest five practical design insights and features in order to increase trust and fluidity of the collaboration between humans and their non-human multi-agent collaborators. We also argue that using animal analogies in general in the design research phase of human-robot interaction supports more secure and fluid collaboration between humans and robot systems.

### *5.1 Five design insights from animal analogies for HRI*

The first theme we detected was that inter-species signal detection in the interaction situation relies heavily on human perceptions, especially on sound. For instance, it seems essential that future robotic fleets signal their human collaborators with humming noises or sounds that inform of the state of the fleet. In addition, different kinds of warning signals or sounds in case of danger or damage matter significantly. This should be developed beyond beeping and red signal lights. In case robots in the fleet are damaged or can pre-emptively warn the humans that some damage might happen, this could assist human-robot bonding.

Sound design that facilitates human-robot interaction is still a new and emerging research area, which may yield many benefits for continued exploration (Orthmann, Leite, Bresin, & Torre, 2023; Pelikan, Robinson, Keevallik, Velonaki, Broth, & Bown, 2021).

The second theme concerned the roles of the bees in the collective. The beekeepers raised in several cases that there needs to be some central agent that is more important than the other agents (i.e., the Queen). It appears that humans would care about robot fleets, which are arranged around a clear "leader" or a "boss." They can observe the well-being of the fleet through the eyes of the leader robot. The beekeepers also interpreted the state of the collective by following bees in different roles, and the division of labor or perceived roles for the individual bees were considered relevant. Not every member of the fleet must be a general tool, so it might be necessary to have different roles for different members of the fleet (analogous to a guard bee, flight bee, Queen bee, and drones). It seems humans wish to see some level of individuality in the individual members of the fleet.

Thirdly, we observed the attachment to the hive seems to come from accomplishing mutual goals. As an analogy, it could mean, that future humans would need to go over several training missions with their robot fleets and have a possibility to repair damaged robots of the fleet. Attachment seems to be taking place after repeatedly overcoming trials and tribulations together. The bonding between human-robot agents could be aided by organizing "gamified training missions" with robot fleets. It seems substantial that each human user/operator has their own fleet of robots with which they interact repeatedly. It needs to be "their swarm.".

Fourthly, we also noticed the beekeepers pay attention to how the bees recognize their presence. Bees primarily function based on scent, and the beekeepers reported that bees recognize them from their scent. As a design analogy, this would suggest that it is essential for the robot fleet to be able to identify their own "beekeeper" and deliver that recognition to their human collaborator.

The fifth insight we noted, especially from the more-than-human design perspective, was that it is clearly meaningful for humans to see that they have a positive impact on their surrounding ecosystem. Some beekeepers reported enthusiastically that the simple act of beekeeping had invigorated some species of plants in their area. The increased awareness of their ecological impact seemed to have a substantial meaning to the beekeepers' identity (i.e., to perceive themselves as stewardesses of nature). As design insight, it could mean that when humans work with robot fleets, the fleets offer the users a sense of empowerment through deeds that tie them meaningfully to a larger community of action matrixes. In other words, people will commit to collaborating with robot fleets if they see the positive impact of their actions.

## *5.2 Assessing the analogy and the method*

As mentioned, one of our goals in this study was to assess if animal analogies provide useful information on the interaction between humans and machine fleets in the design research phase from a more-than-human perspective. The preliminary analysis based on the affinity diagram provides information which can be transformed into design features. This would offer a highly fruitful avenue in advancing design and engineering sciences when the data is analyzed in-depth.

It seems to be relevant to take time to consider a suitable analogy for each situation and context. The multidisciplinary approach increases the possibility of collecting robust data, which includes necessary perspectives widely, not only appropriate for narrow expertise. As is evident, our study would not have been possible without the multidisciplinary expertise involved. Theoretical frameworks from complexity science to evolutionary psychology and attachment, and trust theory were brought into play in the HCI/HRI context.

The topics regarding the generalizability of our findings are at least three-fold. First, our findings highlight aspects of human cognition and perceptual systems that are engaged in interaction with bees. In designing future robots or creating design insights for other objects, a conscious focus on the multimodality of human interaction with their surroundings is important. Second, regarding engagement with future human-robot interaction situations, our study suggests that there needs to be a mutual goal between humans and their artificial interaction partners. Third, all participants mentioned several emotional, affective, and motivational states, which implies that humans engage with robots through their socio-emotional systems. For long-term attachments and dedication to take place, the interaction between humans and robots needs to have survival-related situations where the challenges are overcome with collaboration.

All in all, our interviews suggest that there could be a generalizable pattern of events and factors that could be organized narratively or sequentially. It seems that universal features of human socio-emotional-cognitive life generalize across many different situations. Future research will be interesting, as it will need to weave in more detailed understanding of how human social cognition (e.g., role perception between the bees) and environmental cognition (predicting the weather, future orientation) factor into these issues.

The concept we suggest here still requires further studies, evaluation and validation, and the process of result interpretation into design insights needs to be more robust. However, already we can say that it is possible to gain an understanding widely on how people interact intuitively with animal systems by using animal analogies. As we have demonstrated, there exist no contradictions as to why this kind of insight cannot be used in the context of HRI.

## 6. Discussion

In this paper, we present an example of a concept, of how animal analogies especially related to human-robot fleet interaction design offer an informative approach and reveal unexpected insights into multi-agent systems. Naturally, our concept still needs to be validated through iterative practice and basic research. Additionally, it should be adapted to different kinds of technological contexts where humans need to work with multi-agent fleets, as mentioned in the introduction. The concept should be tested with different kinds of analogies.

However, this innovative approach has the potential to solve major unforeseen design problems in the field of HRI taking into account the planetary perspective.

Solely by observing how humans use their cognitive machinery in situ, major future breakthroughs in design are possible. Our preliminary analysis affirms that humans embed themselves in a larger socio-interactive ecological matrix. Our main conceptual tool was to utilize the "cognitive stance", that treats both humans and bees as goal-striving intentional agents that have a meaningful relationship with each other, themselves, and their ecological surroundings. By using this analytical framework in combination with the affinity diagram, we show that just by using a quick analysis, there is a major potential from the technology design perspective. It is a tool that has potential to be used diversely in multidisciplinary teams.

By studying how humans form bonds and utilize their social cognition, emotions, collaborative motivations, and needs for survival and meaning with other animals and larger ecosystems, we can understand how to solve future problems in design even before the technology is ripe for development. The basic researchers gain a deeper understanding of the processes of human interaction with other beings, and designers can observe firsthand how basic researchers approach this topic and extrapolate it to future object design.

The key to this approach is to understand that humans use their biological cognition (Boyer, 2001; Lewis-Williams, 1998; Mithen, 1996; Dunbar, 2015) in areas where it does not fully function in a way it evolved to function. But this is good, as it creates an epistemic contrast between the proper (cognitive machinery) and actual cognitive domains (ecological reality) humans are interacting with. These shadow, or mismatch, areas of human cognition then reveal those important weak spots in human functioning that designers can enhance. By using this novel more-than-human approach, designers can support human functioning in new areas, such as space or agricultural robotics, and create interfaces that support the development of humans in the new technological era.

So, to summarize, we list three significant takeaways:

1. Animal analogies with a more-than-human design approach broaden the design possibilities in a specific context;
2. interdisciplinarity is almost necessary in order to reach the most comprehensive solutions;
3. this approach makes a new type of science possible, including both basic and applied elements.

Indeed, the amount of information in the context in which we use technology today and the complex nature of technology we are currently developing, require much more capacity than one expert or designer can alone fathom. It is urgent to broaden the scope of unexpected directions and break down the interdisciplinary, sometimes artificial, boundaries that have limited our thinking and flourishing until now. We see this as a strong starting point for a promising branch of future studies and a possibility to strengthen interdisciplinary collaboration in the field of HRI.

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