Animal-Computer Interaction: The emergence of a discipline

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Abstract: In this editorial to the IJHCS Special Issue on Animal-Computer Interaction (ACI), we provide an overview of the state-of-the-art in this emerging field, outlining the main scientific interests of its developing community, in a broader cultural context of evolving human-animal relations. We summarise the core aims proposed for the development of ACI as a discipline, discussing the challenges these pose and how ACI researchers are trying to address them. We then introduce the contributions to the Special Issue, showing how they illustrate some of the key issues that characterise the current state-of-the-art in ACI, and finally reflect on how the journey ahead towards developing an ACI discipline could be undertaken.

1. Introduction

This Special Issue is motivated by the rapid development, in recent years, of a multidisciplinary field of research and practice that has become known as Animal-Computer Interaction (ACI). The issue has two aims; the first is to acknowledge such a development, tracing its motivations in the scientific interests and concerns of the interaction design and other communities of research and practice. This is set against a broader cultural background that has seen a reassessment of the relation between humans and other animals in the face of major social, scientific and environmental transformations. The second aim of this special issue is to bring to the fore the challenges faced by ACI researchers and practitioners, but also the opportunities open to them, and to the field, and to trace a roadmap towards the development of ACI as a discipline around core aims and values. In this respect, the contributions contained in this special issue illustrate the field's state-of-the-art and surface key questions and challenges that ACI researchers are grappling with, as well as the ways in which these might be addressed. At the same time, they highlight the gaps that still exist in the field and directions for further work that could continue to develop ACI as a discipline.

2. Changing perceptions and concerns

For millennia, technology has propelled human evolution, reducing the species' necessity to adapt to the natural environment, and instead making it possible for humans to create environments that meet their needs, to cross space-temporal boundaries, and to develop large social networks and economies. By giving humans significant evolutionary advantages over other animals, technology has been increasingly setting the species apart from the rest of the natural world, thus shaping a multitude of anthropocentric human-animal relations within the most diverse contexts, whether on farms, in laboratories, in zoos, in homes or in the wild. Indeed, for a long time technology was considered a hallmark of the human species and evidence of humans' unique position in the kingdom animalia, until Goodall's discovery of chimpanzees' tool making, and use (Boesch, Boesch, 1990), as socially transmitted practices (Whiten et al., 2005) challenged such an assumption, thus moving back the goalpost for claimants of human exceptionalism. Since then, subsequent research has shown that several nonhuman species can craft and use tools to carry out tasks (Hunt and Gray, 2004) and some animals have even been found to spontaneously exploit human-made devices for their own purposes (Caffrey, 2001).

Arguably, the relationship between animals and technology has been directly informed by humans' socio-technological evolution and this is especially the case with regards to computing, which within a mere seven decades has revolutionised just about every aspect of human activity. Consistent with this, wherever computing-enabled technology has penetrated human society, other animals too have increasingly come into contact with it, sometimes being required to interact with it directly and proactively. Indeed, interactive technology specifically targeted to nonhuman animals has been in existence for the best part of a century, ranging from biotelemetry devices fitted on free-living wild animals during ethological studies (Samuel and Fuller, 1994), to operant interfaces used by laboratory animals in behavioural experiments (Skinner, 1959), and robotic machines used by farm animals in automated agricultural processes (Rossing and Hogewerf, 1997). Similarly, for decades, dogs have been trained to operate domestic interfaces such as light switches or washing machines to carry out tasks on behalf of their assisted human companions (Mancini et al. 2016). Moreover, in recent years, a host of computing-enabled devices such as tracking collars (von Watzdorf and Michahelles, 2010) or teleconferencing systems (Golbeck and Neustaedter, 2012) have appeared on the pet market promising owners to help them to better care for and communicate with their animals.

But what role have animals played in such technological developments? To what extent do these developments reflect the perspective of the animals in question? To what extent have the animals' individual and collective characteristics and requirements informed the design of technologies they find themselves interacting with? To what extent have they shaped the processes through which such technologies are developed? How does the interaction with these technologies influence the animals' capabilities, activities and experience? With regards to the interaction between humans and technology, these kinds of questions have for decades underpinned the development of disciplines such as human-computer interaction and, more recently, interaction design. In contrast, and as noted elsewhere (Mancini, 2013), until relatively recently most technology aimed at animals came from disciplines other than interaction design, such as agricultural engineering (Rossing and Hogewerf, 1997), cognitive psychology (Reiss and McCowan, 1993) or animal behaviour science (Carlson, 2009). Here, the focus of interest and attention seemed to be the outcome of the interaction (e.g. food produce, information about animals, knowledge about humans via animal models) rather than the interaction itself. Indeed, related publications from these domains rarely provide details about the design process or about the rationale underlying specific design choices, or explain in what capacity the animals might have contributed to the development of specific design solutions. Although some evaluation studies of robotic milking systems (Millar, 2000) or biotelemetry devices (Morton et al., 2003) examined how specific technological interventions might have influenced the animals' activities, social dynamics and welfare, it is unclear how these findings might feed back into the kind of iterative design process that interaction designers are well familiar with.

However, at the turn of the last millennium the discourse around the interaction between animals and technology begun to change, when researchers in human-computer interaction and interaction design more broadly started to explore the topic. As a consequence, those values and concerns that are core to these disciplines, such as the importance of the user experience (Forlizzi and Battarbee, 2004), and user-centred (Gulliksen et al., 2010) and participatory design (Muller and Kuhn, 1993), began to provide a new lens through which to consider the interaction between animals and technology. For example, researchers began to explore the applicability of traditional user-centred design frameworks to the development of computing applications for animals (Resner, 2001), the transferability of established methods in animal behaviour research to evaluate animal interfaces (Lee et al. 2006), and the adaptability of standard interaction design approaches to involve animals in the requirement elicitation process (Robinson et al. 2014). Researchers also begun to explore the usefulness of theoretical and critical approaches from fields

such as ethnomethodology (Weilenmann and Juhlin, 2011), biosemiotics (Mancini et al. 2012) and speculative design (Lawson et al. 2015) to examine the interaction between humans, animals and technology. While initially much of this research focussed mostly on applications whose purpose is to mediate playful human-animal interactions (Resner, 2001; Cheok et al., 2011), their interest quickly extended to applications designed to support the activities of human-animal working partnerships (Jackson et al. 2013, Mancini et al. 2016) and to improve the welfare of captive animals (Wirman, 2014; French et al. 2015). In short, a growing body of work has been shaping a new discourse around animals and technology, in which animals themselves and their technological interactions are the central concern.

Interaction design's relatively recent interest in animals, their interactions with technology and, via technology, with humans, and in the broader implications of such interconnections, reflects a wider cultural transformation. Indeed ACI is emerging within a cultural climate in which old oppositions between human agents and natural resources are being increasingly questioned in light of new scientific knowledge about animals, and in the face of major environmental and social crises. In their exploration of issues and approaches to participatory research in "more-than-human" worlds, Bastian et al. (2017) note how these critical changes have motivated a re-assessment of the relation between humans and other animals. Concomitantly, developments in animal cognition (Menzel and Fischer, 2011), animal welfare science (Fraser, 2008) and animal ethics (Sunstein and Nussbaum, 2005) are making it increasingly difficult to ignore evolutionary and social continuities between humans and other animals. Indeed, the need to reconsider society as more-than-human and to take animals seriously as participating agents is evident in the discourses of rapidly developing fields such as animal geographies (Philo and Wilbert, 2000), critical animal studies (Nocella et al., 2014) and multispecies ethnography (Kirksey and Helmreich, 2010), whose authors are increasingly recognised and cited in ACI work. In other words, the study of animal-computer interactions, and the aspiration to do so from the animals' perspective and even with their participation, are in syntony with a much wider movement that is seeing animals emerge from the background of human society and come to the fore as actors of more-than-human worlds. But what does this mean for interaction design research and practice? In particular, what does it mean to include more-than-humans as technology users and research participants? What are the challenges facing researchers in this area and how can these be addressed?

3. Designing for and with animals

In response to the fragmentation of early work in the field, Mancini (2011) called for the systematic development of Animal-Computer Interaction as a discipline, around three core aims: (1) studying and theorising the interaction between animals and technology in naturalistic settings (2) developing user-centred technology to improve animal welfare, support animals in their activities and foster interspecies relationships, and (3) informing the development of user-centred approaches to the design of technology intended for animals, enabling them to participate in the design process as legitimate stakeholders and contributors. These aims closely map onto key concerns in interaction design: the need to understand users, the context in which they live and operate, and how technological interventions affect both; the importance of ensuring that technological interventions deliver value for users; and the significance of including prospective users as participants in the design process so that their perspective can inform the process and their requirements can be met by the resulting design. To address these concerns the discipline has at its disposal a rich arsenal of frameworks, methods and approaches developed over decades worth of research and practice, which has enabled interaction designers to inform the development of technologized words that in most cases meet humans' needs very well.

However, when it comes to understanding the interaction between animals and technology, and to designing technology for animals and with animals, the path seems fraught with obstacles and pitfalls. The most obvious issue is clearly that those who design and develop technology intended for animals are humans, so there is a disassociation between the proponents and the intended beneficiaries, which raises the question as to whether such technology can ever truly represent the animals' interests. This is compounded by the fact that there are significant interspecies differences and communication barriers between humans and other animals, which make understanding animals' interests and designing from their perspective an unlikely possibility. Furthermore, arguably the interests of humans and those of other animals are not necessarily always aligned (e.g. in human practices where animals are used) and are often in direct competition (e.g. over access to environmental resources), which may make taking animals' interests seriously simply undesirable. Finally, even with the best intentions, it is hard to see how humans' interpretation of animals' interests would be free from biases deriving from humans' own world views and value systems, which are not necessarily shared by other animals.

These concerns are clearly voiced by some ACI researchers. For example, in his early work, Resner (2001) argued that while it might be possible to design interactive systems for animals taking into account their biological and behavioural characteristics, it would not be possible for them to participate in the design process, because they lack the capacity to communicate in a way that enables them to respond and contribute to the process. Along the same lines, more recently Lawson et al. (2016) highlighted how animals' inability to articulate complex ideas and opinions inevitably results in a fundamental disparity of power between designers and the animals they propose to design for, and the authors stressed that this leads to the development of technology that is exploitative of animals rather than animal-centred. In other words, for the authors, even the possibility of designing for animals, let alone with animals, is undermined by humans' irreducible anthropomorphism and consequent anthropocentrism.

This fundamental tension, between attempts to include animal stakeholders in the shaping of technologized words and the obvious difficulty of dealing with interspecies a-symmetries, intrinsically characterises ACI as a field of research and practice, just as it characterises other contemporary cultural movements that are grappling with issues of multispecies participation in a more-than-human world (Bastian et al., 2017). For example, work by Resner (2001), Cheok et al. (2011), Pons et al. (2015), Wirman (2014) or French et al. (2015) aimed to provide domestic and captive animals who live confined with playful experiences that could benefit them while, in most cases, also serving as a vehicle of human-animal interaction; but are those technology-mediated experiences what animals want to experience or are they rather what humans want for them and for themselves? Other work by Jackson et al. (2013), Robinson et al. (2015), Zeagler et al. (2014) or Mancini et al. (2016) aimed to provide working animals with tools to facilitate the tasks they are required to complete in partnership with humans; but are those technology-enabled tools needed by the animals or are they rather needed by the humans the animals work for? What might make an interactive technology relevant for animals and how can that relevance be assessed?

While these questions may be very difficult to answer for the reasons discussed above, they are nonetheless open to honest inquiry and exploration, and ACI researchers have endeavoured to deal with them from different angles. For one thing, they have proposed frameworks that conceptualise the interaction between animals and technology, as well as their involvement in the design process, with a view to informing the design of ACI applications in different contexts: Resner (2001) extended traditional user-centred design concepts to develop a remote human-to-dog training system; Paci et al. (2016) and Mancini et al. (2016) revisited interaction design principles to improve the wearability of animal biotelemetry and the accessibility of canine interfaces respectively; Väätäjä (2014) re-examined the concept of interaction and discussed its

possible forms when considering the biological characteristics of other species; Hirskyj-Douglas et al. (2015) drew from child-computer interaction frameworks to define possible degrees of animal participation in the interaction design process; Wirman and Zamansky (2016) proposed a model that integrates concepts form animal studies and human game studies for measuring and designing computing-mediated playful interactions for animals. Drawing from established interaction design frameworks that place humans at the centre of the design process, these conceptual scaffolds explore what placing animals at the centre of the design process might entail. Whether they prove fruitful in designing animal-centred computing- mediated interactions is to be seen, but they do provide directions for reflection and practice.

For another thing, researchers have also tried to address methodological issues related to the study and design of technological interactions involving other animals, with a view to accounting for their role and enabling their participation in these processes. Some researchers explored different methods for actively investigating the interactional dynamics between humans, animals and technology: Weilenmann and Juhlin (2011)'s ethnomethodology focussed on the manifest interaction between human and canine actors in a hunting context, using observation to demonstrate the influence of dog-tracking technology on the interaction between humans and dogs; Mancini et al. (2012)'s multispecies ethnography of human- to-dog tracking practices explored how dogs might establish contextual associations to attribute meaning to technological interventions and discussed how their responses might iteratively guide design choices; Westerlaken and Gualeni (2013) argued for the need to measure animals' behavioural and physiological parameters in order to bring objectivity to the interpretation of animals' responses to technological interactions. Researchers also explored methods for involving animals as contributors in the design process: Lee et al. (2006) applied different forms of preference testing, often used in animal studies, to evaluate the wearer experience of a haptic jacket for chickens designed to enable the birds' owners to stroke their pets remotely; Robinson et al. (2014) used rapid prototyping, often used in participatory design approaches, to elicit canine requirements from medical alert dogs and inform the design of a canine alarm, based on the dogs' responses. Needless to say, all of these methods have limitations that can easily lead to interpretational biases. For example, Ritvo and Allison (2014) recommended caution in the interpretation of animals' responses to alternative choices in experimental settings where they might have to choose between the least undesirable among a limited number of unsuitable solutions. Along the same lines, Hall and Roshier (2016) highlighted the non-trivial problem of interpreting animals' behavioural and physiological data, and the need to beware the illusion of objectivity that may derive from such data. In other words, understanding animals, and their interaction with technology, remains a significant challenge, just as it still is in animal studies; but, just as it is done in animal studies, methods can be devised to achieve a level of insight and reduce the arbitrariness of or biases in choices made by researchers during the design process.

The ethics of ACI research and practice has also received a great deal of attention as of late. Designing user-centred technology for animals and even involving them in the design process clearly raises ethical issues, especially under the assumption that animals are not capable of providing informed consent to their involvement. In this respect, Mancini (2011) proposed a small set of principles requiring the non-discriminatory treatment of animals participating in ACI research, experimental set-ups that give animals control over their own involvement, and their (mediated) consent as a condition for their involvement; Väätäjä and Pesonen (2013) proposed a comprehensive set of guidelines pertaining to the design, execution and reporting of human-computer interaction studies involving animals, which was consistent with current legislation on animal research, particularly the framework of the 3Rs, and required researchers' awareness of and compliance with animal welfare requirements; these values were echoed by Hirskyj-Douglas and Read (2016)'s principles for working with dogs. Again, whether it might ever be possible to

enable animals to truly consent to their involvement in research whose implications they likely do not understand, and to give them control over procedures whose aims they likely ignore, is questionable to say the least. Nevertheless, it is possible for ACI researchers to use these concepts as a guide to reflect on their research design and practices.

Overall, while Animal-Computer Interaction as a discipline is only just starting to take shape, the main challenges facing ACI researchers are already clearly evident. However, it is also clear that ACI researchers are actively exploring a range of approaches to address these challenges, drawing from both interaction design and animal studies, as well as other fields. The contributions included in this special issue illustrate in more depth some of the key issues that characterise the current state-of-the-art in ACI.

4. Overview of contributions

Encompassing various contexts of interest (involving free-living wild animals, wild animals in captivity, working animals, companion animals), this special issue's contributions explore questions the authors have grappled with during their research activities (field studies, designs, evaluations), and how these might be addressed (frameworks, methods, solutions). Importantly, these contributions also illustrate issues of concern that require conscientious investigation, and they question anthropocentric assumptions that still underpin human-animal interactions as well as interaction design as a discipline and practice.

To begin with, in Theorizing animal–computer interaction as machinations, Aspling and Juhlin (2016) demonstrate the complexity and subtlety characterizing interactions between humans, animals and technology, particularly when actors do not have the kind of direct, one-to-one relation typical of humans and their companion animals. Their ethnography of the use of mobile proximity sensor cameras during ordinary wild boar hunting shows how the technology mediates a diffuse, and non-directly observable form of interaction, which involves humans and wild animals in a setting that is both technological and naturalistic and whose subtleties require the use of non-dyadic interpretational paradigms. Thus, with reference to Actor-Network Theory and Goffman's notion of strategic interaction, the authors articulate a game-like interaction that is prolonged, networked and heterogeneous, in which members of each species are opposed to the others in a mutual assessment acted out through a set of strategies and counter-strategies. The authors further highlight the role of theory in helping researchers to grasp the nature of animal-computer interactions and to excite the imagination in a way that is generative for design and that, at the same time, can support the development of ACI as a discipline.

Perhaps there is no better place than the modern zoo to examine a variety of encounters between humans, animals and technology. In Interactive Technology and Human-Animal Encounters at the Zoo Webber et al. (2016) discuss a range of technologies to be found in the zoo and oriented towards different users. These include technologies used by visitors to learn about animals, technologies used by zoo personnel to educate visitors, and technologies used by keepers with resident animals. Through interviews with zoo personnel about their experiences with technology, the authors explore a range of scenarios in which technology mediates and significantly influences, in both constructive and disruptive ways, a multiplicity of indirect, distributed and transient social interactions among many actors. The authors highlight the importance for ACI researchers to study contexts in which such multiple, multispecies socio-technological interactions occur as a matter of course. Their findings also show the importance for ACI frameworks and methods to capture the nuances of such interactions, in order to inform the design and evaluate the effects of technological interventions, so that these can foster positive encounters.

From occasional, distributed and brief interactions at the zoo, we then move to longitudinal, more intimate relations such as those we have with the companion animals we share our daily lives with. In CompanionViz: mediated platform for gauging canine health and enhancing human-pet interactions, Nelson and Shih (2016) examine how technology can mediate the human-animal bond. The authors extend the notion of quantified- self to include non-human users in the specific context of obesity and exercise. They discuss the development and evaluation of CompanionViz, a personal information visualization prototype, designed to inform owners about their dogs' caloric inputs and outputs, and level of physical exercise, whose associated wearable platform repurposes Fitbit sensors calibrated to individual dogs' movement. The authors report on an in-the-wild field study conducted with dog owners to explore the influence that personalized visualizations of the data gleaned from CompanionViz might meaningfully have upon their understandings of, and relationships with, their pets. Based on their findings, they re-emphasize the urgent need for researchers to continue to explore the effects of similar and related technologies.

From using technology to gather information about animals, we move to technology that communicates with animals, making up for human shortcomings during training. In Balancing noise sensitivity, response latency and posture accuracy for a computer-assisted canine posture training system, Majikes et al. (2016) discuss the importance of timeliness and accuracy in human-canine communication, particularly where dogs are expected to learn new things by establishing associations between performing a behaviour and receiving feedback. Here, technology can help humans achieve the precision, in therms of both timeliness and accuracy, required to support dogs' associative learning process. Thus the authors describe the iterative design, development and evaluation, of a wearer-centred canine vest, which they designed with canine ergonomics in mind to ensure the wearer's comfort and which uses sensors to detect the wearer's postures and haptic actuators to give them feedback. They discuss how, in developing the behaviour classification algorithm used by their system, they had to negotiate a trade-off between low system response latency and high detection accuracy to meet the dogs' learning requirements. This work provides an example of how, albeit in a human-controlled context such as training, design can be essentially determined by animals' characteristics and thus better support human-animal co-operation.

This same commitment to supporting human-animal cooperation by developing technologies that are appropriate for the animals' characteristics is demonstrated by Byrne et al. (2016) contribution. In A Method to Evaluate Haptic Interfaces for Working Dogs, the authors present an approach to evaluating a haptic interface for working dogs who might be operating in a variety of contexts including assistance, search and rescue and policing. The authors are motivated by the fact that such working dogs are often required to operate outside the line of sight, or out of voice contact, of their owner or handler and therefore are not able to receive conventional commands and instructions during those times. Drawing on previous work that examined haptic interfaces for humans, the authors describe the implementation of a wirelessly controlled wearable vest for dogs featuring a small vibrating component on the dogs' neck. Experimenting with a number of participants, they show that dogs can learn to respond to haptic cues and to exhibit trained behaviours in response to those cues. Thus, they describe a carefully designed set of protocols to facilitate the accurate training of dogs in order to enable the systematic evaluation of different haptic interfaces. This rigorous evaluation approach could also be applied when introducing dogs to other technologies, which is a growing issue as the ACI community design new, or re-appropriate old, digital devices that animals might be expected to use.

At the other end of the spectrum, Hirskyj-Douglas et al. (2016) demonstrate an approach to elicit requirements for or evaluating interactive technologies, which is almost entirely driven by the

animal participants, in this case dogs. In response to the proliferation of television programmes targeted to dog, in A dog-centred approach to the analysis of dogs' interactions with media on TV screens, the authors investigate canine responses to different kinds of video content. They note how, unlike with technology that aims to support human-animal cooperation around specific tasks, with technology for canine entertainment dogs are the key stakeholder, which has methodological implications for the level of control and autonomy afforded to canine participants when conducting related studies. Thus the authors present dogs, who are free to roam in a familiar room, with different videos displayed on adjacent screens, and they use cameras to record the movements of the dogs' head between screens as an indicator of the dogs' shifting attention. The findings show the viability of the approach, which provides a valuable example of participant-centred research whose ultimate aim is to design user-centred technology for animals.

Finally, the last contribution examines the relation between user-centred design and participant-centred research, within a wider discussion about the ethical implications of ACI, and provides a set of ethical principles for animal-centred research and practice. In Towards an animal- centred ethics for animal-computer interaction, Mancini (2016) examines the limitations of existing regulatory frameworks for the involvement of animals in research, including the 3Rs, against the core aims she had previously proposed for ACI. From these, the author derives implications for a user-centred and participant-centred ethics, including the need to garner animals' mediated and contingent consent to their involvement in research. She further reflects on the relation between the values of animal-centred research aspired to by ACI, and the values that inform human-animal relations in human society, outlining practical implications for dealing with the welfare and autonomy of animals involved in ACI research. Finally, the author notes how the rise of ubiquitous computing requires a reinterpretation of basic interaction design concepts and the development of more universal paradigms, and how ACI can contribute to such a process while fostering the development of a more inclusive, multispecies society.

5. Ways forward

As we have outlined above, the contributions that form this Special Issue illustrate how, consistent with a broader cultural shift, researchers in the field of ACI are endeavouring to study and design technological interactions situated within more-than-human worlds (Bastian et al., 2017). In such worlds, humans can no longer be legitimately considered the only stakeholders, the only participating agents and not even the only design contributors; instead their activities, experiences and lives are inextricably entangled with those of other animals, whose activities, lives and experiences are being equally transformed by interactive technology. In their contributions to this Special Issue, the authors share how they are dealing with this transformation: by exploring a variety of contexts in which animals encounter technology, from hunting fields to zoos, from public places to domestic settings, from work training to entertainment; by studying the subtleties of how technology influences individual animals as well as their social interactions; by designing technology that can support human-animal cooperation or enrich animals' lives; by developing highly controlled or highly naturalistic methods for evaluating and eliciting requirements for animal interfaces; and by pondering the significance and ethical implications surrounding animal-computer interactions as well as related research processes and practices within their socio-cultural contexts. Drawing from the interaction design tradition but also from animal studies, such as animal behaviour or welfare, and social sciences, such as anthrozoology or animal geographies, the diverse body of work exemplified in this Special Issue is gradually shaping Animal-Computer Interaction as a discipline.

Over the past five years, efforts to develop ACI as a discipline have significantly intensified, increasingly leading to the appearance of new theoretical, methodological and empirical work,

which is starting to be recognised in the leading presentation and publication venues of interaction design (this Special Issue being a case in point). This trend is particularly encouraging when considering the benefits that, as a discipline, ACI could potentially yield. These primarily include the improvement of animal wellbeing, and human-animal cooperation and relations more broadly. Additionally, as suggested elsewhere (Mancini, 2013), the development of multispecies research methods and design frameworks could enable interaction designers to better account for the cognitive and ergonomic diversity of their prospective users, whatever their species; furthermore, broadening participation in interaction design could deliver technology that supports multispecies communities and contributes to the development of more sustainable forms of technologically supported living. The potential benefits could be highly significant for animals, humans and the intimately interconnected ecosystems we all share.

However, we are just at the beginning of what will doubtless be a long and arduous journey, full of challenges to be overcome (e.g. figuring out what animals need and want), pitfalls to be avoided (e.g. anthropomorphic biases) and tensions to be negotiated (e.g. between interspecies differences and competing interests). With this in mind, we wish to highlight three areas of reflection, where we hope efforts will intensify going forward. Firstly, at present, ACI's theoretical and methodological arsenal is still very limited and heterogeneous for the purposes of defining the discipline. Arguably, nobody knows how to design user-centred interactive systems better than interaction designers, but on the other hand nobody knows how to understand prospective animal users better than those researchers and practitioners who study, work with and care for them. Thus, it is essential that ACI researchers seek to increase their interdisciplinary collaborations to develop an arsenal of frameworks and methods that are sufficiently robust but also versatile enough to help them deal with the challenges, pitfalls and tensions they will encounter. Secondly, much work in ACI so far has engaged with practices that might be considered more appealing and less controversial than others (e.g. caring for companion animals). Of course, this is somewhat physiological, particularly considering the co-evolution humans share with companion species such as dogs; nevertheless, to be taken seriously beyond the boundaries of its own community and to deliver significant impact in the real world, ACI researchers need to engage with domains that for some may be more controversial or difficult to deal with (e.g. animal farming, animal research), where negotiating existing tensions and competing interests may be harder, but where the number of animals who could benefit is incomparably greater.

Finally, so far much ACI work seems to express anthropocentric concerns to ultimately address human needs (e.g. training working animals, monitoring or playing with companion animals). As discussed above, interspecies communication barriers and power inequalities make it easier for anthropocentric interests to prevail and for technology to become exploitative. Therefore it is key that ACI researchers exercise care in considering the implications of the technologies they design for the welfare and autonomy of their prospective users and that they endeavour to develop technology that is demonstrably relevant and potentially beneficial to prospective animal users. At the same time, North and Mancini (2016) point out how interaction design is a process of incremental approximation where mutual understanding between parties derives from shared practices and associations formed during an iterative process of trial and error. From this perspective, perhaps what is most important in ACI research and practice is how researchers and designers attend to the process, how they remain mindful of what they are trying to achieve; then perhaps it is still possible to negotiate interspecies barriers and differences, and produce something of value for and with more-than-human users and participants. Technology has been happening to animals for decades and will likely continue to do so with or without the involvement of interaction designers. However, by moving from the values, and working with the rigour and creativity, that characterise interaction design's best tradition, ACI researchers could significantly influence the development of animal technology. Difficult as it may seem to

envisage from where we stand today, they could eventually enable animals to make technology happen, having broadened and enriched interaction design along the way.

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