# Animals’ Entanglement with Technology: a Scoping Review

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## Abstract

Animals living alongside humans are navigating a world increasingly filled with technology, yet little is known about how they interface with these systems, whether designed for, with, or around them. Anchored in HCI and ranging across diverse fields, this scoping review analyzes nearly 800 research works to explore the diverse realities of animal-technology research, examining the who, what, why, and how of animal-technology entanglements. Our analysis revealed 11 research objectives and eight types of technologies across six animal contexts. By categorizing the literature based on authors’ aims and intended beneficiaries, we highlight trends, gaps, and ethical considerations. We find that most systems involve animals with limited potential for direct engagement or sense-making. We propose a framework to understand animals as users versus subjects of interactive systems, focusing on feedback, empirical testing, and projected animal benefits. Our findings offer a foundation to understand current and future animal technology research and the diversity of animal user experience.

## CCS Concepts

• **Human-centered computing → HCI theory, concepts and models**; *Interaction paradigms*;

## Keywords

ACI, Animal-Computer Interaction, Scoping Review, Animal Technology, Pets, Farming, Zoo, Working Animals, Wildlife, Laboratory Animals,

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## 1 Introduction

The use of tools in animals across species have been documented as dating back millennia, from chimpanzees building hammers [13] or using sticks to extract termites [142], to dolphins wearing marine sponges to protect their snouts while foraging on the seafloor [150]. Animals have also been interacting with human-made technologies in various forms for over a century, bringing new dimensions to how they engage with the world. Some early examples – often problematic – of animal-technology interaction include pigeons trained in the 1940s to operate touch screens to guide missiles [147], or gorillas such as Koko, trained in 1977 to select icons on a Mac II as part of animal cognition research [121]. As technology advances and our coexistence and relationships with animals evolve, the prevalence of animal-technology interactions appears to be expanding. However, this trend has yet to be fully quantified.

Additionally, conceptual approaches towards developing technologies for animals, along with the consideration of whom these technologies are ultimately designed to benefit, have also evolved in the past decades, notably since the 2011 Manifesto on Animals-Computer Interaction [96]. This paradigm shift towards an animal-centric design philosophy draws from principles established in the Human-Computer Interaction (HCI) community towards more ethical and empathetic design practices. Rather than using animals merely as tools to serve human purposes, there is now a greater emphasis on creating technologies to enhance the welfare and autonomy of the animals themselves. Researchers within the Animal-Computer Interaction (ACI) and HCI communities are recognizing the need to consider an animal’s perspective, which encompasses not only their behavioral responses but also their sensory experiences, preferences, and well-being.

The intersection of animals and technology spans a diverse array of fields, contexts, objectives, and types of technology–where technology can be broadly defined as digital or computational systems involving some form of input and/or output. This broad definition encompasses a wide range of applications, from wearables for assistive dogs [71], to bioacoustic wildlife monitoring systems for conservation [166]. It includes vision-based health monitoring systems in cows aimed at physical health and productivity [165], as well as social enrichment video-calling systems for pets [80]. Given this diversity and evolving perspective, there is value in capturing and disentangling the broad landscape of animal-technology research to chart the varying forms of animal engagement, the diverse approaches to animal understanding and usership, the intended beneficiaries of these systems, and the potential relevance for the broader field of HCI.

In this context, we present a scoping review of technological systems designed for, or used with animals. Following PRISMA-ScR guidelines [160] and Arksey & O'Malley's framework [4], we analyzed 795 research works spanning over 200 venues. Our methodology, beginning with the ACM digital library and extending beyond it through ancestry searching and snowballing, enables us to map the landscape of animal-technology research through multiple lenses: *who* (authors, species, contexts), *what* (technologies), *why* (beneficiaries, objectives), and *how* (empirical testing, ethical standards). The contributions of this work are fourfold:

- A typology of animal-technology research, classifying contexts, technologies, objectives, beneficiaries, and ethical considerations.
- A comprehensive mapping of the animal-technology research landscape between 2000 and 2024, revealing rising trends in conceptual works, context-specific silos in technology application, limited feedback for the animals, and varied approaches to ethical considerations.
- A framework for understanding animals' roles as users vs subjects in interactive systems based on the potential of sense-making through sensory feedback, intended beneficiaries, and empirical testing, complemented by systematic analyses of (1) the distribution of tactile, visual, auditory, and olfactory feedback modalities and (2) the framing of beneficiary roles across different animal contexts and technologies.
- An analysis of ACI's relevance to HCI, identifying eight key intersections, namely: human-in-the-loop design; multispecies interdependence; methodological innovation, physiological diversity, post-human perspectives, environmental sustainability, evolutionary understanding, and designing for otherness.

Based on these findings, we propose concrete recommendations and practical steps for experienced ACI practitioners and HCI researchers interested in extending their work to animals.

This work aims to inform both theoretical discourse and practical application in HCI and ACI communities and for stakeholders across domains. For example, our mapping of ethical considerations and institutional oversight can provide policy makers with data-backed evidence on current gaps in intervention standards. Our analysis of the presence and distribution of feedback modalities (tactile, visual, auditory, olfactive, etc.) for animals to potentially make sense of the interactions, can offer caregivers a road map to explore technologies appropriateness for their own contexts. Our framework for classifying animals as users versus subjects provides developers and researchers with practical criteria to evaluate their approaches. Although the scope of this review is extensive, its breadth enables us to provide a more holistic evidence-based understanding of how animals and technology interact, supporting more thoughtful development of animal-centered technology in research and practice.

## 2 Background

As the field of HCI expands into the animal realm, researchers are increasingly exploring how animals engage with technology, whether as unknowing participants, active users, or coerced subjects [89]. There is value in extending the user-centered principles of HCI to animals, as a way to promote new methods that prioritize animal welfare, engagement, and agency [96]. This section provides an overview of recent works in animal technology, key concepts of interaction within HCI, and the complex roles of animals as users or subjects of technology.

### 2.1 Evolution of ACI

As a young discipline, ACI draws from HCI, adapting its frameworks to consider animals' use of technology. While some areas of ACI focus on non-invasive and seamless inclusion of data without animal awareness, such as health monitoring systems or facial recognition, others have explored agency-enhancing technologies that offer animals more control and choice over their lives and environment [80, 82, 104]. The field has produced a large body of work promoting best practices for improved engagement and ethics [98]. For instance, unlike traditional animal research methods that often rely on food rewards and constrained settings, ACI may rather promote innovative user engagement methods and non-coercive feedback systems that leverage and respect animals' natural behaviors [20]. There has also been efforts to expand such ACI approach to ethics and animal involvement to wider, or more traditional, animal behaviour fields [99].

However, despite growing conceptual work supporting ethical and agency-focused animal-centered principles [98], the application of these principles remains uneven and illusive [6]. Some technologies designed for animals still lack the depth of reflection around usership and engagement seen in human-centered designs. Efforts have been made to explore how animals can inform the design process through their individual characteristics, behaviors, and needs [1]. Yet, only a few have attempted to quantify and characterize the scope of what interaction means in the field.

### 2.2 Literature Reviews of Animal-Technology

In the past few years, a handful of review works have emerged, each providing a distinct lens on animal-technology research. Hirskyj-Douglas' review [59] categorizes studies by type of technology between tangible and physical, haptic and wearable, olfactory, screen-based and tracking interfaces and context. Jukan et al.[75] reviewed 80 studies focused on smart technologies and animal welfare, exploring how these technologies contribute to keeping animals healthy and positively stimulated, particularly in farming settings. Likewise, Egelkamp and colleagues [32] examined a corpus of 72 instances of zoo animals' interactions with screen-based systems, highlighting opportunities for cognitive and enrichment applications. Meanwhile, Gupfinger et al.[50] explored the historical and current uses of technology for auditory expression among animals, particularly in the context of music. Ashooh et al. [5] established a corpus of 79 ACI articles to survey demographic reporting standards across fields. Kresnye et al.[87] reviewed a corpus of 102 studies, categorizing research by animal context (e.g., lab, farm, zoo, companion, wildlife) and methods used, focusing on enrichment-based systems framed for animal welfare, thus not incorporating the many other reasons technology is used with animals in the field. Although the work was not directly focused on animals, Webber and colleagues [168] conducted a scoping review of 103 research works on nature engagement highlighting the relevance of this model of structured approach to the CHI community. Although each of these reviews offers valuable insight, they often focus on specific contexts or technologies, typically examining around 100 studies, many of which are now over seven years old. This leaves a significant gap in our comprehensive understanding of animal-technology interactions across settings.

## 2.3 Conceptualizing Interaction in HCI and ACI

The concept of 'interaction' has been extensively debated in HCI, often in attempts to characterize and understand how users engage with systems, resulting in acknowledging the complexity and variability of the term. Hornbæk [63] quantified the increasing number of modifiers used with the word "interaction" in HCI, suggesting a growing complexity and standardization in how the term is applied. Various definitions have been proposed. For example, some have conceptualized interaction as a dialogue, a cyclical process of taking turns transmitting and receiving acts [116]. Others have defined interaction in terms of tool usage, in which a user manipulates something to have some effect or outcome in the world [64]. Others still have defined interaction in terms of a user's experience and how they experience a product or service [53]. A widely favored model views interaction as a relationship based on a feedback loop between a user and a system, highlighting the importance of system responses in shaping the user experience [47]. In this model, feedback becomes a crucial component of interaction, allowing users to engage meaningfully with technology. In ACI, this feedback loop is often left incomplete, as the animal's understanding of the interaction is rarely fully known and frequently not prioritized in system design [59].

These challenges in designing for and evaluating non-human interaction push us to question our basic assumptions about what constitutes interaction. The study of animals using technology can thus bring new perspectives on the concept of interaction for HCI. However, like early HCI, the terminology used in the animal field about interaction has not yet been clearly conceptualized or defined. ACI researchers have considered interaction broadly, including: systems in which animals exert control over a system [16, 133, 177], technologies that respond to animal behavior [44], tools for quantifying animal's interaction with humans through behavior analysis [90, 106, 113, 130, 161], or human technologies for simulating animal sensory experiences and co-presence to build empathy across species [81, 162, 175]. One of ACI's objectives is to explore how technology can be made more usable for animals and create meaningful experiences for them, studying specific parts of the feedback loop, such as how animals can input to technology [73, 124, 137, 177], how animals can be soothed or stimulated by technology [8, 44], and how animals and humans can connect through technology [21, 91, 106, 113]. However, the application of these HCI concepts to animals presents challenges, particularly when trying to infer understanding or intentionality, which are difficult to assess in non-human users [59].

## 2.4 Animals as Users vs. Subjects of Technology

An important conceptual distinction is in determining when animals are users of technology versus subjects. Usership implies a level of engagement, agency, and potential understanding of technology, moving beyond the traditional view of animals as passive recipients of human-imposed systems. Lawson et al. [89] explore this distinction in terms of consent and the extent to which technologies are imposed on animals. This raises further questions about the criteria needed for animals to be considered users and the role played by feedback and understanding.

Several studies have explored these boundaries, examining how technologies can provide animals with feedback to facilitate sense-making [40, 59]. The so-called "gulf of evaluation" in HCI—where users interpret the outcomes of their actions—has been applied to animals, highlighting the challenges of closing this feedback loop in non-verbal species [115]. As the animal's understanding of what the interaction means is not fully known, this area remains an open field of inquiry, with ongoing debates about what constitutes true interaction and understanding in animals. Although these open questions allow for rich discussions and diverse perspectives, they also present challenges for consistent data-supported approaches and assessments. Our work aims to address these gaps by synthesizing findings across diverse contexts of animal-technology interactions in order to contribute to HCI discussions on user-centered design, feedback, and agency, fostering more inclusive and empathetic technological practices.

## 2.5 ACI Positioning and Relevance for HCI

The relationship between HCI and ACI has been a subject of scholarly discussion, with researchers exploring how these fields inform and enrich each other. Key works examining this relationship include a 2016 ACM NordiCHI workshop "Where HCI meets ACI" [60] and Mancini's seminal paper [97], which argued that ACI is directly relevant to and even encompasses HCI. This work proposed three key benefits of ACI to HCI: strengthening HCI as a discipline through comparative study of interaction, broadening participation in interaction design through multispecies considerations, and supporting sustainability through more inclusive design practices.

To understand this ACI/HCI relationship, it may also be helpful to consider how HCI itself has evolved and whether one can observe parallels or differences in the evolution of ACI. Bødker's highly recognized work identifies three waves of HCI research and practice [11, 12]. The first wave, emerging in the 1970s, emphasized human factors engineering and cognitive science, focusing on optimizing human-machine interaction through controlled experiments. The second wave (1990s) introduced workplace studies and computer-supported cooperative work, recognizing the importance of context and practice. The third wave broadened to consider emotional, social, and cultural aspects of technology use in everyday life. More recently, scholars have proposed an emerging fourth wave characterized by post-humanist perspectives [138] and considerations of human-technology entanglement [39], where questions of ethics and agency become central. These waves parallel what Harrison [52] described as the three paradigms of HCI: Human Factors, Classical Cognitivism, and Phenomenologically-Situated, offering perspectives on the field's evolution.

At first glance, the evolution of ACI can appear to mirror aspects of HCI's development, particularly in the positioning of its subjects: from objects of modeling and study (as seen in Skinner boxes and animal models [148]) to actors supported within their existing communities of practice through technological support in contexts as diverse as working animals [71, 135] or animal agriculture [51]. However, there has been little structured research that has examined either the linearity of this evolution or its implications for HCI research. In this context, where ACI as a field demonstrates potential value for HCI development, we believe that a large-scale review can provide insights into how these domains intersect. Our analysis examines this relationship through two lenses: the temporal evolution of both fields relative to HCI's waves of development, and the specific ways ACI can inform and enhance HCI practices across multiple dimensions and vice versa.

# 3 Methodology

This scoping review aimed to address the *who*, *what*, *why*, and *how* of animal technology research from an HCI perspective focusing on interaction. We sought to paint a general picture of this field, identify gaps and opportunities, and provide insights for researchers focusing on animals as users of interactive technology. This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines [160]. Our approach was guided by the five stages of Arksey & O'Malley's framework for scoping reviews [4]: (1) identifying the research question, (2) identifying relevant studies, (3) study selection, (4) charting the data, and (5) collating, summarizing, and reporting results. The team was composed of two field experts each with over ten years of expertise in ACI (first and last author) who were in charge of creating the corpus, iteratively refining the categories by reflecting on the mapped landscape and analyzing the data. Two trained labelers (second and third author) received training in category classification, reviewed and encoded the papers, consulted with the first author for any questions, and participated in the team discussions.

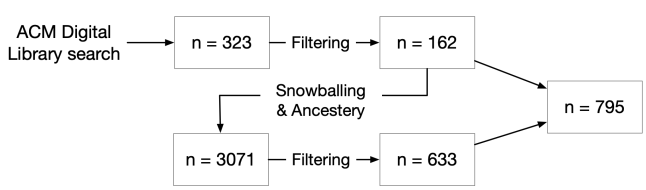



**Figure 1: Paper search methodology illustrating the overall number of papers included in the review with points of exclusion, from ACM library search round evaluations, and the snowballing/ ancestry round evaluation**

## 3.1 Identifying research questions

This work starts with the goal of drawing a broad picture of various fields, objectives, techniques, and contexts where animals meet technology to understand the diversity of how interaction is understood. As this context encompasses a very varied type of work, where animals are involved in a wide range of technology for very diverse objectives, we begin by casting a broad net on the field and establish definition and boundaries. To identify the current landscape, trends, and gaps, we start with the questions of *Who, What, Why,* and *How*.

- **WHO**: Identifies researchers, targeted animals, species, and their roles. It includes the publication venues and author affiliations, as well as the animal species and context.
- **WHAT**: Examines the type of technology used, categorized based on the technological elements described by the authors.
- **WHY**: Explores the stated objectives and beneficiaries, categorizing them into relevant groups.
- **HOW**: Investigates both design and methodological aspects including empirical testing, presence and type of feedback, mention of ethical consideration or institutional approval.

This framework provided a structure to analyze how scholarly work in animal technology has considered the various ways animals and technology interact.

## 3.2 Selecting Relevant Articles

In collaboration with a research librarian, we developed a search strategy to identify relevant literature starting with an initial corpus set, screened independently by two reviewers, then extended with forward and backward citation search, delimited with inclusion and exclusion criteria. The search was conducted from June to August 2024 and included papers published between 01/01/2000, and 06/01/2024.

*3.2.1 Corpus starting set, citations search.* We conducted an initial search of the Association for Computing Machinery (ACM) digital library for the core starting set as a manageable source and to anchor the corpus into interaction-focused systems. A test search of the term "animal" yielded over 400,000 results for full-text search and over 60,000 results for abstract search. Consequently, for manageability, we limited our search of animal-related keywords to the title using singular and plural versions of over a dozen animal species as well as general animal-related terms. As it is common practice in ACM research to use literary devices in their titles, we explored possible euphemistic, metaphorical, and idiomatic terms that could be used to refer to animals. To add focus on the interaction between the animal and the technology, we constrained our search to publications containing interaction-related terms within the abstract, The full query syntax can be found Figure 2.

The search yielded a total of 323 results. We used Covidence, a web-based software platform, to manage the screening process using titles and abstracts [28]. The first and last authors independently screened all titles and abstracts (and when needed, full-text review) against inclusion and exclusion criteria. Disagreements were resolved through discussion, with a third reviewer consulted when necessary. This resulted in 162 items for our corpus starting set. Next, we used SpiderCite [152] to conduct forward and backward citation search to identify additional relevant articles, extending our search beyond ACM. This systematic approach examines both all the works citing our initial papers (forward citation) and works cited by them (backward citation) essentially allowing to navigate both "upstream" and "downstream" in the research lineage related to a particular study. While broader database queries (e.g., through

Query Syntax: "query": Title:("animal" || "animals" || "pet" || "pets" || "zoo" || "aquarium" || "mammal" || "mammals" || "bird" || "birds" ||"wildlife" || "livestock" || "canine" || "feline" || "primate" || "interspecies" || "tail" || "paw" || "claw" || "egg" || "collar" ||"harness" || "dog" || "dogs" || "cat" || "cats" || "parrot" || "parrots" || "fish" || "insect" || "insects" || "reptile" || "reptiles" || "poultry" || "chicken" || "chickens" || "monkey" || "monkeys" || "horse" || "horses" || "bat" || "bats" || "whale" || "whales" || "pigeon" || "pigeons" || "cow" || "cows" ) AND Abstract:("interaction" || "interact" || "interacting") "filter": ACM Content: DL

**Figure 2: Search Query syntax for creation of the corpus starting set form ACM digital library**

Scopus) were considered, anchoring our search in ACM allowed us to specifically examine how the CHI community engages with animal-technology research while maintaining a manageable corpus size. Such citation-based method, which has been shown to yield comparable results to database searches [72], more specifically aims to reveal the evolution of ideas within and beyond a specific community. This search led to an additional 3,071 papers being screened similarly to the starting set. This resulted in an additional 633 items being added to the corpus. Over the two screening phases, the two reviewers obtained an inter-rater reliability score of 87% calculated by Covidence as percentage agreement.

*3.2.2 Terminology and inclusion/exclusion criteria.* Our screening and selection process was based on terminology and agreed-upon definitions of key terms (animals, technology, and interaction) as well as clear inclusion and exclusion criteria iterated upon by the two reviewers based on preliminary field exploration and concretized from the starting-set screening process. We considered the studies that met the following criteria:

- Inclusion 1: Studies focusing on the interaction between animals and technology
- Inclusion 2: Publication date between 2000 and 2024
- Inclusion 3: English language only publications
- Inclusion 4: Peer-reviewed journal articles, conference papers, and book chapters
- Exclusion 1: Publications focused solely on robotic animals or virtual representations of animals
- Exclusion 2: Workshop proposals, doctoral symposium papers, or news articles
- Exclusion 3: Papers that considered animals as an abstraction or metaphor for storytelling
- Exclusion 4: Biological or biomedical research using animals solely as models for human health research

We chose to exclude work related to the use of technology in biomedical research that primarily benefits human health. However, we included enrichment technology for laboratory animals. We excluded applications for farm management but included farming technology that is directly in contact with animals. We excluded research on robot animals or virtual animals but included work using animal data to inform robot design or studies on animals' reactions to robots. The starting set review also helped crystallize our working definitions of key terms used for this review, including animals, technology, and interaction:

**Animals**: We defined animals as non-human, multicellular eukaryotic organisms. This included all life stages, including pre-hatching eggs, but excluded microbes and plants. We included studies on dead animals only if used as a proxy for live animal interaction with technology, like in the case of research on European hedgehogs and automatic lawnmowers, where the research aimed to inform technology design for live animals [129].

**Technology**: We focused on digital or computational systems. We began the work without preconceptions about technology, allowing for a broad exploration of the field. We included both prototypes and fully developed technologies, as well as speculative designs that were conceptualized but not yet implemented. However, we excluded purely methodological or animal training work that did not cover digital or computational elements.

**Interaction**: We defined interaction broadly as a process where an input leads to a change in output within a system [64]. In our context we considered interaction to occur when either an animal-based input has consequences within a technological system, or when a technological system's output is made to be used in the context of animals. We considered interaction regardless of bidirectionality, consciousness, agency, or the animal's understanding of the systems to explore the full range of animal-technology engagements in research.

## 3.3 Charting the Data

Following Arksey et al.'s [4] "descriptive-analytical" method, we processed each paper to extract relevant data.

*3.3.1 General Extraction Process.* We used a multi-step approach involving different levels of detail based on the paper type. A primary extraction template was applied to the full corpus, capturing general metadata, including author affiliations and venues and distinguishing between conceptual works and interactive systems, directing subsequent steps. For interactive systems, further detailed extraction was performed to answer the key questions of WHO, WHAT, WHY, and HOW. These questions guided our understanding of the species involved, technological context, feedback mechanisms, and the intended beneficiaries. Finally, interactive systems that included empirical testing underwent an additional layer of data extraction. Here, we specifically examined for potential feedback provided to animals, and the ethical considerations reported. The extraction template was developed by the first author and iteratively refined through multiple rounds of analysis on the initial starting set, each followed by a reprocessing of the full set.

*3.3.2 Use of AI Tools and Manual Verification.* Each paper was assigned to one of the four authors and a preliminary stage of data extraction was done using Claude.ai [3], a large language model, to standardize and streamline the process. Using an identical query prompt, the AI tool provided an initial pass of data extraction, which was then meticulously reviewed by the assigned author to

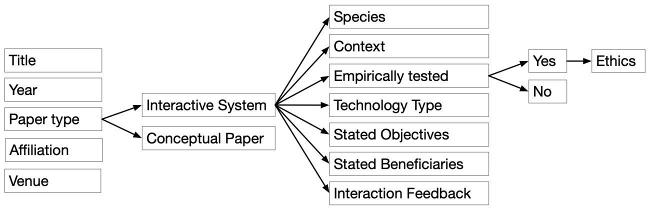



**Figure 3: Search Methodology in three steps: first, the extraction of metadata and paper types from our entire corpus; second, a more detailed extraction for items categorized as "interactive systems," and third, declared ethics statements for empirically tested systems**

correct any inaccuracies and address potential biases inherent in AI processing.

Indeed, recognizing the potential limitations and biases of AI-assisted analysis, we implemented a rigorous manual verification process. Every piece of data extracted by Claude.ai was reviewed and, if necessary, corrected by the assigned author. Although frequent minor corrections were needed, with about 80% of papers requiring some manual adjustment, this process still helped in optimizing our process and productivity due to the large volume of papers. Approximately 90% of the papers were straightforward to chart following this initial extraction. For the remaining 10%, which involved more complex theoretical issues or conflicting interpretations, discussion sessions were held between the first and last author to resolve any discrepancies. This approach helps ensure a balance between efficiency and human expertise.

*3.3.3 Context and Species Classification.* Classification of species and contexts required careful examination of the roles and environments of the animals involved. We categorized the studies into six main contexts: Pets/Home, Working Animals, Farm, Zoo, Lab Animals, and Wildlife. For example, works on parrots, which were often used in both lab and home settings, required careful evaluation to determine the most fitting category. Some contexts were multifaceted, especially when the studies had applications in multiple domains. For example, cognitive testing in primates included both enrichment in zoo settings and behavioral research in labs. Similarly, gait recognition technology in horses could apply to both pets and working animals, and fish technologies could serve both preservation and agricultural needs. For such cases, we followed the contexts stated by the authors and often tagged with multiple contexts to reflect intended applications. Species and contexts where encoded independently from each others, and their distribution within our corpus are represented in Table 1.

*3.3.4 Objectives.* Objectives were directly extracted from the authors' wording and classified into 12 groups: cognitive enrichment, social enrichment, environmental enrichment, physical health, mental health, training, tracking/monitoring, preservation, service/assistance, cognitive/ability testing, human entertainment/education, and productivity. Items were often classified into multiple categories as they addressed more than one objective. The categorizations were refined iteratively based on the continuous review and discussions among the research team. For example, the category "Cognitive/Ability Testing" was introduced after identifying studies using screen-based technology purely for cognitive assessment rather than enrichment or tracking. The categorization process was meticulously managed to ensure consistency, with regular rescreening and updates to maintain accuracy. In categorizing objectives, we paid particular attention to the authors' stated goals rather than inferring additional potential applications.

*3.3.5 Beneficiaries.* We screened each item to determine whether the authors considered animals as direct beneficiaries of the work, basing our assessment strictly on the authors' descriptions. The screening of ambiguous cases led to specific considerations in the labeling of beneficiaries.

In some cases, very similar works could be labeled differently based on the authors' framing. For instance, in the context of health monitoring studies, we particularly scrutinized the authors' wording for work involving young, healthy animals. Health monitoring was not automatically labeled as beneficial, especially in cases where it appeared to be conducted primarily for research purposes, time-saving for humans, or where healthy outcomes could be ensured without the technology, as these instances did not clearly state direct or automatic benefits for the animals involved. For example, in studies such as those on wearables for dog heart rate monitoring, if the authors framed the work based on advantages for human handlers, stating, for example, "There is an increasing interest from dog handlers and veterinarians in an ability to continuously monitor dogs' vital signs" or "may yield measurable benefits to handlers' interactions with their dogs" [17], then animals were not automatically assumed to be primary beneficiaries.

Some studies presented additional ambiguities, especially when introducing stressors or discomfort to animals. We distinguished between cases where technology was introduced to mitigate existing discomfort (for instance, studies on the effect of home technology noise on animals) and those where it introduced new stressors (such as noise, radio, drones, or robots) to establish the extent to which the technology directly addressed their needs versus the needs of researchers or human users. Finally, some studies purposefully introduced potential pain, such as with head-fixation or bodily pain to build facial marker datasets. These were not automatically considered beneficial to the animals involved.

*3.3.6 Feedback.* Initially, we aimed to extract information about animals' "understanding" of technology use; however, we recognized the inherent difficulties in evaluating such an abstract concept. Consequently, we shifted our focus toward assessing sense-making from a more objective standpoint—specifically, the presence of sensory feedback provided to the animal andthe feedback modality (visual, tactile, auditory).

*3.3.7 Ethical Considerations in Empirical Testing.* Empirically tested works were scrutinized for ethical considerations, including whether authors reported an Institutional Animal Care and Use Committee (IACUC), Institutional Review Board (IRB), or other institutional ethical approvals. In the United States, IACUCs are established by federal mandate at institutions that use live, vertebrate animals for research, teaching, and testing activities. The IACUC oversees and evaluates all aspects of the institution's animal care and use program. Our protocol involved searching for specific keywords such as "IACUC," "IRB," "approval," "approved," "institutional board," "waiver," "ethics," "risk", and "comfort" to determine if ethical considerations were addressed and whether this included an official review from an external board. We noted a range of adherence to ethical guidelines, with some studies explicitly stating compliance and others not.

### 3.4 Collating, Summarizing, Reporting Results

We organized our analysis and findings in three stages, corresponding to our levels of analysis and focus. First, we examined the entire corpus (795 papers) to understand its composition in terms of general trends, publication venues, geographical affiliations, and distribution of paper types. This overview provides a broad picture of the field and its evolution. Second, we delved deeper into the subcorpus of interactive systems (526 papers). We compared this subcorpus to the full corpus to establish whether the balance of conceptual vs. applied work was similar across fields and contexts. We then analyzed the distribution of target species and examined the data in terms of species/context distribution, technology types, objectives, and beneficiaries, considering both their evolution over time and their distribution across different animal contexts. Lastly, we focused on empirically tested papers, reporting on their ethical standards and feedback to animals. Based on this analysis, we proposed criteria for considering animals as users, types of feedback provided, the nature of animal benefits, and empirical testing methodologies. Throughout our analysis, we presented quantitative data through descriptive statistics and visualizations, as well as qualitative insights from the papers.

### 3.5 Limitations

Despite a comprehensive approach, this review has several limitations. The choice of initial focus on ACM Digital Library may have led to the exclusion of relevant work from other fields. While this choice anchored our corpus in interaction-focused research, it likely skewed our sample towards HCI perspectives. A different starting point, such as IEEE publications, would have resulted in a different corpus composition.

The reliance on published, peer-reviewed, English-language work can be expected to introduce potential publication and language biases. This may have caused us to overlook insights from unpublished studies, works-in-progress, or non-English sources, limiting the global representativeness of our findings. Additionally, given the rapid evolution of this field, our review may not fully capture the most recent developments due to the lag between research conduct and publication - a common challenge for scoping reviews using such methodology [4].

Further, while the categorization and coding of the papers were agreed upon by all authors, we acknowledge the risk of inherent human biases as part of this process. We also did not systematically evaluate the methodological quality, statistical power, or participant details of the studies included in our corpus, as many did not report such information, particularly those based on pre-recorded datasets.

The final corpus is by no means all-encompassing, nor did it aim to be. It would be beyond the scope of this work to consider the entire field of animal testing using technology or to review all machines used in agriculture. Instead of a systematic review, we propose a scoping approach, anchored in HCI work, to help CHI researchers, and beyond, situate their work within this landscape. Despite these constraints, we believe that this review provides a valuable analysis of the landscape of research on animal-technology interaction from an HCI perspective.

## 4 Overview of the Corpus

Our analysis shows a strong upward trend in publications, with over 81% of the research appearing in the second half of our corpus (post-2012) highlighting the important growth in the past decade.

### 4.1 Publication venues

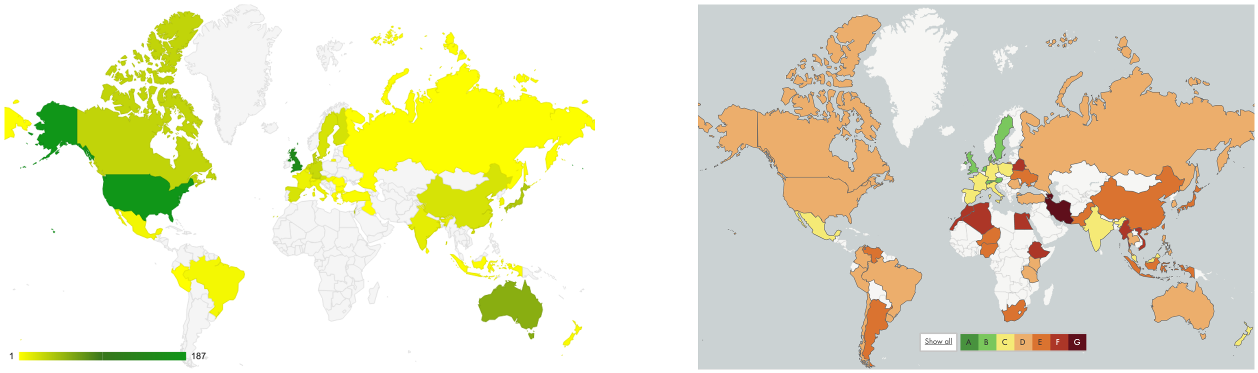
The corpus spans over 200 unique venues, reflecting its multidisciplinary nature. 46% of the papers are published within the Association for Computing Machinery (ACM), with significant contributions from the the ACI and CHI conferences accounting respectively for 40% and 14% of ACM-related papers. Other key ACM conferences include the Conference on Advance Computer Entertainment (ACE) (23 papers), the Conference on Designing Interactive Systems Conference (DIS) (24), and the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp) (15).

The strong representation of ACM is likely tied to the interaction-focused nature of the research, and the initial search focus on ACM publications. This distribution aligns with the history of ACI as a field, which began as a series of satellite events within other major ACM conferences before ACI established itself as a standalone conference in 2016. Early ACI papers were often presented at ACE and NordiCHI, reflecting the evolving visibility of the field.

Beyond ACM, the corpus includes contributions from other significant publishing bodies such as the Institute of Electrical and Electronics Engineers (IEEE), which represents 8.9% of the corpus, Science Direct (7.2%), Frontiers, and PLOS (1.9%). Individual journals with notable representation include "Computers and Electronics in Agriculture" (15 papers), "Animals" (13), "Applied Animal Behaviour Science" (13), "Journal of Dairy Science" (10), and "Nature" (2).

### 4.2 Countries of affiliation

Our corpus includes papers from a total of 54 countries, with dominant representation from the United States (28.46%) and the United Kingdom (22.98%), followed by countries such as Australia (8.52%), Japan (5.63%), Israel (4.57%) and Canada (4.57%). Compared to the overall CHI 2024 submission data used as a proxy for the HCI community, our corpus is slightly less US-centric (-9 percentage points), with a stronger representation from the UK (+ 16 percentage points). International collaborations feature prominently, accounting for 14.6% of the papers. To add context, it is worth viewing these geographical findings alongside the Animal Protection Index (API) map from World Animal Protection. The API ranks 50 countries based on their animal welfare policies, assessed through 10 indicators grouped into four goals. This index highlights disparities in global animal welfare, providing a backdrop against which the geographical distribution of our research corpus can be understood both in terms of countries where researchers are sensitive to animal rights, but also where laws and regulations might be lacking leading to




(a) Heatmap of countries of affiliation of our corpus authors, with darker green demonstrating higher country representation

(b) Heatmap showing the world's categories of animal rights, with A being the highest.

**Figure 4: Two heatmaps demonstrating the overlap between a country's standards of animal rights and publications in developing animal-computer systems**

more animal experimentation or inversely to researchers eager to investigate ways to leverage technology for animals needs.

## 4.3 Type of papers

We categorized the papers into two broad types: conceptual work and interactive systems. Conceptual works include position papers that discuss theoretical concepts, design methodologies, or ethical considerations, without presenting specific systems. This category also encompasses review articles, meta-analyses, and papers introducing animal-related datasets. Additionally, studies that did not engage directly with animals but focused on human perceptions of animal technology (e.g., workshops and surveys with caretakers) were included as conceptual works.

Conceptual works constitute 31.3% of our corpus. Emerging since 2006, their prevalence has remained relatively stable, comprising between 25% and 35% of publications over the past decade. These papers are critical for setting the future direction of the field, offering theoretical insights and framing ethical considerations. However, they often lack the granular details on technology types, species, and practical implementation needed for a deeper analysis of animal-technology entanglements. For a more in-depth analysis, we focus on interactive systems and exclude conceptual papers, and reviews from our detailed examination of species, technology, objectives, and perspectives.

# 5 Interactive Systems for/with/on animals

Papers from ACM venues represented 38.40% of our interactive system subcorpus, still a large share but a slightly smaller percentage (-7 percentage points) than our full corpus. This indicates that ACM presents a higher proportion of conceptual works than other venues. The remainder of the "Interactive Systems" works came from diverse fields, including farming, biology, animal cognition, psychology, engineering, and veterinary sciences, among others.

## 5.1 Species representation

The most represented species in this corpus was dogs, appearing in 178 papers (over 35% of the corpus). Dogs were presented as

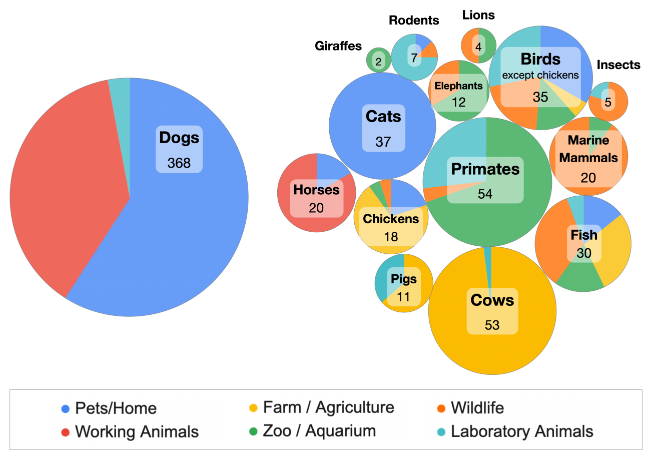



**Figure 5: Bubble graph illustrating the animals within our corpus and in which context the technology developed for them was developed.**

intended beneficiaries 40% of the time and received feedback on the interactions in 40.2% of the cases. These were mostly in the context of pets/home (53%) but were also significantly represented as working animals (35%) and in lab contexts (2.8%), such as research comparing the processing of human emotional faces by pet and lab dogs [7]. For pet dogs, we count frequent instances of wearables, robot interaction, and mental/physical health monitoring. Systems involving working dogs covered many topics often without providing input to the animals, such as gait detection monitor for sled dogs [127] or predicting puppy support dog suitability [26]. However, some works, particularly those around assistive tools helping with job tasks, provided feedback to the animal and required active animal engagement such as vibrotactile wearable for hunting dogs [113].

**Cats** appeared in 33 papers, all in the context of pets/homes, including shelters. The targeted beneficiaries of these works were the cats themselves 28% of the time and they received feedback from the technology 40% of the time. Cat-centered systems included location wearables for location tracking [155], augmented litter box for health monitoring [122] or screen-based interspecies game [161].

**Non-human primates** were also strongly represented with 56 papers, including 12 on chimpanzees, 7 on gorillas, 5 on marmosets, 4 on lemurs, 4 on white-faced saki monkeys, 2 on baboons, and 1 on siamangs. These were exclusively in zoos, lab research, or wild and semi-wild environments, often for cognitive/ability testing but also enrichment. Overall, 60% of these works presented the animals as intended beneficiaries often through auditory, screen-based, or agency-based enrichment [58].

The **avian family** included 35 papers across all contexts. Most predominantly, chickens (18 papers) were often featured in farming contexts but also appeared in pets/home settings. Nine papers focused on eggs-based topics such as fertility detection [30], nest attendance [143] and augmented pre-hatching communication [83]. Fowls were presented as intended beneficiaries 27% of the time. Apart from chickens, the avian category included work on various species of parrots (14 papers, in both lab and pet contexts) in contexts including mediated learning [123] or enrichment [79], pigeons (4 papers in lab context), zebra finches in the context of video voice preference [42], penguins with a bubble curtain enrichment [118], owls vocalization identification [139], and seabirds. These birds were considered the targeted beneficiaries in 40% of the works.

We counted 53 papers on **cows**, with only 13% aiming to benefit the animals directly. These papers were mostly in the context of farming, focusing on monitoring, calving time prediction, vision muzzle detection, and other health, monitoring and productivity aspects. There were 20 papers on **horses** (20% aiming to benefit the animals), spread between working animal and pet contexts, mostly focusing on monitoring, physical health, and mental health. Ten papers on **pigs** identified them as beneficiaries 27% of the time.

We counted 50 papers on **aquatic animals**, including 20 on marine mammals, exclusively in wildlife (90%) and zoo/aquarium (10%) contexts, with objectives spreading from research [2], to preservation [61], interspecies connection [141], cognitive/ability testing, enrichment, and human education/entertainment. The remaining 30 aquatic non-marine-mammal papers covered aquatic animals across pets/home (17%), farms (33%), zoos (20%), wildlife (40%), and labs (7%), making them one of the most versatile species categories. These works included artistic sonic installation based on plankton activity [164], interactive system for straightening fish scans [172], or visual-based monitoring systems to track free-swimming fish [94].

**Elephants** were the focus in 12 studies (67% aimed to benefit them). Among four lions (2 in the wild and 2 in zoos), only one (a feeding and hunting enrichment system for zoos [74]) presented the animals as beneficiaries, while the 2 giraffe studies both stated aiming to benefit the animals either through automatic tracking [31] or for agency-based audio enrichment [48].

We counted 5 papers on **insects**, including cicadas monitoring [56], cockroaches interaction with robots [49] and two systems for bees. Among all insects, only one of the works with bees presented the animals as beneficiaries [149].

Among the least represented species, present in the corpus with only one or two items each, were hamsters, hedgehogs, bears, baboons, bats, deer, and camels.

## 5.2 Animal contexts

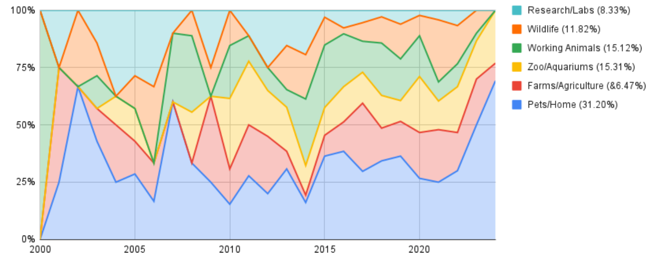



**Figure 6: Timeline distribution of the animal-computing work across contexts in our corpus**

Our initial review identified six main animal context categories: Pets/Home, Working Animals, Zoos, Farms, Lab Animals, and Wildlife. Due to the limited number of publications in our corpus prior 2012, it is difficult to draw clear trends for this period. Focusing on the period after, we observed a mostly stable distribution across contexts. However, in the past three years, we note a noticeable rise in the proportion of papers in the pet/home contexts and a decline in lab animal research (Figure 6). These changes in trends could reflect characteristics of our corpus distribution but also a societal shift towards pet technologies or evolving considerations regarding lab animals.

*5.2.1 Pets/Home.* (31% of papers): This was the most represented context with a total of 161 papers, mainly focused on dogs (60.25%) and cats (20.50%), but also including birds (8.07%), fish (3.73%), small rodents, reptiles, and even chickens in a domesticated context. Technologies ranged widely from wearable devices (30.72%), screen-based systems (29.19%), vision (16.87%) and audio-based systems, sensors (25.47%), interactive toys (11.18%), and robots (10%). They were mainly designed for monitoring/detecting/tracking (43.48%) but also to directly enhance animal physical (14.29%) and mental health (19.88%) and facilitate pet-human interaction. For instance, papers frequently explored systems that monitor dogs' daily activities, or interactive play devices for cats, highlighting the human-animal bond. The bonding aspect was highly present with systems designed for interspecies play for instance, emotion/vocalization recognition [34], social enrichment using remote technology with humans [159] robot [126] or remote interaction with conspecifics [57]. The emphasis on pets aligns with growing societal interest in enhancing pet care through technology, often aiming to improve their quality of life or address behavioral issues. Overhaul interactive systems involving pets provided some kind of feedback to the animal 41.36% of the time and they were considered direct beneficiaries 41.98% of the time.

*5.2.2 Farms.* (16.4% of corpus): This category, the second most represented, primarily focused on livestock such as cows, chickens, and pigs. Technologies were predominantly vision-based systems (50.59%), sensors and monitoring systems (29.41%), and wearables

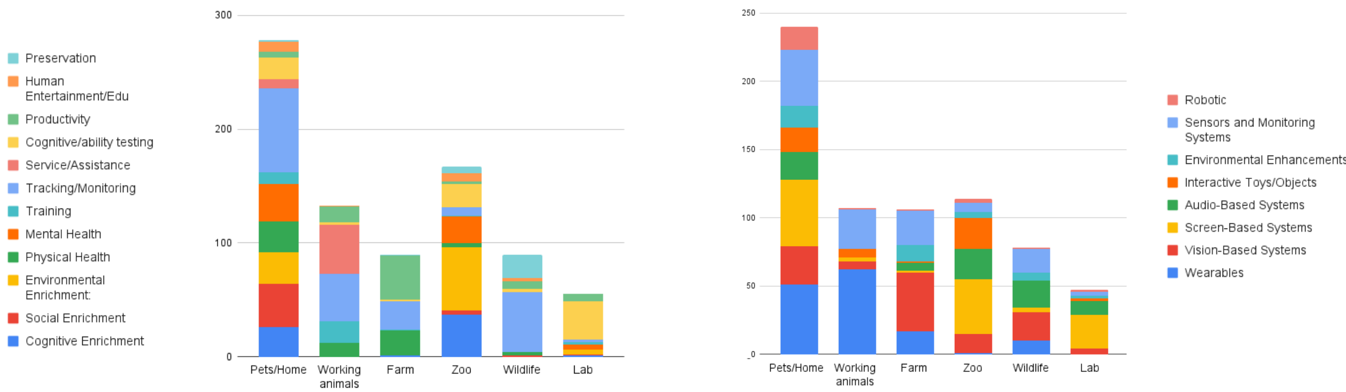



**Figure 7: Graphs showing the distribution of types of objectives (left) and type of technology across the different animal contexts.**

(20%), reflecting the agricultural sector's adoption of precision farming techniques. The main objectives were productivity (45.88%), tracking/monitoring (29.41%), and physical health (25.88%), with a notable absence of mental health or enrichment focus. This distribution highlights the industry's emphasis on efficiency and physical welfare. Animals were considered intended beneficiaries in only 12.94% of the studies, the lowest among all contexts. Examples of innovative approaches include automated health monitoring for dairy cows [22], vision-based individual identification systems [88], and egg incubation monitoring [154]. Some studies explored more advanced technologies, such as virtual fences for controlling cow movement [19] and AI-based systems for animal behavior analysis [105]. This category presents a strong focus on integrating productivity with some level of basic animal welfare, reflecting the challenges and priorities of the sector.

*5.2.3 Working Animals.* (15% of corpus): This group included guide dogs, search and rescue dogs, therapy animals, military dogs, hunting dogs, and trained horses. Technologies were almost exclusively composed of tracking/monitoring (36.71%) systems and wearables (78.48%) [171], which aim to modify the animals existing professional harnesses. Objective-wise, they often targeted human assistance (54.43%), monitoring (52.56%), with a smaller part of training (24.36%), enhancing task performance and productivity (17.95%), and tracking physical health (15.38%) [93]. No work reported directly tackling mental health nor cognitive, social or environmental enrichment. This may be attributed to the typically high standard of care and stimulation these animals receive as part of their working roles and training regimens. The work appeared to be split between providing feedback to the animals (51.28% of the time, more than for pets) and considering dogs as beneficiaries 41.98% of the time. Examples of work include auditory cues for guide dogs or vibrational signals during military tasks [140]. Work that did not provide feedback to animals includes numerous studies on assessing the suitability of puppies to optimize selection for various working roles [26], as well as a focus on position and activity monitoring to enhance performance [15]. This category stands out for its emphasis on technologies that facilitate communication and efficiency between the animal and the handler [169], illustrating the role of feedback and active animal engagement.

*5.2.4 Zoos/Aquariums.* (15.4% of corpus): Most technology-related research in zoos in our corpus appears to be carried out with nonhuman primates (48. 75%) with much smaller parts for other animals such as elephants (10.00%), birds (6.25%), fish (6.25%), marine mammals (2.50%), bears (2.50%), lions (2.50%), and penguins (2.50%). Regarding the type of technology used, the systems were predominantly screen-based systems (50%), audio-based systems (27.5%), and interactive toys/objects (28.75%), with a low representation of wearables (1.25%). This distribution likely reflects the need for non-invasive, adaptable technologies preferred for the constraints of zoo environments. The primary objectives noted were environmental enrichment (68.75%), followed by cognitive enrichment (46.25%), mental health (28.75%) cognitive/ability testing (26.25%), and preservation (7.50%). Animals were intended as beneficiaries in 70% of the studies and received direct feedback 75% of the time, ranking the category first in terms of feedback, indicating a strong focus on animal-agency as a form of enrichment. Examples include sound-based enrichment [77], touchscreen tasks for cognitive assessment [68], and interactive projections for orangutans [20]. While human entertainment/education was present (8.75%), it didn't appear as a primary focus of the works within our corpus.

*5.2.5 Lab animals.* (8.3% of corpus): This category contained primarily non-human primates, rodents, and some avian species such as pigeons, parrots, and zebra finches, using mainly screen-based interfaces (58.14%) and audio systems (23.26%). In terms of objective, we observe predominantly cognitive and ability testing (79.07%), with some accounts of productivity (13.95%) and mental health considerations (11.63%) such as some investigations into music as an enrichment tool [112]. While only 9.30% explicitly positioned animals as beneficiaries, a high proportion of studies (74.42%) provided feedback to the animals, highlighting the non-automatic correlation between the two metrics.

*5.2.6 Wildlife.* (12.1% of corpus): This group covers a diverse range of species from marine mammals, birds, land mammals like elephants and agoutis, and insects. Technologies predominantly consisted of visual-based (33.87%), audio-based (32.26%), and sensor-based monitoring systems (27.42%), with some limited use of wearables (16.13%). The primary objective was tracking and monitoring (85.48%), followed by preservation (33.8%) with minor attention to productivity (9.68%) and physical health (4.84%). Animals were named as immediate beneficiaries in 16.13% of studies and received direct feedback in 6.45% of cases, the lowest among all contexts. This reflects the priority of observing natural behaviors with minimal interference. Examples include passive acoustic monitoring of cetaceans [9], unmanned aerial vehicle surveys [61], and innovative approaches like 3D printed eggs for studying bird behavior [69]. Many studies, for wildlife, used machine learning for animal identification/monitoring.

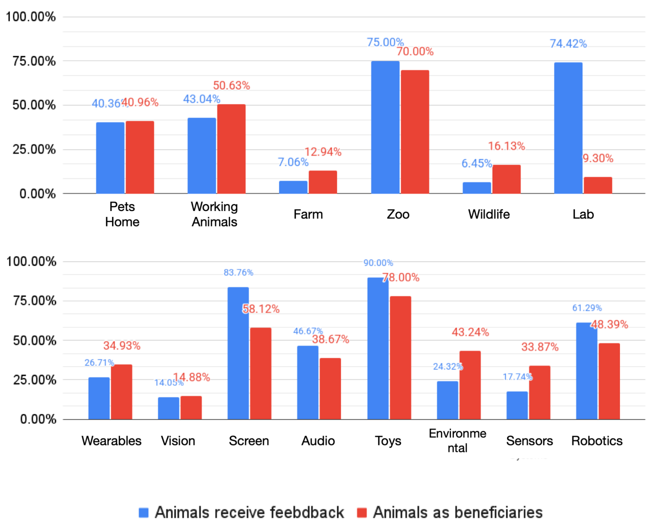



**Figure 8: Percentage of work providing feedback to the animals (in red) and the percentage of papers framing animals are beneficiaries across animal contexts (top) and across technology type (bottom)**

## 5.3 Types of Technologies

Our review revealed a diverse range of technological types.

**Wearables** (27% of the corpus) included, among others, instrumented collars for communication or tracking [171], bracelets for gait monitoring [22], and harnesses for assistive animals [140].

**Sensors and monitoring systems** (24% of the corpus) were used for various purposes, such as passive behavior or health monitoring, including accelerometers for gait analysis [23], automated systems for detecting calving time [178], and remote monitoring of parturition in dairy cattle [120].

**Vision-based systems** (23%) use cameras and computer vision for diverse applications, for example, automated facial recognition for non-human primates [173], muzzle pattern recognition for cattle identification [146], and automated egg fertility detection [95].

**Screen-based systems** (22%) encompassed various interactive screens or tablets, including touchscreen tasks for cognitive assessment in rats [27], problem-solving games for primates [14], and interactive projections for orangutans [20].

**Audio-based systems** (14%) involved various sonic inputs and/or outputs, such as acoustic whale monitoring [9], auditory enrichment for zoo animals [132], and vocalization recognition in farms [145] and zoos [84].

**Interactive toys/objects** (10%) covered various manipulable devices, including but not limited to multi-sensory puzzle for cognitive enrichment [174], robotic toys for pets [176], and enrichment devices for primates in managed care [65].

**Environmental systems** (7%) encompassed technological modifications to animal habitats, such as automated climate control in farming [43], virtual fences for livestock management [19], and bubble curtains for aquatic species [118], among others.

**Lastly, robotics** (6%) involved various mechanical devices for animal interaction, including robotic dogs to study social behavior [176], automated milking systems [62], and robotic enrichment devices for zoos [41].

Beyond these main categories, several technologies emerged in our corpus. These included 3D printed eggs for studying bird behavior [38], fMRI for animal research [10], and scent-based interfaces for olfactory interactions [55].

The distribution of technologies among research objectives reveals additional patterns. Wearables and Vision-Based Systems were predominantly used for Tracking/Monitoring and Physical Health objectives, highlighting their utility in noninvasive data collection. Screen-Based Systems showed a strong association with Cognitive Enrichment and Cognitive/ability testing. Audio-Based Systems were versatile, contributing significantly to Cognitive Enrichment, Environmental Enrichment, and Tracking/Monitoring. Interactive Toys/Objects were primarily used for Cognitive and Environmental Enrichment, emphasizing their role in animal engagement. Sensors, as expected, were heavily used in Tracking/Monitoring and Physical Health research. Notably, there seems to be less exploration of these technologies in Mental Health and Social Enrichment objectives, suggesting potential areas for future research. The provision of feedback to animals varied significantly across technology types as illustrated in Figure 8 (bottom).

## 5.4 Objectives and Beneficiaries

Our results revealed a diverse range of objectives:

**Cognitive Enrichment** (12.7% of the corpus) aimed to enhance mental stimulation, often through interactive puzzles or games with examples including touchscreen tasks for primates [14] and cognitive challenges for elephants [41]. This category showed a high rate of feedback to animals (85.07%), suggesting a strong focus on direct animal engagement.

**Environmental Enrichment** (16.6% of the corpus) focused on improving animals' surroundings. This included auditory enrichment for gorillas [132] and interactive projections for orangutans [20]. With 77.01% of such studies providing feedback to animals, this objective often involved active animal participation.

| | Animal Feedback | Animals Beneficiaries |
|---|---|---|
| Cognitive Enrichment | 85.07% | 88.06% |
| Social Enrichment | 75.00% | 65.91% |
| Environmental Enrichment: | 77.01% | 81.61% |
| Physical Health | 6.25% | 39.06% |
| Mental Health | 73.40% | 77.66% |
| Training: | 60.53% | 47.37% |
| Tracking/Monitoring | 7.84% | 20.00% |
| Service/Assistance | 66.67% | 66.67% |
| Cognitive/ability testing | 74.07% | 19.75% |
| Productivity | 23.94% | 23.94% |
| Human Entertainment/Edu | 47.62% | 38.10% |
| Preservation | 10.71% | 39.29% |

**Table 1: Categorization of animal-computer interaction systems by primary objective: analysis of studies implementing direct animal feedback and explicitly stating animals as intended beneficiaries (expressed as percentage per category)**

**Tracking/Monitoring** (49.1% of the corpus) was the most common objective, involving technologies to observe and record animal behavior or health. Examples include automated systems for detecting calving time in cows [178] and acoustic monitoring of whales [9]. Despite being the most prevalent objective, it had a low rate of feedback to animals (7.84%), indicating its primarily observational approach.

**Physical Health** (12.3% of the corpus) studies focused on monitoring and improving animal well-being. This included gait analysis in cattle [23] and wearable health monitors for dogs [37]. Only 6.25% of these studies provided direct feedback to animals, suggesting a focus on data collection for human interpretation.

**Cognitive/Ability Testing** (15.6% of the corpus) involved assessing animal cognitive capabilities. Examples include touchscreen tasks for rats [27] and problem-solving games for birds [66]. With 74.07% of these studies providing feedback to animals, this objective often involved direct animal interaction with the technology.

**Productivity** (13.7% of the corpus) studies aimed to enhance efficiency in contexts like farming. Examples include automated milking systems [62] and egg fertility detection [95]. Only 23.94% of these studies provided feedback to animals, reflecting a focus on human-oriented outcomes.

**Human Entertainment/Education** 4.20% of the corpus concerned works incorporating animals for human learning or enjoyment. This included artistic endeavours such as the sonification of a fish tank [111], or an immersive experience of animal sensing data for education [85].

**Preservation** (5.34% of the corpus) included studies and systems aimed at animal preservation and conservation in various contexts, for instance by aiming to sensitize zoo audiences to great ape endangerment [167] or using monitoring tools such as drones for surveying marine fauna to protect dugongs [61].

Our results reveal varying degrees of animal engagement across different research objectives in terms of feedback received by the animals and their consideration as beneficiaries, as illustrated in Table1. We observe some disparity across objectives, such as Physical Health where animals are considered beneficiaries but not given feedback, or Cognitive/Ability Testing where the inverse trend is seen. This highlights potential opportunities for developing more interactive approaches in areas traditionally focused on passive data collection, particularly in Tracking/Monitoring and Physical Health research. It also suggests a need for greater alignment between providing feedback to animals and considering them as primary beneficiaries of the research across all objectives.

## 5.5 Feedback

Our analysis revealed that out of all the papers in our corpus, only 38.05% provided some form of feedback to animals. This feedback was predominantly visual (63.32% of feedback papers), followed by tactile (30.65%) and audio (27.64%) feedback. Olfactory feedback was rarely used, appearing in only 1.01% of papers providing feedback. This distribution highlights the prevalence of visual interfaces in ACI, but also suggests potential opportunities for exploring other sensory modalities, particularly olfactory feedback, due to its importance in many animals' sensory worlds.

We observed that while there is some overlap between papers providing feedback to animals and those considering animals as beneficiaries, these metrics are not entirely aligned as seen in Figure 8 (top). This discrepancy supports the idea of pairing these two metrics when considering animals as users of technology. For instance for lab animals there is often feedback 74.42% even if they are considered beneficiaries only 9.3% of the time.

## 5.6 Empirical testing and ethics

Amongst interactive systems described in the corpus, 76.91% were empirically tested with animals beyond the use of pre-existing and pre-recorded datasets. For these 403 studies, we examined mentions of ethics and report of approval (or waiver) from Institutional Animal Care and Use Committees (IACUC or equivalents). Although 64.23% mention ethical considerations, less than half (47.53%) reported review from an official board, the animal context most frequently reporting official institutional review and approval was labs (60. 53%) followed by working animals (48.57%), pets/home (46.90%), farming (36.96%) and finally wildlife with only 27.27%.

We explored the potential correlation between geographical location and the reporting of IACUC approval, considering that ethical review practices could vary due to cultural and regulatory differences across countries. The data reveals noticeable differences across countries: Denmark stands out as the only country where all studies reported ethical approval, reflecting a stringent adherence to ethical review protocols. In contrast, other countries displayed a mixed pattern, with most ranging between 30% and 60% of studies reporting IACUC approval. This variability highlights inconsistencies in how ethical considerations are handled, even within countries that frequently mention ethical aspects of their research. Notably, some countries show significant gaps between studies that mention ethical considerations and those that explicitly report IACUC approval, suggesting that ethical considerations do not always translate into formal review or that different standards might be applied. These findings underscore the need for more consistent and transparent reporting of ethical approvals across the field.

## 6 Discussion

Our analysis of nearly 800 research works maps the landscape of animal-technology research and reveals insights for future development. Following methodological approaches from previous HCI reviews [92, 110, 117], we identify several core themes emerging from our analysis: (1) the persistence of context-specific silos, (2) a proposed framework of animal usership, (3) approaches to ethics and research challenges, and (4) the multifaceted intersections between ACI and HCI. Through examining these themes, we develop concrete recommendations and practical steps for experienced ACI researchers and HCI practitioners looking to expand their work to include animals, while acknowledging the field's complexity and evolving nature.

### 6.1 Context-Specific Technologies, Evolution and Research Silos

This review provides, to our knowledge, the first cross-contextual analysis of animal-technology research from an HCI lens, revealing how different contexts have evolved distinct technological and interactional approaches. This bird's-eye view enables us to identify patterns of specialization across different animal contexts that might not be apparent when examining each domain in isolation.

Temporal analysis also reveals an evolving landscape. In recent years, we see an increase in pet-focused technologies, while the ratio of research involving farm animals, laboratory animals, and wildlife appears to be declining in empirical deployment. This shift might reflect easier access to pet subjects and ethical constraints of involving wild animals. Yet, it also raises concerns about neglecting animals that might be most in need of technological intervention. This trend toward pet technologies, while expanding our understanding of companion animal needs, risks creating a two-tier system of animal-technology research where some animals receive more user-centered consideration than others. Farm and laboratory animals, in particular, remain underrepresented in terms of cognitive and social enrichment technologies, with our analysis showing only 12.94% of farming-context studies considering animals as intended beneficiaries.

Based on the corpus analysis, we identified some prototypical and strongly represented combinations of objectives and technologies for each context. Figure 9 shows the prevalence of each technology used, and each objective targeted across animal contexts. The most common practices that can be summarized as:

- Toys & robots for physical/mental health & bonding with pets
- Wearables for training & tracking working animals
- Screens and audio-based technologies for enrichment in zoos
- Screen-based cognitive testing for lab animals
- Acoustic monitoring for wildlife tracking and preservation
- Vision-based systems to monitor the physical health to increase productivity in farms

These patterns reveal not just technological preferences but fundamentally different assumptions about animals' roles and needs across contexts - from pets as companions deserving enrichment to farm animals primarily as production units. These context-specific approaches mirror early HCI's tendency to develop specialized solutions for different workplace environments, before broader user-centered principles emerged that crossed contextual boundaries [11].

These silos appear to arise from multiple factors and to reflect practical constraints. For instance, wildlife research often requires large-scale monitoring in remote locations, potentially explaining the prevalence of acoustic and vision-based systems. Others might stem from established research traditions: laboratory animal studies typically follow standardized protocols inherited from behavioral research and animals often have to stay on single protocols. Economic factors can also play a role as farms may prioritize productivity-enhancing technologies, while zoo environments may invest in enrichment to address stereotypical behaviors. This may also reflect the structure of academic and industry research communities, where limited cross-pollination between animal behavior researchers, veterinary technologists, and HCI practitioners reinforces context-specific approaches.

Yet the corpus also reveals promising examples that transcend these contextual boundaries. Buchanan-Smith and Badihi's [18] work on environmental control for laboratory marmosets demonstrates how principles of agency and choice - more commonly considered in pet or zoo contexts - can enhance laboratory animal welfare. Similarly, Chiu et al.'s [25] emotion detection system for elephants applies techniques typically used in pet contexts to other scenarios. Hauser et al.'s [54] research on accessible dog toys shows how considering non-working activities for service animals can enrich both animal and human experience.

These cross-context successes suggest opportunities for more diverse technological approaches. While institutional access restrictions, methodological differences, and varying ethical review requirements present real challenges to crossing contextual boundaries, here we suggests concrete steps that researchers could consider to bridge these gaps:

⇒ Familiarize themselves with technologies and approaches used across different animal contexts to identify potential tools and methods beyond their immediate field
⇒ Explore opportunities to adapt successful approaches from other contexts while respecting domain-specific constraints
⇒ Consider how technologies might be extended or combined across species and contexts
⇒ Acknowledge and critically examine context-specific assumptions about animal capabilities and needs
⇒ Seek collaborations across different animal research domains to bridge methodological gaps

The observed cross-context patterns raise questions about how we conceptualize animals' roles in technological interventions. While some contexts position animals as active participants, others treat them primarily as subjects of observation. This variation suggests the need for a more structured way to think about animal engagement with technology and when to consider them users vs subjects of technology research.

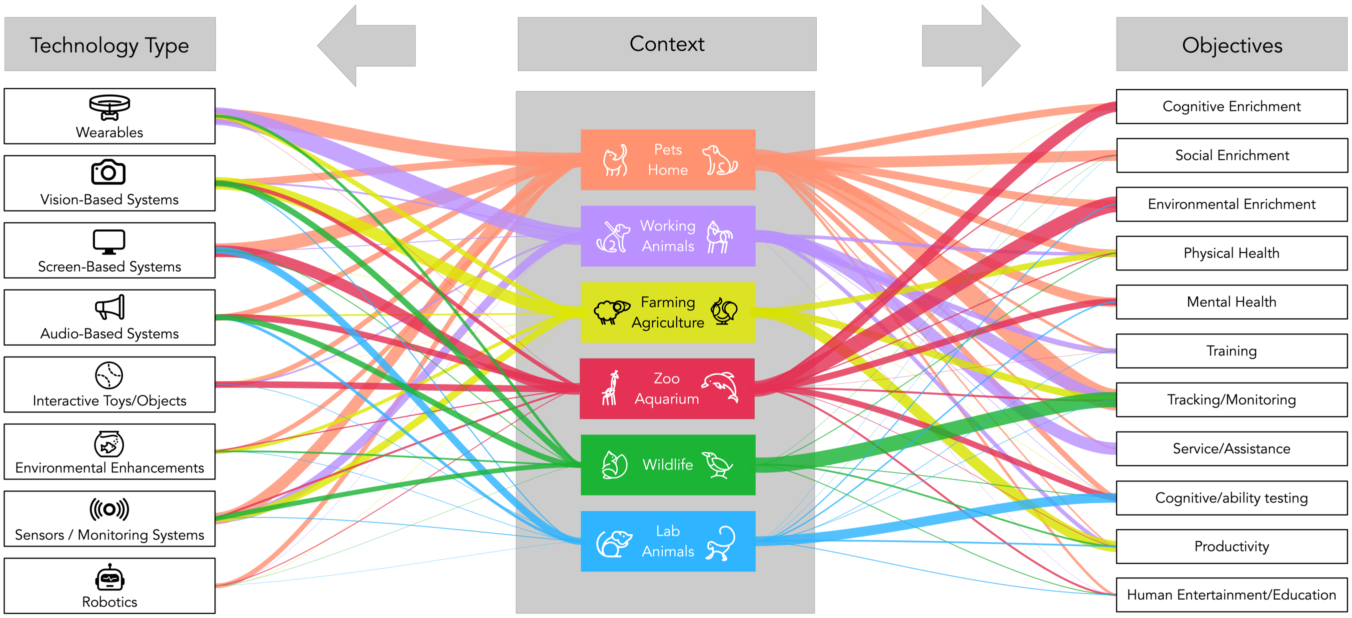



**Figure 9: Visualisation of the number of studies across each context, based on the type of technology used and objectives. The thickness of the connection represents the number of paper corresponding to the category**

## 6.2 Understanding Animals as Users: A Framework

As discussed in sections 2.3 and 2.4, the question of usership in the context of interactive technology research remains contentious in both HCI, and ACI. Based on corpus analysis and building on user-centered design principles, we propose a framework to help researchers think about animals' roles in technological interventions. Reflecting on the various ways animals engage with technology in our corpus, we identify three key criteria to help frame the concept: **feedback, benefits** and **empirical testing**. Each criterion addresses a different aspect of user interaction. Provision of sensory feedback to the animals, while not guaranteeing comprehension, provides the basic foundation for animals to make connections between their actions and system responses and acknowledge animal agency. Framing animals as intended beneficiaries ensures there is fundamental motivation for the interaction beyond human or research needs. Empirical testing moves beyond theoretical proposals to validate whether and how animals actually engage with the system in practice. While no single criterion fully captures the concept of "user," together these three parameters offer a structured way to conceive animal agency and engagement in mediated interventions.

The distribution of these criteria across our corpus reveals additional patterns, as seen in Figure 10. While 82.1% of studies conduct empirical testing, only 38.0% provide direct feedback to animals, and just 36.1% frame animals as primary beneficiaries. All in all, only 22.71% of studies meet all three criteria. These proportions have remained relatively stable over the past 20 years, generally ranging between 10% and 30%, suggesting persistent patterns in how researchers approach animal-technology interaction.

The framework reveals marked variations across contexts: zoo settings lead with 55% of studies meeting all criteria, while farm (1.18%), laboratory (6.98%), and wildlife (1.61%) settings rarely position animals as users. These patterns reflect not just practical constraints but assumptions about animals' roles in different settings. Zoo environments, focused on enrichment and welfare, may more naturally align with user-centered approaches. However, successful examples across all contexts demonstrate the framework's potential value even in challenging settings. For instance, cognitive adaptation feeding systems for pigs [33] show that farm animals can engage as users through audio feedback and control over feeding, while research on lab animals' control over their environment [18] shows how they can be given meaningful agency.

Some limitations and complexities in our framework warrant critical examination. Our classification of animals as beneficiaries relies on authors' explicit statements, which may reflect varying standards across fields or overstate potential benefits - a particular concern in HCI venues where impact claims are standard practice. Moreover, as Williams [170] demonstrates, even systems that acknowledge animal cognition and agency can be coopted to optimize control rather than enhance welfare. The presence of feedback or empirical testing alone does not guarantee meaningful engagement or benefit. This framework should therefore serve not as a checklist for ethical practice, but as a tool to think critically about how we position animals in technological research.

While this framework aligns with a movement from designing "on" animals to designing "for" animals, we also acknowledge its ethical limitations. Recognizing animal sentience and agency can paradoxically serve to refine rather than challenge instrumental approaches to animal research [170]. The presence of feedback, empirical testing, and stated benefits - while important considerations - do not automatically equate to ethical or good research. This framework aims to provide a structured way to examine how we position

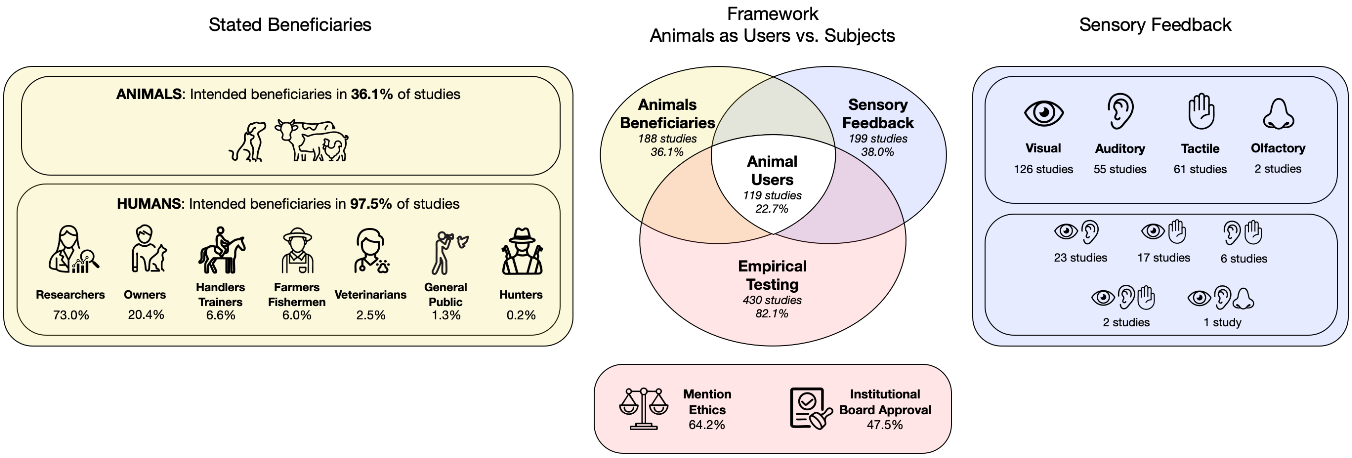



**Figure 10: Diagram of Animals Technology Usership Framework, and its representation within the corpus.**

animals in technological research while remaining mindful of the broader implications of these positions. This aligns with critical animal studies' emphasis on examining not just individual practices but their role in broader systems of human-animal relationships.

For researchers considering this framework, we recommend the following practical considerations:

- ⇒ Consider whether animals should be positioned as users in the system - this may not be necessary or appropriate for all technological interventions
- ⇒ Identify feedback modalities that align with both species-specific sensory capabilities and contextual constraints
- ⇒ Document clear pathways between system design and intended animal benefits
- ⇒ Design validation methods that can meaningfully assess animal engagement
- ⇒ Acknowledge implementation challenges while working to address them
- ⇒ Reflect critically on how your research positions animals within broader systems of human-animal relationships, beyond immediate welfare considerations

With its concrete criteria, this framework contributes to ongoing discussions about animal agency while offering practical guidance for researchers. While aligning with HCI's emphasis on user-centered design, it acknowledges the unique challenges of working with non-human participants and the complex ethical, practical, and legal considerations.

## 6.3 Ethics and Research Challenges

The ethical dimensions of animal-technology research present complex challenges that parallel HCI's own evolution. Just as HCI's adoption of formal human subject protections in the 1990s established research standards [151], our analysis reveals growing attention to ethical considerations. Among studies involving live animal participants (excluding pre-recorded datasets), 64.23% discuss ethical considerations, yet only 47.53% report formal institutional review board approval. This discrepancy between ethical discussion and formal oversight may reflect geographical or cultural differences, misalignment in reporting standards or challenges in obtaining institutional approval.

Understanding this gap becomes particularly important given the potential negative impacts of technology on animal subjects, and it appears to vary across contexts. Laboratory animal research shows the highest rate of institutional review (60.53%), possibly due to studies conducted outside standard protocols or variations in reporting practices. Wildlife studies report the lowest rate (27.27%), reflecting the prevalence of "passive monitoring" approaches where researchers don't provide direct feedback to animals. However, even such observational approaches, particularly those involving audio playbacks or tracking devices, can significantly impact animal behavior and social structures [101, 119]. While the U.S. mandates IACUC oversight, other countries have varying requirements for animal research review.

Thus, obtaining institutional approval can present challenges, particularly for novel technological interventions. Traditional ethical approval boards may be unfamiliar with new technologies or interaction paradigms, while researchers working with pets or wildlife may struggle to fit their work into oversight frameworks designed primarily for laboratory research. These challenges can be of concern given potential negative impacts of technology even in managed care situations. Indeed, some studies deliberately introduce stressors to observe animal responses - for instance, research measuring stress effects of drones or robots on pet behavior [36], or studies involving induced pain for developing facial expression recognition systems [128]. While such work may aim to benefit broader animal populations (like developing better pain detection tools), it raises ethical questions about balancing population benefits against an individuals welfare.

Moreover, even when studies emphasize care practices, this alone may not ensure ethical conduct. As Giraud and Hollin [45] demonstrate in their analysis of laboratory beagle research, care practices can sometimes reinforce rather than challenge experimental objectives. Their work reveals how care can be used to manufacture compliance rather than create genuine ethical transformation, potentially facilitating rather than preventing the instrumentalization of research subjects. This tension extends beyond care practices to broader questions about technological interventions - what Manzini terms "remedial goods" - where improvements in immediate conditions might inadvertently legitimize rather than transform challenging contexts [102].

This creates multiple intersecting tensions that ACI researchers must navigate: between care and ethics, between immediate improvements and systemic change, and between oversight and research accessibility. While technological interventions may offer real benefits for animals in challenging situations, we must simultaneously examine whether our work risks making problematic practices more palatable rather than promoting necessary systemic changes. Yet, pursuing only systemic transformation might mean missing opportunities to improve animals' immediate welfare - a practical reality that researchers working directly with animals must face.

This landscape presents a critical challenge: how to maintain high ethical standards while ensuring research remains accessible to diverse voices and perspectives. The challenges in navigating oversight mechanisms might inadvertently exclude valuable contributions, particularly from practitioners working with animals in non-traditional research settings. Yet, lowering ethical standards risks compromising animal welfare. Our analysis suggests the need for a balanced approach that acknowledges both the value and limitations of technological interventions while developing more flexible, context-appropriate review mechanisms. This is particularly relevant as the field expands to include researchers working with companion animals, wildlife conservation efforts, and technological enrichment in various settings.

- ⇒ Establish early relationships with institutional review boards to bridge understanding of novel technologies
- ⇒ Partner with institutions having established animal research protocols
- ⇒ Document and evaluate potential risks and benefits for both targeted population and individual participants
- ⇒ Adapt human subjects research principles where appropriate
- ⇒ Understand specific regulations in your region and country
- ⇒ Consider how tech interventions might balance immediate welfare needs with potential systemic impacts

As animal-technology research expands beyond traditional laboratory settings, the community needs to develop more adapted approaches to ethical oversight that can accommodate diverse contexts while ensuring animal welfare.

## 6.4 The Multifaceted Relevance of ACI to HCI

Our review reveals a complex and multifaceted relationship between the domains of ACI and HCI. While both fields show evolutionary patterns in time, their relationship is not linear and forms an intricate web of interconnections. Our corpus reveals that most animal technology work remains siloed within specific contexts (pets, working animals, farm animals, etc.), reflecting a stage similar to HCI's second wave's "well-established communities of practice." This suggests that ACI might be poised for its own transition toward broader considerations of animal experience with technology, independent of their prescribed roles in human society, as possibly already suggested by the recent rise of the more-than-human movement [138]. However, achieving this would require overcoming research biases about different categories of animals and their relationships to technology.

The non-linear nature of this relationship becomes particularly apparent when examining methodological developments. While HCI began with robust model-driven approaches (e.g., Fitts' Law, cognitive modeling) likewise early ACI work like Skinner's operant conditioning chambers [148] similarly emphasized systematic research. However, basic ergonomic considerations for animal bodies existed in some form since the 1980s' [121], but have only recently received more traction when researchers begun investigating more fundamental interaction principles for animals, such as ergonomics work on button design for dogs [136] or studies examining Fitts' Law with different species [79]. In addition to this temporal evolution, we identified eight distinct ways in which ACI and HCI intersect and contribute to each other (see Figure 11).

*6.4.1 Human-in-the-Loop:* A primary way that HCI and ACI intersect emerges from our analysis of research beneficiaries. Most animals in our corpus exist within managed care environments, making their human caretakers/owners/handlers integral to any technological intervention. Our analysis reveals a wide range of human beneficiaries: veterinarians using health data [153, 163], zookeepers managing enrichment systems [77, 131], and pet owners engaging with their companions [158, 161]. This human-in-the-loop reality means that technology must often be considered across species. Researchers should consider how their technologies create interfaces that work within existing human-animal pairs.

*6.4.2 Multispecies Interconnectedness:* Besides the animal dependence on humans, our corpus also reveals that many systems, particularly in farming and working animal contexts, recognize that it is not only animals relying on humans but also humans relying on animals. This interdependence is exemplified in context of working dog and assistance animals [134, 137], where systems aim to support the animals in providing support to humans, recognizing the need to support both members of the working team. This is also evident in the farming context [125, 156], where our dependence on animals informs the technology we use with them. In this context humans can also often be considered users and beneficiaries of animal technologies.

*6.4.3 Methodological Innovation:* Beyond the direct user and beneficiary relationships, ACI is relevant to HCI through its innovative methodological frameworks. With only a minority of systems that provide feedback to animals, researchers had to develop alternative evaluation approaches for participants who cannot clearly express preferences or provide direct feedback about their experience. For instance, Cheok et al.'s [24] evaluation methodology combined voluntary engagement patterns and health metrics to assess their mixed-reality system's impact on hamsters, demonstrating how multiple indirect measures could provide robust evidence of user experience. Similarly, Mancini et al.'s [100] semiotic framework analyzed how dogs interpreted tracking devices through their contextualized behaviors, offering insights into how users make sense of technology through natural interactions. These methodological

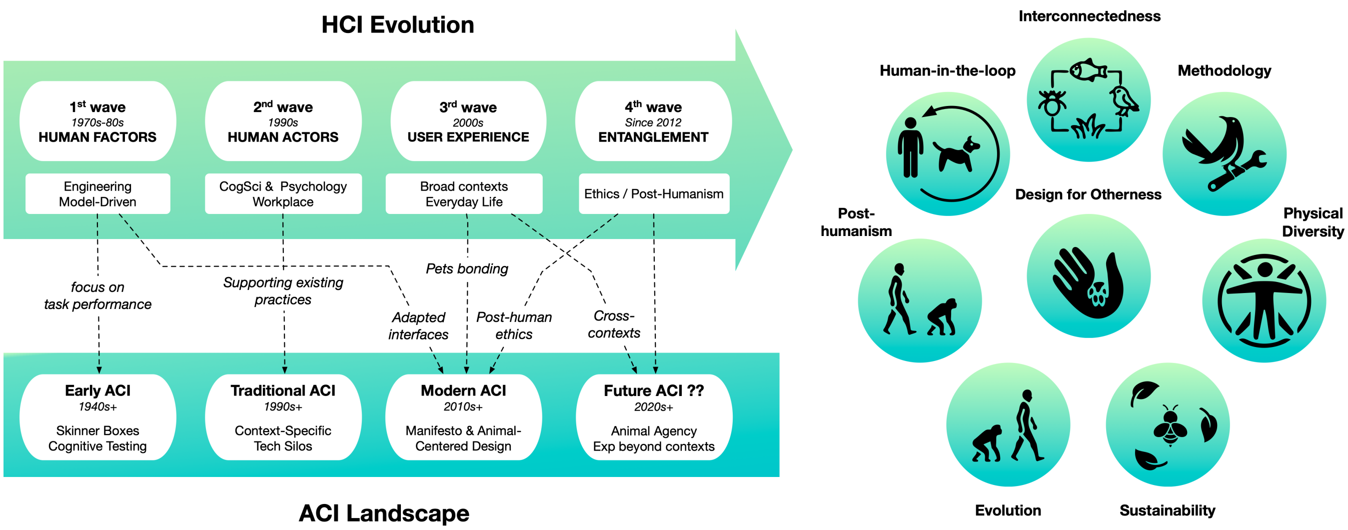



**Figure 11: Multifaceted intersections of HCI and ACI subdomain in a temporal and non-linear manner based on the HCI wave framework (left), and base on the eight categories emerging from the current analysis**

innovations could inform approaches to designing for any user group where traditional feedback mechanisms are challenging, for instance non-verbal individuals or those unfamiliar with technology. Although this parallel requires careful ethical consideration.

*6.4.4 Physiological Diversity in Interface Design:* The challenges of designing for diverse animal bodies and capabilities have prompted ACI research to consider fundamental questions about interface adaptation. Our corpus showed varied approaches across species, from vision-based systems (23%) to wearables (27%) to screen-based interfaces (22%) most of them adapted in a bespoke manner to the animals' unique bodies. Recent work examining interaction principles for animals, such as Robinson et al.'s investigation of dog-appropriate button design [136], demonstrates how designing for different physiologies and sensory abilities can advance our understanding of interface adaptation. This approach to extreme personalization resonates with HCI's growing focus on designing for diverse human bodies and abilities from people with physical disabilities [144] to athletes [109], suggesting that insights from animal interface design could inform more inclusive human interface design.

*6.4.5 Environmental Impact and Sustainability:* Some of our corpus explicitly addresses preservation goals, contributing significantly to HCI's growing focus on environmental sustainability. From wildlife monitoring technologies [86, 114] to sustainable farming practices [46, 149], ACI work often grapples with questions of environmental impact. The inclusion of animal perspectives in technology design aligns with recent calls in sustainable HCI to move beyond human-centric approaches [108], suggesting that ACI's methods could contribute to developing more systemic understandings of environmental challenges. This resonates with emerging discussions in the CHI community about expanding sustainable HCI to consider non-human actors and biodiversity [107], positioning animal-technology research as a valuable contributor to imagining sustainable futures.

*6.4.6 Evolutionary Understanding of Interaction:* The study of animal-technology may provide insights into fundamental aspects of tool use and interaction. From primates using tablets [68] to fish interfacing with digital systems [70], a comparative approach helps illuminate basic principles of interaction that transcend species boundaries and may shed light on deeper shared capabilities of ancestral living creatures. As McGrath [103] notes, this can deepen our understanding of interaction itself. Our corpus reveals numerous instances where technologies developed for one species find applications in others [76]. This pattern of knowledge transfer between species contexts suggests fundamental interaction principles that could inform human interface design.

*6.4.7 Ethics and Post-human Perspectives:* 64.23% of studies mentioned ethical considerations reflecting which echoes the recent rise of the "more-than-human" approaches. As Mancini argues, ACI research fundamentally challenges anthropocentric assumptions about technology design [96]. This aligns with HCI's fourth wave emphasis on post-human perspectives [35] and ethical computing [67], suggesting that ACI's animal-centered design principles could inform broader discussions about ethical technology development.

*6.4.8 Designing for Otherness:* Perhaps most fundamentally, ACI research challenges our assumptions about what it means to design for users who are different from ourselves. Our corpus shows how researchers approaching animal users provide avenues to question assumptions about interaction, preferences, and needs. This explicit recognition of designing for "otherness" aligns with HCI's core principle of user-centered design, as articulated by Dix [29], where the "focus must be on real users in real situations, however different they might be from the designers". The empirical testing of animal technologies in our corpus leads to unexpected patterns of use and interaction, challenging researcher assumptions from zoo animals using interfaces to attract visitors [78, 82], to farm animals enjoying the experience of being pet remotely [157]. These approaches to designing for radical differences can serve as a valuable exercise of empathy to empower animals with rich experience and humans with extended perspectives on sharing the Earth with others.

## 7 Conclusion

Animals' interaction with technology is multifaceted, offering a wide range of applications across research fields, contexts, and species for different motivations. Through an analysis of nearly 800 research works, our scoping review highlights a strong interest but also great disparities. With particular focus on bonding with pets, enriching zoo animals, tracking working animals, monitoring wildlife, and testing lab animals, the field is marked with gaps and paved with opportunities to extend welfare across contexts. By elevating animals as users of technology rather than mere subjects, our proposed framework aims to help researchers situate their work within this dynamic and multidisciplinary landscape. Our work illuminates the complex entanglement between animals and technology—a nexus that demands ethical vigilance yet offers potential for informing our shared future.

## Dataset and Interactive Platform

To allow researchers to further engage with the corpus and our encoding, we provide an interactive paper explorer platform online at https://findapaper.interactanimallab.com This platform is intended as a living project, where we welcome community contributions and updates. The full dataset underlying this analysis will be made publicly available for download. For access to the full dataset and classification, please contact us at contact@interactanimallab.com.

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