What do we really know about intention in animals? A bibliometric analysis

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Abstract

Is the analytical framework used by ethologists sufficient to study the mental states of non-human animals (NHAs) at the appropriate level of complexity? To address this question our strategy was to i) reveal the experimental and analytic habits of scientists of different disciplines in the literature, and ii) use "intention" as a vector in an interdisciplinary prospect of the study of NHAs mental states. Our own intention was to outline the specific orientations and possible impasses of the ethological analytical framework which limits the consideration of NHAs intentions. We conducted a bibliometric analysis of the scientific literature published between 2016 and 2020 in two steps: 1. through a first corpus, we identified the terms used in studies of NHAs intentions and 2. on this basis, 111 articles related to intentions in NHAs were selected. By analysing them using a co-occurrences network of the authors' keywords, ten scientific approaches to intention in NHAs were identified. Our main findings are that i) the term « intention » is very seldom used in studies of NHAs; ii) approaches developed in humans are rarely transposed in these studies; and iii) in such few studies, it is not the NHAs intentions which are under question, but the link between NHAs and human intentions. This study highlights the limitations of the current theoretical framework used to study non-human animals' cognition, which does not allow for the full spectrum of non-human cognitive specificities.

Introduction

Do ethologists have an adequate analytical framework at their disposal to consider the extent of the mental states of non-human animals at the level of complexity at which it can now be studied?

The increase in knowledge about non-human animals' mental states has clearly modified our perception of them. Researchers and society have enriched their initial representation of the animal scheme by adding considerations of sentience, conscious process (Le Neindre et al., 2018) and will (Greiveldinger et al., 2011; Heyes and Dickinson, 1990), among others. Each of these considerations is set against a different theoretical background, which means that the foundations underlying the acceptance of mental states are very discrepant. Why is this the case? Does it impede us from embracing greater complexity?

At the root of the development of cognitive sciences, for humans and non-human animals, we find Brentano's work. Brentano was a philosopher at the end of the 19th century who worked mainly on the question of mental representations through the concept of intentionality. In his book "Psychology From an Empirical Standpoint" (1874), he defined intentionality as the large set of mental states related to representations, the "aboutness". Since this major input, the theoretical definition of the concept of intentionality and its experimental effects have been discussed in the field of ethology. In the following, we propose a non-exhaustive overview of the theoretical and experimental frameworks built on this concept. An overview of these frameworks can help to infer the potential impact of such rooting.

The concept of intentionality, as developed by Brentano, claims to address the issue of mental representations (Jacob, 2019). Based on this proposal, several philosophers have developed theoretical and practical frameworks that support the experimental exploration of mental states so defined. One of the most important proposals has been Dennett's "Intentional Systems Theory" (1983), in which he organised intentionality into four grades (or orders), representing different levels of complexity. To our knowledge, most work on intentionality uses such an ordering system. In addition, Dennett (2009, 1983) has also developed a practical approach or, in other words, a framework for experimenting with and studying intentionality in other species. In his article *Intentional systems in*

cognitive ethology: The "Panglossian paradigm" (1983), he proposes considering the animal under study as an intentional system by describing its behaviour through "*intentional idioms*". These descriptions would, according to Dennett, make it possible not only to explore the capacities of other species more widely, but also to identify the levels of intentionality. For their part, Heyes and Dickinson (1990) proposed the *Intentional theory of action*, which addresses the content of mental states in terms of beliefs, desires and practical inference processes. With this approach, they claim to be able, through minimum analysis, to discern true intentional processes from non-intentional processes. Bratman's (1987) theory was also based on the tryptic belief-desire-intention (BDI), on which a cognitive model of behaviour prediction is based (BDI model). Also in the context of the study of intentionality, Dretske's (1988, 2003) made a significant effort to naturalise intentionality, i.e. to explain it by its causality (for a critical view, see Proust, 1995, 1999).

Such flourishing theoretical work was particularly mobilised by scientists willing to explore and understand mental states and cognition for individuals without (or not having mastered) human verbal language. For ethologists, such theories were particularly useful for adapting these methods not based on verbal report to non-human animals (Boissy et al., 2007). These experimental approaches usually infer mental states and their underlying cognitive processes (inner) from behavioural and physiological expressions (outer) – for a critical view of the validity of this approach, see Dretske, 1980. In short, using the theoretical framework that places intentionality as the expression of mental representations, ethologists explore intentionality through behaviours and actions. Now, if we follow Brentano's theory, intentions play a particular role in the etiology of action (Jacob, 2019). It follows that it will be practically difficult, if not impossible, to separate the study of intentionality from that of intentions.

Based on this knowledge, assessing the mental states of non-human animals would involve, among other things, assessing their intentions as well as their expressions of the same, i.e. being able to recognise and understand what an intention and its expression might be for a given species. The properties (or attributes) of the intentions, to connect the inner and outer, and make the actions representative of the mental states, as outlined by Brentano, are used to develop the analytical framework of ethology without reidentifying that they are at the root. Specifically studying intentions should thus re-evaluate and ultimately add to the current theoretical framework of ethology. Since Brentano, the study of mental states has been drastically enriched, offering new investigative pathways for studying non-human animals.

Several behaviours have been explored as the expression of intentions in other species. Among the behaviours studied to access and/or evaluate intentions, goal-directed behaviours seem central (Vasconcelos et al., 2012). These behaviours have been notably studied in relation to communication, particularly in great apes (Byrne et al., 2017; Gupta and Sinha, 2019; Leavens et al., 2005; Leavens and Hopkins, 1998; Molesti et al., 2020; Schel et al., 2013). Another important part of the study of the expression of intentions through communication is the study of pointing behaviours (gestures to show someone something; for a detailed review, see Krause et al., 2018). Intentions, or their expressions, therefore seem to be assessable through the capacity of a given individual to orient their behaviour and/or attention towards a goal or a subject in a communication situation.

Intentions are also studied through the question of the individual's mental state. For example, intention movements are studies of the expression of motivation (Fischer and Zinner, 2011). Complex approaches linking emotions, intentions and behavioural adaptability around the idea of goal desirability have also been developed (Griffin and Speck, 2004; Seth et al., 2005). In an even more complex understanding, Dickinson and Balleine (2000, p.202) proposed that "the capacity for goal-directed action requires not only the evolution of intentional representations, but also the co-evolution of an interface between these representations and the animal's biological responses to the

goal objects, events, or states". In humans, the concept of intention is also closely associated with an individual's expectations (Ajzen, 2011; Helfer et al., 2015; Kytö et al., 2019) and satisfactions (Diener et al., 2009). This approach has resulted in the widely used "Theory of Planned Behaviour" which claims to predict individual behaviours (for a review, see Ajzen, 1991). In short, from common roots, a variety of theoretical frameworks have developed and are now used to study intentions.

In addition to the approach to the inner state of the individual, studies on intentions are closely linked to those of social behaviour; in particular, through the capacity of an individual to perceive the intention of another. Baldwin and Baird (2001), for instance, propose that the relationship with others relies heavily on judgments concerning the underlying intention of a given behaviour. In other words, it is claimed that we are not interested in the behaviour of others for its own sake, but for what it reveals in terms of intentions. This aspect has been widely studied through the "Theory of mind" (for a review in great apes, see Towner, 2010). Other studies explore intentions as an interface between non-human animals and humans, through the recognition of others' intentions (for examples: in horses, see Trösch et al., 2020; in dogs, see Völter et al., 2023), in the species through the concept of "shared intentionality" (for a definition of shared intentionality and related behaviours, see Tomasello and Carpenter, 2007, and for an example of study, see Genty et al., 2020). In short, intentions and their recognition represent, for the individual, a means of accessing the self, others and the environment; they are therefore studied at all of these levels.

Despite the interest in these methods, the impossibility of directly assessing mental states has an impact on their consideration, which affects the way in which they are studied and evaluated (Tuyttens et al., 2021) and the need to improve the feasibility, reliability and validity of these methods is regularly outlined (Broom, 2011; Tuyttens et al., 2021). This is true of human studies and therefore even more limiting for non-human animals. Volpato (2009) highlighted that knowing that animals are sentient could have an influence on scientific observations (i.e. what is observed and how). In other words, to be able to evaluate intentions in other species, one must first have a representation of these species that allows it. To this first level of representation must be added that of the "intention" itself. To be able to identify an intention, we need to know what is intentional and what is not. Thus, depending on the discipline that studies it, intentions can be studied and defined very differently. This diversity is all the more marked in philosophical reflections on the nature of intentions (see Bratman, 1987; Husserl, 1901; Setiya, 2018 and many others). In short, intention is one of those research objects that reveal as much about those who study them as those who are the subjects of study.

As the study of intentions is central to assessing the mental states but limited by the fact that it takes different approaches due to the discrepancy of theoretical and experimental frameworks, we choose to investigate among the larger possible set of disciplines whether intentions are truly considered in non-human animals. We address the following three questions: 1. Is the concept of intention studied? 2. By whom (i.e. which disciplines/fields)? 3. How is it studied, i.e. by which approaches, and through which questions?

To that end, we developed an innovative method articulated on three steps based on the hypothesis that studying the scientific literature will provide insights allowing a better understanding of the theoretical frameworks currently adopted by the academics (Mukherjee et al., 2022). In the first step, we investigated the evolution of the study of intentions in the academic literature through a general bibliometric analysis. Based on our first results, we gathered a relevant corpus on the study of intentions, but most of the articles focused on humans. The second step was to create a representative corpus of studies on intentions in non-human animals, i.e. also including work that deals with intentions without mentioning them. As it was not possible to focus directly on articles on non-human animals, we identified the terms used to study intentions in order to capture those related to non-human animals.

To this end, we worked on the co-occurrence network of authors' keywords (Donthu et al., 2021; Mukherjee et al., 2022), which reflect communities of questioning (i.e. scientific approaches). This method allowed us to select relevant approaches and associated keywords. In the third step, which was to understand how the intentions of non-human animals are studied, we recreated a new corpus based on the keywords identified in these relevant approaches. Finally, we analysed it by a co-occurrence network of authors' keywords. Indeed, as has been shown for other concepts (Aria et al., 2021; Donthu et al., 2021; Jaakkola, 2020; Mukherjee et al., 2022), we expected through these co-occurrence networks to identify current issues and reveal gaps in the study of intentions in non-humans, and to take a first step towards opening up the current theoretical framework in ethology as well as for proposing original opportunities for future research.

Methods

As each step of our protocol depends on the results of the previous one, the following sections develop the methods for each step chronologically and, where necessary, refer to the relevant part of the results.

1. Step 1: General bibliometric analysis

This first step of our method was to investigate the evolution of the study of intentions in the academic literature and create a relevant corpus on the study of intention.

a. Choice of database

Non-human animals are studied in different disciplines, either directly (where the non-human is the subject of study) or indirectly (where the non-human is a model for understanding human processes; that is, the study of non-human cognitive abilities made to better understand human cognition from an evolutionary and developmental perspective). Thus, to create a corpus representative of the variety of research related to intentions in non-human animals, two multidisciplinary databases were targeted and compared: Web of Science (WoS) and Scopus.

According to Chadegani Arezoo et al. (2013), Scopus covers a wide range of disciplinary fields (20% more than WoS) and a large number of journals. In addition, there are nine times more articles present only in Scopus than in WoS (Chadegani Arezoo et al., 2013). The Scopus metadata format is the best adapted to use for the corpus analysis as author keywords and automatically indexed keywords (i.e. keywords proposed by the database itself) are not distinguished in the WoS when downloading metadata, unlike those of Scopus (Tancoigne et al., 2014). Furthermore, we used the CorTexT platform (IFRIS and INRA, https://www.cortext.net/) to create the co-occurrence networks of author keywords. Indeed, CorTexT was created to quantitatively and qualitatively explore bibliographic data and offers tools to explore relationships between concepts, scientific communities and more (CorText Platform, 2023; examples of studies using CorText: Brás et al., 2017; Chavalarias and Cointet, 2013; Deng and Xia, 2020; Malanski et al., 2021; Mesmoudi et al., 2015; Raimbault et al., 2016; Weisz et al., 2017). A further advantage of CorText lies in its optimal management of metadata in 'Scopus RIS' format. The corpus was therefore created with the Scopus database. We chose to restrict our analysis from 1990 to 2020 – from the year of the oldest articles identified on intentions in Scopus to the last completed year – in order to ensure stability in articles referenced throughout the bibliometric analysis.

b. Creation of the first corpus: intentions in scientific literature

To limit noise due to the verbal form (to intend) and its conjugation, but while remaining as exhaustive as possible, the query focused on the word “intent*” in titles and keywords. Only English papers were selected.

This initial analysis led us to exclude from the query[1] some non-relevant expressions using “intention” (“Intention To Treat Analysis"; "Sensory Deprivation (Intentional)”; "Intentional Contamination"; "Intentional Sampling"; Intended Dietary Use and "Intentional Feeding"; “intentional electromagnetic interference”; “non-intentionally added substances (nias)”). The obtained corpus is referred to hereafter as the “intent*” corpus.

2. Step 2: Identification of the scientific approaches of intentions (human and non-human animals)

The second step was to identify the different scientific approaches to studying intentions in order to reveal those specific to the study of non-human animals as well as the terms associated with them. For this, we used the keyword co-occurrence network as a means of identifying these distinct research communities, i.e. distinct scientific questions (Aria et al., 2021; Mukherjee et al., 2022; Tancoigne et al., 2014). This method is known to allow the identification of different dimensions of the concept of interest (Gauld and Micoulaud-Franchi, 2020) and the types of questions developed to study it (Donthu et al., 2021; Jeanneaux et al., 2012).

a. Creation of the second corpus: intentions in “Agricultural & Biological Sciences”

Through our bibliometric work, we analysed publication trends over the last 30 years in order to determine the period on which we would focus. We found that 2016 was a pivotal year in terms of the increase in the number of articles on intentions. Because of this inflection, we decided to focus on articles published between 2016 and 2020, on the assumption that they would reveal a greater diversity of approaches (see Result 1). Furthermore, limiting the study to those four years ensures that the analysis is representative of current research issues. Then, due to the lack of keywords enabling the search to be restricted to non-humans or to exclude humans, the diversity of disciplines mentioned above and the lack of universal rules for referencing articles by keywords, an accurate focus on non-human animals was not directly possible. Therefore, using the general “intent*” corpus, we decided to develop a method to screen the literature in search of indices of the knowledge on non-human animals’ intentions. After analysing the 20 Scopus subject areas involved in this corpus, we focused on the Scopus subject area “Agriculture & Biological sciences”. This Scopus area covers a wide range of journals related to the study of non-human animals. The list provided by Scopus (last accessed February 2023) includes 31 151 journals. In addition, as the same journal can be assigned to different Scopus areas, journals from other disciplines (such as psychology and neuroscience, for example) can also be found under this label. In other words, focusing on the Scopus area “Agricultural & Biological Sciences” did not exclude any scientific field that may work with non-human animals. Thus, we argue that our corpus, focused on the Scopus area “Agriculture & Biological science”, is representative of the diversity of study on the intentions of non-human animals. The final corpus, hereafter referred to as “Ag&B intent* corpus”, consisted of 936 articles.

b. Selection of keywords analysed by co-occurrence network

In order to focus on the researchers’ specific research questions, which are better represented by the authors’ keywords, we removed from our analysis the keywords automatically indexed by Scopus (Aria et al., 2021). The 200 most frequent author keywords were extracted (for more details see https://docs.cortext.net/lexical-extraction/ on the CorText Platform). Then, while respecting idiosyncrasies, forms with spelling differences (presence/absence of hyphen, plural/singular, British or American spelling differences such as “behaviour” and “behavior”) were grouped. In order to build networks on notions related to intentions, all keywords related to the study population

and to the method (both those related to design and those related to data collection techniques) were removed. This selection of the most frequent keywords had the effect of excluding from the corpus (and therefore from the rest of the work) articles that did not contain any of these keywords. Thus, 715 articles (out of 936) were used to create the co-occurrence network of author keywords (Jeanneaux et al., 2012).

c. Keyword co-occurrence networks corpus “Ag&B intent*” and selection of specific approaches in studies of non-human animal intentions

The CorTexT Platform (IFRIS and INRA, https://www.cortext.net/) was used to create networks of keywords. They were produced as follows: for each keyword, the sum of the number of co-occurrences with all other keywords was calculated (node weight) and then each keyword was associated with the 5 keywords with which it co-occurred the most, according to the proximity measure (edges). This method is a distributional measure which counts the co-occurrence for one term with all other terms in the same context. Thus, the closer the nodes are, the more they co-occurred in a related context. Communities of terms are proposed, based on the classical Louvain resolution (Blondel et al., 2008). This algorithm optimises the modularity of each community (Blondel et al., 2008). Each keyword belongs to only one community. The prevalence of each keyword in a community is given as the weight measure. Each community is named by the two nodes with the highest degree, which corresponds to the centrality measure on the CorText Platform (Brás et al., 2017).

The communities named by the two nodes were more deeply analysed in the objective to be used as highlighters of the scientific approaches in non-human animals that may be backboned by the concept of intention. Three of these were selected because they were formed by keywords used in studies on non-human animals (see Results 2.).

3. Step 3: Identification of the scientific approaches of non-human animals’ intentions

The previous step identified various specific scientific approaches to the intentions of non-human animals and the terms used in them. In this stage, the aim was to obtain a representative view of the way in which intentions are currently studied in non-human animals. To this end, the method developed here was to select a corpus solely focusing on non-human animals and representative of the diversity of current research on the subject of intentions.

d. Creation of the third corpus: intentions in non-human animals

In order to select a corpus representative of the diversity of studies on non-human animal intentions, we decided to build it from the terms identified in the previous step. However, in order to limit the noise of articles unrelated to intentions, and to retain the information carried by co-occurrence, the queries were systematically built around the association of two keywords. Thus, for each community, the highest-weighted keywords were selected. Then, based on their combinations (Table 1), three queries[2] (one per cluster, see Result 2) were created for articles in English and for the period 2016–2020. The resulting corpus contained a total of 1022 articles (one article was identified by two of the three queries, but counted only once in the final corpus). Of these articles, 111 were identified as focusing on non-human animals (see supplementary data Table 8). These 111 articles form the corpus on non-human animals, hereafter referred to as the “Non-human animals’ intentions” corpus.

e. Keyword co-occurrence networks corpus “Non-human animals’ intentions”

As in the previous step, the authors’ 200 most frequently used keywords (except for those related to the methods and the study population) of the “non-human animals’ intentions” corpus were selected. Given the size of the

corpus and the low frequency of keywords, only the 100 most frequent ones were kept. Finally, based on this list, a keyword co-occurrence network was obtained by following the same method as that described in section 3.2.

Table 1
Keyword combinations of the queries used to create the “Non-human animal’s intentions” corpus.

	Keywords selected	Combinations
Community 1	shared intentionality OR cooperation	shared intentionality AND cooperation,
Community 2	referential communication OR social cognition OR domestication	referential communication AND social cognition,
		social cognition AND domestication,
		referential communication AND domestication,
Community 3	language evolution OR flexibility OR vocalization OR intentionality OR language OR gesture	gesture AND vocalization,
		language evolution AND vocalization,
		language evolution AND intentionality,
		language evolution AND flexibility,
		language evolution AND language,
		language evolution AND gesture,
		flexibility AND gesture,
		flexibility AND language,
		flexibility AND intentionality,
		flexibility AND vocalization,
		vocalization AND language,
		vocalization AND intentionality,
		intentionality AND gesture,
		intentionality AND language,
		gesture AND language

[1] *Final query: TITLE ("intent*") OR KEY ("intent*") AND (EXCLUDE (PUBYEAR,2022) OR EXCLUDE (PUBYEAR,2021)) AND (EXCLUDE (EXACTKEYWORD, "Intention To Treat Analysis") OR EXCLUDE (EXACTKEYWORD, "Sensory Deprivation (Intentional)") OR EXCLUDE (EXACTKEYWORD, "Intentional Contamination") OR EXCLUDE (EXACTKEYWORD, "Intentional Sampling") OR EXCLUDE (EXACTKEYWORD, "Intended Dietary Use"*

) OR EXCLUDE (EXACTKEYWORD, "Intentional Feeding") OR EXCLUDE (EXACTKEYWORD, "Intentional Electromagnetic Interference") OR EXCLUDE (EXACTKEYWORD, "Intentional Electromagnetic Interference (IEMI)") OR EXCLUDE (EXACTKEYWORD, "IEMI") OR EXCLUDE (EXACTKEYWORD, "Second Intention Healing") OR EXCLUDE (EXACTKEYWORD, "Second-intention Healing") OR EXCLUDE (EXACTKEYWORD, "Second Intention Wound Healing") OR EXCLUDE (EXACTKEYWORD, "Second-intention Wound Healing") OR EXCLUDE (EXACTKEYWORD, "NIAS") OR EXCLUDE (EXACTKEYWORD, "Non-intentionally Added Substances") OR EXCLUDE (EXACTKEYWORD, "Non-intentionally Added Substances (NIAS)") OR EXCLUDE (EXACTKEYWORD, "Non Intentionally Added Substances (NIAS)"))

[2] ***Query Community 1****: (AUTHKEY ("shared intentionality") AND AUTHKEY ("cooperation")) AND (: LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (LANGUAGE , "English"));* ***Query Community 2****: (AUTHKEY ("referential communication ") AND AUTHKEY ("Social cognition ")) OR (AUTHKEY (" referential communication ") AND AUTHKEY ("domestication")) OR (AUTHKEY (" Social cognition ") AND AUTHKEY (" domestication")) AND (LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016)) AND (LIMIT-TO (LANGUAGE , "English"));* ***Query Community 3****: (AUTHKEY ("gesture") AND AUTHKEY ("vocalization")) OR (AUTHKEY (" language evolution") AND AUTHKEY ("vocalization")) OR (AUTHKEY (" language evolution") AND AUTHKEY (" intentionality")) OR (AUTHKEY (" language evolution") AND AUTHKEY (" flexibility")) OR (AUTHKEY (" language evolution") AND AUTHKEY (" language")) OR (AUTHKEY (" language evolution") AND AUTHKEY (" gesture")) OR (AUTHKEY (" flexibility") AND AUTHKEY (" gesture")) OR (AUTHKEY (" flexibility") AND AUTHKEY (" language")) OR (AUTHKEY (" flexibility") AND AUTHKEY (" intentionality")) OR (AUTHKEY (" flexibility") AND AUTHKEY (" vocalization")) OR (AUTHKEY (" vocalization ") AND AUTHKEY (" language ")) OR (AUTHKEY (" vocalization ") AND AUTHKEY (" intentionality ")) OR (AUTHKEY (" intentionality ") AND AUTHKEY (" gesture ")) OR (AUTHKEY (' intentionality ") AND AUTHKEY (" language")) OR (AUTHKEY (" gesture ") AND AUTHKEY (" language")) AND (LIMIT-TO (PUBYEAR,2020) OR LIMIT-TO (PUBYEAR,2019) OR LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016)) AND (LIMIT-TO (LANGUAGE, "English"))*

Results

1. General bibliometric analysis: intentions are studied in many fields

The following results were obtained on the corpus “intent*” corpus (query focusing on the word “intent*” in the title and keywords and without the identified irrelevant expressions, see Method 2.b). The prevalence of studies on the concept of intention, illustrated in Fig. 1, shows the number of publications on the concept for a given year, weighted by the total number of publications in the Scopus database. This weighting compensates for the exponential growth of scientific production (Bornmann and Mutz, 2014) to reflect the actual evolution of the proportion of studies on the concept of intention. The number of articles studying the concept of intention has increased sevenfold in the last 30 years. An acceleration of this increase in publication is to be noted from 2015 onwards (Fig. 1).

We then wanted to explore the disciplinary dynamics underlying this evolution. To do this, we looked at the “subject area” analysis proposed by Scopus, with each subject area approximately reflecting a specific disciplinary field.

The percentage of each discipline in the total corpus over time, presented in Fig. 2, illustrates the disciplinary dynamics underlying the evolution of the “intent*” corpus. Three dynamics can be identified: the proportion of the discipline in the total corpus that is stable (e.g. social sciences); that which decreases (e.g. medicine); and that which increases (e.g. computer science). The data in Fig. 2 alone does not indicate whether the total number of articles in a given discipline follows the same dynamic. The two types of information presented in Table 2 – the weight of each discipline in the total corpus (total proportion in %) and the evolution of the proportion of each discipline over time (multiplier coefficient) – complete the graph. When combined, this information sheds light on the general dynamics of the disciplines. The scientific output on the concept of intention increased in only ten of the thirty disciplines considered since 1990. The global increase seems to be due to computer science (Multiplier Coefficient: 8.8 and Total Proportion: 15%). Two other disciplines seem to have an impact on the global evolution of the study of intentions; namely, decision science and engineering. Decision science is the discipline that has increased the most (Multiplier Coefficient: 12.9) but its total percentage remains low (4%). Engineering represents a significant proportion of the corpus (9%), with its percentage having doubled. In contrast, the proportions of the major disciplines in our corpus, Social sciences and Medicine and Psychology, have decreased (Multiplier Coefficient respectively: 0.9; 0.5 and 0.4) but they still represent a significant share of the total corpus (respectively: 18%; 11% and 7%). Agricultural and Biological Sciences represent less than 2% of the total corpus but their share has tripled in the total corpus (Table 2).

Table 2
Evolution of the proportion of each discipline between 1990 and 2020 in the "intent*" corpus.

	Intent*	
	MC [a]	Total proportion [b]
DECISION SCIENCE	**12.9**	**4%**
COMPUTER SCIENCE	**8.8**	**15%**
ECONOMICS, ECONOMETRICS AND FINANCE	3.7	4%
AGRICULTURAL AND BIOLOGICAL SCIENCES	**3.3**	**2%**
ENVIRONMENTAL SCIENCE	3.0	5%
EARTH AND PLANETARY SCIENCES	2.3	1%
MATHEMATICS	2.2	3%
ENGINEERING	**2.0**	**9%**
PHYSICS AND ASTRONOMY	1.3	1%
CHEMICAL ENGINEERING	1.1	0%
SOCIAL SCIENCES	**0.9**	**18%**
MATERIALS SCIENCE	0.7	1%
BIOCHEMISTRY, GENETICS AND MOLECULAR BIOLOGY	0.7	2%
BUSINESS, MANAGEMENT AND ACCOUNTING	0.7	2%
HEALTH PROFESSIONS	0.6	1%
PHARMACOLOGY, TOXICOLOGY AND PHARMACEUTICS	0.6	1%
IMMUNOLOGY AND MICROBIOLOGY	0.5	0%
ARTS AND HUMANITIES	0.5	5%
MEDICINE	**0.5**	**11%**
PSYCHOLOGY	**0.4**	**7%**
NURSING	0.4	2%
CHEMISTRY	0.3	0%
DENTISTRY	0.2	0%
ENERGY	NA	3%
MULTIDISCIPLINARY	NA	1%
NEUROSCIENCE	NA	1%
UNDEFINED	NA	0%

	Intent*	
VETERINARY	NA	0,3%

[a] MC: Multiplier Coefficient share of discipline in the annual corpus (SU)

[b] Total share: total share in the corpus (all papers between 1990–2020)

2. Identification of scientific approaches of intentions in the selected corpus “Ag&B intent*”
From this point onwards, the work focused on the period 2016–2020, which corresponds to the period of increased publication on intentions. As previously stated, we believe that this period is the most suitable to explore a maximum of different scientific approaches while reflecting what is currently happening in research.

As previously explained (see Method 1.b), a direct focus on non-human animals was not possible. To circumvent this limitation, we concentrated next on the corpus based on the Scopus area “Agricultural & Biological Sciences”. This garnered 936 articles (“Ag&B intent*” corpus). All results presented in this section, except for the “Frequency %” which was calculated manually, are from the CorText Platform.

a. Author keywords

Of the 200 most frequent keywords in the corpus, 149 were retained after deleting keywords relating to the methods and the population studied. The most frequent keywords appeared in 84 articles, which represented 9% of the total corpus (Table 3), suggesting a great variability in terms of notions involved in the study of intentions. Most of the terms (139) were found in fewer than 10 different articles.

Table 3
Fifteen most frequent author keywords of the “Ag&B intent*” corpus after cleaning. Corpus: Scopus subject area "Agricultural & Biological Sciences". Extraction via the CorText Platform (IFRIS and INRA, https://www.cortext.net/).

Author keyword	Frequency [a]	Frequency % [b]
Purchase intention	84	9%
Theory of planned behaviour	69	7%
Intention	47	5%
Attitude	39	4%
Behavioural intention	30	3%
Consumer behaviour	28	3%
Consumer	20	2%
Organic food	18	2%
Purchase intent	17	2%
Intentionality	16	2%
Trust	14	1%
Emotion	13	1%
Satisfaction	12	1%
Food safety	10	1%
Subjective norm	10	1%

[a] Occurrences, equivalent to the number of articles

[b] Frequency relative to the total corpus

b. Co-occurrence networks of the notions involved in the study of intentions

In the network, each node represents the main form of the keyword. Its size is the sum of its co-occurrences (see Method 3.b) and is given as its weight. The sum of the co-occurrences was calculated only for the 149 most frequent keywords, which means that only the co-occurrences between the words in this list are considered for the calculation of the weight of the nodes. As the frequency was calculated on the totality of the keywords in the entire corpus, the ten high-weighted keywords of the co-occurrence network (Table 4) are not systematically the most frequent ones in the corpus. These ten keywords are associated with communities that approach intentions from the viewpoint of human behaviours and consumption (Fig. 3). The two most important keywords (high-weighted), “intention” and “behaviour”, co-occur twice as often as the third heaviest. It is interesting to observe that they are not at the centre of the network (Fig. 3).

Table 4
The ten high-weighted author keywords in the co-occurrence network “Ag&B intent*” corpus after cleaning. Corpus: Scopus subject area "Agricultural and Biological Sciences". Extraction via the CorText Platform (IFRIS and INRA, https://www.cortext.net/).

Author keyword	Weight [a]	Frequency [b]
Intention	522	47
Behaviour	512	9
Consumer behaviour	262	28
Perception	261	6
Purchase intention	224	84
Attitude	219	39
Theory of planned behaviour (TPB)	209	69
Consumer	194	20
Emotion	116	13
Education	82	5

[a] Co-occurrence sum

[b] Occurrences, equivalent to the number of articles

The geometric organisation of the network (Fig. 3) can be interpreted as follows. Based on the Louvain resolution (with a resolution parameter of 1), 11 stable communities (modularity: 0.75) were detected (Table 5 and Fig. 3). Each community is named by its two high-weighted keywords. They are represented by coloured circles (Fig. 3). The size of each circle is proportional to the number of articles associated with the community (Table 6). All the communities have a high density (Table 5), which means that each keyword co-occurred with almost all the keywords of its community. This is particularly true for the “emotion & purchase intent”; “climate change & adaptation” and “language & gesture” communities. Conversely, the “service quality & behavioural intention” community seems less homogenous.

In the author keywords co-occurrence network (Fig. 3), the communities are organised into three meta-communities (i.e. a spatial grouping of several communities; for details, see Table 5). The main meta-community, in terms of the number of communities belonging to it (referred to afterwards as meta-community 1), is located at the bottom of the network. It is composed of seven clusters, all related to consumption and consumer behaviour. It is interesting to note that the keyword “animal welfare” is linked to the keywords “Knowledge”, “Education” and “Adoption” and not to the keywords of animal behaviour studies. The second meta-community (meta-community 2, the second one up the network) concerns risks linked with the production and consumption of food. The co-occurrence network analysis revealed the most frequent derivatives (expression or word) associated with the word "intent*". In total, 14 different derivatives were found (Table 5).

For a given keyword, the betweenness was normalized between [0;1]. The keywords with the highest betweenness centrality are the most central keywords from the point of view of the geometrical organisation, i.e. they are keywords at the intersection of the shortest paths between the other nodes. The ten keywords with the highest normalised betweenness centrality are presented in Table 5; all these keywords belong to the meta-communities 1 or 2. Finally, the third meta-community (meta-community 3, at the top of the network) is the only one with keywords related to studies on non-human animals' behaviours. It is composed of three approaches: language and gesture; shared intentionality and cooperation; and referential communication and domestication. This meta-community is linked to the others only by the keyword "communication" through the community "language & gesture". Given the centrality of the keyword "communication" in the network and its low betweenness centrality value, meta-community 3 represents relatively few paths between nodes. In other words, there are few connections between the meta-community 3 and the other two (Table 5 and Fig. 3).

Table 5

Communities, meta-communities and betweenness centrality measures of the co-occurrence network of the 200 most frequent author keywords on the study of intentions (2016 to 2020). Corpus: Scopus area “Agricultural and Biological Sciences” plotted by CorText Platform (IFRIS and INRA, https://www.cortext.net/). Community measure: Louvain resolution.

Meta-communities [a]	Communities [b]	Density	Intent* Forms	Normalized Betweenness Centrality.10^{-3}			
				Network [c]		Community [d]	
1	intention & behaviour	0.78	Intention			Perception	7
			Intention to use				
	ecotourism & brand image	0.86	Repurchase intention			Ecotourism	8
			Consumption intention				
			Revisit intention				
			Entrepreneurial intention				
	sensory evaluation & meat	0.78		Sensory evaluation	37	Sensory evaluation	37
				Meat	33		
				Food consumption	25		
				Sustainability	23		
	purchase intention & consciousness	0.78	Purchase intention	Purchase intention	15	Purchase intention	15
	emotion & purchase intent	0.92	Purchase intent	Consumer acceptance	33	Consumer acceptance	33
				Purchase intent	23		
				Emotion	16		
	education & sugar	0.85				Animal welfare	13
	service quality & behavioural intention	0.71	Behavioural intention	Marketing	14	Marketing	14
			Turnover intention				
2	climate change & adaptation	0.97		Climate change	17	Climate change	17
3	language & gesture	0.92	Intentionality			Communication	2
			Intentional				

Meta-communities [a]	Communities [b]	Density	Intent* Forms	Normalized Betweenness Centrality.10^{-3}		
				Network [c]	Community [d]	
	shared intentionality & cooperation	0.86	Shared intentionality		Cooperation	1
	referential communication & domestication	0.88	Intentional communication		Domestication	0.4

[a] Spatial organisation

[b] Louvain Resolution

[c] 10 keywords with the highest betweenness centrality.

[d] Keywords with the highest betweenness centrality for each cluster.

Table 6
Community names and number of articles associated with each community from the co-occurrence network author keywords “Ag&B intent*” corpus. The name of the communities consists of the two high-weighted keywords. Corpus: Scopus subject area "Agricultural and Biological Sciences". Extraction via the CorText Platform (IFRIS and INRA, https://www.cortext.net/).

Community name	Article count
purchase intention & consciousness	208
emotion & purchase intent	160
ecotourism & brand image	51
sensory evaluation & meat	42
language & gesture	37
climate change & adaptation	32
education & sugar	126
shared intentionality & cooperation	13
referential communication & domestication	15
job satisfaction & turnover intention	10
service quality & convenience	21

3. The focus on non-human animals’ intentions

As explained in the method section (see Method 4.b), 111 papers (see supplementary data, Table 9) on non-human animal intention were selected. The same method of analysis was used. All the results presented in this section, except for the "Frequency %" which was calculated manually, are from the CorText Platform.

a. Author keywords

The most frequent keyword ("Language evolution") appeared in 66 articles, which represented 59% of the total corpus, suggesting a lower variability in terms of notions involved in the study of intention in non-humans than in humans. The corpus on non-human animals built upon 6 keywords, all linked to communication except one, "Intentionality" (Table 7). This theme is also central in the spatial organisation of the network: 7 of the 10 high-weighted keywords are related to it (Table 7).

Table 7: The ten most frequent (non-grey cells) and the ten high-weighted (non-grey cells) author keywords in the co-occurrence network. "Non-human animals' intentions" corpus after cleaning. Extraction via the CorText Platform (IFRIS and INRA, https://www.cortext.net/).

Author keyword	Frequency [a]	Frequency % [b]	Weight [c]
Language evolution	66	59%	258
Gesture	19	17%	108
Communication	18	16%	150
Vocalisation	16	14%	189
Intentionality	14	13%	67
Animal communication	12	11%	107
Language	10	9%	223
Social cognition	10	9%	49
Referential communication	7	6%	34
Syntax	7	6%	33
Evolution	3	3%	152
Cognition	5	4%	101
Speech	4	4%	67

[a] Number of occurrences, equivalent to the number of articles

[b] Frequency relative to the total corpus

[c] Co-occurrence sum

b. Co-occurrence networks of the notions involved in the study of intentions in non-human animals
The Louvain resolutions are stable, with 10 communities (modularity: 0.77) organised in two meta-communities (Fig. 4 and Table 8). As for the previous network, the size of the colour circles is proportional to their number of articles and the name of the community is given by the two high-weighted keywords. As in the previous network, all communities have a high density, with the highest density in the "teaching & tradition" community (Table 8). Conversely, the "service quality & behavioural intention" community seems less homogenous.

The main meta-community (meta-community 1), composed of nine of the ten communities, is related to humans either through the origin of human language or through the comparison with humans. The ten keywords with the highest normalized betweenness centrality are presented in Table 8; they all belong to meta-community 1, which

organises the network around it. In addition, eight of the ten central keywords belong to three communities: “mirror neuron and language”; “flexibility & meaning” and “human-animal interaction & domestication” (Table 8). These communities contain keywords related to theories of language origin (“multimodal”, “combinatoriality”, “compositionality”), to the comparison between humans and apes (“comparative psychology”, “referential communication”), and to evolutionary theory (“language evolution”, “language development”). The community “human-animal interaction & domestication” is also related to the neurophysiology that supports language (“broca area”, “prefrontal cortex”) (Fig. 4). Meta-community 1 is organised around two axes: one from eusociality to sociability and the other from audition to language. The first axis is organised (in this order) from “self-domestication & diseases”, “human-animal interaction & domestication”, “mirror neuron & language” to “behavioural flexibility & social context”. The second axis goes from “comparative cognition & auditory” to “handedness & cultural evolution” via “brain evolution & cultural evolution”, “human-animal interaction & domestication” and “flexibility & meaning” (Fig. 4). These two axes are organised around the keyword “gesture”, the most central one in this network (Normalised betweenness centrality: 147.10^{-3}). The “duets & antiphony” community is the only one that does not really lie on these two axes. The second meta-community is that of “teaching & tradition”, and is composed of a single community, linked to the other only by “intentionality” (normalized betweenness centrality: 101.10^{-3}, Table 8). All the keywords of this community are associated with transmission between individuals. It is interesting to note that the two communities in which the notion of emotions appears are “self-domestication & disease” and “teaching & tradition”.

Table 8
Communities, meta-communities and betweenness centrality measures of the co-occurrences network of the 100 most frequent author keywords on the study of intention in non-human animals (2016 to 2020). Corpus: "Non-human animals' intentions" corpus plotted by CorText Platform (IFRIS and INRA, https://www.cortext.net/). Community measure: Louvain resolution.

Meta-communities [a]	Communities [b]	Density	Normalized Betweenness Centrality.10^{-3}			
			Network [c]		Community [d]	
1	behavioural flexibility & social context	0.88	Behaviour	136	Behaviour	136
	human-animal interaction & domestication	0.82	Social cognition	137	Social cognition	137
			Referential communication	120		
	mirror neuron & language	0.83	Speech	91	Speech	91
			Evolution	90		
			Communication	86		
	flexibility & meaning	0.84	Gesture	147	Gesture	147
			Meaning	142		
			Intentionality	101		
	self-domestication & disease	0.84			Self-domestication	66
	comparative cognition & auditory	0.94	Animal cognition	106	Animal cognition	106
	handedness & manipulation	0.95			Language origin	11
	brain evolution & cultural evolution	0.86			Primate communication	83
	antiphony & duets	0.89			Human language	19
2	teaching & tradition	0.98			Imitation	11

[a] Spatial organisation

[b] Louvain Resolution

[c] 10 keywords with the highest betweenness centrality.

[d] Keywords with the highest betweenness centrality for each cluster.

Discussion

In this paper, we hypothesised that the identification in the academic literature of current scientific approaches to intention, and the gaps between them, might allow for a discussion of the current boundaries of the theoretical and

experimental framework of ethology. This would then open new avenues for exploring the intentions of non-human animals. Thus, by developing a “step-by-step” bibliographical method, we identified 111 articles on the intentions of non-human animals that are representative of the current studies. Their analysis revealed 10 different scientific approaches to the concept of intention. In the following section, we discuss the results obtained and their limitations, following each step of our method.

Our work is based on the multidisciplinary Scopus database, which – despite a significant representation of social sciences and humanities – remains limited. For example, with the same query we found approximate 12 000 articles on Scopus compared to 20 000 articles on PsycINFO. However, in order to understand the theoretical environment of ethology researchers (i.e. the knowledge on which they base their own work), it makes sense to focus on the databases used by these communities, rather than trying to achieve exhaustiveness. Our bibliometric analysis revealed an increase in interest in intentions within the global academic literature. This interest increased particularly from 2005, with an acceleration in 2015. Further examination of the underlying disciplinary dynamics revealed that the increase in the number of studies can be caused by two different dynamics: an increase of interest in the concept by a discipline already working on it; and the emergence of new disciplines. The increase in publications on intentions seems to be driven by only six disciplines: computer science, decision science, engineering, social science, medicine and psychology. Two dynamics are identifiable here: the emergence of new disciplines (computer science, decision science and engineering); and increased interest from older ones (social science and medicine). In other words, the concept of intention is not more studied in general but new disciplines have taken an interest in it, while in older disciplines, interest has barely increased or has even decreased. These results could support the idea that intentions *per se* is a useful concept for developing new disciplines and/or new scientific questions. Thus, the exploration of intentions is a way to bring a new epistemological lens to a field, as outlined by Cartmill and Hobaiter (2019), who used intentions as a marker of a particular state of gesture as a window into the minds of great apes.

To assess how intentions are studied in non-human animals, we focused on the Scopus area "Agricultural & Biological Sciences" which covers a wide range of journals related to the study of non-human animals. In the list provided by Scopus (last accessed February 2023), this Scopus area includes 31,151 journals. As the same journal can be assigned to different Scopus areas, journals from psychology and neuroscience, among others, can be found under this label. For example, Animal cognition is tagged under Agricultural & Biological Sciences and in Psychology areas. Thus, we have drastically reduced the risk of exclusion of an entire research field. This allows us to analyse our results as a picture of the study of the intentions of non-human animals in sciences. Secondly, and again with the aim of maintaining a representative aspect of current studies, we chose to base our query on author keywords and indexed keywords. This method allows us to identify those papers in which the authors have used the terms intention or intentionality as well as those that deal with intentions without making it explicit. These include, for example, articles that study behaviours that involve intentions or can be inferred to intentions and those that focus directly on intentions but do not label them as such. We have termed the adaptation by authors of terms used by ethologists to those commonly accepted in zoology, the "self-censorship hypothesis". This phenomenon is already known in another field of ethology; researchers of the concept of emotion in past studies of non-humans (de Waal, 2011) have notably used the term "emotional reactivity" instead of "emotion" (Boissy, 2021). In other words, we found that, based on keywords alone, it was impossible to identify articles on the study of intentions in non-human animals for the following reasons: 1) this term is not always used for the study of intentions and the behaviours from which these mental states are inferred; and 2) researchers do not always specify the subject of the study (whether involving humans or not). To overcome these limitations, we have developed a bibliometric strategy

to narrow the field of investigation and to explore more deeply by focusing on areas in which articles of non-human animals' intentions *per se* can be found.

In the first obtained corpus, built on the keyword "intent*" and centred on the Scopus area "Agricultural & Biological Sciences", the study of intentions involves a great diversity of vocabulary: each keyword is used in few articles. This suggests a fragmentation of research lines around numerous topics of interest carried by small communities. Among these author keywords, it is interesting to note that the 15 most frequent author keywords are not related to the behaviours to which an intention is generally inferred, i.e. those that serve to mark the expression of an intention. On the contrary, these keywords are rather linked to the prediction of a behaviour by studying the intentions that motivate it. These keywords can be divided into four categories: keywords related to the subject who expresses the intention ("consumer"), the object of the intention ("organic food", "food safety"), the consequence of the intention (the subject of study) ("purchase intent / intention", "attitude", "behavioral intention" and "consumer intention") and finally what moderates and/or predicts the intention ("trust", "emotion", "satisfaction" and "subjective norms"). In other words, we do not study intentions through their expression in behaviours but instead we study the prediction of behaviours by speculating on intentions.

These results are confirmed by the co-occurrence network analysis. As proposed by several researchers (see Mukherjee et al., 2022), co-occurrence networks can be used to identify research themes in a particular field, scientific approaches to a theme (Aria et al., 2021; Tancoigne et al., 2014), and even for concept analyses (e.g. Brás et al., 2017). Moreover, by focusing our analysis on the keywords used by the authors, we were able to identify in detail the issues explored by the researchers in their work as well as the underlying theoretical and methodological approaches.

The co-occurrence network of author keywords performed on the keywords "intent*" from the domain-based corpus of Scopus area "Agricultural & Biological Sciences" revealed 11 distinct scientific approaches (communities). Each of these communities has a high density, i.e. all the keywords co-occur with all the others. Thus, each community reflects a coherent and homogenous research theme. The less dense communities ("intention & behavior", "sensory evaluation & meat", "purchase intention & consciousness" and "service quality & behavioural intention") can be explained by the existence of research sub-themes. It would be interesting to explore this dynamic in greater depth in future research. The organisation of this first network reveals that the main themes on intentions in Scopus area "Agricultural & Biological Sciences" focus on consumer behaviours. In this corpus, the main meta-community (the first from the bottom of the network, see Fig. 3) is composed of 618 articles dealing with animal consumption or the impact (environmental, social, etc.) of the production of animal products. This raises the question of where intention studies really stand in terms of the general direction of scientific enquiry.

Let us focus on the specific topic of this first meta-community, such as welfare, which is particularly meaningful. The author keyword "animal welfare" lies in the "education & sugar" community and co-occurs with "education", "meat", "knowledge", "adoption" (which refers to the adoption of behaviours), "food consumption" and "belief". None of these words are related to the study of non-human animals *per se.* Now, when we screen another meta-community (the second one up the network, see Fig. 3), that of "climate change & adaptation", we find 32 articles, all dealing with the notion of risk related to agricultural production. There are four types of risk: socio-economic risk for farmers ("farmer decision making"), risk in the perception of agriculture ("risk communication", "risk perception"), environmental risks ("climate change"), and risks related to food consumption ("obesity"). In brief, the studies of intentions in the set of articles that might best approach non-human animal intentions, i.e. Scopus area "Agricultural & Biological Sciences", outline two meta-communities closely linked to human behaviours or activities,

with different approaches (cognitive, behavioural, social, educative, etc.), and predominantly in relation to human production and consumption. These results, echoed by the 15 most frequent keywords of the corpus, support that in this corpus, researchers are not studying intentions *per se* by inferring them to behaviours, but are rather focusing on how intentions might be a good predictor of specific behaviours (in this case, in particular consumption -related behaviours). In other words, the question seems to be more related to the way in which intentions influence behaviour rather than whether they exist and how they are expressed in the individual being studied.

Finally, the only meta-community which contains keywords fitting to non-human animal studies (the third at the top of the network, see Fig. 3), is the one composed around “language & gesture”, “shared intentionality & cooperation” and “referential communication & domestication”. This meta-community contains only 65 papers of our corpus (all species considered), representing only 9% of the articles indexed to the clusters (715 articles, of the 937 total). Thus, despite the growing interest in recent years in the study of the concept of intention, only a very small fraction is concerned with non-human animal intentions, if those 9% of the most accurate articles are really linked to non-human animal intentions.

This meta-community is linked to the others only by the keyword “communication” (see Fig. 3). If we accept that those articles are really dealing with non-human animal intentions, it indicates that this latter is mainly approached through communication pathways. Yet, we have seen that there are many other approaches, e.g. the expression of behaviours oriented to a goal or a subject that follows the conditions of permanency and adaptability (Burkart and van Schaik, 2020; Leavens et al., 2005). Moreover, all the keywords of the three communities are linked to interaction through communication (e.g. “gestural communication”, “vocalisation”, “communication”, “intentional communication”, “referential communication”), or cooperation (e.g. "cooperative breeding", "cooperation"). Not only does communication seem to be the gateway to study intentions in non-human animals, but it seems that the communication pathways are also indicators of the nature of the intention being studied, i.e. intentions for or in a social interaction. This study of intentions in or through interactions implies a social context and therefore a certain type of protocols. Thus, non-human animal intentions seem to be mostly reduced to a single type of approach based on communication and social abilities, which can only involve a limited number of types of mental and cognitive processes.

To explore further how non-human animals’ intentions are studied and following the concept of the “self-censorship hypothesis”, we created a second corpus based on keywords from the three communities of the third meta-community, where the term related to the study of non-human animals is found. In this corpus, we found only 111 articles related to non-human animals out of the 1022 articles of the corpus (11%). Based on the group of 111 articles, the analysis of author keywords co-occurrence networks revealed 10 divergent scientific approaches of intentions, 9 of which were in the same meta-community. This meta-community (Fig. 2) is organised around two axes: one going from eusociality to sociability and the other from hearing to language. Again, these nine approaches are linked together by the term “gesture”. This ties in with the proposal of Cartmill and Hobaiter (2019) to use gesture (and especially intentional gesture) to access the animal’s mind. The first axis runs from "eusociality" to sociability ("social context", "mating behavior"). The intentions of non-humans seem to be studied in relation to humans, through “human-animal interaction”, including “domestication”, but also an evolutionary approach, whereby the animal is used to explore the origin of human cognitive capacities ("evolution", "language evolution", "comparative psychology", "speech evolution"). This axis also explores social behaviours, in particular those of cooperation, up to and including reproductive behaviours. The second axis moves through the subjects of study related to language, starting with the physiological capacity (hearing), then passing through the cerebral

structures (and their evolution, always in relation to humans), through gesture (and intention) to arrive at language, with spoken language being the furthest point. These two axes allow us to understand how intention is "dissected", and all the skills (physiological, cognitive and social) necessary for intentions to be involved. It is interesting to note that the only community of this meta-community that is not on these two axes, is the only one that is explicitly linked to the study of paradigms (“Antiphony & Duets” community). The latter community, which does not belong to the previous meta-community, is related to “teaching and tradition” through complex abilities and behaviours such as “tool use” and “social learning”. It differs from the other communities not only by the subjects of study, but also by the temporality which is not only horizontal, but also vertical in that it studies the persistence of behaviours over time (“culture”, “tradition”). Here, contrary to the results of previous corpora (Scopus area “Agricultural & Biological Sciences”), intentions are indeed studied for themselves and no longer as a behavioural predictor. Their study is fragmented around several major themes/questions: their origin, with the specific question of the common ancestor with humans, their biological support, their expression through a social context, and their transmission over time. Finally, in this corpus, the question of the existence of intentions in the subject studied seems central.

These results need to be tempered by the limitations and biases that might be involved in creating the corpora. As explained in the method section, it was not possible to focus directly on non-human animals and even less on non-human animal intentions. Thus, during the various steps taken to obtain a corpus focused on non-human animal intentions, choices had to be made (such as the database used, the keywords used, the writing of the queries, etc.). It was therefore not possible to obtain an exhaustive corpus, and some areas of the study of intentions might be missing from our corpora. Moreover, our work on Scopus area “Agricultural & Biological Sciences” only focused on four years (2016 to 2020), in order to obtain a snapshot of the current scientific dynamics on these issues. It might be interesting to compare our results with those of a similar study for other periods. However, despite these limitations, in a first broad bibliometric analysis in which we explored the period from 1990 to 2020 and the keywords “intent”, “intend” and their derivates (data *unpublished*), we found a lower proportion of articles on non-human animals than in the corpus focused on Scopus area “Agricultural & Biological Sciences”. Since the biases on the selection of articles were not the same for these two stages, this confirms that the literature on the intentions of non-human animals is still limited. Thus, despite these biases inherent in the bibliometric method, the ten scientific divergent approaches identified surround, in some way, the concept of intention and its study in non-human animals.

Furthermore, as proposed by Mukherjee et al. (2022), the use of co-occurrence network analyses of terms can not only provide information about the organisation of current academic knowledge, but can also reveal gaps. From this perspective, our results show that current scientific approaches to animal intentions are limited in terms of the subjects of study (focused on the social context through the study of communication), but also from a theoretical point of view, as this work highlights the predominance of approaches on humans in the studies of intentions. On the one hand, our study reveals that humans, because of the origin of the concept of intention, are used as the reference for what intentions are and how they are expressed. On the other hand, non-human animal intentions are mainly studied as a means to better understand the origin of human intentions (and other cognitive capacities). This indicates a lock-in that shadows the possibility of considering non-human animal intentions *per se*. Our study provides tools to open the current theoretical and conceptual framework to intentions on non-human animals. Indeed, the 10 divergent scientific approaches that we have revealed can be reasonably considered to open the current ethological framework. By considering them, it would extend our ability to consider and study the intentions of other species. We have already begun to test the opening of experimental approaches that they allow. In so

doing, we believe it will be possible to explore more broadly non-human mental states, which are still difficult to access and assess.

Finally, in this article, we propose a first step towards a new theoretical framework for studying animal intentions *per se*. Firstly, we provide the theoretical background and tools identified from the current academic studies to develop new ways of considering animal intentions beside analysing the communication pathways. Secondly, it could also be extremely enriching to put forward the hypothesis of "non-human intentions". The point here is that although a first definition and understanding of what constitutes intention must apparently be based on human experience of these concepts, this does not impose a purely comparative approach. It might be possible to start with a narrow human definition and then open it up to other forms of intentions, which could then be expressed in other ways and be carried by other neuro-physiological processes, as is already the case for other cognitive abilities (Mendl et al., 2011). The development of protocols would therefore focus on how to access and measure an intention that cannot be directly conceived. Considering this assumption could have an impact on the design of studies of animal intentions.

In conclusion, this research shows that intentions in animal species other than humans are understudied. In the rare articles we have been able to gather, the studies are supported by 10 scientific approaches. Each of them is different and complementary to the others, but they all fit into the same study paradigm, which is that intentions are expressed through the communication with the other. In other words, the approaches concerning non-humans are locked and limited, contrary to what we have identified in the studies concerning humans. Our analysis of these 10 approaches has given us their constituent elements, their limits and their non-overlapping features, and this can validly serve to open up the theoretical framework. It is an invitation to test this proposal experimentally, initially by seeking to combine several of these approaches with existing protocols. The validation of such a framework should open up great prospects in the experimental investigation of mental states in non-human animals.

Declarations

Ethical Approval

This declaration is not applicable.

Competing interests

The authors declare they have no conflict of interest to report.

Author contributions

Conceived and designed the study: all authors. Sourced the data: ALDM. Wrote the draft manuscript: ALDM. Contributed to improving the text: all authors.

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Availability of data and materials

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Figures

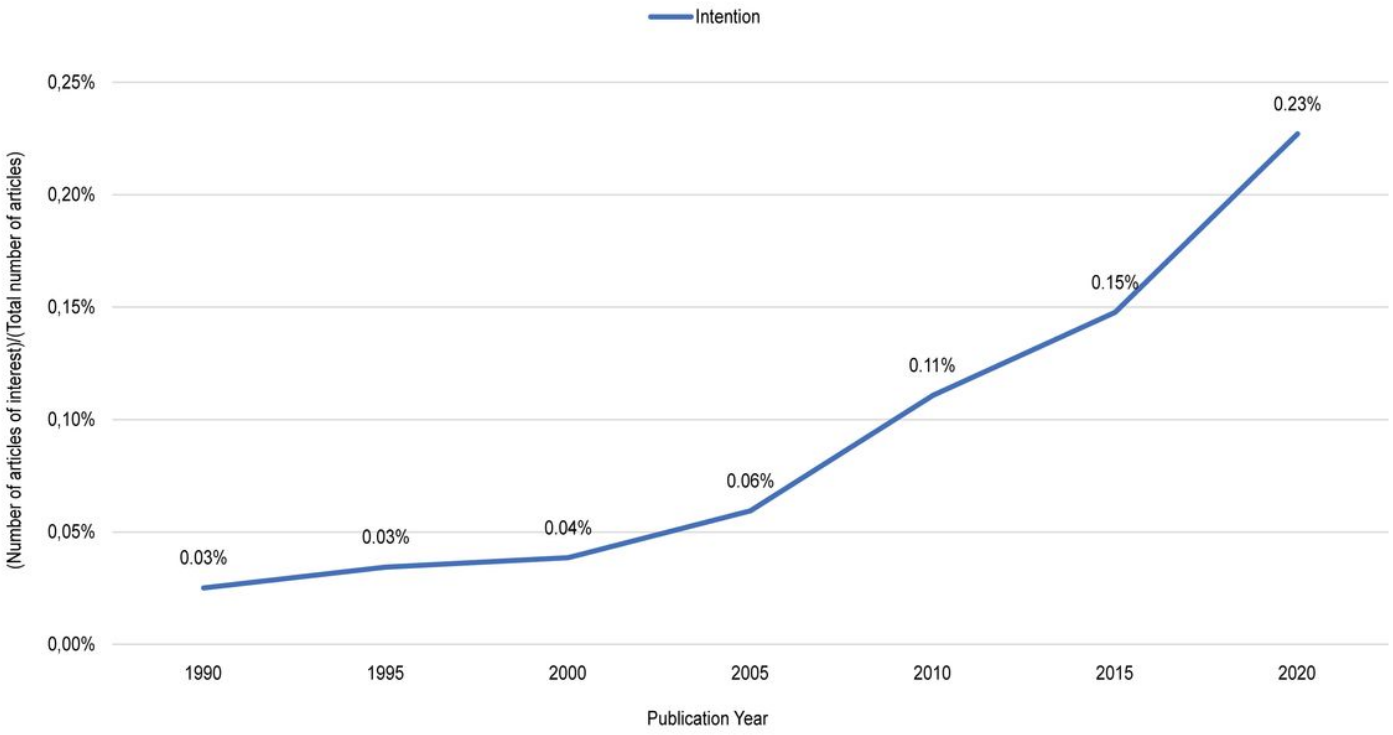

Figure 1

Prevalence over time of the study of the concept of intention on the Scopus database from 1990 to 2020. The query aimed to select the articles with the word « intent » and its derivatives in the keywords and titles (“intent*” corpus). The prevalence is the number of selected articles out of the total number of articles in the database per year. The increase in publications on intent is to be noted from 2015.

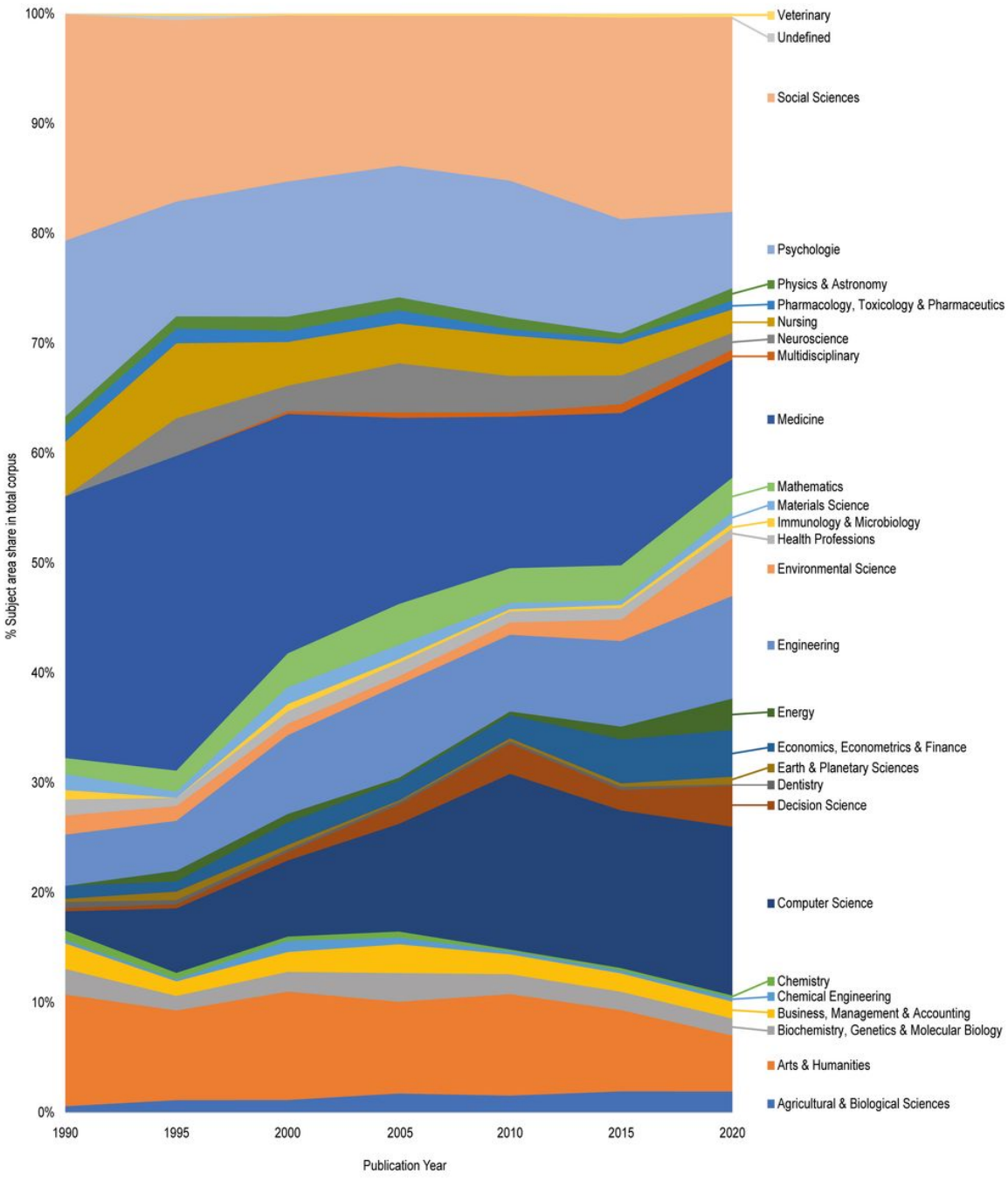

Figure 2

Evolution of the prevalence of Scopus subject area in the “intent*” corpus, per year. Three dynamics can be identified: the proportion of the discipline in the total corpus that is stable (e.g. social sciences); that which decreases (e.g. medicine); and that which increases (e.g. computer science).

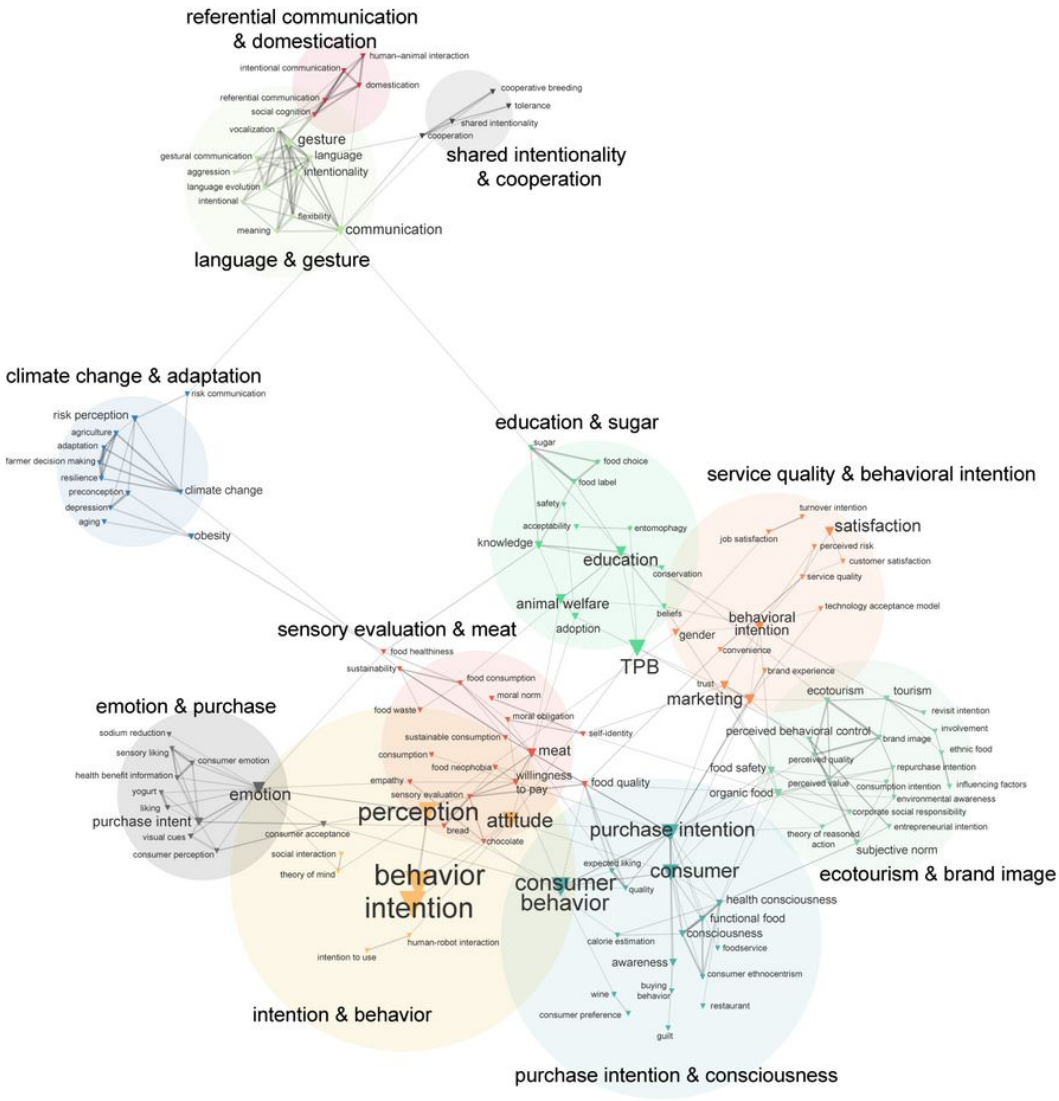

Figure 3

Co-occurrences of the 200 most frequent author keywords on the study of intentions (2016 to 2020), “Ag&B intent*” corpus. Corpus: Scopus area “Agricultural and Biological sciences” plotted through the CorText Platform (IFRIS and INRA, https://www.cortext.net/). The thickness of the edge represents the number of co-occurrences: the thicker the edge, the more the two related words co-occur. For a given node, its position in the network is calculated relative to the position of all other nodes. Thus, the length of the edges can be interpreted as the proximity of two words, i.e. the shorter the edge, the more the words occur in the same context. Measure: distributional. Threshold: top-5 neighbours. TPB: Theory of Planned Behaviour.

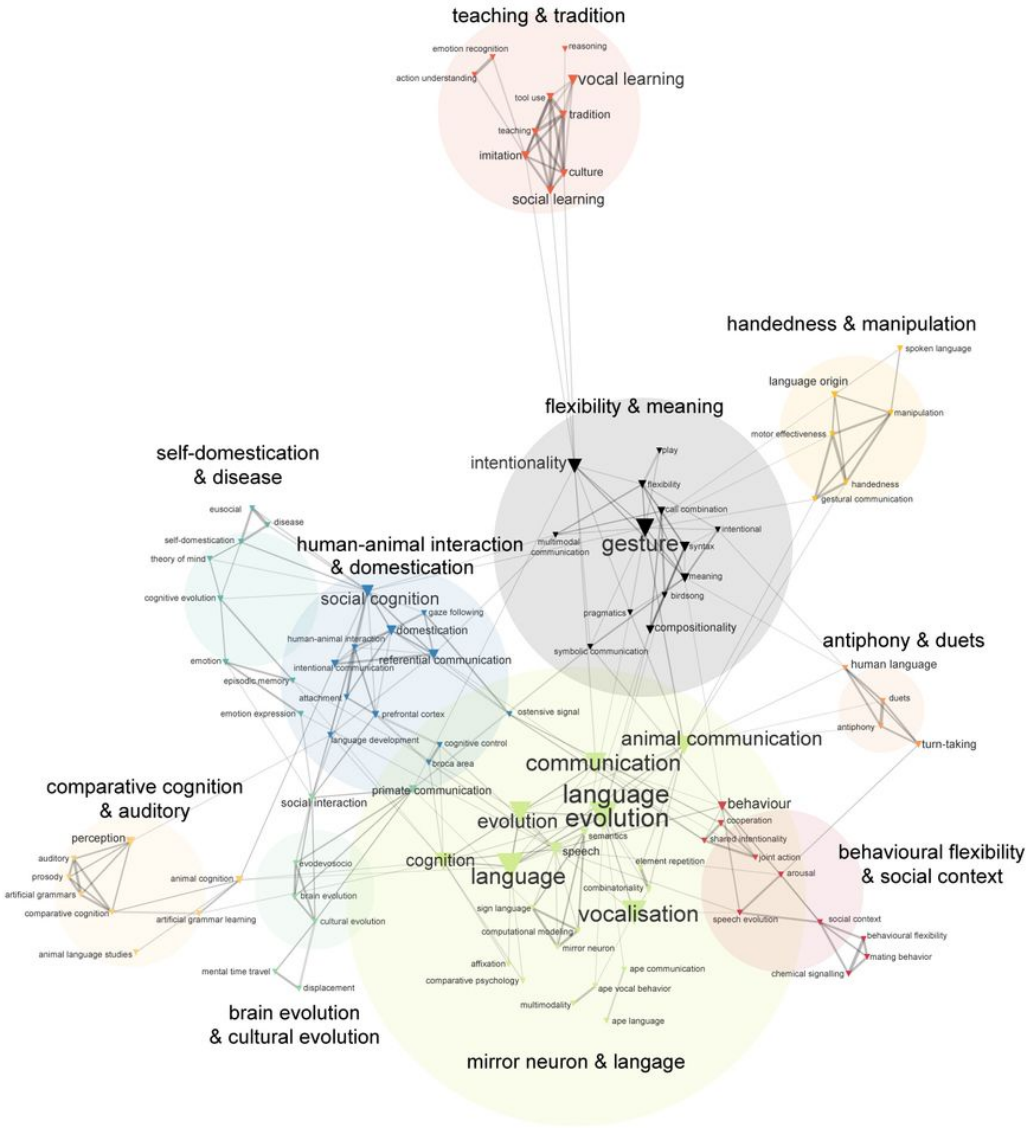

Figure 4

Co-occurrences of the 100 most frequent author keywords on the study of intention (2016 to 2020). Corpus: "Non-human animals' intentions" corpus plotted through the CorText Platform (IFRIS and INRA, https://www.cortext.net/). The thickness of the edge represents the number of co-occurrences: the thicker the edge, the more the two related words co-occur. For a given node, its position in the network is calculated relative to the position of all other nodes. Thus, the length of the edges can be interpreted as the proximity of two words, i.e. the shorter the edge, the more the words occur in the same context. Measure: distributional. Threshold: top-5 neighbours.

Supplementary Files

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