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Artificial intelligence applications in animal behavioral paradigms: A review of emerging technologies

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Abstract

The study of animal behavior is essential for understanding species interactions, adaptation, and ecology. Recent advances in artificial intelligence (AI) have transformed animal behavior research by enabling automated analysis of large datasets, particularly video recordings. AI-based tracking systems accurately monitor animal movements, facilitating studies on social interactions, foraging, territoriality, and migration. Machine learning algorithms can identify and classify complex behaviors, including mating, aggression, and parental care, providing deeper insights into species-specific behavioral patterns. AI also supports real-time monitoring, allowing researchers to assess behavioral responses to environmental changes and external stimuli. Despite these advantages, several challenges remain. Variability in data quality, collection methods, and environmental conditions can affect the accuracy and reliability of AI models. Ethical concerns related to animal welfare, data privacy, and conservation must also be carefully addressed. Furthermore, effective application of AI requires close collaboration among biologists, ethologists, veterinarians, and computer scientists to develop robust and responsible analytical tools. Overall, the integration of AI into animal behavior research offers significant opportunities to enhance scientific understanding while promoting innovative, efficient, and ethical approaches to studying animal behavioral paradigms.

Keywords: AI techniques, animal, behavior analyses, automated tracking

1. Introduction

Learning about the behavior of animals is one of the very important things for conservation and education on the topic because it helps to justify or legitimate the role of humans in conservation as well as it supports better understanding of animal behavior within the animal kingdom. Animals utilize all sorts of behaviors and patterns such as intricate courtship rituals, imaginary networks, and signals efforts (Esbjorn and Zimmerman, 2009) ^[18]. In their study attention almost always is set on their behavior which provides them a solid experience on their evolution, ecological, and biomechanical adaption. The scientist can observe the animals beyond the earth imaging and uncover the operating mechanism of the life on earth. The findings deepen our understanding of mechanisms of physiology but main they are also the antecedent of the other studying throughout like psychology, neurosciences and ecology. Additionally, the data as well as opinions of researches of animal's behavior are very important and they can be used to upgrade a conservation method or design a new medical treatment (Siegford, 2023) ^[52].

Education of man and animals' behavior as a harmonious relationship that they will further have will not be possible without the knowledge of the animal behavior. They assist us to interpret their sign very well at home and in addition to the conservation of wildlife and form a relationship with animals in the wild. By let them to use their instincts and natural tendencies to live in the conditions that are comfortable for them, we may cut fights down and live in the environment that is good for all. In the era of ever increasing environmental hazards, appreciating animal behavior is instrumental for the achievement of conservation objectives (Rabin *et al.*, 2023) ^[48].

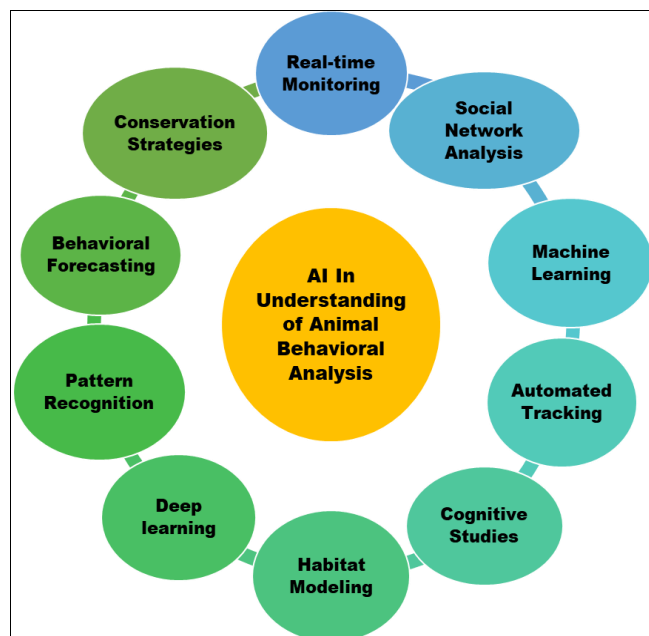


Fig 1: Application of AI in Animal Behavioral Analysis

Understanding the species' response to fluctuating environmental conditions enables designing more precise conservation practices and management approaches which reduce human impact and save biodiversity, habitat and nature reserves. Taking animal behaviour into account is no longer the kind of science that is easy to learn, but rather, it's a notion of our connection with the nature. It emphasizes life in all its aspects, a place where people realize that they are sharing their territory with animals and see nature not as something to control, but live together, and discover amazing differences among all living beings present on Earth.

2. Historical approaches to studying animal behavior

Animal behavioral research is one of the oldest fields of science that has been practiced by people since that world view came into existence. Even now, this sphere of investigation informs us about different ways in which we are unique and how we are similar to the entire animal kingdom. Hence, over time, scientific research has become a way of practicing science as the world gradually learns about the functioning of the animal kingdom with the help of these scientific methods. According to the suppositions made about that period of the past, we can see a very strong impact of such standard of thinking and procedure on the people of our ancestors. Like the foundation of the present study, it helps more in terms of conducting further research that will enable us to have better judgment and understand the issue clearly (Hodges, 2000) ^[29]. Ancient civilizations, such as Egypt, Greece, and China, were among the first to document observations of animals and speculate on their behavior. Philosophers like Aristotle deliberated the motives and instincts of animals, laying the foundation for early theories of ethology (The study of animal behavior in natural conditions). However, systematic methods for exploring animal behavior did not start to appear until the 19th century (Gosling, 2001) ^[24].

The early 19th century witnessed significant advancements in the scientific understanding of animal behavior, spurred by the work of revolutionary psychologists and naturalists. Charles Darwin's theory of evolution by natural selection provided a framework for interpreting animal behavior in terms of adaptation and survival (Dugatkin, 2020) ^[17]. Animal

behavior studies of 'On the Origin of Species', the works of his, laid the foundation of ethology. Then, psychologists like Ivan Pavlov and Edward Thorndike focused on learning principles and conditioning in animals, which especially contributed to the emergence of the experimental approaches to behavioral study in natural laboratories. These early basic experiments were the big impetus for the emergence of behaviorism, a prevailing paradigm in the study of animal behavior which remained for the most part of the 20th century (Guercio, 2018) ^[25].

In the mid of 20th century, ethology gained strong momentum spearheaded by Konrad Lorenz, Nikolaas Tinbergen and Karl von Frisch who focused on studying animals in their natural habitats. Their theoretical revolutions of social dynamics, communication systems and animal behaviors give insight into of-process that influence the animal behavior (Dhein, 2021) ^[15]. Currently there are some methods for looking into animal behavior, such as theoretical modeling, experimental study, and field observation. Through technical advancements such as GPS tracking, remote sensing and bioacoustics, we can now examine animal behaviour in different environments and at varying levels. Identifying how historical approaches have shaped our perception of this interesting subject and the types of perspectives that have influenced it, is a key point to developing our understanding of this complex topic even further. We continue to grapple with the subtleties of animal behaviour and cultivate deeper empathy for the array of life on our planet by expanding on what previous generations knew (Lahoz and Magrath, 2021) ^[34].

3. Introduction to AI and potential impact on the earth

Artificial Intelligence (AI) stands at the forefront of transformative technologies, poised to revolutionize numerous aspects of human life, including the study of animal behavior. With its ability to process vast amounts of data, identify patterns, and make predictions, AI holds enormous potential to enhance our understanding of animal behavior in ways previously unimaginable. When researchers deal with the challenges of burrowing into the intricacies of animal communication, social patterns, and ecological interactions, AI gives them the necessary powers to dig up those new insights and push the discipline forward (Górriz, 2020) ^[23]. Scientists now have a platform to work harmoniously and intentionally in rerouting problems caused by AI and animal behavior studies. The analysis of extremely large data sets that include animal sounds, movements or physiological activity using the machine learning algorithms can help in revealing relations and patterns that are not visible to the naked eye. AI has an effect of accelerating the speed of discovery in that it takes a short time in processing data which enables the researchers more time to focus only on articulating the theories and planning the experiments (Chubb *et al*, 2022) ^[9]. Furthermore, the range of observation is expanded with AI based technology over the limitations of traditional techniques, anyway, the researchers are able to observe the animal behaviour out of box by sensors in a lot of conditions and more real time. For illustration, UAVs with cameras and sensors may give aerial view about nature areas and their habitations and thus show spatial dynamics and resources used by the population (Mangewa *et al.*, 2019) ^[40]. Similar in function, these are the drones fitted for the best camera systems studying the marine life that is the rocket scientists endeavours. The drones also light in on these behaviors that are otherwise obscure AI possesses the potential to not only unearth the mysteries of animal

communication, but also establish a better understanding of cognition in animals (Bekoff, 2002) ^[4]. Machine learning algorithms developed from the same principles that are used in human language processing are being used in animal language analysis and decoding of these creatures' vocalizations, gestures, and facial expressions. Science gains profound behavioral and ecological insights through analysis of animals' complex communication. Animals' social structures, mating strategies, and ecological interactions can be deciphered (Owren *et al.*, 2010) ^[46].

As AI becomes more sophisticated, the influence of AI in the behavioral study of animals is bound to be uninterrupted. AI-assisted methods ranging from assessing the consequences of climate changes on animal populations to the creation of conservation strategies and wildlife management can be the last nail in the coffin of the global extinction problem. Nonetheless, despite its vast potential, the ethical implications should also be taken into account making sure that such technologies are used responsibly and for the good of the animals as well as conservation goals. The merger of machine intelligence and animal behaviour analysis is unlimited in its potential to solve many nature mysteries while at the same time trace the evolution of life on our planet under changing environment. The only barrier to finding the truth and creating new technology is our minds during the exciting journey at the crossroads of biology and technology (Boden, 2018) ^[6].

3.1 Automated tracking systems: Discuss the use of AI-based tracking systems for monitoring animal movements and behaviors in natural environments

In recent years, the integration of Artificial Intelligence (AI) into tracking systems has revolutionized the field of animal behavior research, particularly in monitoring animal movements and behaviors within natural environments. Earlier approaches to monitoring for instance the manual observation and the use of the radiotelemetry have been limited by the scope, accuracy and the limited pace of doing. On the contrary, AI-based tracking technologies are among the most effective countermeasures which can make use of machine learning to process huge volumes of data and unearth true meaning from behaviors that look complicated (Nathan *et al.*, 2022) ^[44]. AI and tracking technologies have made to study animals with tsunami of data and high precision, so resulting in widespread understanding of their ecological interactions, migration patterns, and responses to the variations in environment conditions. Through the integration of different kinds of sensors, such as Global Positioning Systems (GPS), accelerometers, and recording devices with bioacoustics capabilities, the AI-based tracking systems get to record the movement of animals, their living areas and other preferences as well as the physiological states of the animal, in real-time (Hughey *et al.*, 2018) ^[31].

AI trackers can automate data collection and analysis, which is beneficial mainly because this reduces the involvement of humans and debasing the influence of biased observers. Machine learning algorithms enable feeding of sensor data and discrimination of specific states of behavior such as searching food, resting, socializing. At the same time, it allows classification of movement patterns, which are indicative of a certain behavior or environmental events. This automatic method is not only ascertaining the accuracy and reliability of the tracking data but also can be implemented so that the researchers would spend their time on interpreting and developing hypotheses (Heylen, and Nachtsheim, 2018) ^[28]. AI based tracking systems; on the other hand, contribute

to scalability simply because they allow researchers to track multiple species and locations over a wide area and long-term period. Such a skill is very helpful, especially when we deal with animals that have a wide range of movements or are not very easy to understand the behavior, such as migratory birds, marine mammals, or terrestrial predators. Simultaneously detecting continuous data streams from multiple individuals and using AI enables one to reveal mysterious patterns of coordinate behavior, social interactions, and ecological processes that may otherwise be unnoticed (Costa *et al.*, 2012) ^[10].

Besides contributing to deepening scientific understanding, AI-based tracking systems are widely applicable in conservation biology, wildlife conservation, and environmental surveillance. For example, monitoring of herded endangered species or invasive pests enable scientists to determine habitat connectivity, identify conservation priorities, and help develop management policies to facilitate the prevention of human-wildlife conflicts. Likewise, animal behavior monitoring systems based on AI technologies can trace the shifting of the animal behavior due to human activities, the climate change and habitat fragmentation giving the advance warning signals of the ecosystem state and the health level. AI-based tracking systems have the potential to completely transform our knowledge of animal behaviour and its ecological relevance as long as AI's capabilities keep growing. Scientists can solve important conservation concerns and enable informed decision-making for the sustainable management of Earth's biodiversity by using cutting-edge technology to unveil the mysteries of the natural world (Moll *et al.*, 2007) ^[41].

3.2 Social network analysis: Examine AI algorithms for analyzing complex social interactions within animal groups

The issue of animal behavior and group dynamics is principally based on understanding of social interaction among the group members leading to collective behavior, communication skills as well as the success of individual survival and reproduction. Through years observing the intricate patterns of alliances, spirits, and networking connections among animal communities it is possible to develop an in-depth comprehension of the nature and working of animal societies. Researchers are getting more and more AI-powered algorithms, and these may open up new lanes allowing them to predict social networks patterns attributable to different characteristics. In analyzing social networks of the animal kingdom, AI algorithms use methods from network science, machine learning and graph theory, which are able to process the data that is collected from multiple sources such as sweeps, GPS tracking and interviews. These algorithms are able to measure and quantify any kind of social relations between the people by identifying the most important actors and shakers within the network which can also reveal the existing patterns in association and interactions over the time period (Henk *et al.*, 2022) ^[27].

One of the main hurdles of social network analysis is the fact that the amount of data and the harmony of data obtained by looking at animals as they live their normal lives are irregular in the animal groups. Analyzing data by conventional approach becomes an issue, if one needs to evaluate social connections, for example, emerging temporary alliances, forming subgroups or the passage of information through social networks (Krause *et al.*, 2010) ^[33]. AI systems are a good remedy due to the high speed of data processing and the

analysis of big datasets that allows gained valuable insights. For instance, machine learning algorithms can categorize of different social behaviors (behaviors, communication signals, vocalizations, gesturing, or body postures) that have been used for communicating available. Through training AI models on annotated datasets, researchers can teach such algorithms to identify the 'natural' behavior regulation pattern among individuals, distinguish between friendly or aggressive patterns, and finally reconstruct possible social roles and standing within the group (Vinciarelli *et al.*, 2009) ^[55].

AI algorithms also uncover the underlying structure of social networks and quantify network properties, such as centrality, connectivity, and modularity. These metrics provide valuable information about the resilience, stability, and robustness of social systems, as well as the flow of information, resources, and disease transmission within animal populations. By analyzing changes in network topology over time or in response to environmental perturbations, researchers can gain insights into the adaptive significance of social organization and its role in mitigating risks or enhancing reproductive success (Zhang *et al.*, 2020) ^[57].

4. Behavioral analysis

The use of AI for computational animal behavior analysis is an area of research which focuses on using AI to improve the reliability of animal behavior analysis. The role of computerization enabling portrayal of subjects through numbers, and quantification of the psychological states of animals is well recognized within several biological sciences. It has been possible to highlight some main features of this approach that are already having a considerable impact on behavioral analysis: design of dimensional behavioral analysis, analysis speed acceleration, real-time analysis of behavior. Automatic tracking and behavior analyzing systems are increasingly used for different species: wildlife, swine, poultry, insects, and also lot more (Zamansky *et al.*, 2021) ^[56].

4.1 Pattern recognition: Discuss how AI algorithms can identify patterns and correlations in large datasets, revealing hidden behavioral traits

In the age of big data, researchers, regardless the field, would definitely agree that data mining of massive and/or complex data is a hard nut to crack. In studying animal behavior, this complex diversity is foremost and the scientists try to elucidate the elusive facets of individual life, the intricate web of interactions as well as dynamics governing the environment in general and within each species in particular. With the advent of Artificial Intelligence as a new field of Data Analysis, there are now existed many powerful tools that can recognise patterns, trace relationship and thereby discover the hidden behavioral traits and the underlying mechanism which will guide the animal behavior (Zhang *et al.*, 2024) ^[58].

AI algorithms deal with data efficiently and can detect pattern by using algorithms to make predictions on the basis of discovered dependencies. In the investigation of animal behavior what these types of algorithms are able to do is to analyze varied data sets including observational records, sensor's feedback and experimental outcomes, and discover market trends which traditional human observers or statistical methods may not recognize. One of the fundamental advantages of AI algorithms is that they can spot complex patterns and linkages that eliminate untapped knowledge and as well the potential connections that may be crueing. For example, health related issues like heart attacks or diabetes can be linked to air pollution levels over time, non-linear

relationships between variables and emergence of social system properties like dominance hierarchies or complex network structures can be investigated (Stark and Hutson, 2021) ^[54]. Through exploring large data sets of individual actions or interaction patterns, AI software can locate repeated patterns, the leading to the identification of typical motifs, sequences or collective behavior in a certain situation or an environment. In addition, AI algorithms can discover relationships amongst behavioral attributes and surroundings components such as temperature, humidity, and resource abundance. Data from a variety of systems, such as environmental sensors, satellite images, and animal tracking devices, should be combined in order to detect cues from the environment which decide the way an animal behaves, and which will later allow predictions to be made about organism responses to environmental changes (Sih *et al.*, 2011) ^[53].

AI libraries are not only an efficient tool, but they can scale to larger datasets from many individuals, species, and ecological contexts. This capability is especially important in the study of complex systems, including climates, ecosystems or social networks where the interaction between the individual's players give rise to emergent properties, which can be understood, only through systemic view. (Farley *et al.*, 2018) ^[19]

4.2 Machine learning classifiers: Explore the use of supervised and unsupervised learning techniques for categorizing and classifying animal behaviors.

In the context of animal behavior research, the formalization and grouping of behaviors represent important activities that enable researchers identify different mechanisms of animal communication, cooperation and the dynamics of ecological systems the advent of ML classifier has brought forth two techniques that possess great potential for classifying and grouping animal behaviors: the supervised as well as unsupervised learning. These methods use high amounts of observational data to the process of automatically identifying modes, conformities, and contrasts in animal behaviors which in turn eases in the analysis and the interpretation of complex datasets based on behavioral studies. Supervised learning methods provide training data to ML that is characterized by labels, where each potentially behavior or behavioral class associated with observation is provided with an explicitly defined meaning by scientist (observers). The classifier is trained to locate the features and patterns that denote unusual behaviors. Utilizing labeled examples, it correctly categorizes new types of behavior similar to the samples that it has encountered before. Supervised learning algorithms, for instance, SVM, Random Forests, and CNNs, are popular among the large number of algorithms applied to tasks such as gesture recognition, vocalization classification, and activity recognition in animals (Hu *et al.*, 2018) ^[30].

In contrast to supervised learning techniques, unsupervised methods do not require the assignation of labels to data sets; instead, they seek to identify structures or patterns that lay beneath unlabeled data. These algorithms, which are K-means clustering, hierarchical clustering and Gaussian Mixmodels which cluster together similar instances of behavior in terms of their proximity in feature space, thus showing natural groupings or clusters of behaviors. Unsupervised learning which also aids in the exploratory analysis, pattern discovery, and grouping of behavioral categories have been seen to be of great help. Both supervised and unsupervised learning methods provide great benefits and drawbacks of animal behaviour classification (Athey *et al.*, 2019) ^[3]. Methods of

supervised learning thrive when labeled training data is present and the task is to distinguish types of behavior that belong to different determinable categories. On the other hand, they could come in large quantities of data, which is labeled and may report biases, which are introduced by human experts during annotation. On the contrary, unsupervised learning procedures, which are used to investigate groupings naturally or behaviors according to core similarities, may face difficulties with overlapping or ambiguous categories and may not give conclusive outcomes, so require to be confirmed manually (Li *et al.*, 2018) ^[37].

The current scenario with the blending of supervised and unsupervised learning paradigms offers great hopes for a better cognition about the nature and the environmental value of animal behavior. AI classifiers in ML technology promise to ease classifying behaviors, exposing unexpected patterns in behavioral data, and helping researchers gain more profound understanding of an animal's social life, communication, and its decisions. The interdisciplinary collaboration and innovation of methodological approaches lead into the ML classifier of the field of animal behavior research with the aim of delivering knowledge transformation, powered by the differences arising from the technologies of the area (Popovic *et al.*, 2012) ^[47].

4.3 Behavioral forecasting: Investigate AI models that predict future behavioral patterns based on historical data

It is in this frontier of research on animal behavior that the ability to forecast future patterns in animal behavior from past or historical data, through inferences that go a long way, contributes to an understanding of the dynamics of animal populations, social systems, and ecosystems. Artificial Intelligence models, and more particularly those stemming from Machine Learning and Predictive Analytics, provide new panoply of powerful tools for predicting outcomes with unprecedented accuracy and granularity in behavior. For instance, behavioral forecasting uses AI models that learn historical data on animal behaviors in their movements, interactions, and responsiveness to environmental stimulations with an aim of realizing the future behavioral patterns within the *set* alternative scenarios or under modified conditions. Basically, such AI models are run using sophisticated algorithms that handle colossal, complex datasets such that they extract significant patterns and relationships to make predictions based on learned associations (Lewis *et al.*, 2021) ^[35].

The asset that has come up through AI models with the prediction of some of the salient emergent properties, non-linear relationships, and other features in behavioral datasets is realized. The subtle patterns and dynamics that the classical statistical methods tend to miss are what AI models can bring out through the analysis of historical data on behaviors collected through observational studies, sensor networks, or experimental trials. This serves as the basis for the prediction of behaviors of animals under a new or changing environment, or the prediction of the results of an ecological disturbance or management intervention. Possible methods to be used with AI models for behavior prediction are time series analysis, recurrent neural networks (RNNs), or Bayesian inference. The time series analysis techniques, with a relation to the future behavior prediction based on history of data marked with time points, include the autoregressive integrated moving average (ARIMA) models and seasonal decomposition. A second kind of aspect that can be better related is the RNNs, which have the capability to capture time

dependencies of variables and the pattern of sequences of variables within the sequential behavior, hence best for predicting sequential behavior or dynamic interactions in animal groups. AI models can take into consideration environmental variables, like weather and habitat characteristics, and the availability of food and resources, for improved precision in prediction. By integrating data across sources, researchers can come up with comprehensive models that take into account the complex interplay of animal behaviors within an ecological context, thus making more powerful predictions about how behavior is likely to unfold in the future (Cullen *et al.*, 2023) ^[11].

5. Cognitive studies

Understanding and unravelling the complexities in the whole animal cognition and behavior is through the study of cognitive processes of decision-making and learning in animal behavioral research. This is a very powerful tool for AI researchers nowadays in simulating animal decision-making and mimicking learning mechanisms with regard to the cognitive abilities of different species. AI-driven models afford a unique opportunity to study associative learning, memory formation, problem-solving strategies, and other cognitive processes in animals, with the valuable insights on the adaptive significance of behavior and the evolution of intelligence. The principal concept of decision-making models is AI techniques in the simulation of cognitive processes used by animals to estimate options and make choices while adjusting behavior under changing conditions. Most often, these include sensory inputs, internal states, and environmental cues to predict what the outcome of a certain action will be. Subsequently, researchers can train AI-driven decision-making models on behavioral data from animals in natural and experimental settings to investigate the underlying mechanisms of control of the decision-making processes and how animals make trade-offs between the options, assess risks, and maximize rewards. Similarly, the AI algorithms can simulate the learning principles in animals of classical and operant conditioning, reinforcement learning, or even observational learning to investigate how animals can acquire and change behaviors over time. For example, AI agents learn the optimal strategy in reinforcement learning by trying out various strategies, in a similar way that animals learn to associate some particular action with a positive or negative response. Researchers can shed light on the neural mechanisms behind learning and memory formation by training AI models on such behavioral data collected in animal experiments or in the field, including factors determining the speed and flexibility of learning across species (Musall *et al.*, 2019) ^[43].

A clear advantage of AI-based models in studies of animal cognition is that they allow for the simulation of very complex cognitive processes and imaginary scenarios that are otherwise quite impossible to test in a laboratory. Thus, these models may be used to produce predictions that are testable, design targeted experiments, and refine theories of the nature and evolution of animal intelligence through the study of animal decisions and learning. For example, AI approaches have uncovered general laws of cognition that break through the limit of species and yield insights about the evolution of intelligence across divergent taxa. AI algorithms make it possible to probe the neural basis of cognition, reveal the adaptive significance of behavior, and provide more information on the origin and evolution of intelligence within the animal kingdom. And as AI continues to evolve, it will

lead to more and more of these enlightening mysteries in animal cognition and behavior, rendering the future of cognitive ethology and comparative psychology a bright one.

6. Ecological Applications

6.1 Habitat modeling

Understanding the habitat preference and distribution patterns of animals may be key prerequisites in the fields of ecology and conservation biology toward better management of wildlife, habitats, and biodiversity conservation efforts. In AI, for instance, human researchers have a powerful tool for modeling and making precise predictions of animal habitat preferences with very fine grain, not possible before. AI-driven habitat modeling is a process where complex environmental data is subjected to sophisticated algorithms with an aim of deriving meaningful patterns, eventually developing predictive models to be used in shaping conservation strategies and decisions on land use. As for the habitat modeling, it combines many environmental variables in forecasting the suitability of different types of habitats for animal species in relation to climate, topography, vegetation cover, and human disturbance. AI algorithms—such as machine learning, deep learning, and ensemble methods—could be handy tools in the modeling of habitat preferences and distribution patterns with large-scale environmental datasets. Such algorithms will, therefore, help in the identification of non-linear relationships, the capturing of complex interactions among the environmental factors, and the generation of spatially explicit predictions of habitat suitability at fine spatial resolutions (Jain *et al.*, 2020) ^[32].

In general, the major advantages of AI-driven habitat modeling encompass large and heterogeneous datasets where a plethora of environmental variables is represented in different spatial and temporal scales. Machine learning methods, including Random Forests, Gradient Boosting Machines, and Artificial Neural Networks, can work in multidimensional data to find nonlinear relationships between habitat features and animal presence or abundance efficiently. The training of AI models is on historical species occurrence data and environmental covariates, which yields predictive habitat suitability maps into areas of high conservation value or areas that are high-priority candidates for habitat restoration. AI-driven habitat modeling techniques also allow flexible integration of species-specific ecological preference and behavioral trait information into predictive models. For example, ensemble modeling combines model predictions from many different AI algorithms into consensus model predictions, considering uncertainty and variability from the models. Through this, biological knowledge will be fused into AI-driven modeling techniques that could result in a researcher having habitat suitability models that will be in a position to represent varied animal species from wide-ranging mammals to the specialized ones, including amphibians and birds, based on their different ecological requirements and niche characteristics of different animal species, from wide-ranging mammals to specialized amphibians and birds (Linchamps *et al.*, 2023) ^[39].

AI-driven habitat models should project beyond the current predictions of habitat suitability, towards the forecast of future habitat changes, under changing conditions in scenarios like those of climate change, land use, and habitat fragmentation. Impacts can be assessed by the researchers who can approach this through potential human activities on habitat availability and connectivity, identification of areas with habitat vulnerability, and thereafter propose conservation

actions to take care of threats and improvement in habitat resilience by combining predictive models with spatially explicit scenarios of environmental change. AI-driven habitat models have been a critical approach for predicting animal habitat preferences and distribution patterns, which further inform conservation planning and land management decisions. This application provides AI algorithms that give the researcher the opportunity to make strong predictions for habitat suitability over local, regional, and global extents, providing a significant contribution to the understanding of ecological dynamics in animal populations and ecosystems. The development of AI and the potential for revolutionizing habitat modeling in support of evidence-based conservation strategies to secure Earth's biodiversity are gaining significance at an increasing rate (Chen *et al.*, 2023) ^[8].

6.2 Conservation strategies

The increasing rates of environmental change calls for conservation efforts that might protect biodiversity and maintain ecosystems. Fundamental to effective conservation strategies is an understanding of how environmental changes affect animal behavior, because these behaviors are vital for species survival, reproduction, and adaptation. This is where the potential lies within AI technologies to inform aspects of conservation by determining the effects of environmental change on animal behavior. AI technologies provide powerful analytical tools for assessing big complicated data sets that emanates from monitoring movements, interactions and responses of animals in relation to stimuli in their environment. Through integrating data from different sources like remote sensing, GPS tracking and bio-acoustic recordings AI algorithms can measure shifts in animal behavior which result due to changes in the environment such as; pollution, climate change, habitat loss and also human beings' interferences (Ross *et al.*, 2023) ^[49].

The biggest advantage that artificial intelligence technology can contribute to conservation is its ability to detect minute data regularities and interdependencies, which may not be obvious for human observers or traditional statistical methods. On the other hand, machine learning algorithms can identify trending behavioral patterns in historical records of animal behavior and predict future responses. Additionally, by employing AI solutions, conservationists gain knowledge about how animals are adapting to changing environmental conditions and can prioritize sites with higher adaptive capacity for their interventions (Sejian *et al.*, 2022) ^[50]. The use of AI technologies allows scientists to simulate how future environmental conditions could affect animal behavior and provide insight into potential challenges in conservation. Furthermore, this will help them anticipate species distributions changes due to varying migration patterns associated with different climatic scenarios (Heller and Zavaleta, 2009) ^[26]. Consequently, these projections inform the development of management plans for conserving wildlife habitats as well as policy formulation aimed at mitigating biodiversity loss resulting from climate change (Heller & Zavaleta, 2009) ^[26].

It enables adaptive management strategies to be supported by offering real-time monitoring of animal behavior and ecosystem dynamics. Sensor networks, unmanned aerial vehicles (UAVs), satellite imagery with AI algorithms will track the changes in habitat quality, detect disturbances in habitat or monitor the effectiveness of conservation interventions (Dainelli *et al.*, 2021) ^[12]. This timely feedback allows for adaptation of management strategies, more

efficient resource allocation and prompt response to emerging threats to conservation. AI technologies can revolutionize how we conserve wildlife by giving us insights into how environmental changes affect animal behavior. By utilizing AI-based approaches, nature conservationists can create scientifically grounded measures aimed at preserving biodiversity, restoring ecosystems or mitigating climate change impacts. The potential of AI to inform conservation actions and secure a sustainable future for Earth's biodiversity will continue to increase as AI continues to evolve (Shivaprakash *et al.*, 2022) ^[51].

7. Ethical Considerations and Challenges

Addressing challenges such as data bias, interpretability of AI models, and scalability issues is essential to ensure that AI-driven animal research is conducted ethically and responsibly.

7.1 Data bias

Data bias poses a significant ethical challenge in AI-driven animal research, as biased datasets can lead to skewed analyses and erroneous conclusions. Biases may arise from various sources, including sampling methods, data collection protocols, and human observer biases. Consequently, AI models trained on biased data may perpetuate and exacerbate existing disparities, potentially leading to inaccurate predictions and inequitable outcomes. Addressing data bias requires proactive measures to ensure the representativeness and diversity of datasets, as well as transparency in the data collection process (Akter *et al.*, 2021) ^[2].

7.2 Interpretability

Interpretability of AI models presents another ethical concern, particularly in the context of animal research where decisions could have profound effects on animals and their conservation. Opaque, inscrutable models may be created by complex AI algorithms such as deep neural networks that are difficult to interpret or validate. Accountability issues arise from lack of interpretability, which might call into question trustworthiness or even lead to unforeseen outcomes. For transparency in animal research, accountability and ethical decision-making; thus, ensuring interpretable AI models is important (Linardatos *et al.*, 2020) ^[38].

7.3 Scalability issues

Problems with scaling AI technologies create more ethical issues for using AI in animal studies. These issues arise when applying AI tools beyond controlled lab settings, to real conservation efforts or managing animal populations. While AI programs might work well in labs, expanding their use over larger areas and timescales creates difficulties with logistics, techniques, and ethics. Concerns may include data privacy, biased algorithms, and unintended effects from AI-driven actions. Prudently considering ethical implications is needed before deploying AI technologies across diverse ecological communities and environments (Murphy *et al.*, 2021) ^[42].

7.4 Prevention of ethical considerations and challenges

Ethical challenges that the anticipated technological and scientific advancements pose should be addressed in a multi-disciplinary and inclusive way that creates a dialogue among researchers, ethicists, policymakers, and local residents. Joint work in the amendment of ethical guidelines, best practices, and governance frameworks that support users to behave responsibly and equitably in animal research should be

conducted. Addressing the like validation data bias, interpretability of AI models, and scalability issues will help us to move on with the AI technologies in parallel with the respect of ethical principles and protection of the animal world and its conservation objectives (De Paula and Anthony, 2020) ^[13].

8. Future directions

AI has constantly been progressing at a speedy pace and its application in the study of animal behavior opens a welcoming avenue for meaningful discoveries and now we have a better understanding of the intricacies of nature. Starting with innovating sensors and the like machine learning algorithms, AI is changing the way we used to observe and analyze animal behavior and this is just the beginning. While we look to the future, these cutting-edge AI technology and their impacts on wildlife behavioral science opens up a lot of new opportunities to do scientific research and conservation as well (Ahmad *et al.*, 2022) ^[1]. The coming together of AI and sensor technology gives us the chance to gather and review pretty detailed data on animal behaviors in diverse ecosystems that we have not been able to examine before. Microscale sensors, including accelerometers, GPS tracking device, and bioacoustics technologies, are revolutionizing the way researchers collect and analyze animal behaviors data because they are more precise and detailed. Combined with AID driven data analytical techniques these sensor technologies grant researchers to explore hidden patterns, predict behavioral outcomes and attain in depth information pertaining to the cognitive, social and ecological dimensions of the animal behavior (Fosch *et al.*, 2020) ^[20].

In the future, the technology of AI will join with other novel domains like affective computing, natural language processing, and human-animal interaction. This is an indication that there are more undiscovered dimensions of animal behaviour studies available for exploration. Through AI-driven methods the researchers decode the reproduction, the emotional states, the communication signals and cognitive abilities of animals with a high degree of sophistication and accuracy. By bringing people and animals closer to such extent, these technicalities have crucial consequences in the sphere of interspecies relationships, empathy and animal protection (Neethirajan, 2023) ^[45].

On the other hand, more elaborated technology will raise a new introduction of AI in meetings of different conservation world problems and efficiently form sustainable management strategy. Predictive modeling approaches enabled with AI-based algorithms are capable of predicting the effect of environmental changes on animal populations, identifying corridors of wildlife, and consequently designate the conservation strategies. Autonomous systems are the systems that include sensors on drones and underwater robots developed to carry AI controlled functions they open fresh opportunities for wildlife monitoring, enforcement of wildlife laws, and protection of endangered species through access to hard to reach or remote habitats (Bertram *et al.*, 2022) ^[5].

9. Conclusion

In conclusion, the use of artificial intelligence (AI) in studying animal lives necessitates a major breakthrough in the investigation of the natural world. Along with the reading of the challenging social instructions, AI-based methods provide scientists with a powerful analytical apparatus, which allows making reasonable choices between the different habitat preferences and the assessment of the consequences for

animals when the environment changes. Largely due to use of AI technologies, researchers are capable of processing big data collections with super-fast, precise, and accurate rate, as well as with comprehensive efficiency. Machine learning algorithms conduct a searching for such slight features, connections and trends through a particular behavior data by the means of which we can reveal the mechanisms which drive animals' cognition, communication and decision-making. AI helps creating predictive models that can see into the future and content with threats to animal population's resilience to natural forces. These models thereby inform conservation strategies, wildlife management practices, and policy-related matters, so the attempts to protect the biodiversity and the entirety of ecosystems for the future generations are managed. The next stage will be reaching a point where machine intelligence will be the major actor in the exploration of animal behavioral paradigms and thus discover new scientific concepts, find innovative solutions in wildlife conservation and nature preservation, and bring about a progress in living in harmony with nature. Respectively, by continuing with the investment in research, technology, and ethics, the potential of AI to not only increase our understanding of the world around us, but to also drive our admiration of the amazing diversity that exists in nature is unlocked.

Conflict of Interest

Not available

Financial Support

Not available

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