Extension of the boid towards a bird-bot ontology for coordinating surveillance robotic devices

by

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This is a mini dissertation submitted to the Department of Computer Science and Information Technology, Sol Plaatje University, in partial fulfilment of the requirements for the award of the degree of Master of Science in e-Science.

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DECLARATION

I, Vhutshilo Mawela, student number 202002064, declare that:

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2. Accordingly, all quotations and contributions from any source whatsoever (including the Internet) have been cited fully. I understand that the reproduction of text without quotation marks (even when the source is cited) is plagiarism.

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Signature: **Date:** November 2023

DEDICATION

I want to convey my heartfelt appreciation to my father, Marubini Ronald Mawela, for his unwavering love and steadfast support throughout my academic journey. His encouragement and guidance have been instrumental in my academic success, and I am deeply thankful for his contributions to my growth and achievements. Additionally, his wisdom and constant encouragement have been a source of inspiration, motivating me to strive for excellence in all my endeavours. I am truly fortunate to have a father who has been such a positive influence on my academic career, and I look forward to continuing to make him proud of my accomplishments.

ACKNOWLEDGEMENTS

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ABSTRACT

This study extended the boid model to a bird-bot ontology for coordinating robotic devices deployed for surveillance purposes. The key attributes of the ontology are the boid rules, the environment, and meta-data on how each component interacts with other components. Apart from the boid rules, controlled robotic device actions such as orientation, movement, and speed are integrated into the ontology to bring about realism and visually appealing simulations. The proposed ontology was experimentally evaluated for usability and validity in the surveillance of stationary objects like buildings and dynamic targets like vehicles. The bird-bot ontology demonstrated superior performance in surveilling stationary targets when modifying the variable values of control routines (actions) compared to controlled bird-bots. In the experiments, deployment points were controlled to allow experiment repeatability. Usability was measured by quantifying the emergent behavior that emanated from applying the ontology. We looked at how closely robotic devices stayed together, how they moved in the same general direction, and how they avoided collisions. We evaluated the time it took for the bird-bots to locate the target and commence surveillance, which directly reflected the speed and quality of their emergence. We assessed whether the robotic devices maintained appropriate spacing and demonstrated avoidance behaviours, preventing overcrowding and collisions. We also assessed whether robotic devices maintained their velocities to match those of their neighbours, resulting in smooth and coordinated movement. Results indicated that the proposed ontology had causal properties. Robotic devices achieved successful area coverage with desirable efficiency and speed. Effective separation, cohesion, and alignment were observed. Properties such as fault tolerance, adaptability, and robustness emerged. To be precise, the logic in the ontology can be applied to optimise traffic flow in urban areas, highways, and transportation systems. It can inform the design of public spaces, pedestrian

walkways, and urban layouts. This ontology can also be used to develop strategies for search and rescue operations. During natural disasters, such as earthquakes or wildfires, people often need to evacuate quickly and safely. The ontology can guide the development of evacuation plans that ensure a smooth flow of people and minimize the risk of stampedes. These features insinuate that an understanding of the ontology can aid in managing large crowds during events, protests, or gatherings. Even intriguing is the likelihood of this ontology successfully guiding the movement of autonomous vehicles or sensors in environmental monitoring tasks.

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Mawela, V; Chibaya, C., 2020, “Generation of virtual reality environments in which to evaluate swarm adherence to prescribed control rules”. In the proceedings of the IMITEC 2020 Conference” and in the IEEE Xplore digital library.

CHAPTER 1: INTRODUCTION

Swarm intelligence refers to the collective behaviour exhibited by groups of decentralized, self-organized entities, whether they are artificial or naturally occurring (Glasgow & Ahmed, 2012). These systems consist of swarm members interacting with one another and their environment at a local level (Alakwe, 2017). Drawing inspiration from various natural phenomena, such as the flocking of birds, the foraging of ants, and the schooling of fish (Meng, Gao, Lu, Liu, Zhang, 2015), computational swarm intelligence models have been developed.

The interactions among swarm members give rise to collective intelligence, enhancing their problem-solving capabilities (Yang, 2010). Utilizing swarm intelligence models has demonstrated significant advantages over traditional physics, chemistry, or mathematics-based approaches in problem-solving (Hamann, 2012). By emulating natural systems, swarm intelligence systems are more robust, fault-tolerant, effective, and efficient. For instance, challenges in resource planning can be better addressed using swarm intelligence compared to mathematical methods (Fujisawa et al., 2012). Moreover, in scenarios where expensive specialized equipment might hinder productivity, employing a swarm of inexpensive and autonomous robotic devices can be more cost-effective (Pagliarini & Lund, 2017). Such swarm intelligence concepts extend to networking challenges, where decentralized peer-to-peer architectures often out-perform dedicated servers in terms of resilience and reliability (Johnson & Waterfield, 2004).

Teamwork lies at the core of swarm intelligence models, wherein teams of robotic devices collaborate to solve problems, surpassing the capabilities of individual robots or traditional approaches (Wagner & Gerekke, 2007). In the literature, a "boid" is defined as a computer application that simulates the flocking behaviour of birds (Reynolds, 1987). It represents an algorithm used to model such behaviour (Steffen, 2014). Boid can be used on the Internet of Things industry, and the development of Internet-based systems with logical control capabilities (Yamagishi & Suzuki, 2017).

Possessing dynamic traits like device mobility, wireless connectivity, and information exchange (Wallar & Plaku, 2014), boid has shown the potential in solving various challenges. This study introduces the concept of "bird-bot robotic devices", referring to swarm members inspired by the flocking behavior of birds and the characteristics of boid. Coordinating swarms of these bird-bot robotic devices holds promise for addressing problem-solving tasks due to their robustness, fault tolerance, and endurance.

Their application is especially advantageous in hazardous environments where human presence is not viable (Wagner & Gerekke, 2007). Bird-bot robotic devices offer heightened accuracy, efficiency, and the potential to enhance product quality (Ivanov, 2017). They do not require breaks, leave, or salary increments, making them economically attractive (Girdhar, 2015). This mini-dissertation focuses on understanding the construction and coordination of bird-bot robotic devices to create coherent swarm behavior, thus, filling the existing gap in the literature regarding the specificity and explicitness of individual swarm member actions.

Numerous swarm intelligence technologies in nature provide emulation possibilities, such as the flocking algorithm (Rathore, 2016), ant colony optimization (Brioccia, 1992), and honeybee foraging systems (Peters, Peleg, Salcedo & Mahadevan, 2018). Each of these technologies draws inspiration from specific natural systems, but the critical question remains: How do individual swarm members contribute to the emergent behaviour observed at the swarm level? The choice of which natural swarm to emulate holds significance.

As a proof-of-concept, this mini-dissertation explores the behavior of bird-bot robotic devices to establish a bird-bot ontology, facilitating the coordination of a swarm of robotic devices to achieve area surveillance. By formalizing a computational language, the bird-bot ontology, the study aimed to answer the fundamental question regarding the contributions of individual swarm members to the emergent behaviour at the swarm level.

The project goes beyond merely implementing bird-bot rules and proposes a bird-bot ontology as its primary focus. The insights gained from understanding the fundamental building blocks of flocking behavior in birds may pave the way for tackling various challenges in the context of the Fourth Industrial Revolution (Girdhar, 2015). Successfully applied bird-bot algorithms could be instrumental in creating wireless communication networks, addressing bioinformatics challenges, and solving dynamic and multi-objective problems.

1.1 Rationale

Studying the behavior of birds served as the main inspiration for creating the bird-bot ontology. The application of swarm intelligence extends to cutting-edge endeavours, like the development of self-driving cars (Dautenhahn, 2007). These exciting advancements in technology have sparked the motivation for undertaking this study. Additionally, the proposed bird-bot ontology showcases optimization capabilities, enabling its application in solving various optimization problems such as exploration, mapping, monitoring, inspection, and construction tasks, among others (Fahimi, 2008).

The eagerness to contribute to this area has been a driving force behind this research. Furthermore, the data generated from this study is real-time data, allowing for the calculation of emergence speed and quality, as well as the overall performance of the swarm. The ability to quantify emergent behavior and analyze the effectiveness of a swarm intelligence system provides valuable insights in this field. The sense of contributing to knowledge propelled me further to complete this study.

1.2 Problem statement

This study aimed to address a critical issue concerning the control routines governing bird-bots in simulations and their translation into computational algorithms. The goal was to develop a bird-bot ontology capable of solving real-life problems. To achieve this, we systematically identified and integrated specific bird-bot rules, parameters, and relationships. This effort culminated in formalizing a bird-bot swarm communication language known as the bird-bot ontology. This ontology served as a comprehensive knowledge domain, facilitating the coordination of bird-bot robotic devices during surveillance operations.

1.3 Aim

The project aimed to explore and identify the control routines governing bird-bots in simulation. As a result, these control routines were translated into computational algorithms, leading to the development of a comprehensive bird-bot ontology. The practical utility of the bird-bot ontology in performing surveillance on static and moving objects was assessed.

1.4 Objectives

We formulated five objectives as follows:

1. To analyze the actions (control routines) exhibited by birds that lead to emergent behavior at the swarm level.
2. To translate these identified control routines into computational algorithms.
3. To develop a comprehensive bird-bot ontology by integrating the control routines, parameters, rules, and their interrelationships.
4. Assessing the practical effectiveness of the proposed bird-bot ontology in performing surveillance on both static and moving objects.
5. To observe the effects of adjusting the variable values of the control routines in response to changes of values (increase or decrease the control routines degrees) in our bird-bot ontology.

1.5 Research questions

We formulated five questions in line with the five objectives as follows:

1. Which discrete actions performed by bird-bot robotic devices result in emergent behaviour? To answer this question, we seek to pinpoint a finite list of the individual actions of bird-like robotic devices that collectively cause emergent behaviour.
2. How do we translate the discovered control routines into computational algorithms? This question seeks an illustration of the physical and logical designs of the proposed bird-bot ontology.
3. What specific rules, parameters, and relationships govern the interactions of bird bots, and how can they be integrated into a cohesive bird-bot ontology?
4. How can we evaluate the practical effectiveness of the proposed bird-bot ontology in conducting surveillance on both static and moving objects? Additionally, what are some real-life scenarios where implementing the bird-bot ontology could offer solutions?
5. How can we adjust the variable values of the control routines in response to changes of values in our bird bot ontology? To answer this question, we developed the control routines with a slider, which meant we could increase or decrease the slider from 0 to 20 degrees.

1.6 Hypothesis

The null hypothesis that represents the default assumption to be tested and the alternative hypothesis that represents the effect we aimed to demonstrate (Travelers, Cook, 2017) are presented. The outcome of this hypothesis testing exercise helps us to make informed decisions and draw conclusions based on statistical evidence.

In this case, the null hypothesis, denoted as H_o stated that the proposed bird-bot ontology has no effect on the speed and quality of finding and performing surveillance on a target, whether the target is stationary or in motion. Essentially, the null hypothesis suggests that control routines have no impact on the observed emergent behavior.

However, the alternative hypothesis, denoted as H_1 proposes that the proposed ontology possesses causal properties to the speed and quality of finding and performing surveillance on a target, whether the target is stationary or in motion. This study was designed to test these hypotheses and gather evidence, either in support of the null hypothesis or in favor of the alternative hypothesis, helping us draw meaningful conclusions about the impact of the proposed bird-bot ontology on the emergent behavior observed.

1.7 Expected outcomes

We anticipated that the proposed bird-bot ontology would yield plausible results. By adjusting certain factors, we expected to be able to make our bird-like robotic devices do surveillance faster and better, whether the target is static or moving. These insights are essential for improving robotic technology and making robotic devices smarter in virtual environments. Below are the envisioned deliverables of this study:

1. A comprehensive list of actions performed by simulated birds, discerned at the individual level of the bird bots.
2. The development of a code that translates the identified critical actions into computational forms.
3. Creation of the bird-bot ontology, serving as a representation of knowledge for the bird bots.
4. To assess the practical effectiveness of the proposed bird-bot ontology in performing surveillance on static and moving objects
5. Provide some real-life scenarios where the implementation of the bird-bot ontology could provide solutions?
6. This mini dissertation documenting the research findings.

1.8 Research ethics statement

This project strictly adhered to ethical guidelines, and it is crucial to emphasize that neither humans nor animals were involved in any aspect of the study. The development of the bird-bot ontology solely relied on readily available resources in the form of extant literature. To create the NetLogo program, we followed the typical software development life cycle implemented on a standalone computer. This cycle comprised phases such as issue identification, systems analysis, systems design, implementation, testing, and deployment of the software product thereto.

Throughout the study, we maintained transparency and integrity by reporting simulated results as they were generated. No external parties were engaged at this stage, and we committed to remain truthful and honest in our approach. Given the nature of the project, we thoroughly examined its implications, and we concluded that there were no ethical issues to be considered in this context.

Furthermore, the dissemination of research findings was conducted openly to raise awareness among the wider public regarding both technological advancements and the ethical considerations pertinent to surveillance coordination. Additionally, the research proposal underwent a comprehensive review by appropriate institutional review boards to ensure unwavering adherence to ethical guidelines throughout the research process.

1.9 Overview of the mini dissertation

The upcoming chapters are structured as follows: the literature review explores into the existing knowledge concerning swarm intelligence inspired by bird like robotic devices. We detail our methodologies to explain the conduct of our research, followed by a thorough explanation of experiments' procedures and data collection. The results section showcases our findings, while the conclusion encapsulates their implications. Additionally, the references section lists all cited sources, and the appendices provide supplementary materials. Collectively, these sections form a coherent and comprehensive document guiding readers through our research process and its outcomes.

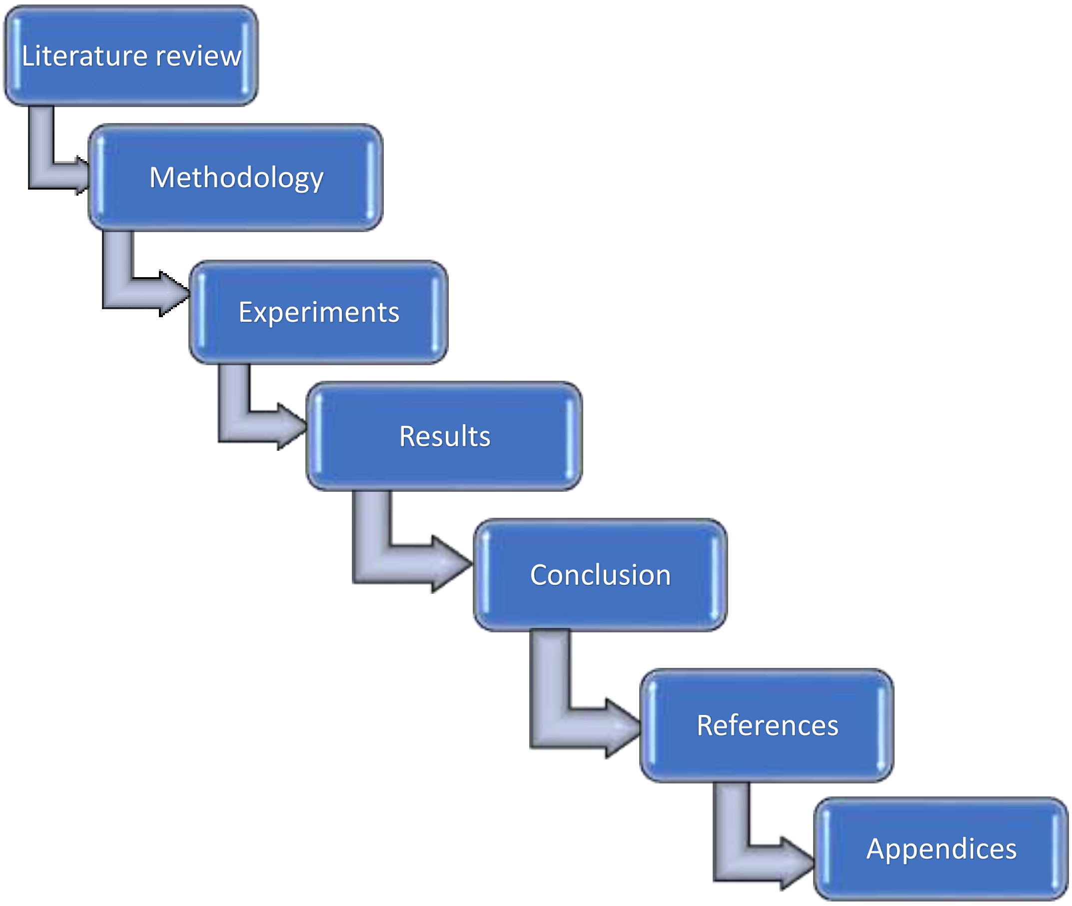

Figure 1 Overview of the mini dissertation

1.10 Summary

Chapter 1 serves as the introductory foundation for the research project. It introduced the concept of swarm intelligence, inspired by natural phenomena like bird flocking and its applications in computational models. The chapter underscored the emergence of collective intelligence, with a focus on "bird-bot robotic devices," which emulate bird-like behaviors and hold potential for real-world problem-solving.

The chapter presented the research's rationale, objectives, research questions, and hypotheses, to explore and formalize the behavior of these bird-bot robotic devices. It also addressed ethical considerations, emphasizing computer simulations and transparency. The chapter concluded with expected outcomes, notably the development of a bird-bot ontology with broad application possibilities in wireless networks, bioinformatics, and Fourth Industrial Revolution problem-solving. The next chapter discusses the literature related to this study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In literature, the application of the boid concept involves three essential component units or sub-routines: cohesion, separation, and alignment. Cohesion routine allows bird bots to move towards other bird bots in sync, it tells bird bots to try and occupy the centre of mass of the swarm. The separation routine brings about collision avoidance in the swarm, it steers bird-bots away from one another when bird-bots get too close to each other. The alignment routine causes bird bots to seek to follow the vectors of their surrounding counterparts. A successfully simulated boid was first achieved by Reynolds (1987). Although Reynolds (1987) achieved a successful simulation of the boid, the specific coding, sequencing, and integration of these routines for each bird bot, along with the parameters and relationships between these units, remained unclear. Figure 1 below is an illustration of boid rules.

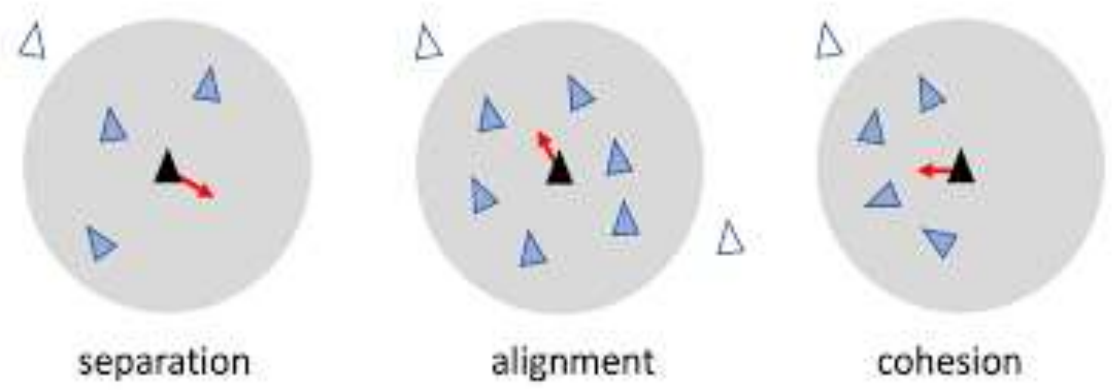

Figure 2 Illustration of boid rules

This study aimed to extend the boid technology to create a comprehensive bird-bot ontology that explicitly captures all the components, parameters, and relationships among these elements. Swarm intelligence heavily relies on the environment in which the swarm members are deployed (Girdhar, 2015). The environment serves as a crucial meta-component of swarm intelligence systems, enabling realistic simulations of swarms of robotic devices.

In the proposed bird-bot ontology, each bird-bot contributes to the mission by communicating with others in the swarm, necessitating a clear understanding of the relationship between bird-bot activities and their environment. The ontology seeks to encompass all these features within a swarm knowledge representation framework, capturing components, semantics, and relationships to enhance practical problem-solving.

2.2 Categories of swarm control models

The design of bird-bot control rules can be approached from various perspectives. Some models are purely bio-inspired, considering leader bird bots and hierarchical task performance, while others adopt physicomimetic principles, inspired by physical forces of attraction and repulsion. Mathematical viewpoints have also been considered. However, none of these approaches have explicitly addressed the computational design of the rules used.

2.2.1 Calculus-based swarm control model

Two models in this category were introduced in the literature. The first model focused on swarm performance based on density, using control rules related to cooperation and inference (Hamann, 2012). It provided examples of swarm experiments to demonstrate its effectiveness. However, it required robotic devices capable of complex calculations, which may not be suitable for practical use. The second model presented an abstract model of collective decision-making inspired by urn models, utilizing control rules related to feedback and consensus. Like the first model, it also relied on sophisticated robotic devices, making it less practical for 4IR interventions.

2.2.2 Vector-based swarm control models

Vector-based swarm control models are widely used, with one model designed for optimizing a stand-alone PV system's power tracking controller (Gharaveisi, Heydari & Yousofi, 2014). This algorithm operates in a multi-dimensional vector space, with vectors oriented towards a global optimum as the algorithm progresses. However, this approach involves extensive computations before robotic device orientation. We advocate the use of simple autonomous robotic devices that do not rely on these advanced capabilities.

2.2.3 Physics inspired swarm control models

These are swarm control models grounded in principles of physics, including laws of motion, forces of attraction and repulsion, and magnetic concepts. This category of swarm control models characterizes swarm agents as particles within the simulation. Each particle is equipped with sensors to detect environmental objects as either attractive or repulsive (Kadrovach & Lamont, 2002). The swarms exhibit safe separation while maintaining a level of cohesion. When applied to wireless sensor networks, these principles offer efficient coverage and a robust communication system. Nevertheless, sensor-mounted robotic devices can be complex and costly to construct, particularly in economically challenged regions like South Africa. Hence, the focus shifts towards developing control rules suitable for simple, autonomous robotic devices.

2.2.4 Herds and crowds inspired swarm control models

The models in this category are initially designed to simulate food foraging behavior but can also be applied to explore safe locations and predator-prey interactions. They achieve this by utilizing a robust method, where swarm fragments interact with each other and the environment to create a guiding flow for each member of the swarm. This collective action leads to a transformation in their positions (Alnahhas, AlKabbani, Alshami & Alkhous, 2016). However, it is worth noting that, in many instances, the agents in this category are quite advanced and not suitable for simple or naive applications.

2.3 Motivation for this research

This study aims to fill this knowledge gap by developing a bird-bot ontology that consolidates specific computational rules, parameters, and relationships, representing the knowledge domain of bird-bot robotic devices for coordinated surveillance. The design of the proposed ontology is the primary focus of this research, aimed to contribute to the existing body of knowledge. Inspired by the study of bird behavior, the creation of the bird-bot ontology emerged as the primary motivation for this research.

Similarly, the application of swarm intelligence in cutting-edge endeavors like self-driving cars (Dautenhahn, 2007) has sparked interest in enhancing technology, giving impetus to this study. Furthermore, the proposed bird-bot ontology exhibits optimization characteristics, enabling its application in solving various optimization problems such as exploration, mapping, monitoring, inspection, and construction (Fahimi, 2008). This desire to contribute to this domain has fuelled this research study.

The data generated from this study would be in real-time, facilitating the calculation of emergence speed, quality, and overall swarm performance. Quantifying emergent behavior and analyzing the performance of swarm intelligence systems would provide valuable insights into this field, instilling a sense of knowledge creation and further propelling the completion of this study.

2.4 Gap

In summary, our work addresses a gap in the literature by creating a structured bird-bot ontology that consolidates computational rules, parameters, and relationships; thereby enhancing the understanding and implementation of bird-bot behavior in swarm intelligence systems.

2.5 Summary

This chapter introduced the boid concept, drawing inspiration from natural phenomena. It emphasizes the significance of the environment in swarm intelligence and highlights the research's drive to contribute to technological progress, and bridge knowledge gaps in computational swarm control rules. It elaborates on the categories of swarm control models explored previously. Additionally, it explores the motivation behind our research. Acting as a foundational background, this chapter set the stage for the research, outlining its background, and explaining the relationships among boid rules.

CHAPTER 3: METHODOLOGY

In this chapter, we explore the components of the bird bot ontology using various diagrams such as entity-relationship diagrams, data flow diagrams, and warnier orr diagrams. These diagrams helped us to understand the bird bot ontology better. Firstly, we drew the entity-relationship diagrams to break down and show how various parts of the bird bot ontology (virtual environment, bird bot, and surveillance) are connected and worked together. Subsequently, we drew data flow diagrams to elucidate the flow of information within the bird bot ontology.

To ensure clarity, we created distinct diagrams for surveillance and the bird bot ontology, providing a comprehensive overview of how data circulates within the system. Lastly, we used warnier orr diagrams, which resembled special maps, to illustrate how all the elements in the bird bot ontology fit together, and how various components relied on one another.

The diagrams in the chapter progressed in a particular sequence. First, we had the entity-relationship diagram for the virtual environment, the entity-relationship diagram for bird bot, and the entity-relationship diagram for surveillance.

Next, we followed with the data flow diagram for surveillance and the data flow diagram for the bird bot. Finally, we explored the warnier orr diagram for bird bot and warnier orr diagram for an ontology. For each diagram, we provided a comprehensive explanation to ensure our understanding of how the bird bot ontology would work, encompassing its structure and operational aspects. Our aim was to gain a complete understanding of the intriguing ontology emerging at the end.

3.1 Entity relationship diagram for the virtual environment

The entity relationship diagram for the virtual environment in which the bird bots are deployed, provides a visual representation of how different components within the virtual environment relate to one another. This diagram outlines the connections and interactions between elements like the virtual environment, bird bot, and surveillance. It serves as a foundational map for understanding how these components work together to create a dynamic and responsive environment.

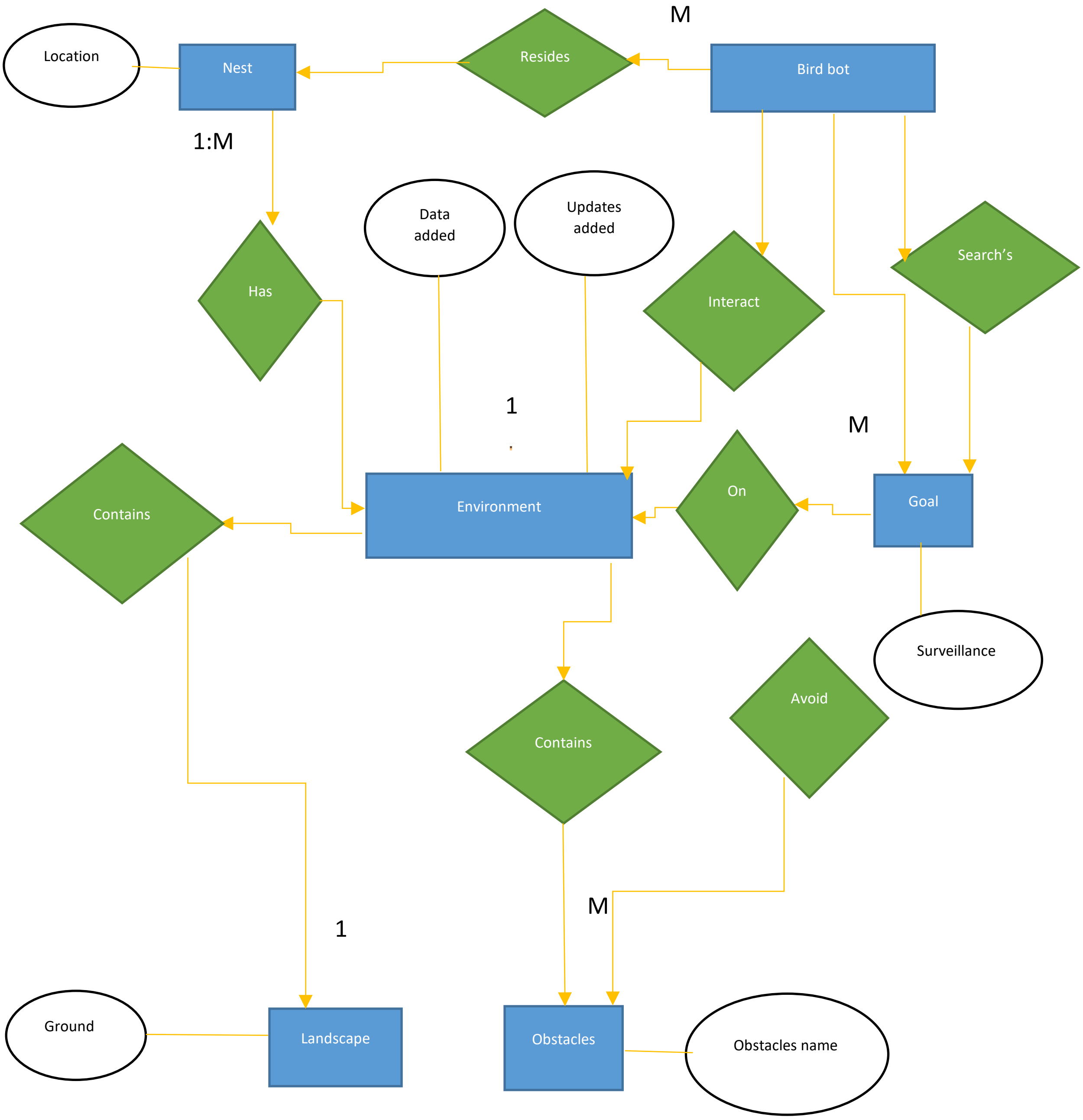

Figure 3 Entity relationship diagram for virtual environment

This entity relationship diagram in figure 3 illustrates the structure of a virtual environment. Within this virtual space, a bidirectional interaction occurs between one virtual environment and multiple bird bots. These bird bots, in turn, can communicate and coordinate their actions with the same virtual environment. The virtual environment is designed to be dynamic and adaptable, allowing for the incorporation of fresh data.

Crucially, the virtual environment accommodates one or more nests, each defined by specific location and size attributes within the virtual domain. The overarching objective of the virtual environment is to facilitate surveillance operations. The bird bots exhibit impressive versatility, as they are equipped to perform surveillance on both stationary and mobile objects within the virtual environment. This adaptability enhances their effectiveness across diverse scenarios.

Within this environment, a variety of obstacles may be encountered, including trees, substantial walls, houses, or buildings. The bird bot dwells within its nest, evading obstacles while seeking a goal. These elements add complexity to the environment's landscape. Additionally, the environment's temperature fluctuates to reflect the prevailing weather conditions, creating a more immersive and realistic virtual setting.

3.2 Entity relationship diagram for a bird bot

The entity relationship diagram in figure 4 for the bird bot presents a visual representation of how various elements within the bird bot system are interconnected. This diagram offers a clear illustration of the relationships and interactions among bird bot, shedding light on how these entities cooperate and engage with one another. It serves as a valuable tool for gaining a deeper understanding of the structure and operations of the bird bot component.

The entity relationship diagram in figure 4 provides an insight into the intricacies of the bird bot. Within this system, multiple bird bots possess the remarkable ability to independently modify their directions, and foster adaptability and agility. Crucially, these bird bots are tightly integrated with a singular environment, resulting in a dynamic and interconnected ecosystem. Bird bots are equipped with a range of sophisticated actions, exemplifying their capacity for collective behaviour.

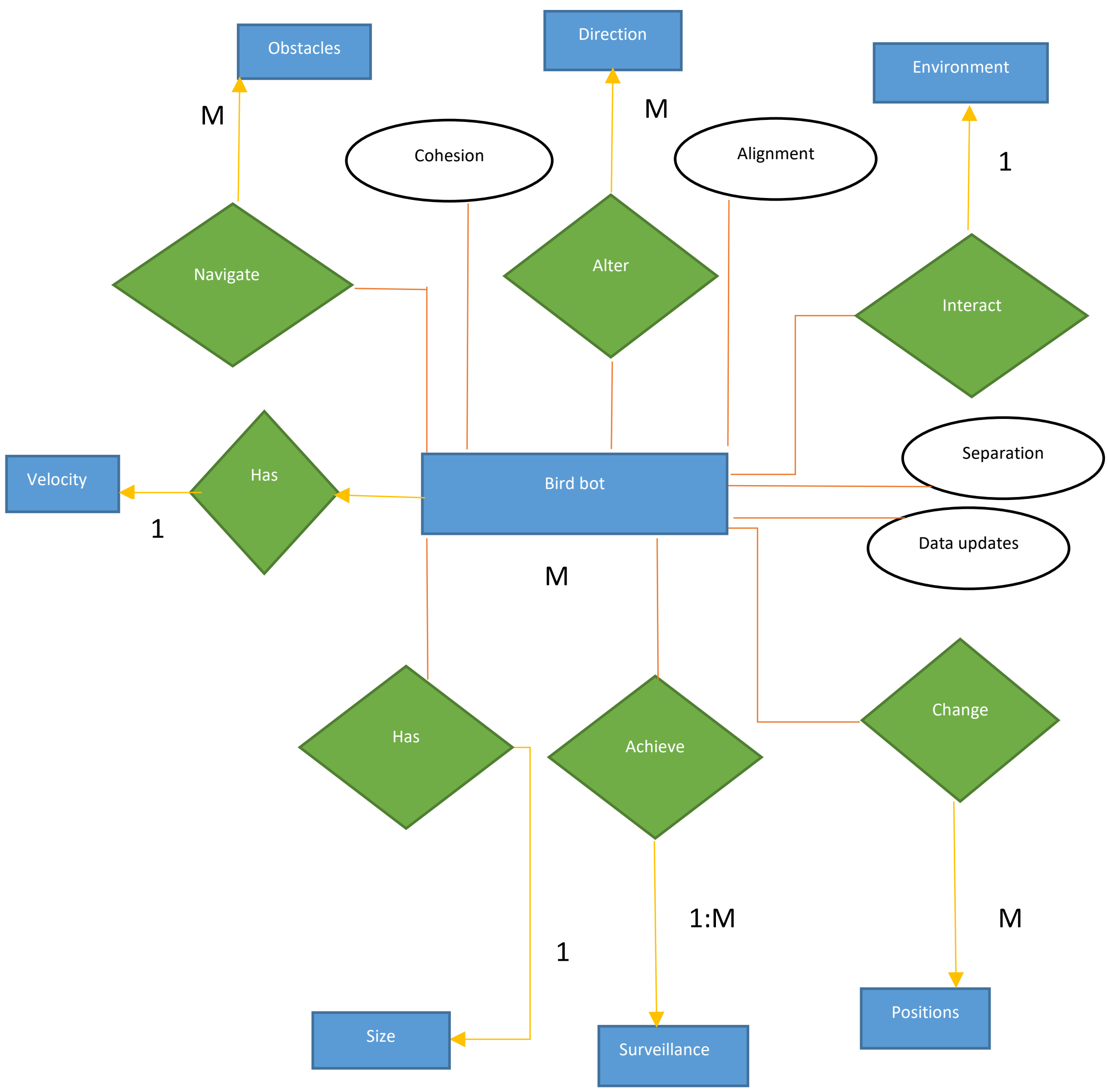

Figure 4 Entity relationship diagram for bird bot

The cohesion action encourages bird bots to draw closer to neighbouring birds, promoting unity and synchronization within the group. Similarly, the separation action ensures that bird bots swiftly adjust their course to avert potential collisions, with this rule temporarily taking precedence to maintain a safe separation distance. Meanwhile, the alignment action dictates that each bird bot harmonizes its direction with the prevailing group dynamics, ensuring seamless collective movement. Moreover, bird bots are not static entities. They have the remarkable capability to change positions, reflecting their adaptability in the ever-changing environment.

The velocities of the bird bots vary, enabling different movement speeds, and they can synchronize these speeds for coordinated actions. A central function of these bird bots lies in their aptitude for achieving surveillance. They interact dynamically with the environment, skill-fully navigating through obstacles to monitor and respond to target locations effectively. Each bird bot has a distinctive size, contributing to the diversity and complexity of the bird bot collective. This diverse range of sizes can influence how they interact with their surroundings, demonstrating the flexibility of the bird bot system.

3.3 Entity relationship diagram for surveillance

The entity relationship diagram in figure 5 for surveillance provides a visual representation of the relationships and connections between different components involved in surveillance. This diagram offers insights into how surveillance elements within our bird bot ontology, such as sensors, data storage, and monitoring devices, are interconnected. It serves as a crucial tool for understanding the structure and interactions of surveillance-related entities and data flows within the broader bird bot ontology framework.

structure. Bird bots involved in monitoring operations have the capability to synchronize their speeds with neighbouring entities. Additionally, surveillance bird bots possess the flexibility to change both their direction and positions as needed.

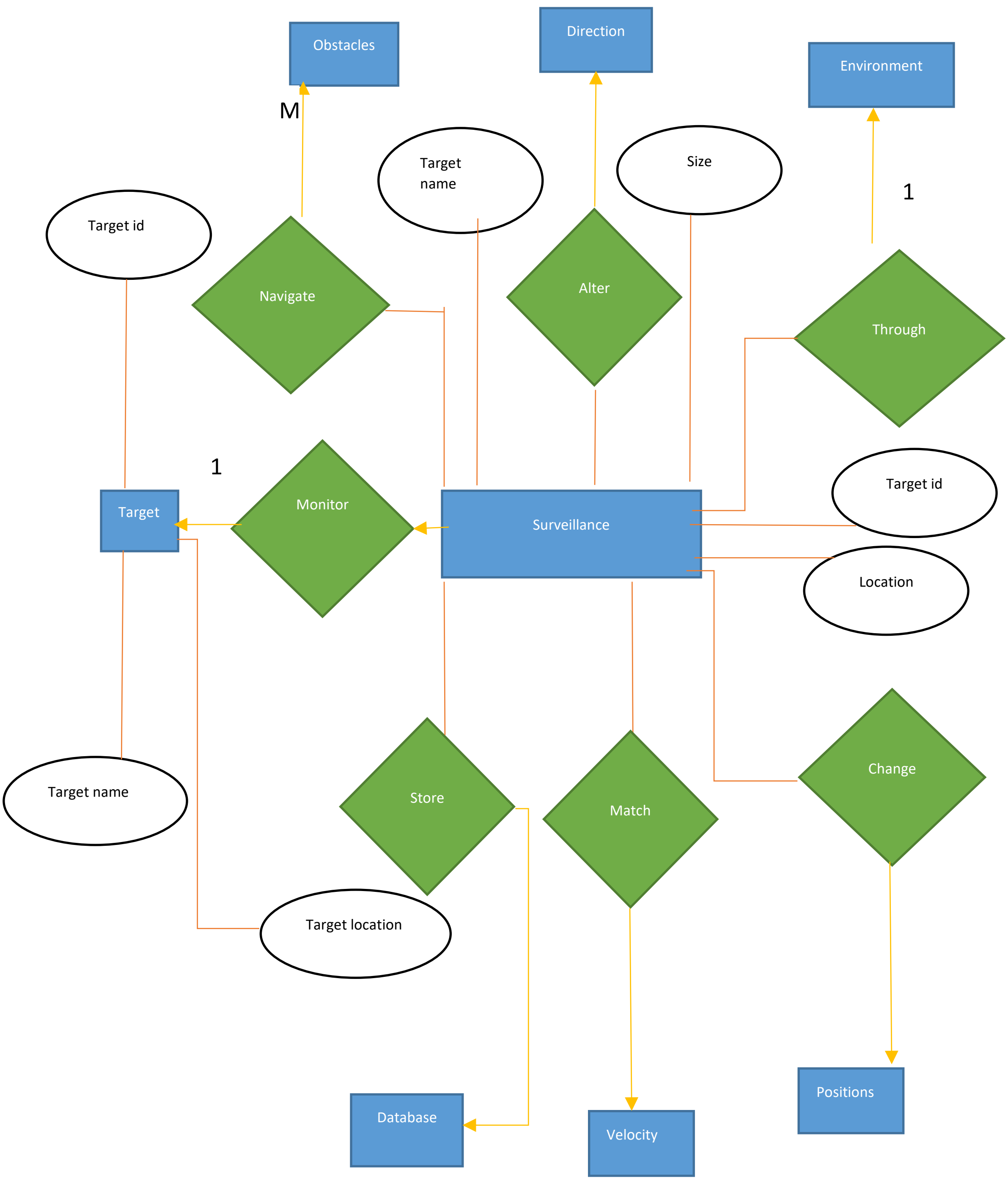

Figure 5 Entity relationship diagram for surveillance

Surveillance primarily hinges on interactions with the environment, particularly in pursuit of specific goals or targets. Surveillance activities, including speed data, are stored in the database. To achieve their objectives, surveillance bird bots navigate adeptly through obstacles in their path. These surveillance actions may necessitate alterations to the direction of the bird bots. This entity relationship diagram in figure 5 depicts the surveillance system's

The designated targets for surveillance can either be stationary or mobile and include objects like cars. These targets encompass essential attributes such as a unique name, identification, and location data. When conducting surveillance on cars, specific identifiers, such as unique number plates, are employed to distinguish one vehicle from another.

3.4 The data flow diagram for surveillance

The data flow diagram in figure 6 for surveillance is a visual representation that outlines how information flows within the surveillance system. It illustrates the pathways through which data is collected, processed, and disseminated in the context of surveillance activities within bird bot ontology. This diagram is essential for comprehending how data moves and is managed in surveillance scenarios, ensuring effective monitoring and information handling in the broader bird bot ontology framework.

In figure 6, the bird bot conducts surveillance on the environment, utilizing data stored in the database. Next is a discussion of how this process unfolds. Surveillance operation: The bird bot initiates surveillance activities in environment. It involves searching for a target and gathering relevant information. Database interaction: Bird bot can communicate with a database, both requesting and receiving information. The database contains recorded data about the environment and other pertinent details. Obstacle navigation: Bird bot is capable of navigating through obstacles within the environment. This is essential for comprehensive area surveillance. Target identification: When the bird bot successfully identifies the target from the database, it performs surveillance and then returns to the nest to alert other bird bots. Obstacle proximity: If the bird bot detects obstacles, it navigates through the obstacles to find the target. Nest interaction: The bird bot can exchange information with the nest.

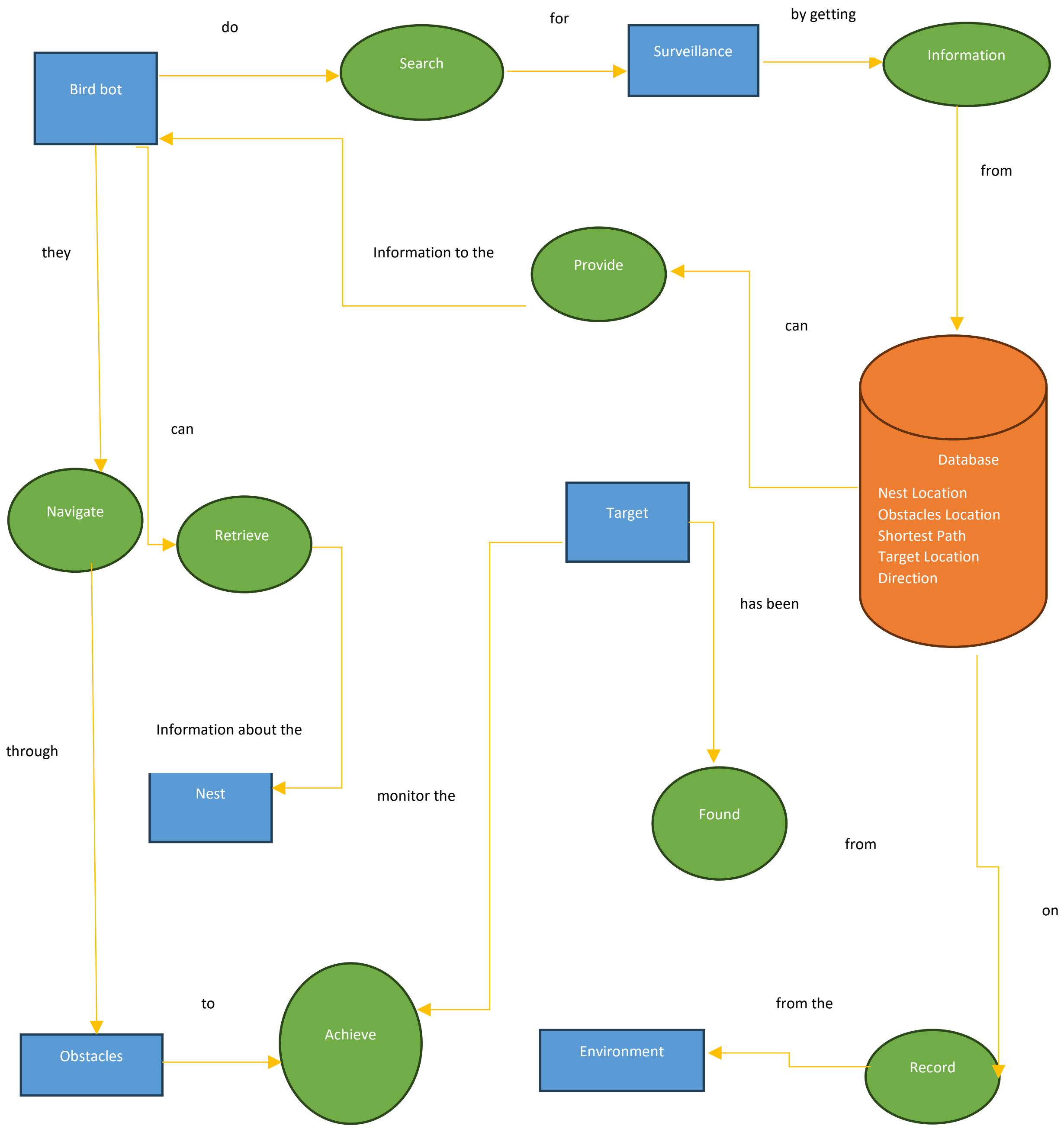

Figure 6 The data flow diagram for surveillance

This interaction can involve retrieving information from the nest or sending information to it. The system's flow of data and the bird bot's behavior are governed by effective surveillance and obstacle avoidance, while actively pursuing the identified target.

3.5 The data flow diagram for a bird bot

The data flow diagram in figure 7 for the bird bot outlines how information is exchanged and flows within the bird bot ontology framework in the context of bird bot robotic devices. It visually represents the data pathways, processing stages, and interactions between various elements in the bird bot ontology. It provides a clear understanding of how data is captured, processed, and shared within the bird bot system, ensuring effective communication and data management within bird bot ontology.

he data flow diagram in figure 7 illustrates the complex interactions within an ontology, involving entities such as bird bots, environment, target, nest, obstacles, and surveillance. The bird bots actively engage with their environment to gather crucial information, while the environment reciprocates with feedback.

The environment itself plays a pivotal role by requesting information from the database. This database acts as a comprehensive repository, housing vital data such as the locations of nests, details on obstacles, the shortest viable paths, and the precise coordinates of the target locations. Through the database's relay, the bird bots receive vital information that empowers them to adeptly navigate through challenging obstacles in pursuit of their surveillance objectives.

Upon the target's discovery, the collective intelligence of the bird bots is harnessed. They regroup and head towards the nest to share the precise coordinates of the target location. After disseminating this vital information, the bird bots work collaboratively, ensuring seamless surveillance and monitoring of the target. Crucially, the database retains records of the target's whereabouts and the details of the surveillance activities.

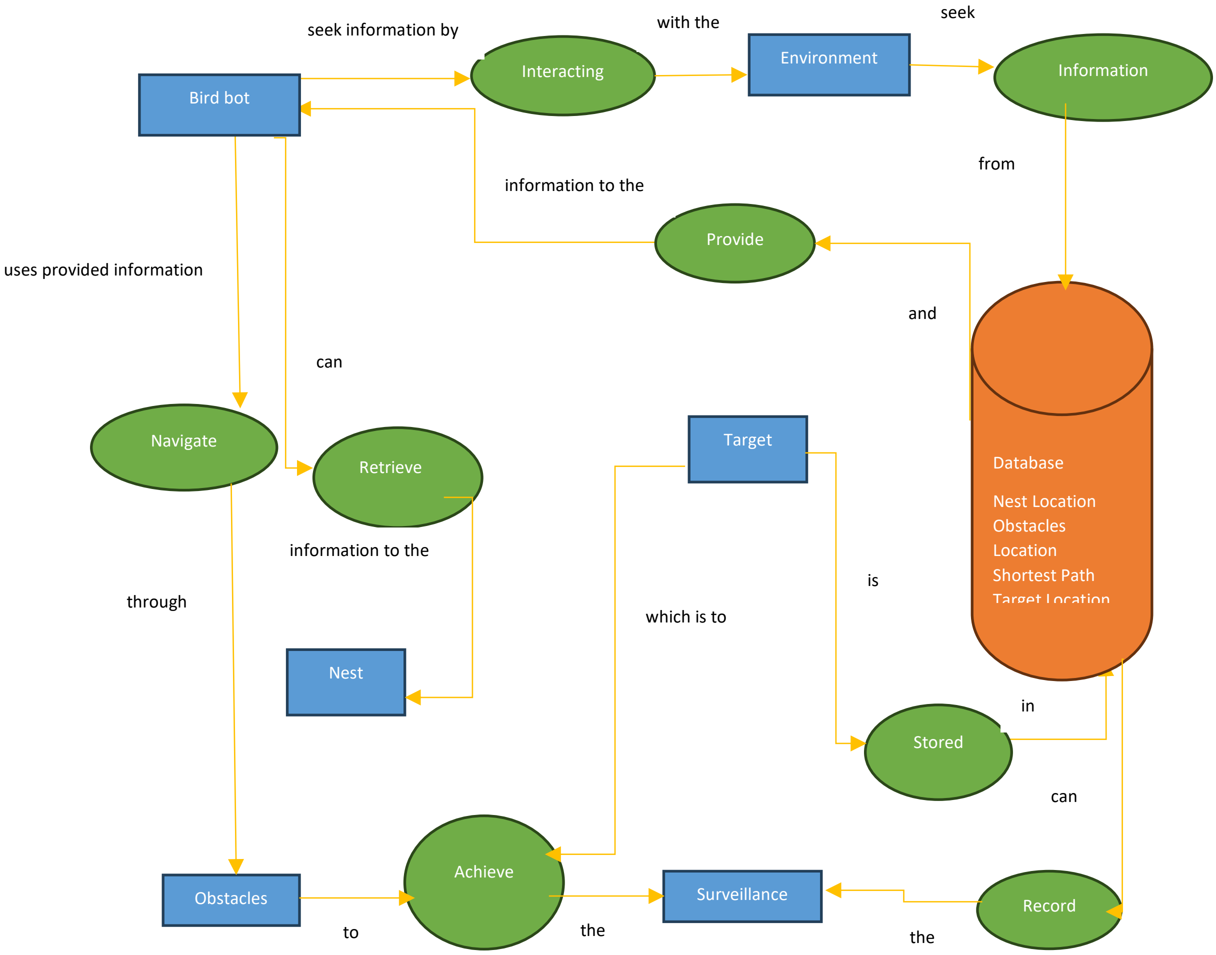

Figure 7 The data flow diagram for a bird bot

Notably, the bird bots also possess the ability to retrieve information regarding the nest, enhancing their overall operational efficiency. Then the ultimate accomplishment is signified by the uniform transformation of all bird bots to the green state, denoting the achievement of their surveillance goals. This intricate system offers a perspective on the capabilities and communication methods of bird bots within this ontology.

3.6 Warnier orr diagram for a bird bot

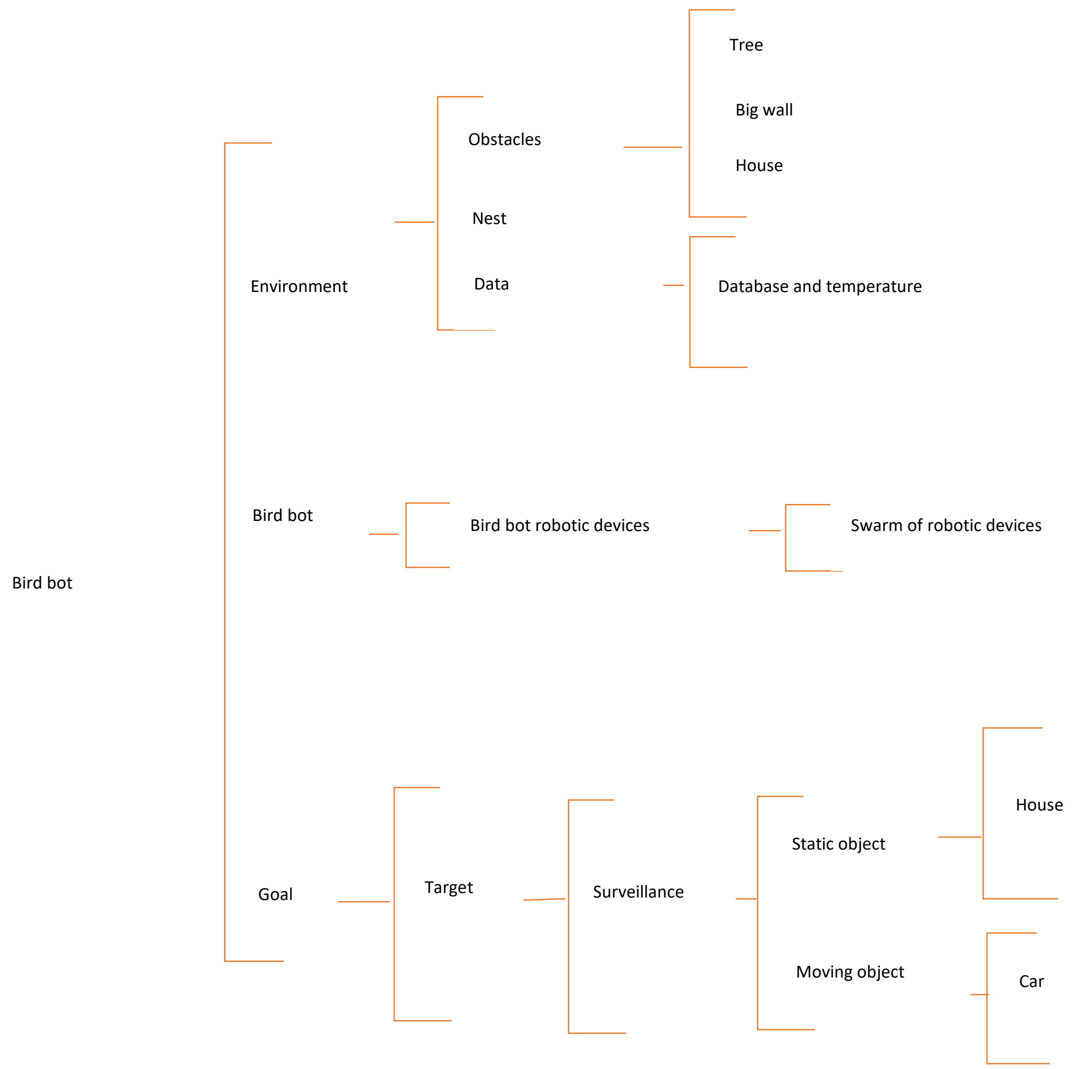

Figure 8 Warnier orr diagram for our bird bot

The Warnier-Orr diagram in figure 8 for our bird bot is a specialized visual representation that acts like a blueprint for illustrating how different components within an ontology fit together and depend on each other. This diagram provides a detailed overview of the interconnectedness of various elements within the bird bot ontology, emphasizing their interdependence and the way they collaborate to achieve their objectives. It serves as a vital tool for understanding the structural and operational relationships between various parts of the bird bot, enhancing the comprehension of this complex bird bot.

The Warnier Orr diagram is like a detailed map showing a complex system. In this system, bird bots live in nests and try to move through an obstacle that is blocking their way, to find the goal which is to perform surveillance. They aim to watch over many different things, like houses and cars. These bird bots work together with an environment and database. They talk to this database to get important information, which helps them find their way around the obstacles and reach their surveillance targets. This teamwork between the bots and the database is the key to how they do their job, helping them to keep going and perform surveillance on the target.

3.7 Warnier orr diagram for an ontology

Figure 9 represents the warnier orr diagram for an ontology. Our ontology comprises of several components which are virtual environment, bird bots, nest, obstacles, objects, database, surveillance (goal) and data. Virtual Environment: This refers to a simulated or computer-generated setting where the bird bots operate. It's a digital space designed to mimic real-world conditions, providing a platform for testing, and running simulations without physical constraints. Bird Bot: These are robotic devices inspired by birds' behavior. Bird bots mimic certain aspects of birds' actions or movements, often used in groups (swarms) to achieve collective objectives, like surveillance or exploration.

Nest: This is the habitat or dwelling place for the bird bots within the virtual environment. It is where they reside when not actively engaged in surveillance tasks. Obstacles: These are objects or structures like walls, houses, or trees strategically placed within the environment. They serve the purpose of obstructing or challenging the bird bots in their mission by hindering their access to the surveillance target. Objects: objects can be anything the bird bots monitor or observe. These can range from stationary items like buildings or to moving entities like vehicles or animals.

Database: In this scenario, a database serves as a repository of information accessed by the bird bots. It stores essential data, which the bird bots can retrieve to aid in decision-making, navigation, or understanding their environment. Surveillance (Goal): The primary objective or goal in this scenario is surveillance, which involves the systematic observation, monitoring, or tracking of objects or areas within the environment. The bird bots aim to accomplish this surveillance task effectively and efficiently.

Data: This category includes various elements such as the landscape, ground characteristics, and other environmental factors like temperature. These data points provide essential information to the bird bots as they navigate and carry out surveillance activities. The typical workflow involves the bird bots searching the virtual environment for their surveillance goal. Once they locate the target, they return to their nest to share information with other bird bots regarding the identified surveillance target.

Summary of figure 9 above, bird bots, inspired by bird behaviour, operate within a virtual environment. They utilize a database as a source of essential information while residing or returning to their designated base known as the nest. Their primary objective is surveillance, observing both stationary objects, such as buildings, and moving entities like vehicles. To achieve this goal, the bird bots navigate through the environment, adjusting their velocities to vary their movement speeds. They possess the capability to synchronize their speeds, enabling coordinated actions among the swarm. However, during their surveillance tasks, they encounter obstacles that challenge their movement and require navigation strategies. The database serves as a crucial resource, offering guidance and aiding decision-making processes for these bird bots as they navigate the simulated environment to fulfil their surveillance objectives effectively.

3.7 Summary

This chapter presented a comprehensive representation of the bird bot ontology through the utilization of various illustrative diagrams, encompassing entity-relationship diagrams, data flow diagrams, and warnier orr diagrams. Each diagram was accompanied by a detailed explanation, which facilitated a profound understanding of the ontology's intricate components and their relationships. This chapter aimed to provide readers with a comprehensive insight into the conceptual framework of the bird-bot ontology, making it accessible and comprehensible.

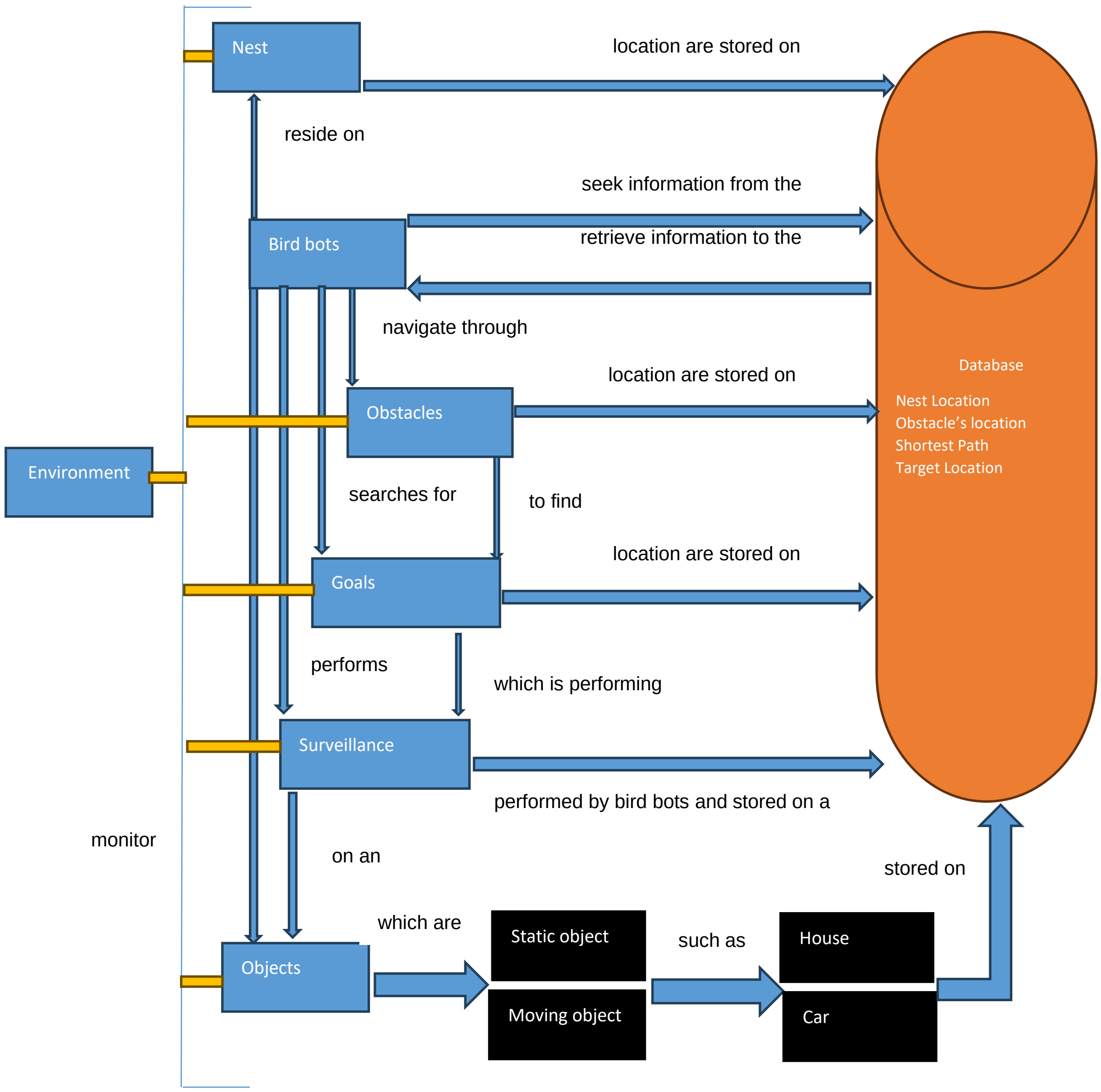

Figure 9 Warnier orr diagram for an ontology

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CHAPTER 4: EXPERIMENTS, RESULTS, AND DISCUSSIONS

In this part of the dissertation, we present the experiments, the results, and the discussion thereof. We explain how the experiments were administered and how the results were collected, and then discuss what those results tell us. This is where we really dig into the heart of our research. We opted for the "descriptive statistics" approach to assess preferences between different settings.

To conduct this analysis, we employed the kolmogorov-smirnov test for normality. It was selected for this analysis due to its ability to provide a clear perspective on user preferences. Sometimes it is referred to as a test of independence, which aligns with our objective of determining whether factors such as separation, cohesion, alignment, the number of bird bots, the presence of a nest, and the target (e.g., surveillance on a car or a house) influence participants' perceptions of realistic behavior.

The significance level of 5 percent was employed throughout the experiments. The code for the simulations were implemented using the NetLogo platform. NetLogo is a multi-agent programming language and modelling environment primarily used for simulating and studying complex systems. It was developed by Wilensky (1999) and is widely used in various fields such as biology, social science, economics, and ecology, to explore and understand the behaviour of systems composed of individual agents interacting with each other and their environment.

4.1 Hypothesis

The experiments administered in this chapter were guided by the hypotheses stated in section 1.6 in Chapter 1. Thus, the focus of this study revolves around a hypothesis-testing exercise, aimed at gathering evidence to either support or refute the null hypothesis in favor of the alternative hypothesis.

4.2 Experimental design

We ensured a consistent total of 1000 bird bots in each swarm, referred to as the bird-bot population. A series of experiments were conducted utilizing varying quantities of bird-bots, ranging from 1 to 1000, depending on the specific number required for deployment within the virtual environment at a given time. Our primary aim was to investigate whether the quality, speed, target acquisition, and ability to perform surveillance on objects depended on the number of bird-bots deployed.

To maintain the integrity of our results, we conducted these experiments in a controlled and disturbance-free environment, enabling accurate recording of the simulation outcomes. These experiments were executed using a secure laptop equipped with the NetLogo application, which we utilized to craft the simulation code for our bird-bot ontology and conduct the experiments. To describe the variables evaluated within the program, the tests were divided into two segments.

The first part involved the adjustment of parameters such as vision, encompassing the range of vision, with 10 patches representing the distance each bird could see within a 360-degree radius. Throughout the experiments, we strictly recorded the results obtained while varying the values of these crucial variables. For a comprehensive overview of our interface, refer to the attached screenshot in Figure 10.

4.3 The visualized simulation

To begin, we specified the desired number of birds for the simulation and adjusted the bird bot population slider or values (increase or decrease from 0 to 20 degrees) accordingly. We then pressed setup to generate the bird-bots, and then clicked go to initiate their flight within the simulation. The default slider settings typically resulted in effective flocking behaviour. We had the flexibility to experiment with them to achieve different outcomes such as three-turn angle sliders that allowed us to regulate the maximum angle by which bird bots can turn in response to each rule.

We played with other parameters to customize the behavior of the simulated bird flock. These sliders offered control over specific aspects of the simulation such as vision, which is the distance at which birds can perceive and react to their surroundings. Higher values grant bird bots a wider field of vision, while lower values limit their awareness. We had separation, which controls the minimum distance birds maintain between each other. Increasing it results in bird bots keeping a more significant gap, while decreasing it leads to closer interactions.

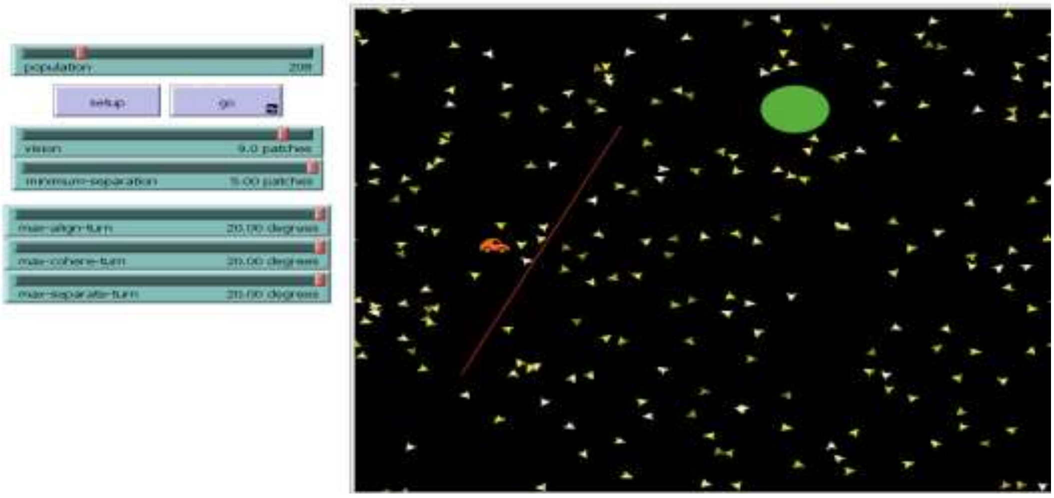

Figure 10 The interface

We had alignment and we could modify the slider (values) to determine how strongly bird bots align their movement with nearby flock mates. Higher values resulted in more pronounced alignment, while lower values allowed for more individualistic movements. We had a cohesion slider that governs the extent to which bird bots are inclined to group together. Raising the value encourages birds to stick closer to one another while lowering it allows for more dispersed flocking behaviour. Adjusting these sliders provided us with a higher degree of control and customization for our simulated bird flock.

As shown in Figure 10, the red line represents an obstacle or a wall that hindered our surveillance efforts and made it challenging to locate our target. Our target, in this case, was an orange car which moved within the virtual environment. Additionally, the green circle in our virtual environment served as the nest, the central hub for all the bird bots. It is worth noting that we could introduce multiple nests, bird bots, targets, and obstacles into our virtual environment concurrently, as depicted in Figure 11 and figure 12 below.

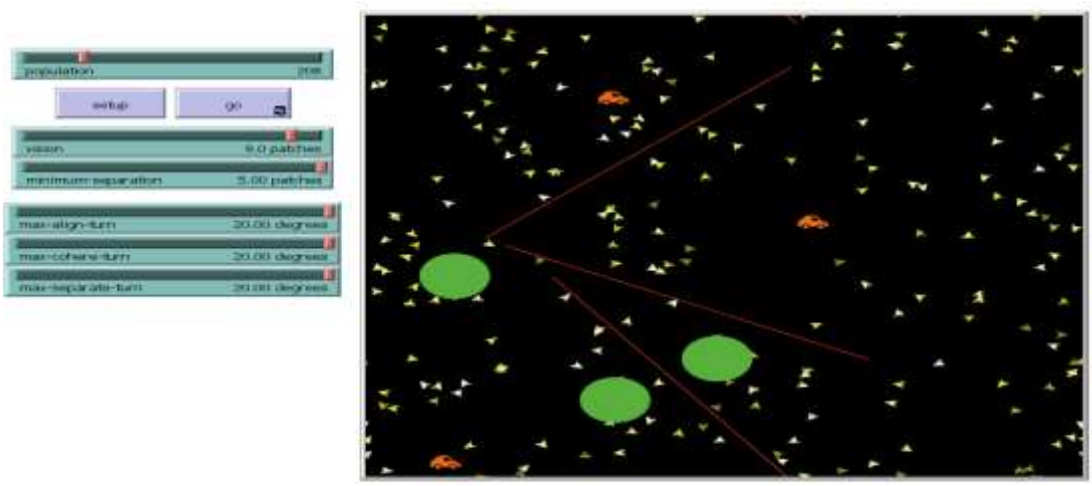

Figure 11 interface with many nests, obstacles, and targets (cars)

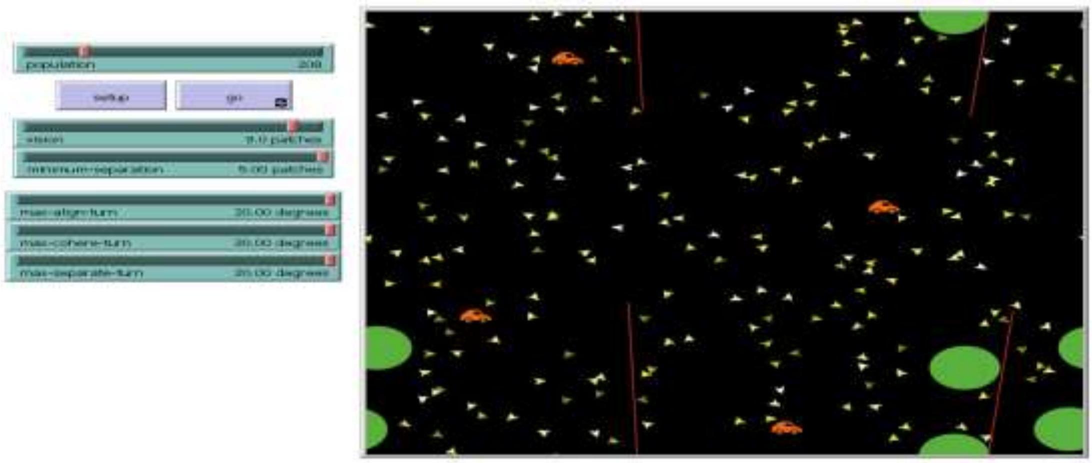

Figure 12 interface with many nests, obstacles, and targets (cars)

4.4 Experiment 1: Surveilling a stationary target

In this section, we explore the execution of our first experiment. We commence by outlining the hypothesis under examination and its corresponding alternatives. We also provide a detailed exposition of the metric we employed for measurement. Subsequently, we present the configuration of the experimental setup. The ensuing section entails the presentation of our findings, and an analysis of central tendencies and measures of dispersion.

4.4.1 Speed of emergence

The speed of emergence is the time it takes for half of the bird bots deployed on the environment to reach the target, measured in seconds. To calculate this speed, a group of bird bots (one thousand bird bots' population) is placed in a virtual environment. They start from a specific location and aim to reach and perform surveillance on the stationary target, which was a house in our scenario. A short time to find the target is good, indicating faster completion of the task. We analyzed these time values statistically. We ran fifteen (15) tests, adjusting variable values to see how much time it would take for the bird bots to locate and perform surveillance on the stationary target.

4.4.2 Experiment setup

In this experiment, we focused on one crucial dependent variable: the speed of finding the target and conducting surveillance. We manipulated two independent variables: simulation time and the bird bot ontology controlled through control routines. To clarify, a dependent variable is what we observe and measure, while an independent variable is what we change to see how it affects the dependent variable. Controlled variables are aspects we maintain consistently across multiple experiment runs. Specifically, we maintained a constant bird bots population density and a fixed target of 60% of the population, with both set at 1000 bird bots.

Subject: The impact of surveilling a stationary target (a house)

Null-Hypothesis: *H_0: $\mu_1 = \mu_2$* – The speed of finding and performing surveillance on a target are the same, regardless of whether the target is stationary or in motion.

Alternate Hypothesis: *H_1: $\mu_1 < \mu_2$ – control rules increase values.*

Alternate Hypothesis: *H_2: $\mu_1 > \mu_2$ – control rules decrease values.*

Dependent variables: *Speed (time until 60% of devices hit the target)*

Independent variables: Time it took to find the target.

Controlled variables: *1000 bird bots' population, number of hits (600).*

Agenda: *We created a setup with a nest, obstacles, and a target within the environment. The swarm consisted of 1000 bird bots' population. These bird bots were evaluated until 600 of them reached the target and performed surveillance. We recorded the time it took for 600 bird bots to locate the target. This process was repeated 15 times.*

4.4.3 Algorithm 1

```
setEnvironment (nest, obstacles, target)
setBirdBotsSize (1000)
for all bird bot [controlled, change_ control_routines]
{       for each simulation [1 to 15]
        {
        While (hits < 600)
        {
                NavigateThroughEnvironmentObstacles ()
                FindTargetAndPerformSurveillance ()
        }
        record speed
      }
 }
```

Data collection:

Run	Bird bots	
	Changing variables values of parameters	Controlled bird bots (speed in seconds)
1		
:		
15		

4.4.4 Findings for experiment 1

Table 1 Simulation run for bird bot's speed of emergence

Simulation run	Bird bot's (in seconds)	
	Changing variables values for bird bots control routines	Controlled bird bots
Simulation no 1	8	30
Simulation no 2	12	44
Simulation no 3	15	50
Simulation no 4	11	54
Simulation no 5	13	49
Simulation no 6	19	49
Simulation no 7	14	65
Simulation no 8	15	66
Simulation no 9	16	69
Simulation no 10	12	40
Simulation no 11	11	63
Simulation no 12	16	73
Simulation no 13	17	69
Simulation no 14	20	70
Simulation no 15	13	75

The data in Table 1 reveals that most bird bots needed 8 to 20 seconds to locate a stationary object and begin their surveillance task. This variation in time was primarily influenced by adjustments in the variable values of their control routines. Conversely, when these variable values remained constant, the time required to locate the static target and initiate surveillance extended to 30 to 75 seconds. For instance, in the first simulation, it took 8 seconds to locate the static target, whereas in scenarios with controlled bird bots, the same task took 30 seconds. This indicates that the model performs effectively when the degrees or parameters of the bird bot ontology are modified.

4.4.5 Results for experiment 1

Here, we present summaries of tests that help us understand the data better. We look at whether the data follows a normal pattern, how the data clusters around the middle, and how it spreads out. These summaries are essential for us to draw meaningful conclusions. In Table 1, we compare the speeds at which the two models (controlled bird bots and changing variable values of control routines) achieve emergence in finding the target and performing surveillance. The changing of the variable values (such as separation degree, speed, alignment degree, and cohesion degree) was better than controlled bird bots, showing their faster speeds of emergence compared to the controlled bird bots.

We represent this on the line and bar graph, where smaller values mean quicker bird bots. We provide detailed information and tests about the normality of the data for the changing of variable values on control routines and controlled bird bots, respectively. These figures help us understand the shape of the data and whether it follows a typical pattern. The dots on the line graph represent individual simulation runs. In this specific scenario, we conducted fifteen simulations, which explains the 15 dots on each of the line graphs depicted.

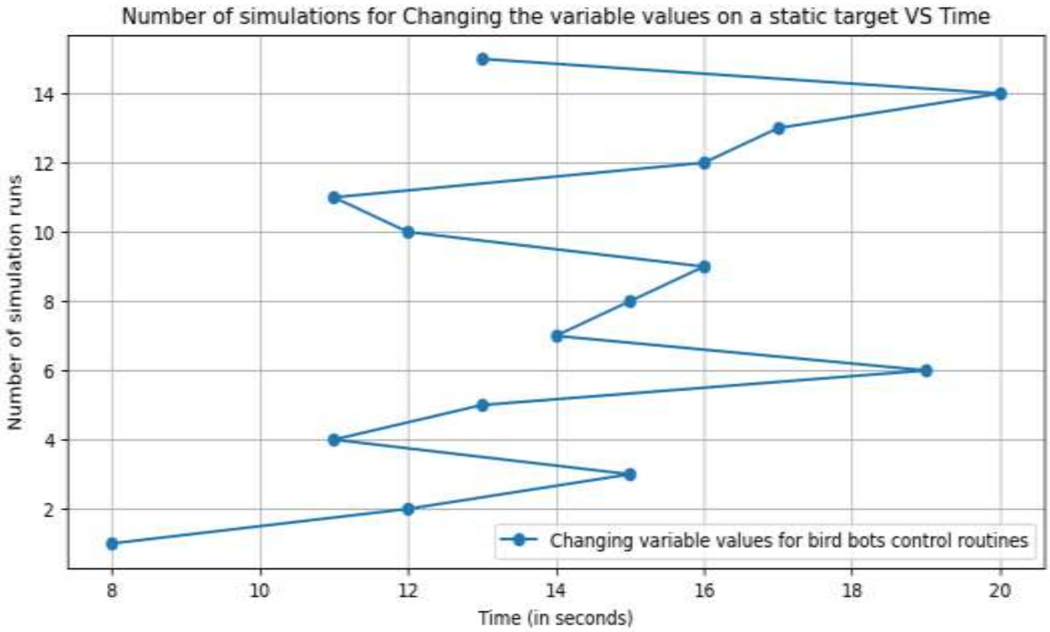

Figure 13 Number of simulations to change the values of static target VS Time

Figure 13 displays data extracted from Table 1 (changing of bird bots control routines column), which records the variations in variable values for control routines applied to a static target over time. The line graph provides a visual representation of these changes. Notably, the first simulation run required 8 seconds to locate the static target and initiate surveillance. On number 14 simulation, it is evident that the time taken to locate the target and execute surveillance increased to 20 seconds, which is the maximum time it took in all simulation ran.

Figure 14 below highlights data obtained from Table 1 (specifically, the "controlled bird bots" column). This data records the fluctuations in variable values related to control routines applied to a stationary target over time. The line graph visually illustrates these fluctuations. Remarkably, the first run required 30 seconds to pinpoint the stationary target and commence surveillance. By the 14th simulation, it became evident that the time required to locate the target and initiate surveillance had risen to 70 seconds.

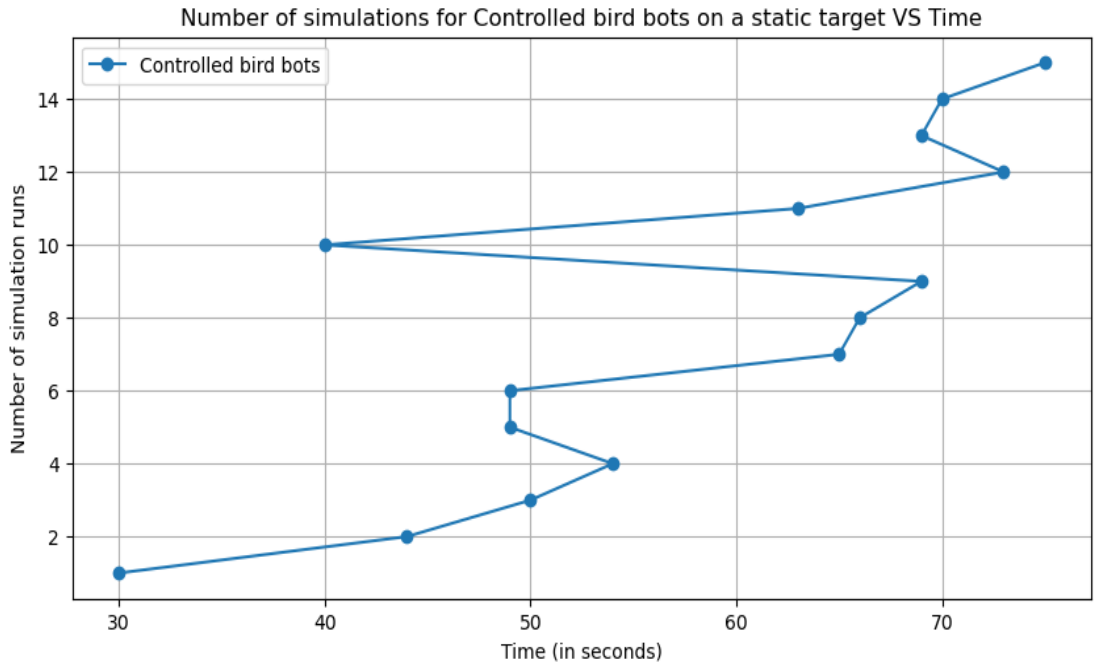

Figure 14 Controlled bird bots on static target VS Time

Figure 15 below highlights data obtained from Table 1 for both columns. This data records the fluctuations in variable values related to control routines applied to a stationary target over time. The line graph visually illustrates these fluctuations. This line graph in Figure 15 illustrates the contrast between the data from Figure 13 and 14. Clearly, the blue line represents a notably quicker time for target localization and surveillance compared to the orange line, which is positioned farther to the right. This indicates that the orange line required significantly more time than the blue line to accomplish the same tasks. This implies that, when we modify the variable values for control routines, the model performs more efficiently compared to when no changes are made to the model.

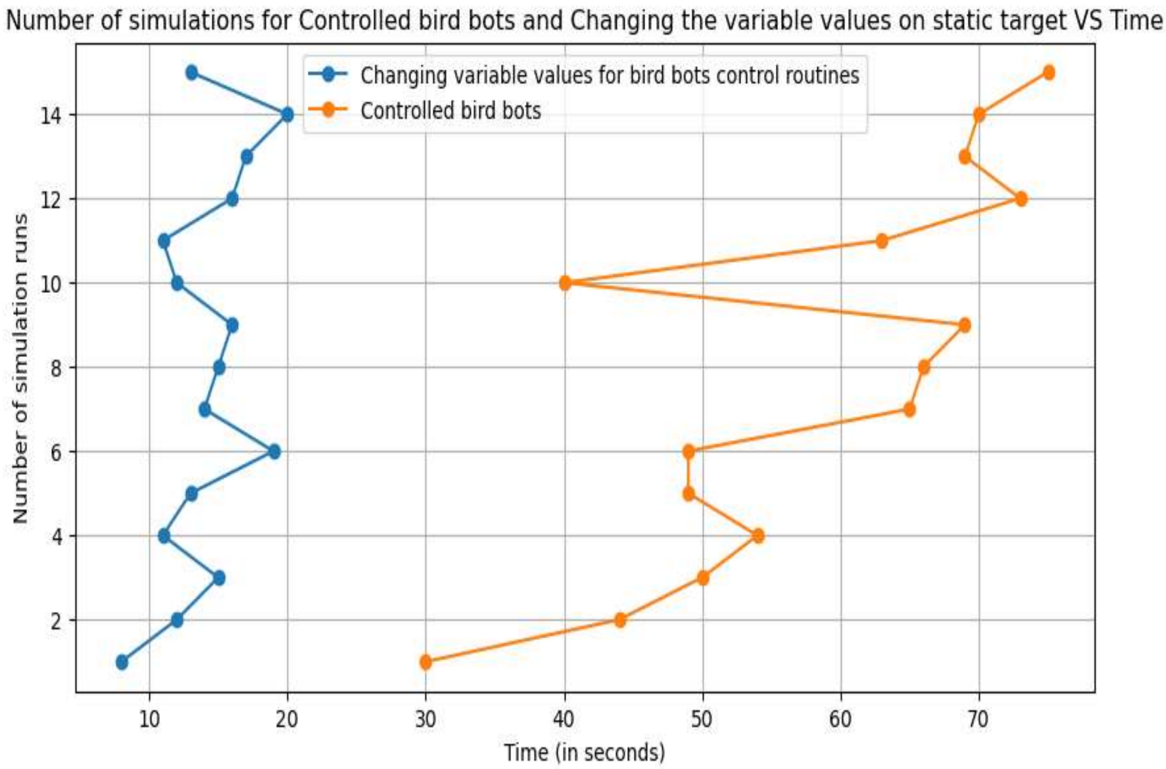

Figure 15 Controlled values for control routines on static target VS Time

In Figure 16 below, we constructed a bar graph to vividly depict the contrast between adjusting the variables in the control routines of the bird bot ontology and keeping them unchanged. It is apparent that the controlled bird bots (represented by the orange bars) took a more extended period to locate the target and conduct surveillance compared to the scenario where variable values in the control routines were altered in the model, with different values or degrees.

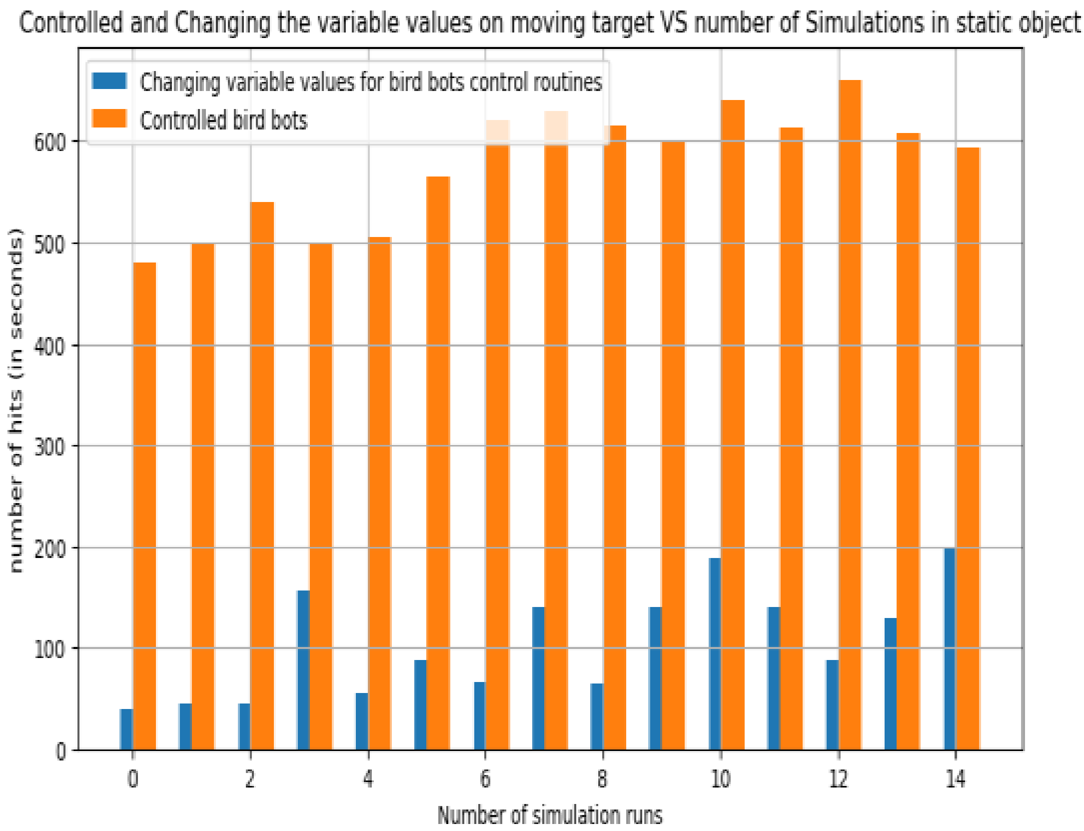

Figure 16 Controlled values of control routines on static target VS Time

Figures 17 and 18 below provide a summary of the descriptive statistics and p-value obtained from our testing. In Figure 17, data was extracted from the “changing of variable values” column in Table 1, yielding mean, median, standard deviation, skewness, and kurtosis values as displayed. Notably, our p-value stands at 0.98474, signifying a normal distribution of the data.

In Figure 18, data was extracted from the “controlled bird bots” column in Table 1, yielding mean, median, standard deviation, skewness, and kurtosis values as displayed. Notably, our p-value stands at 0.5909, signifying a normal distribution of the data. Our p-value for figure 17 is better than our p-value in figure 18, which means that changing of the variable values has more effect on the model than not changing any variable values.

Your Data

8
12
15
11
13
19
14
15
16
12
11
16
17
20
13

Distribution Summary

Count : 15

Mean: 14.13333

Median: 14

Standard Deviation: 3.204164

Skewness: 0.101396

Kurtosis: -0.129583

Result: The value of the K-S test statistic (D) is .10953.

The *p*-value is .98473. Your data does *not* differ significantly from that which is normally distributed.

Figure 17 Descriptive statistics for changing variables values of bird bots control routines on static target

Your Data

30
44
50
54
49
49
65
66
69
40
63
73
69
70
75

Distribution Summary

Count : 15

Mean: 57.73333

Median: 63

Standard Deviation: 13.582902

Skewness: -0.553753

Kurtosis: -0.709521

Result: The value of the K-S test statistic (D) is .18925.

The *p*-value is .5909. Your data does *not* differ significantly from that which is normally distributed.

Figure 18 Descriptive statistics for controlled bird bots on static target

Both the controlled bird bots and the changing variable values for control routines demonstrated normality in the statistical tests. However, the changing variable values for control routines achieved a more favorable p-value of 0.98473 compared to the controlled bird bots. This suggests a closer approximation to a Gaussian distribution. Furthermore, the proximity of the mean and median speeds implies a distribution with less skew. These observations indicate a high level of confidence when applying inferential statistics to the data.

4.5 Second experiment: Impact of surveilling a moving target (a car)

In this section, we explore the execution of our second experiment. We commence by outlining the hypothesis under examination and its corresponding alternatives. We also provide a detailed exposition of the metric we employed for measurement. Subsequently, we present the configuration of the experimental setup. The ensuing section entails the presentation of our findings, and an analysis of central tendencies and measures of dispersion.

4.5.1 Quality of emergence

We define the "quality of emergence" as the evaluation of the number of bird bots that successfully reach the moving target (a car) and conduct surveillance within a predetermined time. To gauge quality, we deployed an identical set of x bird bots in the same virtual environment and tasked them with locating and surveilling the moving target. We recorded the frequency of successful hits within the initial 10 seconds. In this context, larger values were preferable, signifying that a greater number of bird bots swiftly locate the target and engage in surveillance. This numerical metric was subjected to further analysis.

4.5.2 Experiment setup

In this experiment, we focused on a crucial dependent variable, the "quality of emergence." Two key independent variables were manipulated, the duration of the simulation, and the alterations in the control routines' variable values. The bird bot's population density was kept constant at 1000. The experimental setup is detailed below.

Subject: The impact of surveilling a moving target (a car)

Null-Hypothesis: $H_{0:}$ $\mu_1 = \mu_2$ – The quality of finding and performing surveillance on a target are differ, regardless of whether the target is stationary or in motion.

Alternate Hypothesis: $H_{1:}$ $\mu_1 < \mu_2$ – *control rules increase bird bot's variable values.*

Alternate Hypothesis: $H_{2:}$ $\mu_1 > \mu_2$ – *control rules decrease bird bot's variable values.*

Dependent variables: *Speed (time until 60% of devices hit the target)*

Independent variables: Time it took to find the target

Controlled variables: *1000 bird bots' population, number of hits (600).*

Agenda: *We created a setup with a nest, obstacles, and a target within the environment. The swarm consisted of 1000 bird bots' population. These bird bots were evaluated until 600 of them reached the target and performed surveillance. We recorded the time it took for 600 bird bots to locate the target. This process was repeated 15 times.*

4.5.3 Algorithm 2

```
setEnvironment (nest, obstacles, target)
setBirdBotsSize (1000)
for all bird bot [controlled, change_ control_routines]
{
        for each simulation [1 to 15]
        {
         While (hits < 600)
         {
                NavigateThroughEnvironmentObstacles ()
                FindTargetAndPerformSurveillance ()
         }
         record speed
        }
 }
```

Data collection:

Run	Bird bots	
	Changing variables values for bird bots (Number of hits in 10 seconds)	Controlled bird bots (Number of hits in 10 seconds)
1		
:		
15		

4.5.4 Findings for experiment 2

Table 2 Simulation run for bird bot's quality of emergence

Simulation run	Bird bot's (Number of hits in 10 seconds)	
	Changing variables values for bird bots	Controlled bird bots
Simulation no 1	40	480
Simulation no 2	45	500
Simulation no 3	44	540
Simulation no 4	156	499
Simulation no 5	56	505
Simulation no 6	88	565
Simulation no 7	67	620
Simulation no 8	140	630
Simulation no 9	65	615
Simulation no 10	140	599
Simulation no 11	188	640
Simulation no 12	140	613
Simulation no 13	88	660
Simulation no 14	130	608
Simulation no 15	200	593

The data in Table 2 reveals that most bird bots needed 40 to 200 seconds to locate a moving object and begin their surveillance task. This variation in time was primarily influenced by adjustments in the variable values of their control routines. Conversely, when these variable values remained constant, the time required to locate the moving target and initiate surveillance extended to 460 to 670 seconds. In the first simulation, it took 40 seconds to locate the moving target, whereas in scenarios with controlled bird bots, the same task took 480 seconds. This indicates that the model performed more effectively when the degrees or parameters of the bird bot ontology are modified even when finding a moving target. This implies that altering the variable values is relevant even when locating a moving target.

4.5.5 Results for experiment 2

Here are summaries of the tests for data normality, central tendencies, and variability of the data from Table 2. Figure 19 illustrates a line graph of the differences in the qualities of emergence between the two models. In general, the

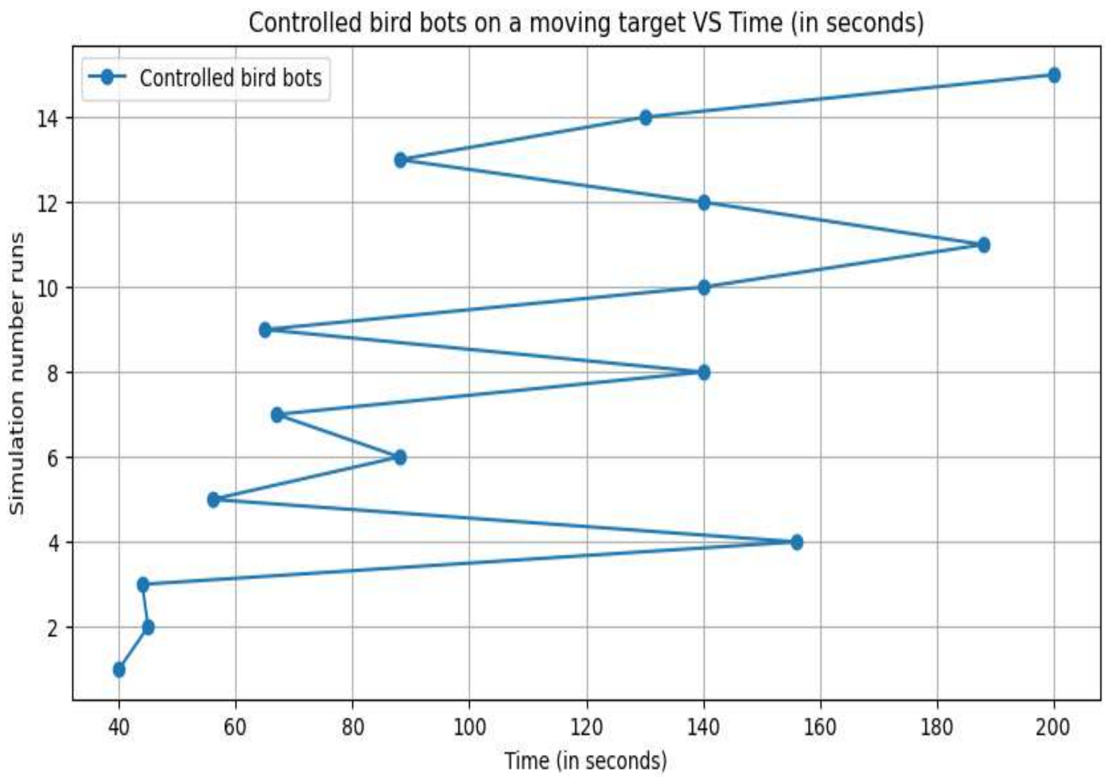

Figure 19 Controlled bird bots VS Time (in seconds) line graph on a moving object (car)

changing of variable values on control routines model exhibited superior quality of emergence, surpassing the controlled bird bots' counterparts. Furthermore, there were more hits within the first ten seconds in the changing of variable values on control routines compared to the controlled bird bots', suggesting the presence of causal factors in the controlled bird bots – specific routines contributing to the emergence.

Figure 22 bar graph provides an overview of the distribution characteristics of the qualities of emergence in the changing of variable values on control routines and controlled bird bots, while Figure 23 and figure 24 display the qualities generated by the descriptive statistics for changing variable values of bird bots control routines on moving target.

Figure 23 below displays data extracted from Table 2 (changing of bird bots control routines column), which records the variations in variable values for control routines applied to a static target over time. The line graph provides a visual representation of these changes. Notably, the first simulation run required 40 seconds to locate the static target and initiate surveillance. On the 15th simulation, it is evident that the time taken to locate the target and execute surveillance increased to 200 seconds.

Below is Figure 20, which highlights data obtained from Table 2 (specifically, the "controlled bird bots" column). This data records the fluctuations in variable values related to control routines applied to a stationary target over time. The line graph visually illustrates these fluctuations. Remarkably, the first run required 480 seconds to pinpoint the stationary target and commence surveillance. By the 113th simulation, it became evident that the time required to locate the target and initiate surveillance had risen to 660 seconds, which is the highest time it took. Below, we highlight data obtained from Table 2 for both columns. This data records the fluctuations in variable values related to control routines applied to a stationary target over time. The line graph visually illustrates these fluctuations. This line graph in Figure 21 illustrates the contrast between the data from Figure

19 and 20. In Figure 21, the blue line represents a notably quicker time for target localization and surveillance compared to the orange line, which is positioned

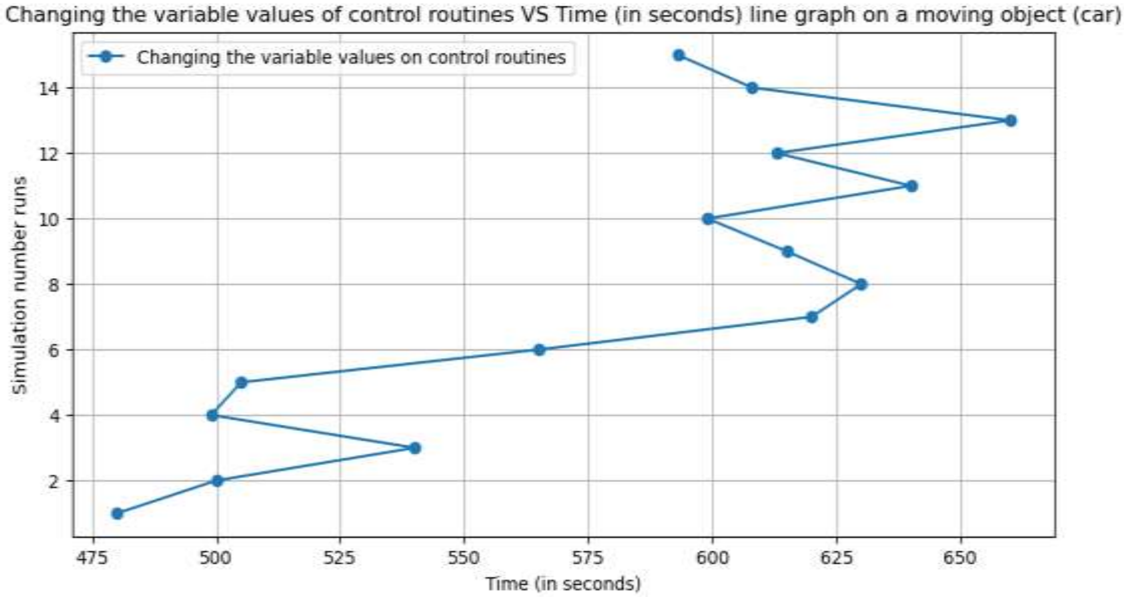

Figure 20 changing the variable values of control routines VS Time (in seconds) line graph on a moving object (car)

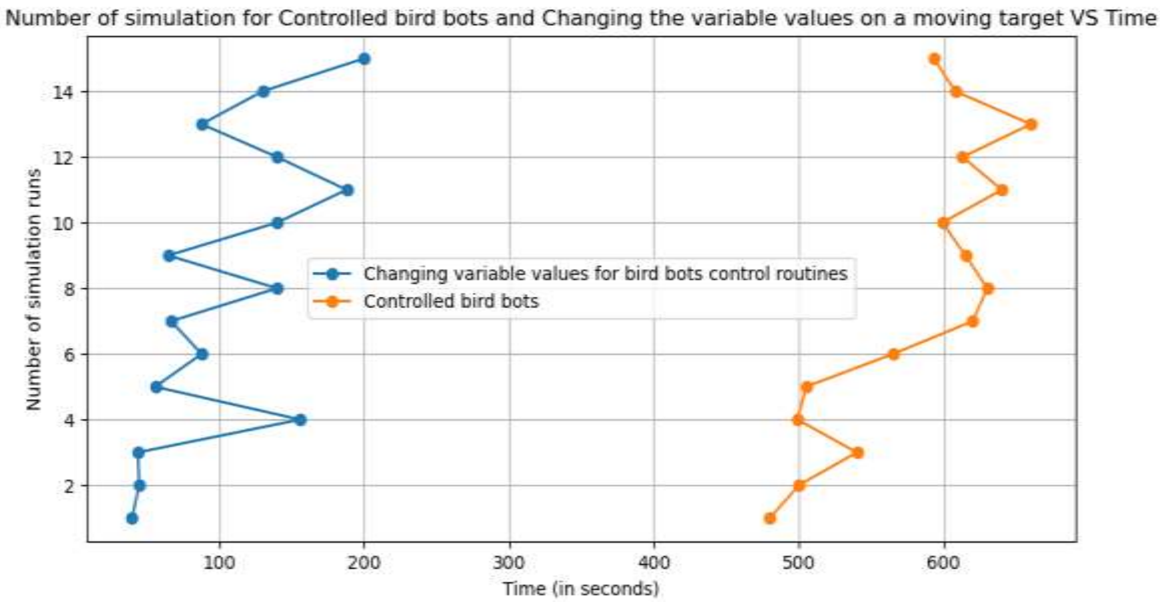

Figure 21 Controlled bird bots and changing the variable values on moving target VS Time

further to the right. This indicates that the orange line required significantly more time than the blue line to accomplish the same tasks. This implies that, when we modify the variable values for control routines, the model performs more efficiently compared to when no changes are made to the model.

Figure 22 below presents a bar graph to vividly depict the contrast between adjusting the variables in the control routines of the bird bot ontology and keeping them unchanged. It is apparent that the controlled bird bots (represented by the orange bars) took a more extended period to locate the target and carry out surveillance compared to the scenario where variable values in the control routines were altered in the model with different values or degrees.

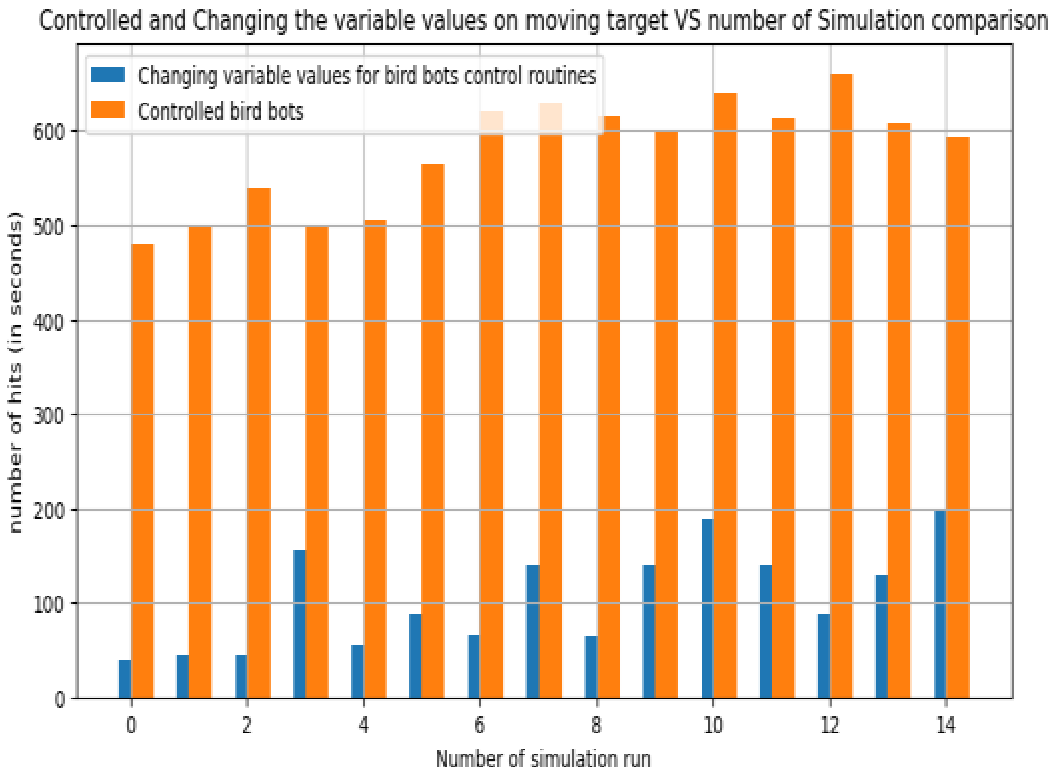

Figure 22 Controlled and changing the variable values- moving target VS Time

As illustrated, adjusting the parameters for the bird bots significantly enhances their proficiency in locating the target and conducting surveillance. This is vastly different from when we did not change any settings, as shown in the line graph in Figure 19 and the bar graph in Figure 22.

Figure 23 and 24 presented below provide a summary of the descriptive statistics and p-value obtained from our testing. In Figure 23, data was extracted from the “changing of variable values” column in Table 1, yielding mean, median, standard deviation, skewness, and kurtosis values as displayed. Notably, our p-value stands at 0.69999, signifying a normal distribution of the data.

Your Data

40
45
44
156
56
88
67
140
65
140
188
140
88
130
200

Distribution Summary

Count : 15

Mean: 105.8

Median: 88

Standard Deviation: 53.701822

Skewness: 0.34336

Kurtosis: -1.211447

Result: The value of the K-S test statistic (D) is .17273.

The *p*-value is .69999. Your data does *not* differ significantly from that which is normally distributed.

Figure 23 Descriptive statistics for changing variables values of bird bots control routines on moving target

In Figure 24, data was extracted from the “controlled bird bots” column in Table 2, yielding mean, median, standard deviation, skewness, and kurtosis values as displayed. Notably, our p-value stands at 0.4859, signifying a normal distribution of the data. Our p-value for figure 17 is much better than our p-value for figure 24, which means that changing of the variable values has more effect on the model than without changing any variable values.

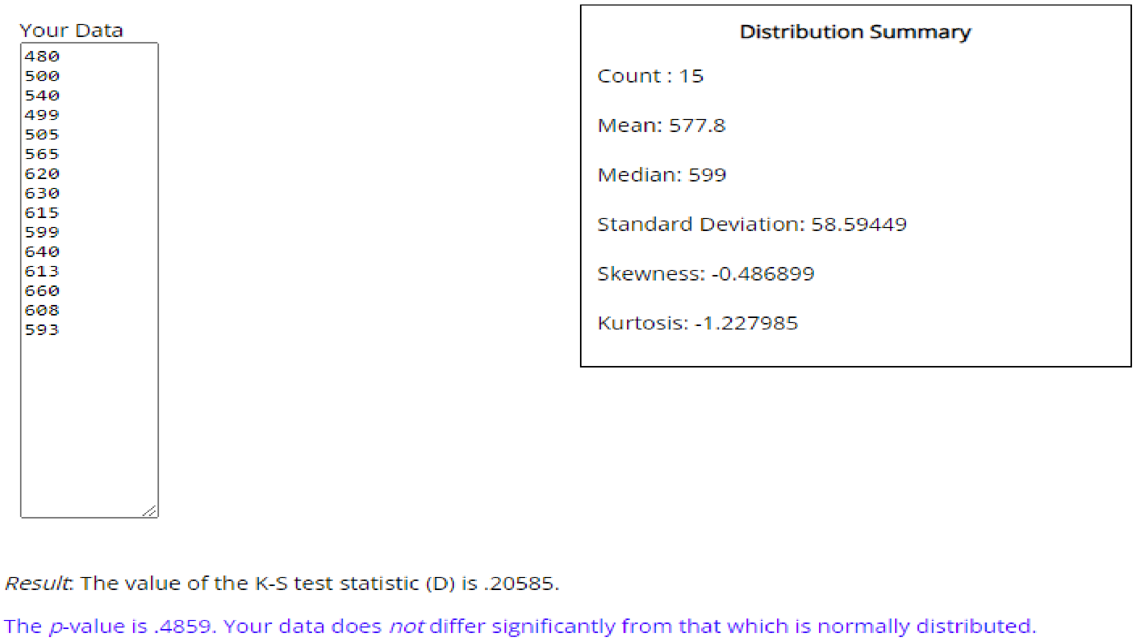

Figure 24 Descriptive statistics for controlled bird bots on moving target

Both the controlled bird bots and the ones with changing settings for control routines showed typical results in our statistical tests. However, the bird bots with changing settings had a better p-value of 0.69999, while the controlled bird bots had a p-value of 0.4859. This suggests that the bird bots with changing settings were closer to a normal distribution. Also, the similar mean and median speeds indicate a less skewed distribution. These findings made us more confident when using statistics to analyze the data.

4.6 Discussions

In conclusion, our experiments revealed that our bird bot ontology excelled at locating stationary targets but faced challenges when tracking fast-moving ones. The adjustments in control routine values, ranging from 1 to 20 degrees, had a considerable influence on swift target detection and effective surveillance. This validated our alternative hypothesis, which asserts that locating static and mobile targets differs, with quicker results observed for stationary targets.

CHAPTER 5: CONCLUSION

In conclusion, the study successfully extended the boid model into a bird-bot ontology for managing robotic devices used in surveillance. This ontology combined boid rules, environmental considerations, and interaction metadata, enhancing realism in simulations. Experimental testing showed that the bird-bot ontology excelled in surveilling stationary targets when adjusting control routines, surpassing controlled bird bots. Usability testing demonstrated its effectiveness in promoting desirable robotic behaviors, including spacing, collision avoidance, and coordination. The ontology's causal properties were evident in achieving efficient area coverage, adaptability, and fault tolerance. Beyond surveillance, its applications extended to traffic optimization, urban design, search and rescue, crowd management, and environmental monitoring, offering potential solutions to various human challenges, emphasizing safety and efficiency.

5.1 Answers to the research questions

Research questions below have been answered:

1. Which discrete actions performed by bird-bot robotic devices result in emergent behaviour? To respond to this query, we outlined a finite list of individual actions performed by bird-like robotic devices. These actions, including velocity (speed), cohesion, separation, alignment, orientation, movement, vision, and population, collectively result in emergent behavior as detailed in chapter 3 and 4.
2. How do we translate the discovered control routines into computational algorithms? This question seeks an illustration of the physical and logical designs of the proposed ontology. To respond to this query, we successfully illustrated our bird-bot ontology using entity relationship diagrams, data flow diagrams, and the warnier orr diagram in chapter 3. Additionally, please see figure 9 that shows Warnier orr diagram for an ontology.

3. What specific rules, parameters, and relationships govern the interactions of bird bots, and how can they be integrated into a cohesive bird-bot ontology? To respond to this query, please see figure 3,4,5,6,7,8, and 9 on chapter 3 that shows the relationship or interactions of an ontology.
4. How can we evaluate the practical effectiveness of the proposed bird-bot ontology in conducting surveillance on both static and moving objects? Additionally, what are some real-life scenarios where implementing the bird-bot ontology could offer solutions? Refer to the experiments conducted in Chapter 4 to explore the practical effectiveness of the proposed bird-bot ontology in surveillance of both stationary and mobile objects. This ontology can be used real-life applications, such as preventing overcrowding and collisions, optimizing urban traffic flow, and formulating strategies for search and rescue operations.
5. How can we adjust the variable values of the control routines in response to changes of values in our bird bot ontology? To answer this question, we developed the control routines with values, which meant we could increase or decrease the values from 0 to 20 degrees.

5.2 Recommendations

Recommendations for modelling bird-bot robotic devices include prioritizing realism with complex environmental factors, enhancing agent attributes, developing adaptive behaviour algorithms, aligning simulations with real-world metrics, optimizing scalability, validating results, integrating machine learning techniques, and promoting interdisciplinary collaboration.

5.3 Contributions

In this study, my contributions comprised of several important aspects of bird-bot ontology and its practical implications. I explained how bird bots behave. I also showed how we can turn their actions into computer rules. I talked about specific rules and how these bird bots interact with one another. I also tested how good these bird bots are at watching (monitoring or performing surveillance) and following things, like cars or buildings. I explained how these bird bots can be useful in real life, for example, in traffic or finding people in emergencies. I also helped create rules that can change to fit different situations for these bird bots.

This study's contribution lies on the development of a versatile and effective ontology that extends the boid model's capabilities to address real-world surveillance and coordination needs while offering innovative solutions applicable to a wide range of scenarios beyond its original scope. It is apparent that an understanding of the design of the proposed ontology has the potential to address various challenges and improve various aspects of human life. By leveraging the principles of collective behavior, the proposed ontology offers innovative solutions that enhance safety, efficiency, and collaboration in various contexts.

5.4 Future Works

Future work can explore into optimizing and parallelizing the simulation to handle larger-scale scenarios with a higher number of agents and more complex interactions, thus, increasing its scalability and utility in real-world robotics and surveillance systems. Overall, future work in this domain should aim to make the simulation more realistic, adaptable, and applicable to real-world scenarios. These include enhancing surveillance techniques for bird bots, integrating AI for better object recognition, and exploring adaptive learning mechanisms for improved behavior.

Further investigations might focus on scaling bird-bot swarms in larger environments, ensuring resilience in challenging conditions, and exploring practical implementations in fields like disaster management or urban planning. Additionally, studies could explore human-robot interaction improvements and ethical considerations surrounding bird-bot technology deployment, contributing to responsible and beneficial integration into various domains.

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APPENDICES

Appendix A

Approval letter from the Senate Research ethics committee (SREC)

SOL PLAATJE UNIVERSITY

Light from Africa - for Humanity • Lesedi la Afrika - go Batho • Lig uit Afrika ~ vir die Mensdom

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Tuesday, 10 October 2023

V Mawela
Student number: 202002064
Master of Science in e-Science
School of Natural and Applied Sciences

Reference Number: SREC 0535/2023m

Dear V Mawela

Research Project: *Extension of the boid to a bird-bot ontology for coordinating surveillance robotic devices*

Approval of the above application for ethics clearance was granted by the Senate Research Ethics Committee (SREC) at its meeting held on 10 October 2023.

Yours sincerely,

Dr Jody P. Cedras
University Registrar

Approval letter from SHDC

SOL PLAATJE UNIVERSITY

SENATE HIGHER DEGREES COMMITTEE

PROPOSAL REVIEW SHEET

Student Number: 202002064______ ____________

Name of Scholar: Vhutshilo_____ _______________

Name of Supervisor: _ Dr. Colin Chibaya _____ ___

Proposal Reviewer: _ Dr Tite Tuyikeze ____

Date of Review: __17/04/2023__________________

REVIEW CRITERIA

1.Clarity of the title:
The title is very clear and well aligned with the research problem and objectives
2.Clarity of the research goals:
The four objectives that the study addresses are well articulated and formulated. These objectives are:
1.To identify the actions (control routines) of birds that cause emergent behaviour at the swarm level.
2.To convert those control routines into computational algorithms.
3.To create a bird-bot ontology from combining the control routines, parameters, rules, and their relationships.
4.To evaluate the usefulness of the proposed bird-bot ontology in solving real-life problems.
5.Alignment of title, research goal, research questions, objectives, conceptual/theoretical ideas and methodology:
Yes, the research goal, research questions, objectives, conceptual/theoretical ideas and methodology are well aligned.
6.Conceptual Coherence:
The key terms of the research project are well discussed in the literature review and introduction. There is clear interconnection of these terms.
7.Coherence and appropriateness of the research design:
Under the section 9.3.4, the researcher refers to the diagram below… BUT the diagram is missing. The methodology is well articulated and the 2 experiments are well explained.

1. **Ethical considerations:**
   The nature of this study does not require ethical issues as there will be no human and animals involved in the data collection.
2. **General comment:**

The proposal is well writted. Good work

Recommendation:

___ A: Approved.

Appendix B

Our bird bot ontology code

```
turtles-own [
  flockmates         ;; agentset of nearby bird bots or turtles
  nearest-neighbor   ;; closest one of our flockmates
  nest-location
  goal-location      ;;Static or moving target (Surveillance)

]

to setup
  clear-all
  create-turtles population
    [ set color yellow - 2 + random 7  ;; random shades look nice
      set size 1.5  ;; easier to see
      setxy random-xcor random-ycor
      set flockmates no-turtles ]
  create-turtles 2 [
    set color green  ;; Color for the nest
    set size 7       ;; Size of the nest
    set shape "circle"
    ;;set speed 0
    setxy 0 0
    set nest-location patch 0 0
    setxy [pxcor] of nest-location [pycor] of nest-location
  ]
  create-turtles 1 [
    set color orange  ;; Color for the target
    set size 3      ;; Size of the target
    set shape "car"
    set goal-location patch 15 0
    setxy [pxcor] of goal-location [pycor] of goal-location
  ]


  create-turtles 1 [
    setxy random-xcor random-ycor
    set color red
    set size 40  ; Adjust the size as needed
    set shape "line"  ; Set the shape to a square
    set goal-location patch 0 0
    setxy [pxcor] of goal-location [pycor] of goal-location
  ]
  reset-ticks
end
```

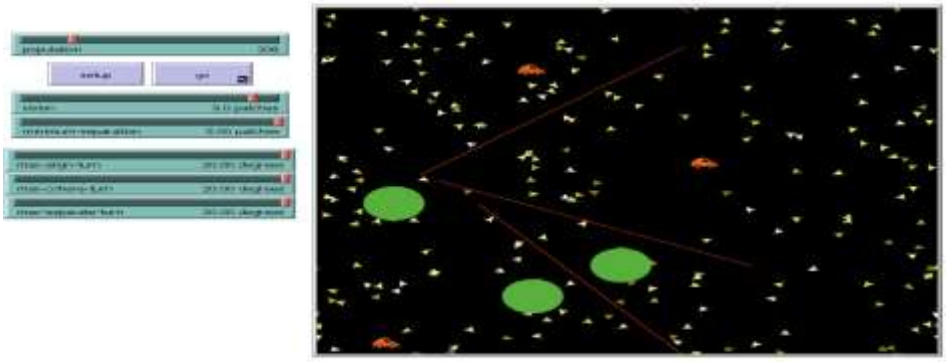
```
to go
  ask turtles [ flock ]
  ;; the following line is used to make the turtles
  ;; animate more smoothly.
  repeat 5 [ ask turtles [ fd 0.2 ] display ]
  ;; for greater efficiency, at the expense of smooth
  ;; animation, substitute the following line instead:
  ;;   ask turtles [ fd 1 ]
  tick
end

to flock  ;; turtle procedure
  find-flockmates
  if any? flockmates
    [ find-nearest-neighbor
      ifelse distance nearest-neighbor < minimum-separation
        [ separate ]
        [ align
          cohere ] ]
end

to find-flockmates  ;; turtle procedure
  set flockmates other turtles in-radius vision
end

to find-nearest-neighbor ;; turtle procedure
  set nearest-neighbor min-one-of flockmates [distance myself]
end

;;; SEPARATE

to separate  ;; turtle procedure
  turn-away ([heading] of nearest-neighbor) max-separate-turn
end

;;; ALIGN

to align  ;; turtle procedure
  turn-towards average-flockmate-heading max-align-turn
end
```

```
to align  ;; turtle procedure
  turn-towards average-flockmate-heading max-align-turn
end

to-report average-flockmate-heading  ;; turtle procedure
  ;; We can't just average the heading variables here.
  ;; For example, the average of 1 and 359 should be 0,
  ;; not 180.  So we have to use trigonometry.
  let x-component sum [dx] of flockmates
  let y-component sum [dy] of flockmates
  ifelse x-component = 0 and y-component = 0
    [ report heading ]
    [ report atan x-component y-component ]
end

;;; COHERE

to cohere  ;; turtle procedure
  turn-towards average-heading-towards-flockmates max-cohere-turn
end

to-report average-heading-towards-flockmates  ;; turtle procedure
  ;; "towards myself" gives us the heading from the other turtle
  ;; to me, but we want the heading from me to the other turtle,
  ;; so we add 180
  let x-component mean [sin (towards myself + 180)] of flockmates
  let y-component mean [cos (towards myself + 180)] of flockmates
  ifelse x-component = 0 and y-component = 0
    [ report heading ]
    [ report atan x-component y-component ]
end

;;; HELPER PROCEDURES

to turn-towards [new-heading max-turn]  ;; turtle procedure
  turn-at-most (subtract-headings new-heading heading) max-turn
end

to turn-away [new-heading max-turn]  ;; turtle procedure
  turn-at-most (subtract-headings heading new-heading) max-turn
end
```

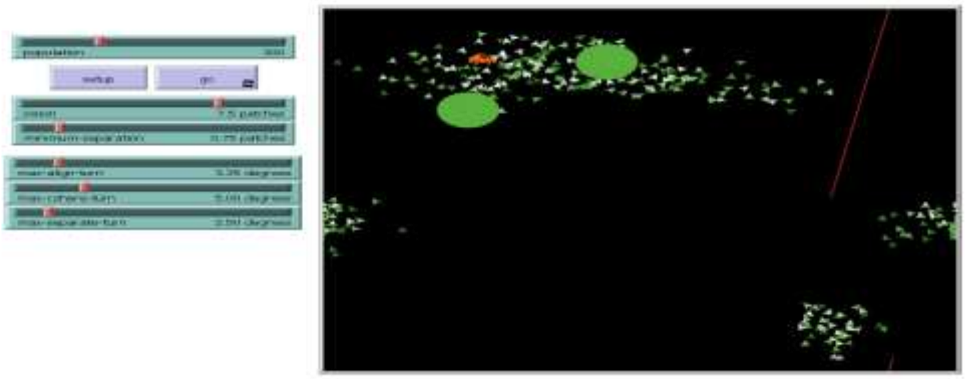
```
to-report average-heading-towards-flockmates  ;; turtle procedure
  ;; "towards myself" gives us the heading from the other turtle
  ;; to me, but we want the heading from me to the other turtle,
  ;; so we add 180
  let x-component mean [sin (towards myself + 180)] of flockmates
  let y-component mean [cos (towards myself + 180)] of flockmates
  ifelse x-component = 0 and y-component = 0
    [ report heading ]
    [ report atan x-component y-component ]
end

;;; HELPER PROCEDURES

to turn-towards [new-heading max-turn]  ;; turtle procedure
  turn-at-most (subtract-headings new-heading heading) max-turn
end

to turn-away [new-heading max-turn]  ;; turtle procedure
  turn-at-most (subtract-headings heading new-heading) max-turn
end

;; turn right by "turn" degrees (or left if "turn" is negative),
;; but never turn more than "max-turn" degrees
to turn-at-most [turn max-turn]  ;; turtle procedure
  ifelse abs turn > max-turn
    [ ifelse turn > 0
        [ rt max-turn ]
        [ lt max-turn ] ]
    [ rt turn ]
end

;;The code writen by Mr Vhutshilo Mawela
```

Appendix C

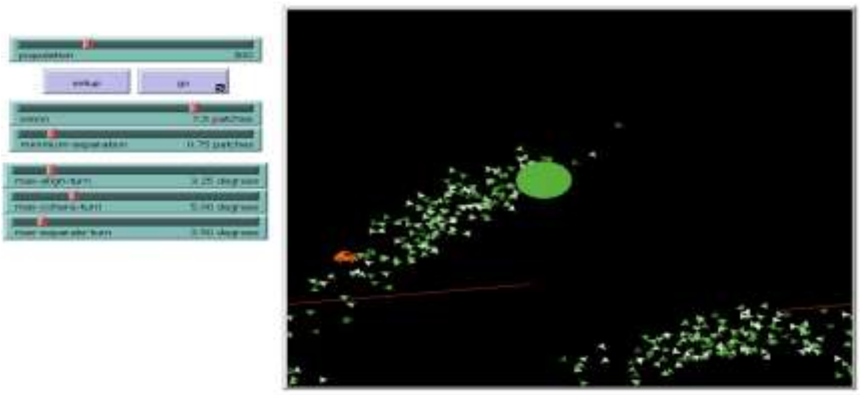
Screenshot with 3 targets, 3 nests and 3 obstacles



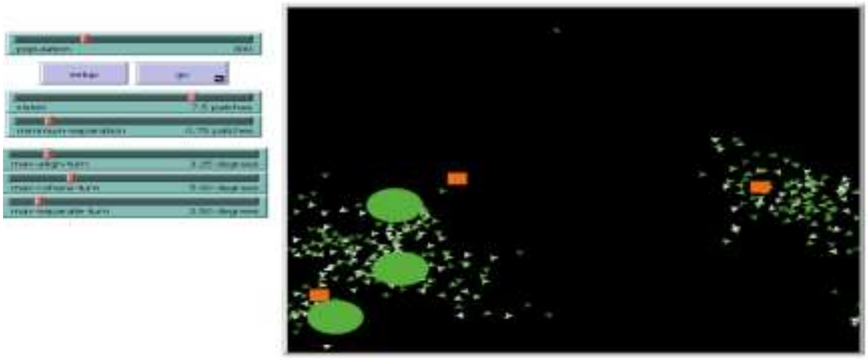
Screenshot (showing coherent behaviour of bird bots) with 1 target, 2 nest and 1 obstacle



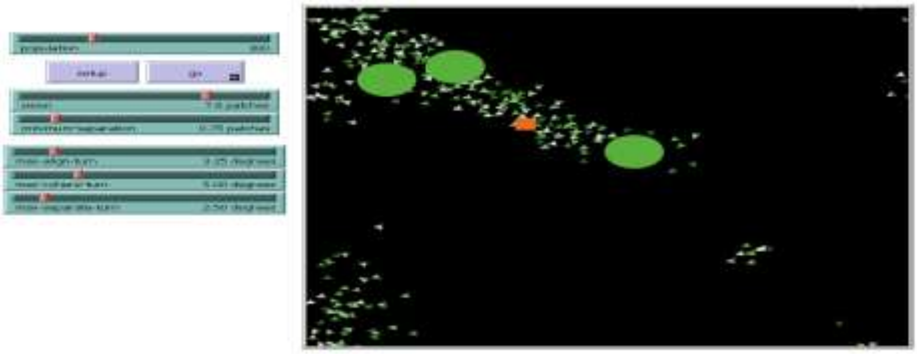
Screenshot (showing coherent behaviour of bird bots) with 1 moving target, 1 nest and 1 obstacle



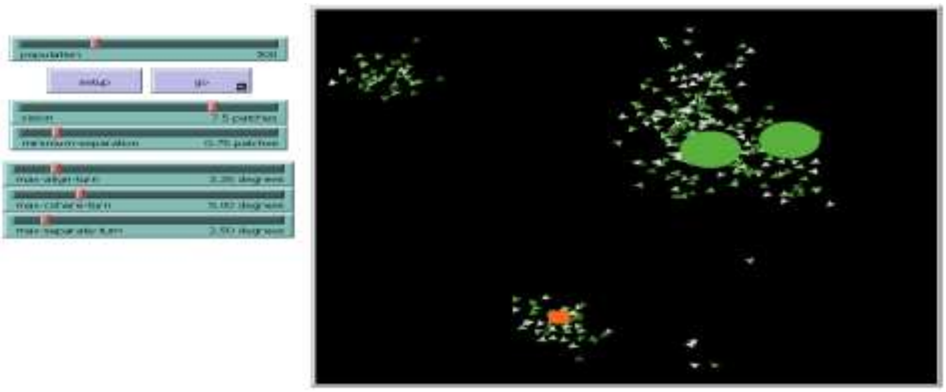
Screenshot (showing colour coded once found the target) on static target (house) with 3 targets, 3 nests and without obstacle



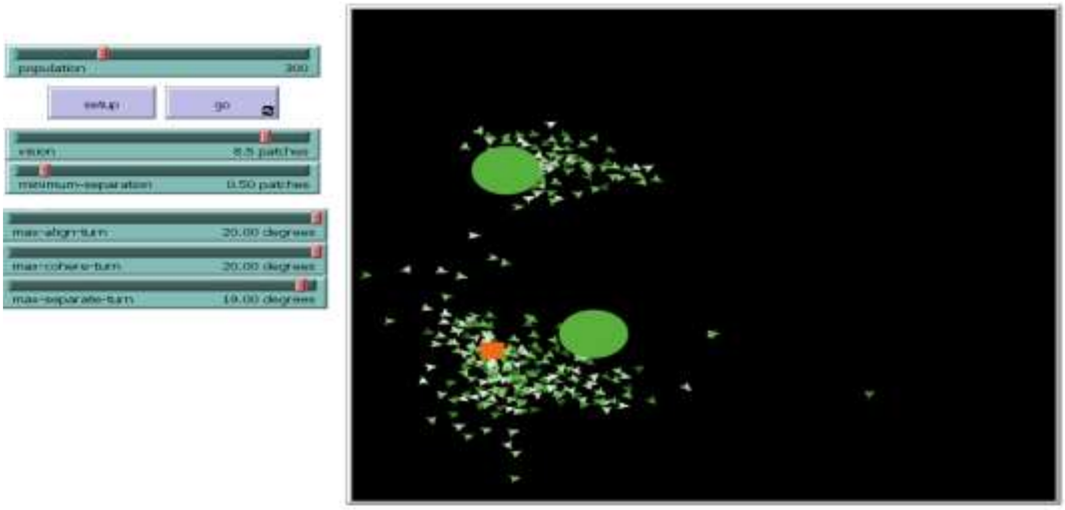
Screenshot (showing coherent behaviour of bird bots) on static target (house) with 1 target, 3 nest and without obstacle



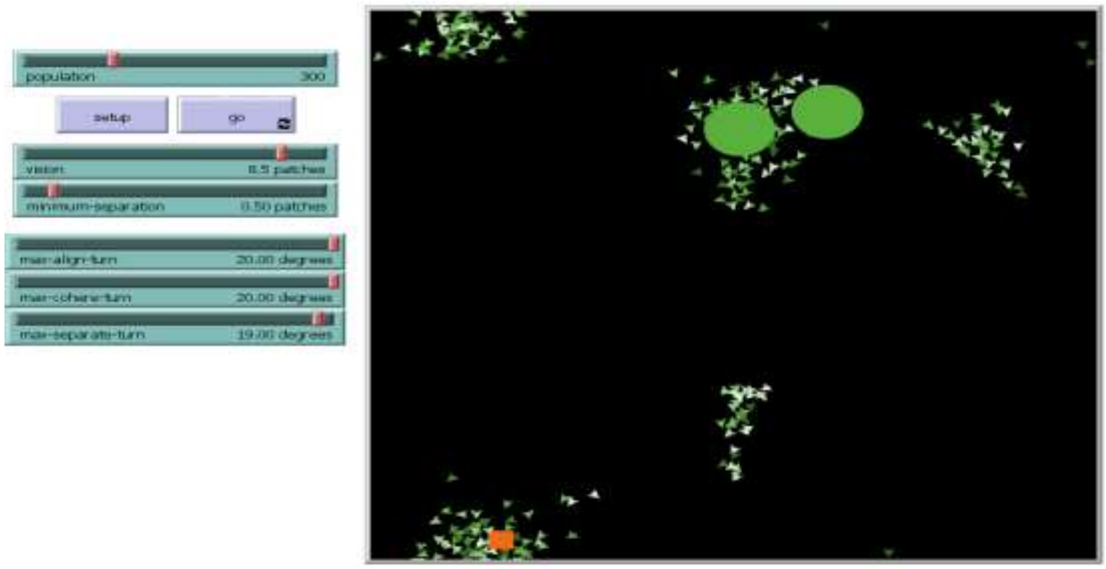
Screenshot on static target (house) with 1 target, 2 nests and without obstacle once it founds the target



Screenshot on static target (house) with 1 target, 2 nests and without obstacle once it founds the target



Screenshot on static target (house) with 1 target, 2 nests and without obstacle once it founds the target



Appendix D

Language editor's certificate

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18 November 2023

RE: CERTIFICATE OF LANGUAGE EDITING

To whom it may concern

I hereby confirm that I have proofread and edited the following **Mini-Dissertation** using Windows 'Tracking' System to reflect my comments and suggested corrections for the author(s) to action:

Extension of the Boid towards a Bird-Bot Ontology for Coordinating Surveillance Robotic Devices

REFERENCE

Author(s):	Vhutshilo Mawela
Student No:	202002064
Affiliation:	Sol Plaatje University

Although the greatest care was taken in the editing of this document, the final responsibility for the product rests with the author(s).

Sincerely

SIGNATURE

18.11.2023

This certificate confirms the language editing I have done in my personal capacity and not on behalf of SPU