Extended Abstract: Simulation of Interactions between Beehives

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Abstract

The interdisciplinary EU project HIVEOPOLIS aims to develop a new generation of intelligent beehive which might help bees in coping with adverse environmental factors. As a part of the HIVEOPOLIS project, this extended abstract reports on our ongoing work on the simulation of a decision-making process based on interactions between HIVEOPOLIS units and bee colonies which are not equipped with HIVEOPOLIS systems using the Mesa simulation framework.

Keywords

Multi-agent systems, Bio-hybrid systems, HIVEOPOLIS

1. Introduction

The impact of humans on the environment is difficult to exaggerate. Habitats of different species have been reduced, transformed or damaged as a result of monocultural agriculture, pesticide pollution, etc [1]. These changes in addition to colony diseases dramatically affect insects including bees. As a result, one of the concerning issues has become the sharing of valuable food sources, such as pollen and nectar as well as the limited habitat between native bee species and honeybees, as invasive species [2, 3].

The interdisciplinary EU project HIVEOPOLIS aims to develop a new generation of intelligent beehive which might help bees in coping with these adverse environmental factors and provide a synergistic added value to the colony, to its owner, and to the ecosystem in general [4, 5]. The intelligent beehives will form connected bio-hybrid systems. One concrete example is an active selection of foraging grounds, which could enable a mutually beneficial distribution of resources among several beehives and avoidance of areas affected by pesticides. Bees communicate beneficial foraging locations through a specific *waggle dance* [5, 6]. A HIVEOPOLIS beehive will be equipped with a technology, which enables decoding, suppressing and imitating such dances and allows the system to actively influence the foraging locations of the bees [5, 6]. A prototype of such robot, called RoboBee, was introduced in [6]. And as observed in [7], HIVEOPOLIS unit may incorporate one or more dancing robots which interact with honeybees to communicate them directions to floral resources. From that perspective a bio-hybrid HIVEOPOLIS beehive can be seen as an autonomous robot making autonomous decisions and negotiating with other

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beehives, e.g., send the bees to a particular region or, potentially, prevent them from harvesting in another.

Bees are able to exhibit complex swarm behaviors like decentralized target selection and workload balancing [8]. A decision mechanism steering the behavior of a whole bee swarm requires a model describing how waggle dances generated by robots which mimic honeybees would influence the behavior of the bees and their interaction with the environment. The first results of such modeling experiments for foraging choices in a bee swarm were introduced in [7] where the authors investigate the effect of robots on the hive's foraging decisions using a mathematical model. Further, such models can form a basis for a decision process based on anticipation as described in [9].

In this paper we introduce a proof of concept rule-based decision-making process and simulate behavior of bees' colonies and their interaction with the environment using agent based modeling approach. We aim to simulate different scenarios and study direct and indirect interactions between native bee colonies and honeybee colonies with integrated external regulation mechanisms and gain insights about possible competitive factors as well as cooperative strategies.

2. Modeling Methods

Behavior and interactions are the two key issues for modeling ecosystem organization. Using the Mesa framework [10], we direct our attention on a simulation of a decision-making process based on the interactions between agents (bees) and the environment, while bee agents' behavior is reduced to honeybees' foraging behavior, and the surrounding landscape is modeled as a simplified forage map [11].

2.1. Mesa

In comparison to the other well-known simulation tools, like NetLogo [12] and Mason [13], this framework has several competitive advantages. First of all, it is python-based and can be extended with modern python libraries and other python-based tools (e.g., Jupyter Notebook and Pandas tools) in order to create more complex simulations or analyse collected data. The collected data can be stored in a JSON or Pandas DataFrame format for further analysis. Second, Mesa consists of decoupled components, which can be replaced or used independently from each other. Third, visualization is browser-based, which provides additional opportunities for sharing of visualisation via the Internet. Since all components in the Mesa framework are decoupled, visualisation modules can be customized, extended, replaced, or removed.

2.2. Simulation

The environment of our simulations is discrete, modeled as a squared grid, with three types of agents: bee, beehive, and field. The beehives are modeled as hierarchical multi-agent system which consists of two levels: bees' level and beehives' (or colonies') level. A bee swarm is considered to be a multi-agent system with a non-hierarchical structure, where every bee is modeled as a separate agent. On the other hand, every beehive itself is considered an agent.

Despite the fact that HIVEOPOLIS unit has been conceived and, in reality, may be designed as a robotic honeybee imitating waggle dancing, in our simulations we implemented HIVEOPOLIS unit on the beehives' level as a separate type of beehive agent. Figure 1 (Right) demonstrates one of our simulations, which consists of two beehives ((1) is a beehive with an integrated HIVEOPOLIS unit and (2) is a wild beehive) with bees (e.g., (6), (7)) and three possible food sources ((3), (4), (5)), green-colored cells represent field agents without available food sources. For the sake of simplicity, we do not model the whole complex social organisation of an individual colony, ignore the diversity of bees' casts (workers, drones, queen) and food sources (nectar, pollen, water). Bee and beehive agents are described with a limited number of parameters (e.g., maximum flying distance, collected amount of food, coordinates of a known field, abundance of a field, etc). Floral sources are described using only three relevant parameters: amount of available resources, blooming tag, flowering period. We simulate agents' movements as discrete events. An activation order of agents is randomized in order to reduce its impact on the model.

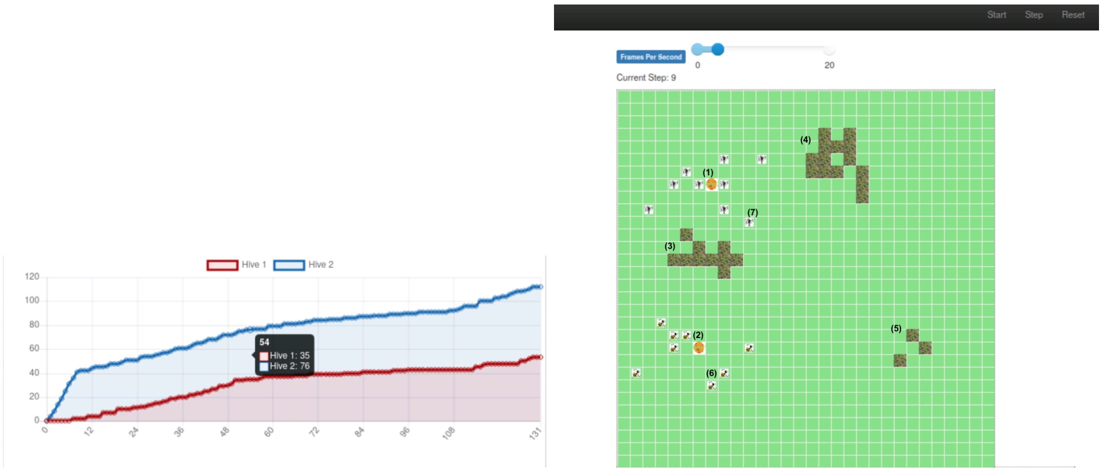

Figure 1: Simulation of the environment with two beehives. Left: graphs of collected food for each beehive. Right: a 2D view of the environment.

We implemented two foraging strategies for bees agents: *random foraging search* and *targeted foraging on the known floral patch*. We also considered two different interaction strategies between agents. The first one, a direct interaction, occurs on the bees' level, when the information about known foraging resources is communicated between simulated bees from one colony. So, for instance, the wild bees start with the random search strategy, as seen in Figure 1 (Right). After a discovery of a field with available floral resources (e.g., field (3) in Figure 1 (Right)), the bees return back to the hive and share the information about the found floral resource with other bees which are also in the hive. Bees might follow the communicated directions, in this case, they switch to the targeted foraging strategy, but might also ignore this information about the found food sources. The second one, an indirect interaction, occurs on the beehives' level, where the internal robot is supposed to define the most optimal food source and communicate it to the bees. This type of interactions is implemented only in the beehives with HIVEOPOLIS units. We assume that it will make autonomous decisions regarding optimal foraging sources based on information about the surrounding landscape, weather and other information received from the external sources as well as its predictions about behavior of the other beehives from the surroundings. The implementation details of the HIVEOPOLIS' interior robot are outside the scope of this work. In our simulations, the optimal fields are determined using rule-based decision-making approach which is based on three parameters: a distance parameter, a flowering period of fields, and an abundance of fields. In every simulation step, it is checked if there are any bees in the hive. If there are any, then a new optimal field is being calculated on the beehive's level and communicated to the bees on the bees' level. Also a decision, to follow the communicated coordinates or ignore them is being simulated on the bees' level. Data generated during simulation is displayed in the real-time mode in the live chart (see Figure 1 (Left)), the x axis shows the number of simulation steps, the y axis – the foraging dynamics of the modeled hives.

3. Results and Discussion

Bees are not only important pollinators but also a prime example of swarm intelligence [8]. Such modeling tools, like BEESCOUT [11] and BEEHAVE [14], can be useful for better understanding and exploration of the possible realistic scenarios of colony natural dynamics, bees' searching behavior in habitats with different landscape configuration as well as interactions between bees. Nevertheless, these tools are NetLogo based and cannot be applied for simulations of interactions between several colonies.

We are not the first, who is aiming to simulate decision-making processes in bees' swarms. A multi-agent simulation able to simulate the dynamics of honeybee nectar foraging was conducted using NetLogo tool and introduced in [8]. The authors implemented experiments reported in [15] and other works of T. Seeley, who investigated decision-making mechanisms within bee swarm.

Nonetheless, in our work, we aim to model and simulate decision-making processes not only within one colony, as it was done in [15, 8], but in a system of beehives and HIVEOPOLIS units. For this reason, we examined the factors relevant for a selection process of foraging sources. In [15] the authors highlighted three main factors, which are being considered during a process of choosing nectar sources: *distance*, *quality* and *the abundance of the food*. The factors determining the quality of food sources are, for instance, *difficulty of feeding at the source*, *direction in relation to the wind*, and *the colony's need for food*, etc [15]. In our first attempt of simulations, we focus on a distance from hive and abundance of patches. We also added one more parameter, which was not mentioned by [15], but can be relevant for our purposes, – flowering period of floral patches. *Quality* of food resources is a complex factor which is hard to capture and implement without any real data. Nonetheless, we hope to find a way how to integrate this parameter in our further simulation scenarios.

A HIVEOPOLIS bio-hybrid system could serve as a mechanism for implementing interactions on the beehive level and having an influence on the colony decisions regarding chosen food resources. Such centralized control mechanism might be beneficial for cases in which several bee colonies have to share limited floral resources, floral resources are difficult to discover due to the morphology of the beehive surrounding area, or a gentle way to redirect the bees to

the desired fields is required. It might be a feasible path to make safer or ecologically more important food sources more attractive to bees, even if these sources are energetically less profitable [7].
Our simulations don't capture the whole complexity of a decision-making process yet. We are going to continue our work on simulations with different combinations of possible competitive factors such as a food diversity. We consider evaluation of collected data to be a non-trivial task, which will require expertise from other scientific fields. The collected data are strongly affected by the parameters (e.g., number of bees per hive), which are relative values. Nevertheless, all parameters can be changed without much extra effort. Simulation experiments have low computational cost and can be run repeatedly.

4. Conclusion

Mesa is a convenient, powerful tool, which provides a solid base functionality for easy and comfortable simulation implementations as well as enough capabilities for customization of created models and their visualisation. Since the framework is based on Python, it might be advantageous and handy for a wide range of researchers.
Multi-agent systems are useful for problems integrating social and spatial aspects and suitable for simulation of complex systems. Models and simulations of beehives have been studied for a long time, so that we can draw experience from a rich library of literature. The novel direction of this work is the study of the simulation scenarios as a basis for a decision mechanism, which would allow a bio-hybrid beehive to act autonomously in a way beneficial to itself and its environment. Our preliminary results have shown coherent behaviors of the whole simulation, nevertheless, the model parameters require further tuning and scientific justification. Our further work will be focused on extension and improving of the existing simulation model. In order to increase credibility of our simulations, we aim to utilise geospatial data. The goal is to integrate an augmented map of a landscape and model the distribution of the floral resources and landscape features more precisely. Further, we are planning on collecting additional data and storing it in DataFrame format for further analysis using modern data science libraries.

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