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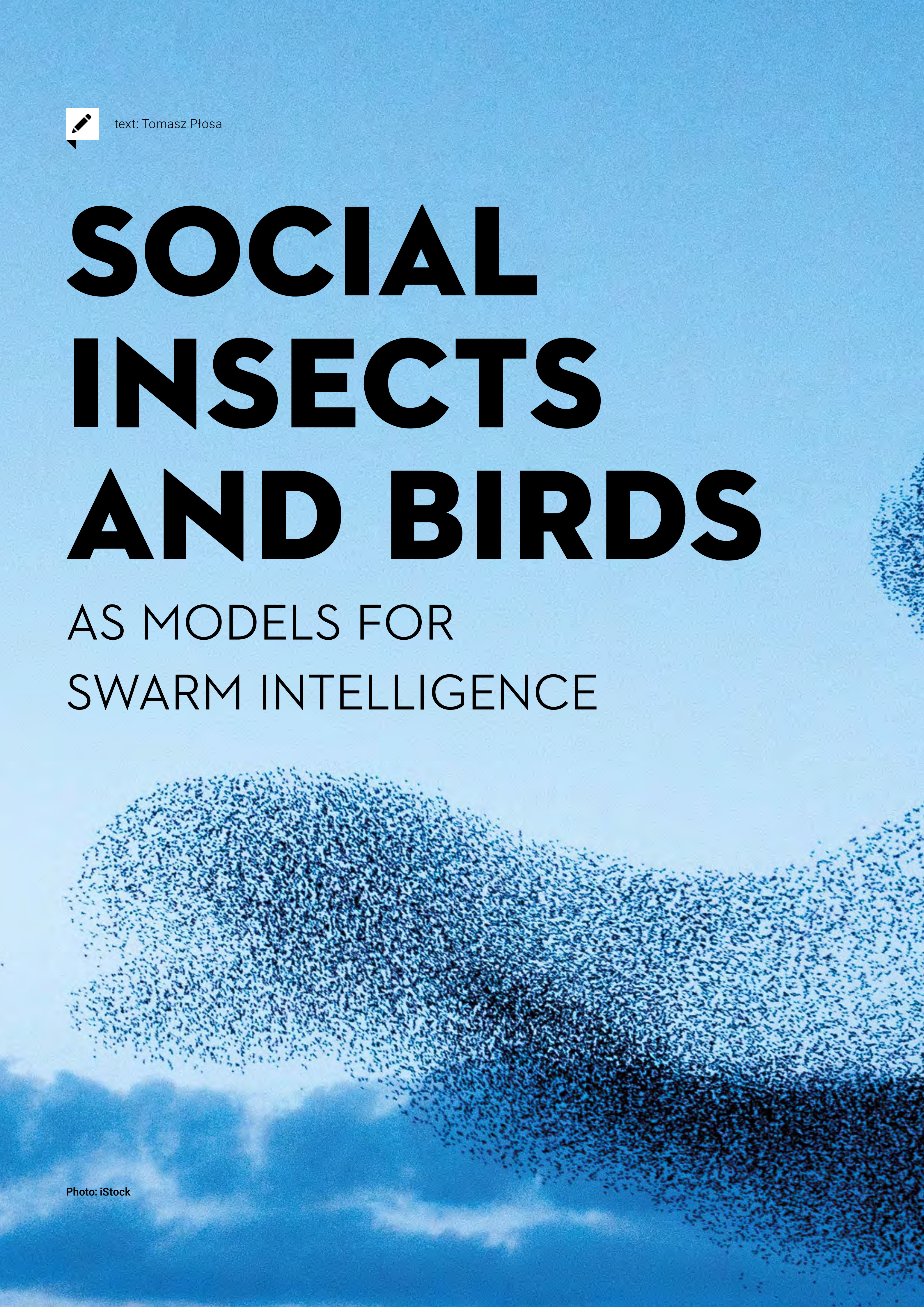
SOCIAL INSECTS AND BIRDS

AS MODELS FOR SWARM INTELLIGENCE



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It is very possible that, at least once in our lives, everyone of us was impressed by the fluidity of movement of wild birds flying in a flock or by a bank of colorful fish presented in a nature documentary. Both birds and fish move in a harmonious and coordinated way, steering in a given direction in a symmetrical pattern or even suddenly changing their direction – but without bumping into each other or breaking their formation. This is a true phenomenon of nature, and precisely these are the phenomena that researchers not necessarily associated with natural science began to look at. Subsequently, they created artificial intelligence algorithms based on mathematical models observed in the natural world which are useful for solving specific optimization problems.

The collective pattern of individual behavior in self-organizing systems such as flocks of birds, banks of fish, or colonies, was used to create an artificial intelligence technique called swarm intelligence (SI).

In the Polish language, the more direct translation of the word "swarm" (or "herd") is reluctantly resorted to, partially due to the fact that it features negative associations, such as "to act in a herd," which implies unintentional or unconscious action, and therefore we rather speak of "dispersed intelligence," says Prof. Urszula Boryczka of the University of Silesia at the Faculty of Science and Technology, who in her research work deals with e.g. metaheuristic algorithms, including algorithms based on natural phenomena. – We speak of metaheuristics or higher-level heuristics because such algorithms do not enable us to solve a given problem but only suggest how to find an algorithm capable of doing it.

Can the search for metaheuristic algorithms be treated as part of bionics? No, since bionics is the industrial application of specific technologies based on solutions found in nature, such as ultrasonic sonars (modeled on echolocation used by bats and dolphins) or the famous swimming suits produced by Speedo for the Olympic Games in Sydney in 2000. Their texture resembled shark skin, and 83 percent of gold medals were won by swimmers wearing this particular suit. In the case of swarm intelligence, we rather speak of biological mimesis or biomimicry.

"Regardless of whether we are talking about bionics or biological mimesis, it is worth to carefully look at what nature is telling us. Stanisław Lem used to say that technology is an extension of nature, and that is why we place such emphasis on searching for a phenomenon in nature," says Prof. Urszula Boryczka. "As a result, we also have algorithms based on the phenomenon of bioluminescence in glow-worms or on the waggle dance of bees."

So, as a reminder: first, we observe what happens in nature, then – by analyzing the behavior of a given population, which consists in finding a mechanism of communication and interaction between its individuals (agents) aimed at learning to improve their behavior – an appropriate mathematical model is created. It later serves as the basis for an algorithm applied to solve a particular optimization problem, i.e. the one related to the efficiency of action. Thus, for example, the Particle Swarm Optimization (PSO), an algorithm proposed by social sociologist James Kennedy and his fellow engineer Russell C. Eberhart as a simulation of collective behavior, is used to solve global optimization problems. Moreover, inspired by the way birds and fish move, in the 1980s Craig Reynolds created the algorithm of a swarm whose agents are so-called boids. This technique of artificial intelligence was used for the first time in the movie *The Lion King*, in the scene when a herd of antelopes scared by hyenas runs down a ravine, and Mufasa is killed as a result. This algorithm was used a few years later in the famous *Lord of the Rings* adaptation to move the Orc forces, but at first the Sauron's Orcs scattered in different directions due to the fact that incorrect parameters had been entered. This is because the need to tune and adjust parameters is the biggest obstacle to the correct application of a given metaheuristic.

Another very well-known algorithm based on distributed intelligence is the Ant Colony Optimization (ACO) algorithm proposed by Marco Dorigo, Vittorio Maniezzo, and Alberto Colorni, derived from the behavior of ants during foraging i.e. looking for food outside the anthill. Ants leave their colony and, moving in a completely random manner, extensively search a certain space and leave a so-called pheromone trace. When their mission of finding food is successful, they return to the "base," thus reinforcing that mark on their path. When other ants encounter it, they start to follow the same path, marking it even more with pheromones, which subsequently "attract" more of their kin (positive feedback, autocatalysis occurs). However, the pheromone trail evaporates after a while, so

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the most popular paths will be the shortest ones i.e. those which make it possible to most quickly transport food to the anthill and to leave the strongest pheromone trace. It is thanks to them that indirect communication takes place between two agents on the basis of stigmergy – one agent modifies the environment, and the other responds to this modification in the new environment, and later reinforcement learning occurs.
The ant algorithm can help to solve optimization problems with graph representation, such as the traveling salesman problem. The gist of the problem is this: a salesman, when setting off from point A, must visit several other points and return to point A at the least possible cost. This is a rather abstract example, but ACO has also been applied in the creation of transport networks (in order to avoid the most congested places or those where accidents occurred) or with the purpose of automatically creating computer programs (by formulating the goals that a given program should pursue, on the basis of the so-called anthropoid programming).
It is worth noting that in the recent years there has been a major breakthrough in the field of algorithmics. Until recently, it was believed that an algorithm must guide us from the input data to a specific result by applying procedures or constraints. Thus, the tendency was towards determinism, completely ignoring randomness, the positive aspect of which was also pointed out by Stanisław Lem in his writings.
"It can be presented using the metaphor of a drawer with socks," says Prof. Urszula Boryczka. "Imagine you have one black sock and want to find a matching second black sock in a drawer, among many socks of different colors. In the past, algorithmics would postulate an integer search that would give us a specific result: we would either find the second black sock of the pair, or we would come to the conclusion that there is no such match at all. Contemporary metaheuristic algorithms allow us to perform a rough search of the possible solutions, thanks to which we obtain a satisfactory one i.e. we conclude that we can choose a sock in color which is similar to black – after all, wearing two different socks is becoming increasingly fashionable."
What are the challenges algorithmics has to face? Prof. Boryczka has no doubt that the greatest of them is to create a mathematical model of human consciousness for the purpose of building artificial intelligence. There has already been some success in this field (IBM's Deep Blue computer winning over chess world champion Garry Kasparov in 1997 or DeepMind's AlphaGo program winning against professional players in the ancient Chinese game *go* in 2015 and 2016), but the way to mimicking the functioning of our brain, a phenomenon which has been looked at by algorithmics since at least the 1960s, is still very long. In order to attain this goal, a description of such elusive elements as intuition, self-awareness, or feelings influencing decision-making would be necessary. Systems that mimic honeybee behavior and are able find a consensus (Bee Colony Optimization, BCO) could be used for this purpose.
According to Prof. Urszula Boryczka, however, if we could create a full mathematical description of the decision-making process that takes place in our brains, we would be one step away from understanding the workings of the human mind. Deep Learning, which uses neural networks as well as machine learning algorithms, will give us a hint of the direction we should take in the future.

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