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Phil Husbands,  
University of Sussex, United Kingdom

REVIEWED BY  
Larry Bull,  
University of the West of England, United  
Kingdom  
Andrea Roli,  
University of Bologna, Italy

\*CORRESPONDENCE  
Jonas Kuckling,  
✉ jonas.kuckling@ulb.be

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# Recent trends in robot learning and evolution for swarm robotics

Jonas Kuckling\*

IRIDIA, Université Libre de Bruxelles, Brussels, Belgium

Swarm robotics is a promising approach to control large groups of robots. However, designing the individual behavior of the robots so that a desired collective behavior emerges is still a major challenge. In recent years, many advances in the automatic design of control software for robot swarms have been made, thus making automatic design a promising tool to address this challenge. In this article, I highlight and discuss recent advances and trends in offline robot evolution, embodied evolution, and offline robot learning for swarm robotics. For each approach, I describe recent design methods of interest, and commonly encountered challenges. In addition to the review, I provide a perspective on recent trends and discuss how they might influence future research to help address the remaining challenges of designing robot swarms.

## KEYWORDS

swarm robotics, robot evolution, robot learning, automatic design, neuro-evolution, automatic modular design, embodied evolution, imitation learning

## 1 Introduction

Robot swarms are decentralized systems of relatively simple robots that only rely on local information to operate (Breni, 2005; Sahin, 2005; Brambilla et al., 2013; Dorigo et al., 2014; Haddad, 2018). Like animal swarms in nature, a robot swarm is a group of robots that are efficient at performing tasks due to their cooperation. Robot swarms are multi-robot systems that exhibit some particular characteristics. They are decentralized and highly redundant. The high redundancy requires that there is no role in the swarm that can only be executed by a single robot<sup>1</sup>. Furthermore, in a robot swarm, there exists no single central point of control (neither internal nor external to the swarm), as a centralized point of control would be a single point of failure. Therefore, complex collective behaviors, such as task allocation, cannot be planned and orchestrated by an operator. Instead, the swarm is required to be self-organizing: the collective behavior of the swarm must emerge from the interactions between the individual robots. Additionally, the robots in the swarm are relatively simple (both in terms of hardware and software) with respect to the task they perform and have only local sensing and communication capabilities.

<sup>1</sup> Classically, a robot swarm is a homogeneous system—i.e., all robots have the same capabilities and execute the same software. There have been examples of heterogeneous robot swarms (Dorigo et al., 2015), in which parts of the swarm are specialized in such a way that their role cannot be performed by some of the other robots in the swarm. Yet, in these examples, heterogeneous swarms are also redundant to some degree, as each role has at least several robots being able to perform it.

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