Multi-agent Learning of Heterogeneous Robots by Evolutionary Subsumption

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Abstract. Many multi-robot systems are heterogeneous cooperative systems, systems consisting of different species of robots cooperating with each other to achieve a common goal. This paper presents the emergence of cooperative behaviors of heterogeneous robots by means of GP. Since directly using GP to generate a controller for complex behaviors is inefficient and intractable, especially in the domain of multi-robot systems, we propose an approach called Evolutionary Subsumption, which applies GP to subsumption architecture. We test our approach in an "eye"-"hand" cooperation problem. By comparing our approach with direct GP and artificial neural network (ANN) approaches, our experimental results show that ours is more efficient in emergence of complex behaviors.

1 Introduction

Genetic Programming (GP) has proven successful in designing robots capable of performing a variety of non-trivial tasks [7,11]. However, the fields' focus is almost exclusively on single-robot systems. Many tasks can be solved more efficiently when a multi-robot system is used; while some tasks cannot be solved at all with single-robot systems. Therefore, recently more and more researchers have applied evolutionary computation techniques to the design of various types of multi-robot/agent systems [3,4,5,6,8,9].

In a multi-robot system several robots simultaneously work to achieve a common goal via interaction; their behaviors can only emerge as a result of evolution and interaction. How to learn such behaviors is a central issue of Distributed Artificial Intelligence, which has recently attracted much attention. It is very important and interesting to study the emergence of robots' behaviors in multi-robot systems by means of artificial evolution.

Most of the aforementioned researches are on homogeneous systems. Although D. Floreano et al. [3] presented a heterogeneous system, the relationship between the two robots is competitive. In this paper we address the issue in the context of a heterogeneous multi-robot system, in which two real robots, i.e., Khepera, are evolved using GP to solve a cooperative task.

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Since directly using GP to generate a program of complex behaviors is difficult, a number of extensions to basic GP have been proposed to solve these control problems of the robot. For instance, J. Koza employed GP to generate a subsumption architecture control program [7]. W.F. Punch et al. proposed an approach to solve robot navigation problems, it incorporated subsumption principles into the Echo Augmented Genetic Programming approach [12]. H. Iba et al. studied the emergence of the cooperative behavior in multiple robots/agents by means of GP and proposed three types of strategies, i.e., homogeneous breeding, heterogeneous breeding, and co-evolutionary breeding, for the purpose of evolving the cooperative behavior [4]. They used a heterogeneous breeding approach of GP, evolving a multi-agent learning system, to solve robot navigation and Tile World problems [5]. They also applied the proposed GP system to a homogeneous cooperative multi-robot system and tested their approach in an "escape problem" [8]. These researches showed that GP is efficient in multi-robot/agent learning.

We report an improvement of GP, called Evolutionary Subsumption–which combines the GP with Brooks' subsumption architecture [1] and compare our approach with direct GP and ANN approaches. Our experiments show that this method is effective in solving such complex problems of robot control.

The rest of this paper is organized as follows: in Sect. 2 we will analyse the target system and its complexity, our approaches will be presented in Sect. 3, and in Sect. 4 the experimental result with comparison of evolutionary subsumption and direct GP will be reported. Finally, discussion and some empirical conclusions are presented.

2 Task Domain and Complexity

The approaches are evaluated in an "eye"-"hand" cooperation task. In this task two heterogeneous robots learn complex robotic behaviors by cooperation. One of them, which is mounted with a digital camera, acts as the "eye" and the other, which is mounted with a gripper, acts as the "hand" (Fig. 1). Their task is: the "eye" tries to find a cylindrical object[1], and then navigates the "hand" to pick it up and then navigates it to carry the cylinder to the goal. The two robots are heterogeneous–they have different sensors and actuators, and have different roles in the system. Their behaviors are complex: including tracking, path planning, and communication, etc.

We classify the similar problems into three difficulty levels, according to the relationship of the observer–"eye" and actor–"hand":

[1] There are two cylinders in our system, one is the object that the "hand" needs to grip in the first stage and the other is the goal, which the "hand" needs to put the first object near in the second stage. In the following text, in order to ease the depiction, we use the word 'cylinder' to indicate the object or the goal according to the stage, except where we distinguish them explicitly.