Comparison of Different Exploration Schemes in the Automatic Modular Design of Robot Swarms*

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The main challenge on the design of robot swarms is that no general methodology exist to anticipate the global behavior of a robot swarm based on the behavior of a single individual [2]. A promising approach to overcome this difficulty is the design of collective behaviors by automatic design methods [1].

In this work, we study different exploration schemes in the context of automatic modular design methods—such as AutoMoDe-`Chocolate`, proposed by Francesca *et al.* [4]. Exploration schemes are an essential part of many collective behaviors, and yet, they have never been thoroughly evaluated in the context of automatic modular design. Our hypothesis is that the exploration schemes—such as random walks [3, 5] and the ballistic motion used in `Chocolate`—have a noticeable influence on the exploration capabilities of automatically designed robot swarms. To test our hypothesis, we conceived AutoMoDe-`Coconut`—a variant of `Chocolate` with multiple configurable exploration schemes embedded within its modules. We assess `Coconut` in the design of collective behaviors for missions that require robot swarms to explore in different manners: aggregation—searching for a specific location to aggregate; foraging—traveling back and forth from two locations; and grid exploration: uniformly covering the workspace. We conduct realistic simulations in workspaces that are either bounded or unbounded (i.e. robots might leave the workpsace) and we compare the performance of `Coconut` and `Chocolate`. We expect `Coconut` to appropriately select and configure its exploration schemes for the missions in hand. We also expect `Coconut` to outperform `Chocolate`—we conjecture that `Chocolate` produces swarms with lesser exploration capabilities due to its single exploration scheme, the ballistic motion.

We observed that `Coconut` is prone to select exploration schemes that fit the requirements of the workspace, as shown by Figure 1a. In bounded workspaces, `Coconut` uses mainly the ballistic motion—this allows robots to cover large distances and lead the swarm to explore widely. In unbounded workspaces, `Coconut` uses mainly the random walk—this maintains robots to explore in small areas and lead to behaviors that keep the robots within the workspace. However, contrary to our expectations, `Coconut` performs similarly to `Chocolate`, as shown by Figure 1b. Originally, we expected that ballistic motion would perform poorly in unbounded workspaces—the steady straight motion could easily lead robots to

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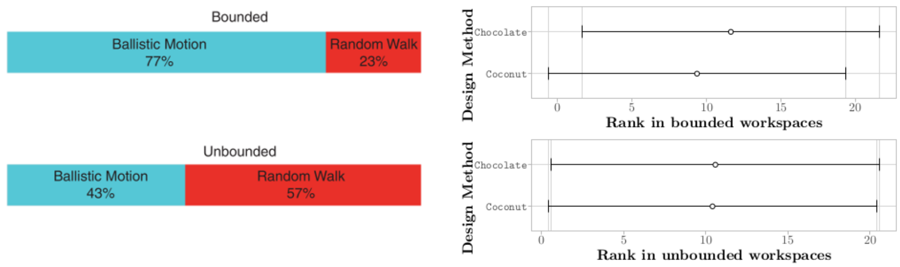

(a) Exploration schemes distribution (b) Comparative performance results

Fig. 1: Aggregated experimental results in bounded and unbounded workspaces: (a) Distribution of exploration schemes in `Coconut` when the robots explore; (b) Comparative performance results between `Coconut` and `Chocolate`.

leave the workspace. However, `Chocolate` is able to design collective behaviors that prevent the robots to leave the workspace by combining its different modules. This result is interesting as it allows us to make the following observation: the exploration capabilities of modular control software come from the high level interaction between modules and not only from the exploration schemes embedded within them. In this sense, automatic modular methods such as `Chocolate` can produce complex exploration strategies even if they are endowed with simple exploration schemes—in part confirmed by the effective design of collective behaviors in previous studies [4]. We hence conclude that ballistic motion is a sufficiently appropriate exploration scheme for classes of missions with bounded workspaces. Still, whether an exploration strategy based on random walk could be a suitable solution in other contexts needs to be further explored.
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