

Effectively Rearranging Heterogeneous Objects on Cluttered Tabletops

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Abstract—Effectively rearranging heterogeneous objects constitutes a high-utility skill that an intelligent robot should master. Whereas significant work has been devoted to the grasp synthesis of heterogeneous objects, little attention has been given to the planning for sequentially manipulating such objects. In this work, we examine the long-horizon sequential rearrangement of heterogeneous objects in a tabletop setting, addressing not just generating feasible plans but near-optimal ones. Toward that end, and building on previous methods, including combinatorial algorithms and Monte Carlo tree search-based solutions, we develop state-of-the-art solvers for optimizing two practical objective functions considering key object properties such as size and weight. Thorough simulation studies show that our methods provide significant advantages in handling challenging heterogeneous object rearrangement problems, especially in cluttered settings. Real robot experiments further demonstrate and confirm these advantages.

Source code and evaluation data associated with this research will be available at <https://github.com/arc-1/TROL> upon the publication of this manuscript.

I. INTRODUCTION

In pick-n-place-based multi-object rearrangement problems, a robot is tasked to move objects, generally one at a time, from a start arrangement to a desired goal arrangement. Multi-object rearrangement is a fundamental robotic task in commercial, domestic, and many other settings. In supermarkets, a robot can assist in maintaining organized shelves. At home, a robot can be utilized for tasks such as cleaning up kids’ rooms or reorganizing a messy desk.

Among rearrangement problems, Tabletop Object Rearrangement with Overhand grasps (TORO) has been extensively studied due to its many applications to real-world scenarios. The apparently simple setup is in fact NP-hard to optimally solve [1]. The difficulty is due to the overlaps between the start and goal arrangements, which makes it impossible to directly move some objects to the goal poses before some other objects are first moved away. For example, in Fig. 1 (Right), the white bag cannot move to the goal pose before the black mug moves away from the current pose. When many such dependencies exist, they entangle and give rise to a combinatorial challenge. Deciding the best sequence to untangle the dependencies and minimize the total number of temporarily displaced objects makes the problem NP-hard.

In addition to the combinatorial challenge of minimizing the total number of displaced objects, another potentially more thorny issue in solving TORO is finding ideal locations



Fig. 1. [Left] Our hardware setup for evaluating tabletop rearrangement of multiple heterogeneous objects. One of the test cases is also shown. [Right] The illustration of an example instance where many objects of drastically different sizes and weights are to be rearrangements.

(i.e., *buffers*) for temporarily placing objects that cannot be directly moved to their goals. This issue appears when the workspace is cluttered with limited free space. In the example from Fig. 1 (Right), the book and the phone cannot move to the goal pose before the other object is moved away, so at least one of these two objects needs to be moved to a *buffer* to break the mutual dependency. Suppose we are limited to using the tabletop as the workspace, it is not immediately clear which object should be moved away and where within the tabletop the moved object should be temporarily displaced. We denote this subclass of TORO as TORI (a TORO in which temporarily displaced objects must remain *internal* to the tabletop workspace) [2].

Until now, algorithmic research on TORI is limited to solving instances with mostly homogeneous objects [1]–[4]. The assumption of homogeneous objects leads to a relatively simple model where each object manipulation action has the same or very similar cost, which in turn limits the applicability of the resulting methods. In many real-world tabletop rearrangement problems, objects are often heterogeneous. For example, in Fig. 1, some objects are small and thin, e.g., pens, while others can be bulky, e.g., the white bag. Intuitively, objects’ sizes and shapes impact the rearrangement planning process – it is more difficult to relocate larger objects temporarily. Furthermore, other properties, such as weight, affect the effort needed to move them around. This further complicates the computation of optimal rearrangement plans. We thus ask a natural question here: Can we leverage objects’ properties to guide multi-object rearrangement planning?

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