A Deep Reinforcement Learning Approach for the 3D Multiple-Bin Packing Problem

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20th ESICUP Meeting

Abstract

This study investigates a variant of the 3D Bin Packing Problem (3DBPP), a computationally challenging NP-hard task involving the optimal packing of cuboid boxes into containers with limited capacity while satisfying non-overlapping constraints between the different objects. 3DBPP is a major problem faced by many companies and is much more difficult to solve than the 2D version. First due to the combinatorial nature of the problem induced by a third dimension, but also since additional constraints must be taken into account to handle real-life problems; e.g. multiple bins context, vertical stability, horizontal stability, fragility, weight distribution... Our work investigates the case of the 3D Multiple-Bin Packing Problem (3D-MBPP), taking into account the stability.

Obtaining good feasible solutions for such complex problems remains a challenge for traditional Operations Research methods. Some authors therefore started to consider alternative approaches from other research streams, namely Artificial Intelligence (AI) and Machine Learning (ML). In particular, Reinforcement Learning (RL) has been adapted and tested in the literature in order to accommodate combinatorial problems. In RL, an "agent" interacts with an "environment" by performing actions and receiving feedback in the form of "rewards," iteratively learning optimal action sequences. Deep Reinforcement Learning (DRL) further enhances this approach by incorporating ML into the process, essentially to deal with the huge size of the solution space.

While this DRL approach represents a significant step forward, our literature review reveals limitations in previous studies. Existing works often address a too-restricted set of constraints, or neglect crucial aspects like stability and orientation constraints. Additionally, the focus heavily leans towards single-bin scenarios, overlooking the more realistic multiple-bin setting.

Therefore, this research addresses these three main challenges outlined hereabove: (1) the inherent complexity of 3DBPP rendering classical methods inefficient, (2) the limited constraint consideration in prior DRL applications, and (3) the lack of attention to multiple-bin scenarios.

We build upon an existing DRL model for 3DBPP only, which considered one infinite-height bin and did not take the stability of the packing into account. We developed a Python-based implementation to test our DRL approach on several artificial instances of different sizes with identical bins (Single Bin Size Bin Packing Problem). After an initial training of several hours, our system is able to provide, in a few seconds, highly packed solutions for realistic large-scale instances (100 heterogeneous parcels loaded in identical $120 \times 120 \times 100$ bins with a 1cm precision).

Keywords: Combinatorial Optimization, Bin Packing Problem, Container Loading Problem, Logistics, Artificial Intelligence, Machine Learning, Reinforcement Learning