Improving e-commerce logistics with Augmented Reality and Machine Learning: The case of the 3D bin packing problem

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1 Introduction and context

The volume of activity in e-commerce increases every year. It leads to new challenges on the logistic side to deliver all the goods worldwide in a minimal amount of time. Indeed, the volume of goods delivered by air, sea or land is now gigantic: according to Pitney Bowes (2018), 87 billion of parcels were shipped in 2018. Amazon itself delivers an average of 2.5 billion packages each year (Sheetz, 2019). Alibaba, with the Asian market, has even more customers and targets now Europe with a first European hub in Belgium through a deal struck in 2018. Moreover, customers have grown more demanding in terms of delay. Nowadays it is not uncommon to see the major players offering delivery in less than 24 hours for some destinations and products. This is only possible by optimizing all the elements of the supply chain.

We focus in this paper on one important task in the process: the packing of parcels in containers before shipping by air, truck, train or sea. Being able to pack objects quickly and efficiently has become an increasingly important problem in the world of logistics. The goal is, at the same time, to speed up the operations and to pack more in a same volume; i.e. to be able to deliver faster and more per carrier. In this study, we design a new approach based on a combination of traditional OR and of new machine learning techniques: more specifically Reinforcement Learning (RL).

Even when an optimal packing planning is provided, its implementation is usually not straightforward. It requires from the operators very good spatial awareness capabilities to transform a 2D paper solution into an actual 3D process. We believe that Augmented Reality (AR) is the solution to this question. We developed under Unity 3D an AR tool to guide, or train, the operators in the filling of containers or construction of pallets based on solutions computed in real time by our algorithm.

In partnerships with companies at Liege Airport, the 8th largest cargo airport in Europe and the base of FedEx and soon of Alibaba, we tested our approach with Microsoft HoloLens headsets on simulated and real instances.

2 Literature Review

Deciding how to pack parcels is known in Operations Research (OR) as the 3D bin packing problem (see Martello et al., 2000); a kind of three-dimensional game of Tetris. It is a well-known and extremely complex combinatorial problem (NP-hard class) for which no exact algorithm is able to find a solution for realistic size instances.

It is an NP-hard problem of which the principle is the following: given a finite set of small rectangular objects and a variable number of larger hollow objects, fit the entire set of small objects using as few of the larger objects as possible. Traditionally, this problem is solved in approximations using carefully designed heuristics. Multiple versions of the problem have been identified as well as a handful of sub-problems. The problem under its different forms has been tackled by many authors; see e.g. Wäscher et al. (2007) for a topology, Coffman et al. (2012) for a recent survey and Paquay et al. (thesis 2017) for a few algorithms in air transportation. Most notably, it is uncommon to consider irregular shapes for the smaller objects as it makes it difficult to formalise the problem mathematically. The specific bin packing problem tackled in this project will be the single bin-size bin packing problem (SBSPB). Moreover, the particular type of SBSPB here will be the three dimensional variant.

As a subfield of machine learning, reinforcement learning allows statistical models (for example artificial neural networks) to reason about environments they exist in and learn from it (see Kaelbling et al., 1996, for a comprehensive presentation of this family of methods). Previous research results of reinforcement learning include the well-known AlphaGo program which beat the world champion of Go in 2015 (see Silver et al., 2016, for a description of the algorithm).

The motivation behind using such techniques is that it is possible to learn interesting behaviours or strategies that a regular operator might overlook. Indeed, by contrast to common exact approaches or heuristics that require a good preliminary understanding of the problem and the way to solve it, RL algorithms have to train to find by themselves implicit and hidden policies. It is only when the training is completed that, based on the acquired knowledge, the algorithm can provide instantaneous directions to the operator.

3 Methodology

The novelty of our work is first to consider RL to solve instances of the 3D bin packing problem. Most of the algorithms designed up to now comes from the OR field and only a few authors (see e.g., Hu et al., 2017, Shouraki and Haffari, 2002) have started to apply machine learning approaches to this problem. There is room for improvement. For the training phase of the RL model, we created artificial instances by simulating a huge number of possible cases as well as their solutions. Indeed, the larger the training sample is, the richer and more reliable the result is. The solutions are then graded according to a given performance metric which can be swapped with other metrics as a model hyper-parameter.

The second novelty of our work is to feed in real time the operators with the solutions found by our algorithm. When the solver will be reliable and stable, a multi-user software architecture will be devised. It will be made of a central server maintaining bilateral connections with AR headsets. This server will fetch contextual information from a given operator, for instance the state of the bin they are working on and provide a sequence of actions to follow in real time. The next parcel to add in the container is highlighted by augmented reality and its optimal location in the bin appears as a hologram thanks to the Hololens headset. This could potentially be used by inexperienced operators during training, or even by experienced operators to ease their workload.

Once the previous two points are operational, the third phase of the project can start. It will consist in assessing the added value of the developed toolset. The idea is to gather a heterogeneous sample of people with varying degrees of expertise in bin packing. Ideally, the sample should be made both of people who have a significant amount of experience working as operators in logistics, as well as people who have never touched the world of logistics. The sample will be divided into multiple groups: a control group who will just serve as a baseline and a group of people, both experts and novices that will be asked to complete their parcel using the developed training software. Several metrics will be measured and used as a basis for a comparative study on the influence of AR headsets for daily bin packing tasks performed in warehouses or other supply chain settings. Other samples could be formed for instance to compare performance in different contexts (multi bin-size VS single bin-size, regular shapes VS irregular shapes, …).

4 Expected Results

We expect the RL models to learn a correct utility function for the single bin-size bin packing problem. Potentially, it could also learn problem-specific heuristics on its own. Ideally, we would like to compare the learned behaviour of the RL models with the heuristics currently used in practice by operators. Through contacts at Liège Airport, we expect to be able to observe and formalise operators' behaviour accurately.

It is also expected that using AR training should influence the performance of subjects on the bin packing task. We expect results to highlight a link between the use of such technology and the training time required to perform the given task efficiently. Such results were already suggested in the study made by Boud et al. (1999).

Furthermore, we expect the machine learning architecture to serve clients relatively well. However, we expect that the end result will probably not be completely scalable according to industry standards.

5 Conclusion

In this paper, a brief overview of the bin packing problem was shown as well as a motivation to pairing RL and AR techniques on top of it. Then, a methodology for training operators on the bin packing problem was proposed in a step-by-step approach. Finally, the research hypothesis based on previous studies or preliminary results were presented. Some developments still remain to be done, however; preliminary results are expected to be available once practical experimental trials have begun.

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