Packing with complex shapes in Supply Chain Networked Warehouse Management Systems.

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ABSTRACT: In this article we are particularly interested in packing objects defined by complex shapes encountered in logistics using Constraint Programming, Metaheuristics and non-linear inequalities.

1. INTRODUCTION

In this article we are interested to highlight the contribution of Constraint Programming, Metaheuristics and numerical solvers using non-linear inequalities in solving a set of problems encountered in logistics and particularly in a warehouse management systems (WMS). Existing WMS systems provide advanced features to manage the movement of items within the warehouse, but fail to comply with the increasing need for more automation of customer-oriented demands, such as how to pack fragile items in a pallet and in which order, how many packaging material are needed, the order of loading pallets in a truck according to the customers to visit. Generally, they lack optimization functionalities like advanced packing tools, optimal filling of containers and trucks subject to delivery constraints. Our contribution is the development of new tools for this sector activity.

Bin packing is a classical combinatorial optimization problem which has a wide range of real-world applications in industry, logistics, transport, parallel computing, circuit design and other domains. In this articles we report two major studies carried in the research project Net-WMS2. First, we start describing an example of application and the current solvers based on Constraint Programming (CP) used in the industry. Second, we introduce the first study based on handling complexes shapes with non-linear inequalities. Finally, we introduce the study of the evaluation of the covariance matrix adaptation evolution strategy (CMA-ES2) [3], one of the most powerful evolutionary algorithm for continuous optimization with arbitrary objective functions, on hard packing problems including square shapes, curve shapes, mixed square and curve shapes, and also continuous rotations.

2. OPTIMIZATION PROBLEMS

The problem addressed is taken from warehousing and distribution. It concerns the order preparation of large orders for intermediate platforms or important customers like manufacturers in different sectors. The problem consists of packing products of various shapes and sizes into available pallets (larges boxes) in a way which optimizes the total number of pallets. The objective is to minimize the total number of pallets whist handling several types of pallets and subject to orientation, fragility, stackability, weight and volume constraints.

2.1 Constraint Programming and 3D Packing

KLS OPTIM has developed a set of solvers using CP and Metaheuristics for a class of problems known in the literature as Multidimensional Bin Packing Problem (MD-BPP). They integrate many constraints (orientation, fragility, stackability, weight and volume constraints) and preference packing rules. In this problem, bins might of different sizes. The objective is always to minimize the total number of bins. For more information we advise the reader to refer to [1]. Solvers are integrated in Full Web applications and operational since many years. All objects are boxes or cylinders. For real time applications the optimal solution is no longer required. One of the major advantage of CP is the ability to exploit its incremental aspect and to model users' strategies in order to calculate quality solutions which are more suitable. For some applications hybrid solvers combining CP and Metaheuristics like tabu search are more qualified for computing quasi-optimal solutions.

The first study and innovative approach is the extension of the non-overlapping constraints in Choco, which is used for example for 3D packing, to complexes shapes with non-linear inequalities. The study proposes a numerical approach for the wide class of objects described by non-linear inequalities. The goal here is to calculate the non-overlapping constraint, that is, to describe the set of all positions and orientations that can be assigned to the first object so that intersection with the second one is empty. This is done using a dedicated branch & prune approach. The study first show that the non-overlapping constraint can be cast into a Minkowski sum, even if we take into account orientation. We derive from this an inner contractor, that is, an operator that removes from the current domain a subset of positions and orientations that necessarily violate the non-overlapping constraint. This inner contractor is then embedded in a sweeping loop, a pruning technique that was only used with discrete domains so far. The study finally come up with a branch & prune algorithm that outperforms Rsolver, a generic state-of-the-art solver for continuous quantified constraints. Experiments are carried on for two complexes shapes: packing simple ellipsis and peanut shapes [5].

2.2 Handling Curve shapes with CMA-ES algorithms

The project aims to carry many studies for complex objects. Among them solving curve shapes. In this second study, in addition to packing problems for polygons, we consider continuous packing problems with curve shapes. In addition to the problem of packing circles in a rectangular, we consider packing problems mixing square and curve shapes, such as polygons and circles, and three dimensional packing problems mixing boxes, spheres and cylinders. On square packing problems, exact methods have been used to find optimal solutions and prove optimality. On curve packing problems, inexact methods like for instance genetic algorithms or hybrid simulated annealing with tabu search methods [2, 5], are usually used to compute suboptimal solutions. In this study, we evaluate the covariance matrix adaptation evolution strategy (CMA-ES2), one of the most powerful evolutionary algorithm for continuous optimization with arbitrary objective functions, on hard packing problems including square shapes, curve shapes, mixed square and curve shapes, and also continuous rotations.

In order to measure the overlaps between objects, we show that instead of taking the intersection area as overlap measure, other measures, monotonic with respect to the intersection area, can better guide the search. We define such monotonic measures for polygons and circles. In addition, we consider a real world application for loading boxes and cylinders in a container. On problems on which the optimal costs are known, we show that CMA-ES computes solutions at typically 14% of the optimal bin size in time comparable to the best dedicated algorithms for finding optimal solutions. On circle packing, we show that CMA-ES computes solutions at 2% of the best known algorithms in the same time limit. On our real-world application for loading a container with boxes and cylinders, CMA-ES computes valuable solutions in typically less than 15 minutes per run for 59 objects. These results show that solving packing problems by continuous optimization using monotonic overlap measures provides an interesting trade-off between generality and efficiency, and that CMA-ES in particular succeeds in computing quality packing solutions on very hard problems. Results are detailed in [4].

3. CONCLUSION

The work carried in the project is to evaluate several optimization algorithms to solve several bin packing problems encountered in logistics. Depending on the problem to solve some algorithms are more adequate than others. In some cases there is a need to combine them. In reality users' constraints are numerous and in some cases they are hard to model as constraints. Furthermore, because of the complexity of business requirements in industrial packing problems and in the handling of complex shapes, there is a need for using very high level modelling languages and to develop efficient search strategies, which are under development. The presented work is the result of the national and European research projects and particularly the NET-WMS2 project (French ANR).

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