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Max–min Bin Packing Algorithm and its application in nano-particles filling

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ABSTRACT

With regard to existing bin packing algorithms, higher packing efficiency often leads to lower packing speed while higher packing speed leads to lower packing efficiency. Packing speed and packing efficiency of existing bin packing algorithms including NFD, NF, FF, FFD, BF and BFD correlates negatively with each other, thus resulting in the failure of existing bin packing algorithms to satisfy the demand of nano-particles filling for both high speed and high efficiency. The paper provides a new bin packing algorithm, Max–min Bin Packing Algorithm (MM), which realizes both high packing speed and high packing efficiency. MM has the same packing speed as NFD (whose packing speed ranks no. 1 among existing bin packing algorithms); in case that the size repetition rate of objects to be packed is over 5, MM can realize almost the same packing efficiency as BFD (whose packing efficiency ranks No. 1 among existing bin packing algorithms), and in case that the size repetition rate of objects to be packed is over 500, MM can achieve exactly the same packing efficiency as BFD. With respect to application of nano-particles filling, the size repetition rate of nano particles to be packed is usually in thousands or ten thousands, far higher than 5 or 500. Consequently, in application of nano-particles filling, the packing efficiency of MM is exactly equal to that of BFD. Thus the irreconcilable conflict between packing speed and packing efficiency is successfully removed by MM, which leads to MM having better packing effect than any existing bin packing algorithm. In practice, there are few cases when the size repetition of objects to be packed is lower than 5. Therefore the MM is not necessarily limited to nano-particles filling, and can also be widely used in other applications besides nano-particles filling. Especially, MM has significant value in application of nano-particles filling such as nano printing and nano tooth filling.

1. Introduction

Nano-particles filling is widely applied [1–3]. For example, nano-particles filling is one of the most essential technologies of nano printer [4–6] and the process of nano printing is actually the process of nano-particles filling. The 3D printers based on DLP technology use ultraviolet LEDs or UV light to solidify nano materials (usually photosensitive resin). iBox Nano 3D printer is the existing smallest one, which can realize printing via Wi-Fi and web browser or Android or iOS device. HP and Canon prepare ink filled with nano dye for printing. The nano-particles filling technique developed by NaturalNano, a nano technology developer, serves to improve product performance packaging and construction materials. Relevant measures include prolonging service life of automobile tyre by filling with spherical rubber particles around 50 mm in diameter, applying nano materials to rhinoplasty and face lipofilling, and filling ABS/PP alloy composite with modified basic magnesium chloride (nano-BMC) whisker to realize better tensile strength and

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impact strength. The whole process of nano-particles filling can be controlled via computer or other device. Although such technology needs to be improved, its application represents the practical needs and is the prevailing trend. Nano-particles filling prominently differs from other types of objects filling in quantity. It is rare for other types of objects filling to involve thousands of objects and bins. Nano-composite involves the use of nanomaterials (NMs), which have external dimensions of less than 100 nanometres (nm). In ordinary cases nano-particles filling concerns quadrillions of nano particles (in correspondence to objects to be packed) and interstices(in *correspondence to bins*). Due to such enormous quantity, nano-particles filling is highly sensitive to packing speed. Among existing bin packing algorithms, the Next Fit algorithm (NF) has the highest speed and the time complexities of NF is $O(n)$, while Best Fit Deceasing algorithm (BFD) is the one with the slowest packing speed and the time complexities of BFD is $O(n\log n)$. The difference between them can be described by $O(n\log n)/O(n) = O(\log n)$, in which the base number of log is usually defined as 2. In application of such two algorithms to ordinary objects filling (maximum of quantity n of objects: usually about ten thousands), the speeds of the two algorithms would differ by at most 10 times, which is a huge yet acceptable difference; if such two algorithms be applied to nano-particles filling (minimum of quantity n of nano particles: usually about quadrillions), the speeds of the two algorithms would differ by at least 60 times. Thus it can be seen that nano-particles filling attaches especially great importance to packing speed.

For bin packing, in case of constant quantity of objects to be packed, higher packing efficiency means smaller quantity of required bins. For the nano-particles filling, in case of constant quantity of nano particles to be packed, higher packing efficiency means smaller quantity of required packing interstices, which would result in more compact packing, i.e. higher packing density. Although NF algorithm is much faster than BFD algorithm in speed, the packing efficiency of NF is far lower than that of BFD. In consequence, with respect to nano-particles filling, NF realizes a far lower packing density than BFD despite advantage in packing speed. Most cases of application of nano-particles filling, such as tooth filling with nano particles and carbon nano tubes filling with metal particles, require as high density of nano-particles filling as possible, and hence bin packing algorithm with as high packing efficiency as possible should be selected in application of nano-particles filling. However, with regard to existing bin packing algorithms, higher packing efficiency often leads to lower packing speed while higher packing speed leads to lower packing efficiency. Packing speed and packing efficiency of existing bin packing algorithms correlates negatively with each other, thus resulting in the failure of existing bin packing algorithms to satisfy the demand of nano-particles filling, which demands both fast speed and high efficiency.

The paper provides a new bin packing algorithm, Max–min Bin Packing Algorithm (MM), which realizes both high packing speed and high packing efficiency. MM has time complexity equal to the least time complexity among that of existing bin packing algorithms. The ranking of time complexity of MM and existing bin packing algorithms is MM=NFD=NF < FF=FFD=BF=BFD. The packing efficiency of MM is close to the highest packing efficiency among that of existing bin packing algorithms. The ranking of packing efficiency of MM and existing bin packing algorithms is BFD>=FFD>=MM > BF > FF > NFD > NF. It is worth mentioning that when a specific condition “the amount of objects to be packed was approximately 5 times more than the amount of different sizes of objects” (i.e. the size repetition rate of objects to be packed is over 5) is satisfied, the packing efficiency of MM is close to the highest packing efficiency among that of existing bin packing algorithms. With respect to application of nano-particles filling, there would always be a great number of nano particles in the same size, and thus such specific condition is always satisfied. In other words, the size repetition rate of nano particles to be packed is thousands or even ten thousands in general, far higher than 5 of course, and therefore such specific condition can be easily satisfied. Consequently, MM can fully bring its advantages into application of nano-particles filling. In application of nano-particles filling, the packing efficiency of MM equals to that of BFD bin packing algorithm, i.e. the highest packing efficiency among that of existing bin packing algorithms. Therefore, the MM can achieve both the highest packing speed and the highest packing efficiency. Thus the irreconcilable conflict between packing speed and packing efficiency is successfully removed by MM, which leads to MM having better packing effect than any existing bin packing algorithm.

Although MM has unique advantage in application of nano-particles filling, MM is not necessarily limited to nano-particles filling. Such unique advantage exists as well in filling objects with a size repetition rate higher than or equal to 5 where MM can realize both the highest packing speed and almost the highest packing efficiency. It can produce better packing effect than any existing bin packing algorithm because existing bin packing algorithm cannot realize both high packing efficiency and high packing speed. In existing bin packing algorithm, higher packing efficiency often leads to lower packing speed while higher packing speed leads to lower packing efficiency.

2. Existing bin packing algorithm

It is a common math problem in industrial production to put objects into bins. Bin packing is a classic combination optimization problem that is widely applied, even in daily life. Supposing there are lots of bins with the same load, $B_1, B_2, \ldots, B_n$, in a sufficient quantity for fulfilling a certain purpose. Load (such as length or weight or size) of each bin is d. There are n objects $J_1, J_2, \ldots, J_n$ and J_i with load Si (0 < Si < C , $i = 1, 2, \ldots, n$) to be packed. Bin packing means seeking for a method that putting $J_1, J_2, \ldots, J_n$ into the smallest quantity of bins. The bin packing problem is an NP problem, which means that an exact solution cannot be found within polynomial time. In general approximation algorithm, i.e. heuristic algorithm, would be adopted, for rapid acquisition of a satisfactory solution instead of an optimal solution. Existing packing algorithms include NF (Next Fit algorithm), FF (First Fit algorithm) , FFD (First Fit Decreasing algorithm) , BF (Best Fit algorithm) and BFD (Best Fit Deceasing algorithm).