

# Pack Allocation Algorithms

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## 1 Description of Problem

Allocate the number of bakery products  $m$  to a finite types of packs with sizes (number of units)  $V_i$  for  $i = 1, 2, \dots, n$ . The allocation result can be described as  $a_i$  for  $i = 1, 2, \dots, n$ , which means the required number of pack  $i$  is  $a_i$ . An optimal solution is to minimize total number of required packs

$$B = \sum_{i=1}^n a_i,$$

subject to

- $v_i > 0$  is a positive integer
- $a_i \geq 0$  is a non-negative integer
- all products are allocated to packs:  $\sum_{i=1}^n a_i V_i = m$ , where  $m$  is the quantity of products to be allocated

The total price of the products can be calculated as

$$P = \sum_{i=1}^n p_i a_i,$$

where  $p_i$  is the price of pack  $i$ .

## 2 Algorithms

This allocation problem is NP-hard. An exhaustive search would be computationally expensive. I have therefore proposed a first-fit greedy approximation algorithm, which is verified with the exhaustive algorithm.

### 2.1 Greedy Heuristic

This greedy heuristic always try to allocate the items to the largest possible pack. If this is a reminder, try to allocate the reminder to the next smaller pack until the smallest. If it is still not allocable, remove one large pack and add the items  $V_i$  to the reminder and try again above allocation process. The greedy algorithm is implemented in a recursive manner:

1. Sort the packs by their sizes, so that  $V_0 > V_1 > \dots > V_n$ .
2. Start from the largest pack  $i = 0$ . Let the reminder  $r$  equals  $m$
3. Divide  $r$  by  $V_i$ , let  $a_i$  is the quotient and  $r$  is the reminder

Table 1: Example test cases

product code	quantity ( $m$ )	pack sizes ( $v_i$ )	allocation ( $a_i$ )	test result
VS5	10	[5, 3]	[2, 0]	pass
MB11	14	[8, 5, 2]	[1, 0, 3]	pass
CF	13	[9, 5, 3]	[0, 2, 1]	pass

4. If  $r = 0$ , return the allocation result
5. If  $r > 0$ , try next smaller pack  $i = i + 1$ , go to Step 3
6. If still not divisible and  $a_i > 0$  remove 1 current pack and add items to  $r$  and repeat Step 3 - 6 until  $a_i = 0$
7. If still  $r > 0$  at the end. The products are not allocable by these packs.

## 2.2 Exhaustive Search

The exhaustive algorithm is also implemented in a recursive manner. For all  $i = 1, 2, \dots, n$ , try  $a_i = 0, 1, \dots, \text{remainder}[r/V_i]$ . At the end of each step, subtract allocated items from the remainder  $r$ , this reduces the upper bound for next loop.

## 3 Validation and Test

### 3.1 Example Test Cases

The greedy heuristic is tested against the test cases from the specification. See Table 3.1 for the test cases.

### 3.2 Verification

The completeness the greedy heuristic is validated with the exhaustive algorithm. Two criteria are tested for  $m$  in 1, 2, ...100.

- If the exhaustive finds at least a solution, the greedy heuristic also finds one.
- If the greedy heuristic does not find a solution, no solution can be found by exhaustive search.

Specially, under configuration in Table 3.1. I have also verified that the greedy heuristic is able to find the optimal solution.

## 4 Performance

### 4.1 Accuracy

The greedy method is a heuristic, it allocates the products to packs from large to small and return the allocation results immediately if it has found one. For example, These are two optimal allocation methods for MB11 under configuration [8, 5, 2], which are [1, 0, 3] and [0, 2, 2]. The greedy method is able to find the first one.

Under more complex pack configuration, the greedy method may not give the best solution. for example, If  $V = [6, 5, 2]$  and  $m = 10$ . The heuristic gives [1, 0, 2]. The exhaustive search can find the optimal allocation [0, 2, 0]. However, it has been tested that under current pack configuration, the greedy heuristic is able to find one of the optimal allocation solutions.

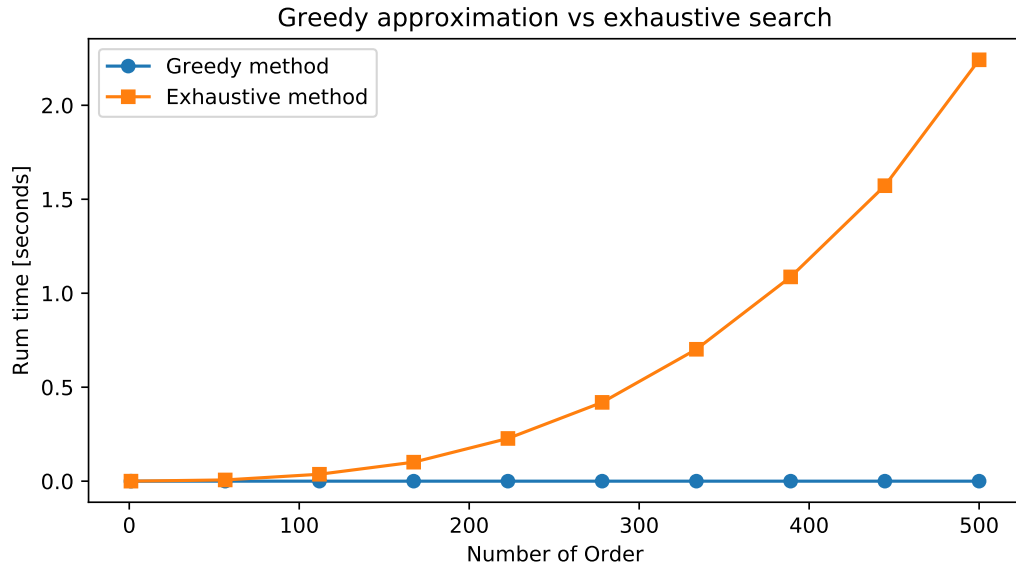


Figure 1: The speed performance of the greedy approximation and the exhaustive search

## 4.2 Time complexity

The run time of the exhaustive algorithm increases almost exponentially with the order quantity. When  $m = 1000$ , it requires  $\sim 36s$  to complete the run using my machine, which is inapplicable and the greedy approximation heuristic becomes a must. In the simple pack configuration, the time complexity of the greedy heuristic is  $\sim O(1)$ .