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A further addendum to “Some thoughts
on the 2-approximation algorithm for
knapsack problems: A survey”

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A further addendum to “Some thoughts on the 2-approximation algorithm for knapsack problems: A survey”

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Abstract

We herein add a knapsack problem that has a 2-approximation algorithm similar to the conventional one for the 0-1 knapsack problem, and also add a tiny thing as to the unbounded knapsack problem. Further we point out a case in which the conventional is useful.

keywords: combinatorial optimization, knapsack problem, 2-approximation algorithm, greedy

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Given an item $j \in N := \{1, 2, \dots, n\}$ of profit p_j and weight w_j , both of which are positive integers, we pack the items into a knapsack of capacity c so that the total profit of packed items is maximized. The classical 0-1 knapsack problem (KP) could be formulated as $z^* := \max_{S \subseteq N} \{\sum_{j \in S} p_j \mid \sum_{j \in S} w_j \leq c\}$. We call the z^* maximized *optimal value*. In addition we call a subset of N solution, albeit a little bit unusual, and also call $\sum_{j \in S} p_j$ (resp. $\sum_{j \in S} w_j$) the profit (resp. weight) of S . Namely, a solution represents items packed in the knapsack. Furthermore we assume $w_j \leq c$ in order for an item being of use.

To our knowledge the simplest 2-approximation algorithm for KP will act as follows: after sorting all items in nonascending order of efficiency p_j/w_j we set $s := \min\{k \mid \sum_{j=1}^k w_j > c\}$ ¹ and choose the

better between $\{1, 2, \dots, s-1\}$ and $\{s\}$ (see, e.g., Korte and Vygen [6, p. 462]). In what follows we call this a conventional 2-approximation algorithm for KP, or the conventional for short.

In [2] we not tricked but treated 14 types of knapsack problem in relation to the conventional for KP. Besides the three dealt with in [3] namely SKP, MKP and MSSP, we would here like to add one more knapsack problem that also relates to the conventional. The k -item knapsack problem (k KP) is a variant of KP, in which we cannot pack over $k (\leq n)$ items. Caprara et al [1] proposed a PTAS for the k KP, and their PTAS involves a 2-approximation algorithm for k KP, named $H^{1/2}$. The algorithm is similar to the conventional for KP; but, it copes with at most two fractional items given by an LP solution—admitting a fractional (non-whole) item—of k KP whereas KP includes at most one fractional item in its LP solution (the fractional item is, if any, s introduced previously and part of it contributing to the LP solution is $(c - \sum_{j=1}^{s-1} w_j)/w_s$ less than 1 (i.e., not the whole) because of $\sum_{j=1}^s w_j > c$). In a case of the number of fractional items being one or less, indeed, a solution produced by $H^{1/2}$ is constructed in the same manner as the conventional (in a case of no fractional item, especially, we can suppose the conventional returns optimal $\{1, 2, \dots, s-1\}$ exactly like $H^{1/2}$). In passing in the same paper, Caprara et al [1] proposed a PTAS for KP too, which involves the conventional for KP (p. 338).

On the other hand, I said in [2] that when we

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¹The ‘s’ is for split (item). In some papers ‘b’ is used instead, which is for break.

apply the conventional to the unbounded knapsack problem (UKP), in which every item is available unboundedly, we shall take account of two candidates such that $\{1\}$ and $\{1, 1, \dots, 1\}$ of cardinality $\lfloor c/w_1 \rfloor (\geq 1)$ where item 1 is of the highest efficiency; nonetheless, needless to say $\{1\} \subseteq \{1, 1, \dots, 1\}$, and it allows us to discard $\{1\}$ and take $\{1, 1, \dots, 1\}$ only into account.

In connection with the conventional for KP, Ext-Greedy involved in $G^{3/4}$ can be replaced with the conventional. Ext-Greedy [5, p. 34] is another 2-approximation algorithm for KP, selecting the better between a solution by greedy algorithm—After sorting all items in nonascending order of efficiency too, we get a greedy solution by packing items as many as possible within c , see [5, Fig. 2.1 (p. 16)]—and $\{\ell\}$ where $\ell := \arg \max_{j \in N} p_j$. Although Ext-Greedy is the second one amongst the three mentioned in [3], as already stated in [3] a solution by Ext-Greedy cannot be worse than that of the conventional, because the greedy solution may find item $j' (> s)$ of $\sum_{j=1}^{s-1} w_j + w_{j'} \leq c$ in addition to $\{1, 2, \dots, s-1\}$ and $p_\ell = \max_{j \in N} p_j \geq p_s$, so Ext-Greedy's solution's profit is $\lceil z^*/2 \rceil$ or more, too. Also, $G^{3/4}$ is a 4/3-approximation algorithm for KP—in time proportional to the polynomial of n , it returns profit not less than $\lceil 3z^*/4 \rceil$ given by a solution whose weight is within c —presented by Kellerer et al [5, Fig. 2.10 (p. 35)]. Roughly speaking $G^{3/4}$ behaves as follows: packing a pair of items $\{i, k\}$, $G^{3/4}$ applies Ext-Greedy to $S (\subseteq N)$ determined according to the $\{i, k\}$ already packed (described later). $G^{3/4}$ investigates all pairs and returns maximum profit amongst all, which shall be referred to as z^A afterward.

In actual fact, in the proof of Theorem 2.5.5, $p_{i^*} + p_{k^*} \geq z^*/2$ of Case I is equivalent to $z_S^* \leq z^*/2$, provided $z^* = p_{i^*} + p_{k^*} + z_S^*$ where p_{i^*} and p_{k^*} indicate the highest and the second highest profit in the pieces of z^* and z_S^* indicates the optimal value of KP restricted to $S := \{j \mid p_j \leq \min\{p_{i^*}, p_{k^*}\}\} \setminus \{i^*, k^*\}$. Let z_S^G be profit obtained by applying the conven-

tional to S . Then,

$$\begin{aligned} z^A &\geq p_{i^*} + p_{k^*} + z_S^G \\ &= z^* - z_S^* + z_S^G \geq z^* - \frac{z_S^*}{2} \geq \frac{3z^*}{4}. \end{aligned}$$

In the light of $G^{3/4}$ investigating all pair of items, the first inequality is clear. In Case II ($p_{i^*} + p_{k^*} < z^*/2$), since $\sum_{j=1}^s p_j$ that appears whilst applying the conventional to S is beyond z_S^* , we have

$$\begin{aligned} z^* &= p_{i^*} + p_{k^*} + z_S^* \\ &< p_{i^*} + p_{k^*} + \sum_{j=1}^{s-1} p_j + p_s \\ &= p_{i^*} + p_{k^*} + z_S^G + p_s < z^A + \frac{z^*}{4}. \end{aligned}$$

As in the proof of Theorem 2.5.5, $p_{i^*} + p_{k^*} < z^*/2$ of Case II leads to an item in S being of profit $< z^*/4$; thus, $p_s < z^*/4$ follows. As for $z_S^G = \sum_{j=1}^{s-1} p_j$, if $z_S^G = p_s$ then it's a contradiction that $2z_S^G = 2p_s < z^*/2 < z_S^*$. Moreover, even if $\sum_{j \in S} w_j + w_{i^*} + w_{k^*} \leq c$, it follows that $z^A = z^*$ due to $z_S^G = z_S^*$.

Although the conventional can stop at just exceeding c at once, Ext-Greedy ends after examining whether the last item n of the lowest efficiency fits into remaining capacity or not, and further it shall provide $\max_{j \in N} p_j$. If we merely require profit equal to $\lceil 3z^*/4 \rceil$ or more then employing the conventional instead will make $G^{3/4}$ easier to be implemented.² The statement on $G^{3/4}$ above can be seen in [4] in Japanese.

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²Incidentally, the conventional works in $O(n)$ time—that is, we needn't order items. For further details, see, for instance, Korte and Vygen [6, Section 17.1].

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