

High Average-Utility Itemset Sampling under Length Constraints

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Abstract. This supplementary document presents a first the proofs which were stated in the article titled “High Average-utility Itemset Sampling under Length Constraints”. Then, it ends with additional experimental results.

1 Recalls

Definition 1 (Occurrence of a pattern). Let φ be a pattern defined on a language \mathcal{L} of a database \mathcal{D} . If it exist a transaction t_j of \mathcal{D} such that $\varphi \subseteq t_j$, then φ_j is an occurrence of the pattern φ in the transaction t_j . The utility of the pattern φ in the transaction t_j , denoted by $\mathbf{uOcc}(\varphi, t_j)$, is equal to 0 if $\varphi \not\subseteq t_j$ or $\varphi = \emptyset$, else $\mathbf{uOcc}(\varphi, t_j) = \sum_{e \in \varphi} (q(e, t_j) \times p(e))$.

There are also utilities that are independent of any database such as length-based utilities. In the following, we consider the length-based utility defined by $\mathbf{uLen}_{[m..M]} = 1/|\varphi|$ if $|\varphi| \in [m..M]$ and 0 otherwise. Thus, a pattern whose length is larger than M or smaller than m will be deemed useless.

Definition 2 (Average-Utility of a pattern under length constraints). Let \mathcal{D} be a database, \mathcal{L} its language, m and M two integers such that $m \leq M$. The average-utility of the pattern $\varphi \in \mathcal{L}$ in \mathcal{D} under minimum m and maximum M length constraints, denoted by $u_{[m..M]}^{avg}(\varphi, \mathcal{D})$, is the product of the sum of utilities of its occurrences and its length-based utility. Formally, $u_{[m..M]}^{avg}(\varphi, \mathcal{D}) = (\sum_{(j,t) \in \mathcal{D} \wedge \varphi \subseteq t} \mathbf{uOcc}(\varphi, t)) \times \mathbf{uLen}_{[m..M]}(\varphi)$.

It is important to note that $u_{[m..M]}^{avg}$ is not a length-based utility.

2 Proofs of the theoretical results

Property 1 (Item weights $\omega_\ell^\bullet(t[i], t)$). The weight $\omega_\ell^+(t[i], t)$ is the sum of the utilities of the occurrences of length $\ell - 1$ in the transaction $t^i = t[i + 1] \cdots t[n]$ to which we add the item $t[i]$. Formally, for all $\ell \in [m..M]$ one has:¹

$$\omega_\ell^+(t[i], t) = \sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell - 1} \mathbf{uOcc}(\{t[i]\} \cup \varphi, t) = \omega_1(t[i], t) \times \binom{\ell - 1}{|t^i|} + \sum_{\star \in \{+, -\}} \omega_{\ell - 1}^\star(t[i + 1], t)$$

¹ by convention $\binom{k}{n} = 0$ if $k > n$ and 1 if $k = 0$

$$\omega_{\ell}^{-}(t[i], t) = \sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell} \text{u0cc}(\varphi, t) = \sum_{* \in \{+, -\}} \omega_{\ell}^{*}(t[i+1], t)$$

with $\omega_1^{+}(t[i], t) = \text{u0cc}(t[i], t)$ for all $i \in [1..|t|]$ and $\omega_{\ell}^{*}(t[i], t) = 0$ for all $i > |t|$.

Proof (Property 1). Let's start by showing that $\omega_{\ell}^{-}(t[i], t) = \sum_{* \in \{+, -\}} \omega_{\ell}^{*}(t[i+1], t)$. By definition, $\omega_{\ell}^{-}(t[i], t)$ is the sum of the utilities of the set of patterns of length ℓ in t^i , $\omega_{\ell}^{-}(t[i], t) = \sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell} \text{u0cc}(\varphi, t)$. This set can be split into two parts: the one that contains the patterns starting with the item $t[i+1]$ whose sum of their utilities is equal to $\omega_{\ell}^{+}(t[i+1], t)$ by definition, and the one that contains the patterns not starting with $t[i+1]$ and whose sum of their utilities is equal to $\omega_{\ell}^{-}(t[i+1], t)$. That implies that $\sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell} \text{u0cc}(\varphi, t) = \omega_{\ell}^{+}(t[i+1], t) + \omega_{\ell}^{-}(t[i+1], t) = \sum_{* \in \{+, -\}} \omega_{\ell}^{*}(t[i+1], t)$. (1)

Let's now show that $\omega_{\ell}^{+}(t[i], t) = \omega_1(t[i], t) \times \binom{\ell-1}{|t[i]|} + \sum_{* \in \{+, -\}} \omega_{\ell-1}^{*}(t[i+1], t)$. We know by definition that $\omega_{\ell}^{+}(t[i], t)$ is the sum of the utilities of itemsets of length ℓ in t^i which start with $t[i]$ following the total order relation $>_{\mathcal{I}}$. Formally, we have: $\omega_{\ell}^{+}(t[i], t) = \sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell-1} \text{u0cc}(\{t[i]\} \cup \varphi, t)$. But $\text{u0cc}(\{t[i]\} \cup \varphi, t) = \text{u0cc}(\{t[i]\}, t) + \text{u0cc}(\varphi, t)$ by definition. Then, $\omega_{\ell}^{+}(t[i], t) = \sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell-1} (\text{u0cc}(\{t[i]\}, t) + \text{u0cc}(\varphi, t))$. Which implies: $\omega_{\ell}^{+}(t[i], t) = \sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell-1} \text{u0cc}(\{t[i]\}, t) + \sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell-1} \text{u0cc}(\varphi, t)$. However, we know on the one hand that $\sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell-1} \text{u0cc}(\{t[i]\}, t) = \text{u0cc}(\{t[i]\}, t) \times \binom{\ell-1}{|t[i]|}$ and that by definition $\text{u0cc}(\{t[i]\}, t) = \omega_1^{+}(t[i], t)$, so $\sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell-1} \text{u0cc}(\{t[i]\}, t) = \omega_1^{+}(t[i], t) \times \binom{\ell-1}{|t[i]|}$. On the other hand, $\sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell-1} \text{u0cc}(\varphi, t)$ is the sum of the utilities of the set patterns of length $\ell-1$ in the transaction t^i . From (1), we can also say that $\sum_{\varphi \subseteq t^i \wedge |\varphi| = \ell-1} \text{u0cc}(\varphi, t) = \sum_{* \in \{+, -\}} \omega_{\ell-1}^{*}(t[i+1], t)$. D'où, on a: $\omega_{\ell}^{+}(t[i], t) = \omega_1(t[i], t) \times \binom{\ell-1}{|t[i]|} + \sum_{* \in \{+, -\}} \omega_{\ell-1}^{*}(t[i+1], t)$. Hence the result. \square

Property 2 (Transaction weight). The weight of a transaction t under minimum m and maximum M length constraints, denoted by $\omega_{[m..M]}^{avgU}(t)$, is the sum of the average-utilities of the occurrences it contains. Formally,

$$\omega_{[m..M]}^{avgU}(t) = \sum_{\ell=m}^M \left(\frac{1}{\ell} \sum_{i=1}^{|t|} \omega_{\ell}^{+}(t[i], t) \right) = \sum_{\ell=m}^M \frac{1}{\ell} (\omega_{\ell}^{+}(t[1], t) + \omega_{\ell}^{-}(t[1], t)).$$

Proof (Property 2). By definition, the weight of the transaction t is the sum of the average-utilities of the pattern occurrences it contains. According to Property 1, the weight of the transaction t under the minimum m and maximum M length constraints is nothing more than the sum of the sum of the average-utilities of pattern occurrences that start with the item $t[1]$ and respect the imposed length constraints, $\sum_{\ell=m}^M (\frac{1}{\ell} \times \omega_{\ell}^{+}(t[1], t))$, and that of the patterns that do not start

with the item $t[1]$ but respect the length constraints, $\sum_{\ell=m}^M (\frac{1}{\ell} \times \omega_{\ell}^{-}(t[1], t))$. However, we know that $\sum_{\ell=m}^M (\frac{1}{\ell} \times \omega_{\ell}^{+}(t[1], t)) + \sum_{\ell=m}^M (\frac{1}{\ell} \times \omega_{\ell}^{-}(t[1], t)) = \sum_m^M \frac{1}{\ell} \times (\omega_{\ell}^{+}(t[1], t) + \omega_{\ell}^{-}(t[1], t))$. Hence the result. \square

Lemma 1. Let ℓ be the length of the itemset to output, $\mathbb{P}_{\ell}^t(t[i]|\varphi, \ell')$ the probability to draw item $t[i]$ in the transaction t after drawing $\ell - \ell'$ items and storing them in φ , with $e >_{\mathcal{I}} t[i]$ for all $e \in \varphi$. The probability to draw the $t[i]$ knowing φ and ℓ' can be formulated as follows:

$$\mathbb{P}_{\ell}^t(t[i]|\varphi, \ell') = \frac{\sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} \mathbf{u0cc}(\varphi \cup \{t[i]\} \cup \varphi', t)}{\sum_{\varphi' \subseteq t^{i-1} \wedge |\varphi'| = \ell'} \mathbf{u0cc}(\varphi \cup \varphi', t)}.$$

Proof (Lemma 1). By definition, the probability to draw the item $t[i]$ of the transaction t after having drawing on it $\ell - \ell'$ items and store them in φ is nothing but the probability of drawing a pattern that begins with $\varphi \cup \{t[i]\}$, according to the order relation $>_{\mathcal{I}}$, among the set of patterns that start with φ . On the one hand, we know that the set of patterns of length ℓ that start with $\varphi \cup t[i]$ is defined by $\{\varphi'' \subseteq t : (\varphi'' = \varphi \cup \{t[i]\} \cup \varphi')(\varphi' \subseteq t^i)(|\varphi'| = \ell' - 1)\}$. The sum of the utilities of the patterns of this set is equal to $\sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} \mathbf{u0cc}(\varphi \cup \{t[i]\} \cup \varphi', t)$. On the other hand, we know that the set of patterns of length ℓ that start with φ is defined by $\{\varphi'' \subseteq t : (\varphi'' = \varphi \cup \varphi')(\varphi' \subseteq t^{i-1})(|\varphi'| = \ell')\}$. The sum of the utilities of the patterns of this set is equal to $\sum_{\varphi' \subseteq t^{i-1} \wedge |\varphi'| = \ell'} \mathbf{u0cc}(\varphi \cup \varphi', t)$. So $\mathbb{P}_{\ell}^t(t[i]|\varphi, \ell') = \frac{\sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} \mathbf{u0cc}(\varphi \cup \{t[i]\} \cup \varphi', t)}{\sum_{\varphi' \subseteq t^{i-1} \wedge |\varphi'| = \ell'} \mathbf{u0cc}(\varphi \cup \varphi', t)}$. Hence the result. \square

Property 3. The probability to draw the item $t[i]$ in the transaction t knowing the itemset φ and the length ℓ' , with $|\varphi| = \ell - \ell'$, denoted by $\mathbb{P}_{\ell}^t(t[i]|\varphi, \ell')$, is given by the following formula:

$$\mathbb{P}_{\ell}^t(t[i]|\varphi, \ell') = \frac{\left(\sum_{k < i \wedge t[k] \in \varphi} \omega_1(t[k], t) \right) \times \binom{\ell' - 1}{|t[i]|} + \omega_{\ell'}^{+}(t[i], t)}{\left(\sum_{k < i \wedge t[k] \in \varphi} \omega_1(t[k], t) \right) \times \binom{\ell'}{|t[i]|} + \left(\sum_{* \in \{+, -\}} \omega_{\ell'}^{*}(t[i], t) \right)}.$$

The probability that the item $t[i]$ is not drawn knowing φ and ℓ' is $1 - \mathbb{P}_{\ell}^t(t[i]|\varphi, \ell')$.

The proofs of these two formulas follow from the fact that the probability of drawing $t[i]$ depends on the utilities of the items already drawn and those of the items which follow it to form a pattern of length ℓ .

Proof (Property 3). From the lemma 1, we have:

$$\mathbb{P}_{\ell}^t(t[i]|\varphi, \ell') = \frac{\sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} \mathbf{u0cc}(\varphi \cup \{t[i]\} \cup \varphi', t)}{\sum_{\varphi' \subseteq t^{i-1} \wedge |\varphi'| = \ell'} \mathbf{u0cc}(\varphi \cup \varphi', t)}.$$

First, by definition we have $\mathbf{u0cc}(\varphi \cup \{t[i]\} \cup \varphi', t) = \mathbf{u0cc}(\varphi, t) + \mathbf{u0cc}(\{t[i]\} \cup \varphi', t)$. Let $z_i = \sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} \mathbf{u0cc}(\varphi \cup \{t[i]\} \cup \varphi', t)$. That implies that $z_i = \sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} (\mathbf{u0cc}(\varphi, t) + \mathbf{u0cc}(\{t[i]\} \cup \varphi', t))$. We then have:
 $z_i = \sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} \mathbf{u0cc}(\varphi, t) + \sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} \mathbf{u0cc}(\{t[i]\} \cup \varphi', t)$. But

$\sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} \text{u0cc}(\varphi, t) = \text{u0cc}(\varphi, t) \times \binom{\ell' - 1}{|t^i|}$ and $\sum_{\varphi' \subseteq t^i \wedge |\varphi'| = \ell' - 1} \text{u0cc}(\{t[i]\} \cup \varphi', t) = \omega_{\ell'}^+(t[i], t)$ by definition. Then $z_i = \text{u0cc}(\varphi, t) \times \binom{\ell' - 1}{|t^i|} + \omega_{\ell'}^+(t[i], t)$. We also know that $\text{u0cc}(\varphi, t) = \sum_{k < i \wedge t[k] \in \varphi} \omega_1(t[k], t)$. So we have : $z_i = \left(\sum_{k < i \wedge t[k] \in \varphi} \omega_1(t[k], t) \right) \times \binom{\ell' - 1}{|t^i|} + \omega_{\ell'}^+(t[i], t)$.

Second, we have $\text{u0cc}(\varphi \cup \varphi', t) = \text{u0cc}(\varphi, t) + \text{u0cc}(\varphi', t)$. By setting $Z_i = \sum_{\varphi' \subseteq t^{i-1} \wedge |\varphi'| = \ell'} \text{u0cc}(\varphi \cup \varphi', t)$, we get then $Z_i = \sum_{\varphi' \subseteq t^{i-1} \wedge |\varphi'| = \ell'} \text{u0cc}(\varphi, t) + \sum_{\varphi' \subseteq t^{i-1} \wedge |\varphi'| = \ell'} \text{u0cc}(\varphi', t)$. But $\sum_{\varphi' \subseteq t^{i-1} \wedge |\varphi'| = \ell'} \text{u0cc}(\varphi, t) = \text{u0cc}(\varphi, t) \times \binom{\ell'}{|t^{i-1}|} = \left(\sum_{k < i \wedge t[k] \in \varphi} \omega_1(t[k], t) \right) \times \binom{\ell'}{|t^{i-1}|}$ et $\sum_{\varphi' \subseteq t^{i-1} \wedge |\varphi'| = \ell'} \text{u0cc}(\varphi', t) = \sum_{\star \in \{+, -\}} \omega_{\ell'}^{\star}(t[i], t)$, so $Z_i = \left(\sum_{k < i \wedge t[k] \in \varphi} \omega_1(t[k], t) \right) \times \binom{\ell'}{|t^{i-1}|} + \sum_{\star \in \{+, -\}} \omega_{\ell'}^{\star}(t[i], t)$.

Finally, $\mathbb{P}_{\ell}^t(t[i]|\varphi, \ell') = \frac{z_i}{Z_i} = \frac{(\sum_{k < i \wedge t[k] \in \varphi} \omega_1(t[k], t)) \times \binom{\ell' - 1}{|t^i|} + \omega_{\ell'}^+(t[i], t)}{(\sum_{k < i \wedge t[k] \in \varphi} \omega_1(t[k], t)) \times \binom{\ell'}{|t^{i-1}|} + \sum_{\star \in \{+, -\}} \omega_{\ell'}^{\star}(t[i], t)}$. \square

Property 4 (Correctness). Let \mathcal{D} be a transactional database having utilities on items with a total order relation $>_{\mathcal{I}}$, and m and M two integers such that $m \leq M$. HAISAMPLER randomly draws a pattern φ from the language $\mathcal{L}(\mathcal{D})$ with a probability equal to $u_{[m..M]}^{avg}(\varphi, \mathcal{D})/Z$ where Z is the constant of normalization.

Proof (Property 4). Let m be the minimum and M the maximum length constraints, the probability of drawing the pattern φ of length ℓ in the database \mathcal{D} denoted by $\mathbb{P}_{[m..M]}(\varphi, \mathcal{D})$, and Z a normalization constant defined by $Z = \sum_{\varphi' \in \mathcal{L}(\mathcal{D})} u_{[m..M]}^{avg}(\varphi', \mathcal{D})$. We know that : $\mathbb{P}_{[m..M]}(\varphi, \mathcal{D}) = \sum_{(j,t) \in \mathcal{D}} (\mathbb{P}_{[m..M]}(t_j, \mathcal{D}) \times \mathbb{P}_{[m..M]}(\varphi, t_j))$. But $\mathbb{P}_{[m..M]}(t_j, \mathcal{D}) = \frac{\omega_{[m..M]}^{avgU}(t_j)}{Z}$, then

$$\mathbb{P}_{[m..M]}(\varphi, \mathcal{D}) = \sum_{(j,t) \in \mathcal{D}} \left(\frac{\omega_{[m..M]}^{avgU}(t_j)}{Z} \times \mathbb{P}_{[m..M]}(\varphi, t_j) \right). \quad (1)$$

We also know that: $\mathbb{P}_{[m..M]}(\varphi, t_j) = \mathbb{P}_{[m..M]}(\ell|t_j) \times \mathbb{P}_{[m..M]}^{t_j}(\varphi|\ell)$. (2)

But we have: $\mathbb{P}_{[m..M]}(\ell|t_j) = \frac{\omega_{[\ell..M]}^{avgU}(t_j)}{\omega_{[m..M]}^{avgU}(t_j)}$ and $\mathbb{P}_{[m..M]}^{t_j}(\varphi|\ell) = \frac{\text{u0cc}(\varphi, t_j)}{\omega_{[\ell..M]}^{avgU}(t_j) \times \ell}$ then

by substituting the two terms in (2) we obtain $\mathbb{P}_{[m..M]}(\varphi, t_j) = \frac{\omega_{[\ell..M]}^{avgU}(t_j)}{\omega_{[m..M]}^{avgU}(t_j)} \times \frac{\text{u0cc}(\varphi, t_j)}{\omega_{[\ell..M]}^{avgU}(t_j) \times \ell} = \frac{\text{u0cc}(\varphi, t_j)}{\omega_{[m..M]}^{avgU}(t_j) \times \ell}$.

$$\frac{\text{u0cc}(\varphi, t_j)}{\omega_{[m..M]}^{avgU}(t_j) \times \ell} = \frac{\text{u0cc}(\varphi, t_j)}{\omega_{[m..M]}^{avgU}(t_j) \times \ell}.$$

Now, if we replace $\mathbb{P}_{[m..M]}(\varphi, t_j)$ in (1) by its last expression, we get:

$$\mathbb{P}_{[m..M]}(\varphi, \mathcal{D}) = \sum_{(j,t) \in \mathcal{D}} \left(\frac{\omega_{[m..M]}^{avgU}(t_j)}{Z} \times \frac{\text{u0cc}(\varphi, t_j)}{\omega_{[m..M]}^{avgU}(t_j) \times \ell} \right) = \frac{1}{Z} \times \sum_{(j,t) \in \mathcal{D}} \frac{\text{u0cc}(\varphi, t_j)}{\ell}.$$

But by definition, we have $\frac{\sum_{(j,t) \in \mathcal{D}} \text{u0cc}(\varphi, t_j)}{\ell} = u_{[m..M]}^{avg}(\varphi, \mathcal{D})$, so $\mathbb{P}_{[m..M]}(\varphi, \mathcal{D}) = \frac{u_{[m..M]}^{avg}(\varphi, \mathcal{D})}{Z}$. Hence the result. \square

3 Additional experiments

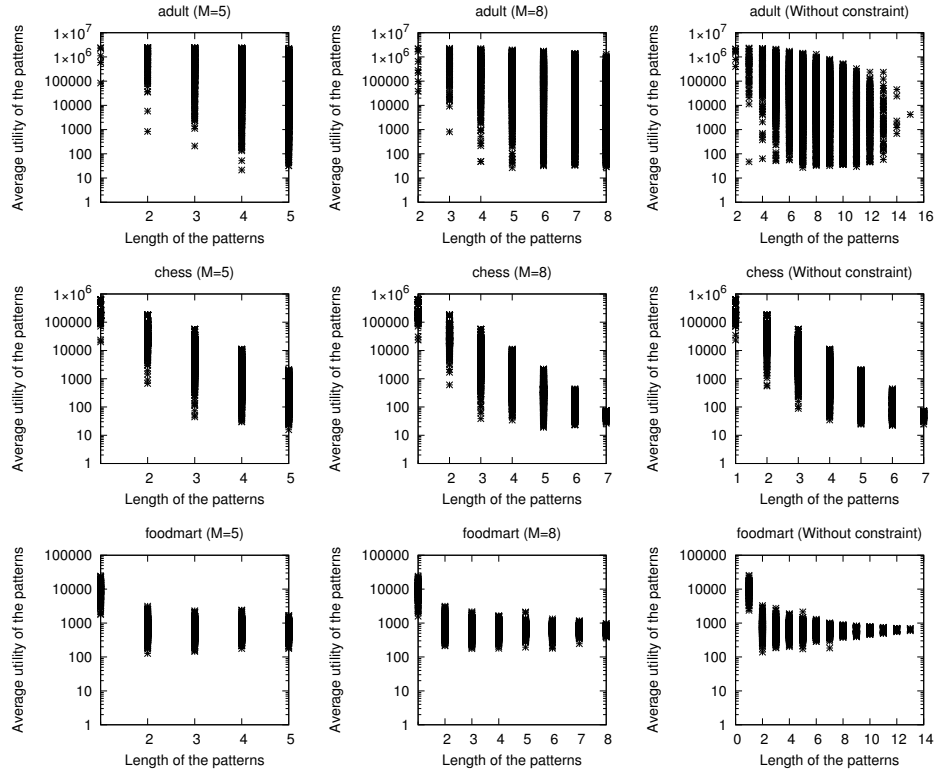


Fig. 1. Dispersion of average utilities of 10,000 sampled patterns