Overview

- Combine a utility and cost model to mine cost-effective guidance patterns in E-learning event logs.
- Design measures to evaluate the correlation between patterns and the binary utility.
- Design a pruning strategy to improve algorithm’s performance.
- A case study in real life E-learning dataset shows some interesting pattern.
- Detailed experiments and the visualization patterns’ properties demonstrate our models’ accuracy and usefulness.

High-utility sequential pattern mining

Input

Quantitative sequences with purchase quantities (internal utility)
sequence 1: $\langle(a, 3), (b, 3), (c, 1), (b, 4)\rangle$
sequence 2: $\langle(a, 1), (e, 3)\rangle$
sequence 3: $\langle(a, 6), (c, 7), (b, 8), (d, 9)\rangle$
sequence 4: $\langle(b, 3), (c, 1)\rangle$
Unit profits (external utility)
$a = 5\$,\ b = 1\$,\ c = 2\$,\ d = 1\$$

a minimum utility threshold ***(e.g. minutil = 30)***

Output

All **sequences** having a $\boldsymbol{utility \geq minutil}$)

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sequence 1: $\langle \boxed{(a,3),(b,3)}, (c,1), (b,4)\rangle$
sequence 2: $\langle (a,1), (e,3)\rangle$
sequence 3: $\langle \boxed{(a,6)}, (c,7), \boxed{(b,8)}, (d,9)\rangle$
sequence 4: $\langle (b,3), (c,1)\rangle$
Unit profits (external utility)
$\boxed{a = 5\$}\ \boxed{b = 1\$,}\ c = 2\$,\ d = 1\$$

a minimum utility threshold ***(e.g. minutil = 30)***

Output

All **sequences** having a $utility \geq minutil$)

The **sequence** <ab> **is a high utility pattern because:**

$$u(<ab>) = \underbrace{3\times5+3\times1}_{\text{Sequence 1}} + \underbrace{6\times5+8\times1}_{\text{Sequence 3}} = 56 > minutil$$

Limitations

- **High utility pattern mining** aims at discovering patterns that have a high utility.
- But it ignores the cost or effort required to obtain these benefits.
- May find patterns that have:
  - **a high utility but a very high cost**
- **Cost of a pattern:** *time*, *money*, *resources consumed* or *effort*.

Our proposal: Find Cost-effective Patterns →

Sequential Activity Database

- A **sequence** is a series of activities, each having a cost.
- The **utility** of a sequence is a binary class.

Sid	<Activity : cost>	Utility
S_1	<(a:4)(b:2)(e:4)(c:4)(d:5)>	Positive
S_2	<(b:3)(c:2)(f:1)(d:1)(e:2)>	Negative
S_3	<(a:2)(f:2)(e:1)(c:3)(d:5)>	Positive
S_4	<(a:2)(b:2)(c:1)(f:2)>	Negative

(e.g. cured or died after some medical treatments)

Two problems

Discover **low-cost high utility patterns** when:

1. The utility is ***binary classes***. Only records representing the **positive class** are used.
2. The utility is **binary classes.** All records are used.

The *support* measure

Sid	<Activity : cost>	Utility
S_1	<(**a**:**4**)(**b**:**2**)(e:4)(c:4)(d:5)>	...
S_2	<(b:3)(c:2)(f:1)(d:1)(e:2)>	...
S_3	<(a:2)(f:2)(e:1)(c:3)(d:5)>	...
S_4	<(**a**:**2**)(**b**:**2**)(c:1)(f:2)>	...

The **support** of a pattern p:

$$\text{sup}(p) = |S_s|p \subseteq S_s \in DB|$$

(number of sequences containing p)

e.g. *sup*(<**ab**>)=|{S_1, S_4}| = **2** sequences

This measure is used to remove noise.

The *cost* measure

Sid	<Activity : cost>	...
S_1	<(**a**:**4**)(**b**:**2**)(e:4)(c:4)(d:5)>	...
S_2	<(b:3)(c:2)(f:1)(d:1)(e:2)>	...
S_3	<(a:2)(f:2)(e:1)(c:3)(d:5)>	...
S_4	<(**a**:**2**)(**b**:**2**)(c:1)(f:2)>	...

The **cost** of a pattern p:

$$c(p, S_s) = \sum_{v_i \in first(p, S_s)} c(v_i, S_s)$$

$$\mathbf{c(ab,}\ \boldsymbol{S_1}\mathbf{)} = 4 + 2 = \mathbf{6}$$

This measure is used to assess the effort or resource spent.

The **average cost** of a pattern p:

$$ac(p) = \frac{\sum_{p \subseteq S_s \in DB} c(p, S_s)}{|\sup(p)|}$$

$$\mathbf{ac(ab)} = \underbrace{6}_{\textbf{Sequence 1}} + \underbrace{4}_{\textbf{Sequence 4}} / 2 = \mathbf{5}$$

Problem1:

Positive Patterns in a binary DB

Find each p such that:

$$\sup(p) \geq minsup$$

$$ac(p) \leq \text{maxcost}$$

Sid	<Activity : cost>	Utility
S_1	<(a:4)(b:2)(e:4)(c:4)(d:5)>	Positive
S_3	<(a:2)(f:2)(e:1)(c:3)(d:5)>	Positive

e.g. minsup=2 maxcost=7

Pattern	sup	ac	Pattern	sup	ac
a	2	3.0	e	2	2.5
c	2	3.5	ac	2	6.5
d	2	5.0	ae	2	5.5
ec	2	6.0			

Problem1:
Limitations of positive patterns in a binary DB

1. Some positive patterns may be misleading to users as they may also appear in negative sequences.

2. The correlation between a pattern and utility is not measured.

Problem 2:

Finding all cost-effective patterns in a **binary DB**

Sid	<Activity : cost>	Utility
S_1	<(a:4)(b:2)(e:4)(c:4)(d:5)>	Positive
S_2	<(b:3)(c:2)(f:1)(d:1)(e:2)>	Negative
S_3	<(a:2)(f:2)(e:1)(c:3)(d:5)>	Positive
S_4	<(a:2)(b:2)(c:1)(f:2)>	Negative

A **pattern** p is **cost-effective** if:

$$\sup(p) \geq minsup$$

$$ac(p) \leq \mathrm{maxcost}$$

$$occup(p) \geq minoccup$$

Furthermore, we measure the **correlation of** a **pattern** p with the desirable outcome:

$$cor(p) = \frac{ac(D_p^+) - ac(D_p^-)}{Std} \sqrt{\frac{|D_p^+||D_p^-|}{|D_p^+ \cup D_p^-|}} \quad \in [-1,1]$$

a positive correlation is desirable

Pattern	support	average cost	correlation
<ac>	3	5.3	0.80

More details…

The **correlation** of a pattern p:

$$cor(p) = \frac{ac(D_p^+) - ac(D_p^-)}{Std}\sqrt{\frac{|D_p^+||D_p^-|}{|D_p^+ \cup D_p^-|}}$$

$where, ac(D_p^+), ac(D_p^-)\ denotes\ pattern\ p's\ average\ cost\ in\ positive\ and\ negative\ sequences, respectively.$

- $ac(D_p^+) - ac(D_p^-)$, indicates the difference in terms of average cost for positive and negative sequences.
- *Std*, standard deviation of the cost to avoid absolute values.
- $\sqrt{\frac{|D_p^+||D_p^-|}{|D_p^+ \cup D_p^-|}}$, measures distribution difference to indicate patterns' effect on the outcome.
- The *cor* measure values are in the [-1,1] interval.
- The greater positive(negative) the *cor* measure is, the more a pattern is correlated with a positive (negative) utility.

How to reduce the search space? (1)

Sid	<Activity : cost>	Utility
S_1	<(a:4)(**b:2**)(e:4)(**c:4**)(d:5)>	…
S_2	<(**b:3**)(**c:2**)(f:1)(d:1)(e:2)>	…
S_3	<(a:2)(f:2)(e:1)(c:3)(d:5)>	…
S_4	<(a:2)(**b:2**)(**c:1**)(f:2)>	…

We propose a **lower-bound** on the **average cost**:

$$ASC(p) = \frac{1}{sup} \sum_{i=1,2,..,minsup} c(p, S_i)$$

where c(p,S_i) are sorted in ascending order.

e.g. For *minsup = 2*

c(***bc***,S_1) = 6 c(***bc***,S_2) = 5 c(**bc**,S_4) = 3

ASC(***bc***) = (3+5) / 2 =2.67

Properties of *ASC*

$$ASC(p) = \frac{1}{sup} \sum_{i=1,2,..,minsup} c(p, S_i)$$

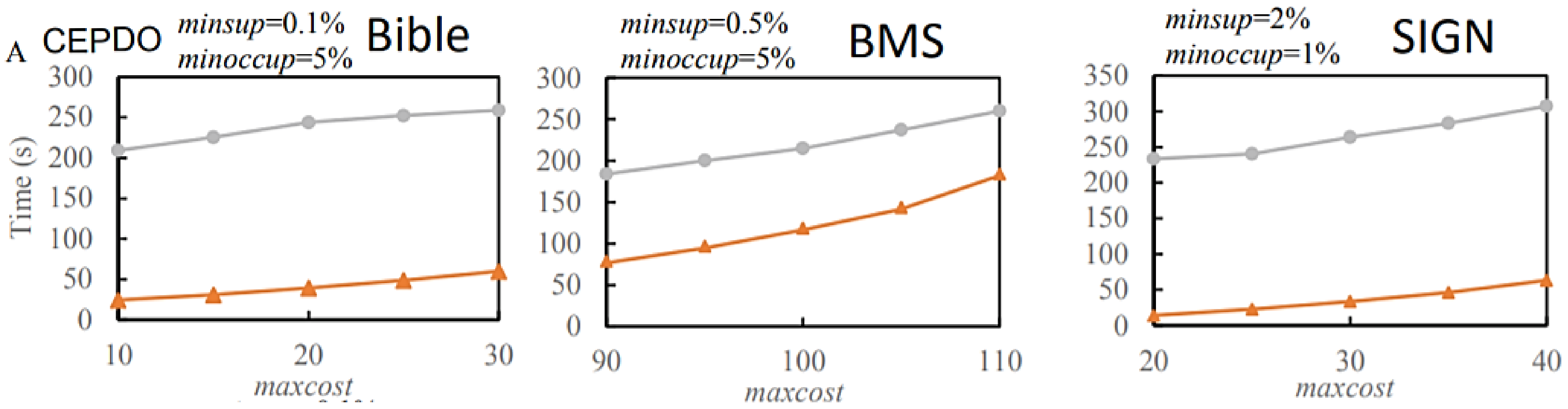
Properties of the ASC:

I. **Underestimation**: The ASC of a pattern p is smaller than or equal to its cost, $ASC(p) \leq c(p)$

II. **Monotonicity**: Let p_x and p_y be two patterns, $If \;\; p_x \subset p_y \; then \;\; ASC(p_x) \leq ASC(p_y)$

III. **Pruning**: For a pattern p, if $ASC(p) >$ maxcost, then pattern p can be eliminated as well as its supersequences.

Execution times



gray line: no pruning strategy / orange line: using *ASC*

results: up to 10 times faster

BMS, Bible and SIGN are benchmark datasets

Case Study: data review

- Six session, each session contains 115 students' study records.
- In each session, 15 activities and 13 features in system are documented.

e.g

```
1, 1, Es, Other, 2.10.2014 11:25:33, 2.10.2014 11:25:34, 0, 0, 0, 0, 0, 84, 0
1, 1, Es, Aulaweb, 2.10.2014 11:25:35, 2.10.2014 11:25:42, 218, 0, 0, 4, 0, 397, 0
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1, 1, Es, Deeds, 2.10.2014 11:26:34, 2.10.2014 11:26:41, 4933, 0, 0, 2, 0, 268, 0
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1, 1, Es, Other, 2.10.2014 11:27:16, 2.10.2014 11:27:17, 140, 0, 0, 0, 0, 99, 0
1, 1, Es_1_1, Study_Es_1_1, 2.10.2014 11:27:18, 2.10.2014 11:27:45, 165188, 0, 0, 4, 0, 715, 0
1, 1, Es_1_1, Deeds_Es_1_1, 2.10.2014 11:27:46, 2.10.2014 11:27:49, 234, 0, 0, 2, 0, 214, 0
1, 1, Es_1_1, Study_Es_1_1, 2.10.2014 11:27:50, 2.10.2014 11:27:50, 0, 0, 0, 0, 0, 77, 0
1, 1, Es_1_1, Deeds_Es_1_1, 2.10.2014 11:27:51, 2.10.2014 11:33:57, 11510470, 0, 0, 230, 54, 16970, 7
1, 1, Es_1_1, Properties, 2.10.2014 11:33:58, 2.10.2014 11:33:59, 31, 0, 0, 0, 0, 189, 0
1, 1, Es_1_1, Deeds_Es_1_1, 2.10.2014 11:34:0, 2.10.2014 11:36:3, 2396565, 5, 0, 50, 0, 2811, 0
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1, 1, Es_1_1, Deeds_Es_1_1, 2.10.2014 11:36:13, 2.10.2014 11:36:55, 819129, 0, 0, 2, 0, 116, 0
```

Case study 1: binary e-learning DB

Database

- 115 students
- A **sequence** is a series of learning sessions, e_1 to e_6.
- **Cost**: time to complete a session.
- **Utility**: to *pass* or *fail* the final exam.

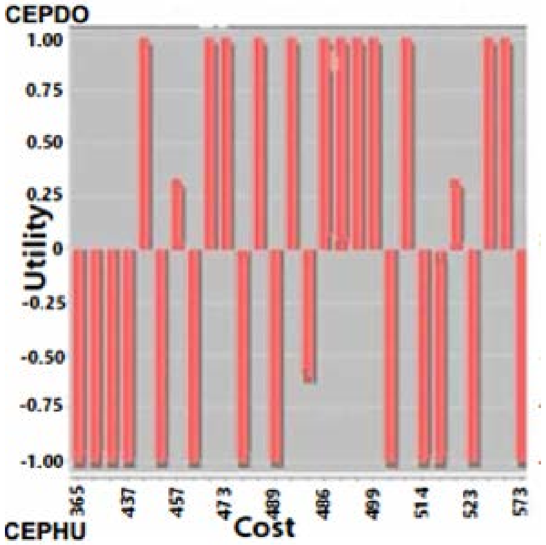
Cost-efficient patterns

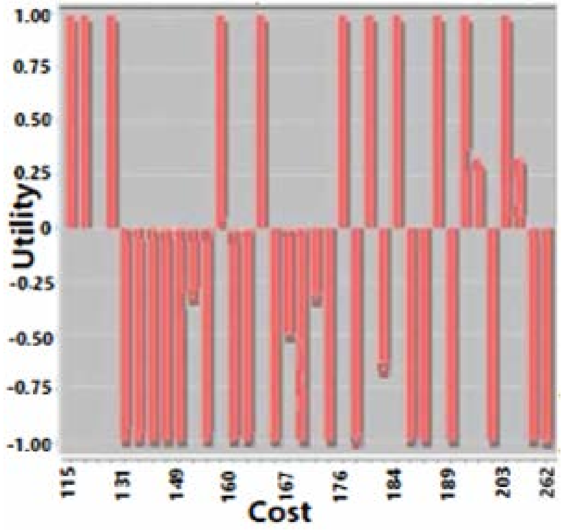
Pattern	Correlation	Average Cost	Support
$\langle e_1, e_6 \rangle$	0.210	250.2	39
$\langle e_1, e_2, e_5, e_6 \rangle$	0.209	485.7	34
$\langle e_2, e_6 \rangle$	0.208	298.4	41
$\langle e_1, e_2, e_6 \rangle$	0.204	391.9	36
$\langle e_1, e_5, e_6 \rangle$	0.194	344.3	37
$\langle e_6 \rangle$	0.193	157.2	50
$\langle e_1, e_4 \rangle$	−0.004	169.1	41
$\langle e_1, e_5 \rangle$	0.002	186.0	41
$\langle e_2, e_3 \rangle$	0.001	284.1	40
$\langle e_3, e_4, e_5, e_6 \rangle$	0.001	469.5	40
$\langle e_1, e_4, e_5 \rangle$	0.003	263.2	38
$\langle e_1, e_2, e_4 \rangle$	−0.003	311.5	36
$\langle e_2, e_3, e_4 \rangle$	−0.005	358.2	38
$\langle e_5 \rangle$	−0.147	96.3	53
$\langle e_4, e_5 \rangle$	−0.109	171.0	49
$\langle e_1, e_3 \rangle$	−0.099	234.6	37
$\langle e_1, e_3, e_4 \rangle$	−0.081	311.2	35

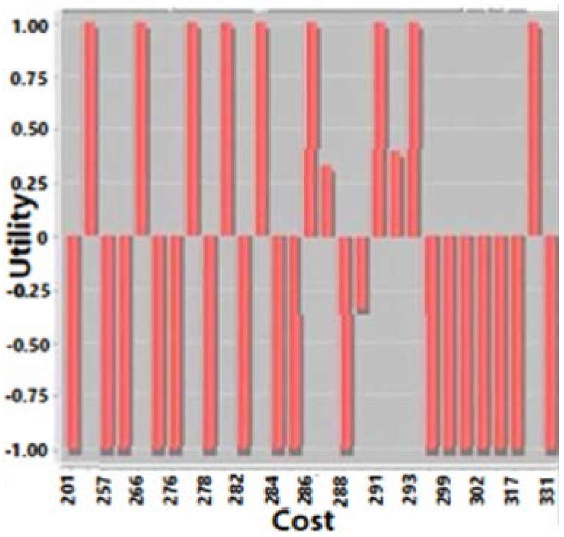
Observation: now the point threshold for passing the exam is set to be 60, when the threshold **decrease**, the **correlation** values **increase**.

Visualization and Interpretability

<e_1,e_6> **<e_4,e_5>** **<e_2,e_3>**







cor(<e_1,e_6>)=0.210

positive correlation

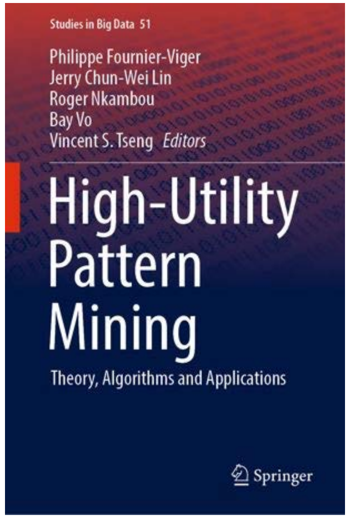
cor(<e_4,e_5>)=-0.109

negative correlation

cor(<e_2,e_3>)=0.001

no correlation

The difference distribution in terms of cost shows the measure’s rationality.



Open source Java data mining software, **150 algorithms**
http://www.phillippe-fournier-viger.com/spmf/