CHARM: An Efficient Algorithm for Closed Itemset Mining

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Introductions

When we are mining association rules in a database, a huge number of frequent patterns (itemsets) will be generated.

- Database: {(1,2,3,4),(1,2,3,4,5,6)}
- Minimum support = 50%
- 63 frequent itemsets ({(1),(2),(3),(4),(5),(6),(1,2),(1,3),…,(1,2,3,4,5,6)})

Introductions

Closed frequent itemsets are non-redundant representations of all frequent itemsets.

Mining association rules on closed frequent itemsets is a much easier task.

In the previous database, the number of closed frequent itemsets is only 2, (1,2,3,4) and (1,2,3,4,5,6).

Closed frequent itemsets

- A frequent itemset *X* is closed if and only if there is no itemset *Y* such that
  - *Y* subsumes *X*
  - every transaction that contains *X* also contains *Y*

Database: {(1,2,3,4),(1,2,3,4,5,6)}
Itemset (1,2) is not a closed itemset.
Itemset (1,2,3,4) is a closed itemset.

Example Database

DISTINCT DATABASE ITEMS

Jane Austen	Agatha Christie	Sir Arthur Conan Doyle	Mark Twain	P.G. Wodehouse
A	C	D	T	W

DATABASE

Transaction	*Items*
1	A,C,T,W
2	C,D,W
3	A,C,T,W
4	A,C,D,W
5	A,C,D,T,W
6	C,D,T

ALL FREQUENT ITEMSETS
MINIMUM SUPPORT = 50%

Support	*Itemsets*
100%(6)	C
83%(5)	W,CW
67%(4)	A,D,T,AC,AW,CD,CT,ACW
50%(3)	AT,DW,TW,ACT,ATW,CDW,CTW,ACTW

Horizontal/Vertical format database

- Horizontal format database
  - Each record is a set of items.
  - Each record is assigned a distinct number named transaction id.
- Vertical format database
  - Each record is a set of transaction id about an item.
  - This item occurs in these transactions.

Vertical format database

A	C	D	T	W
1	1	2	1	1
3	2	4	3	2
4	3	5	5	3
5	4	6	6	4
	5			5
	6			

Notations

Given an itemset *X*, *t(X)* is the set of all tids that contains *X*.

For example: t(ACW) = 1345

Given a tidset *Y*, *i(Y)* is the set of all common items to all the tids in *Y*.

For example: i(12) = CW

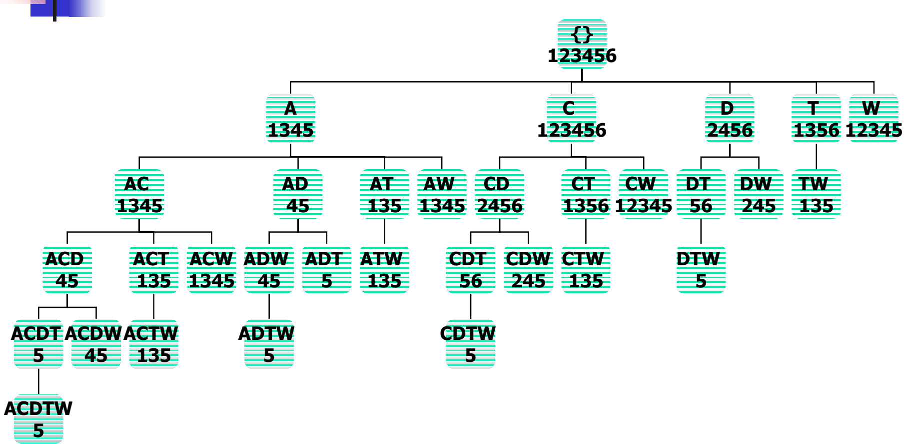
Given an itemset *X*, *c(X)* is the smallest closed set that contains *X*.

For example: c(A)=c(C)=C(W)=ACW

Itemset-Tidset Search Tree (IT-tree)

- Each node in the IT-tree is an itemset-tidset pair, $X \times t(X)$.
  For example: AT×135
- All the children of node *X* share the same prefix *X* and belong to an equivalence class

Example of IT-tree



Theorem 1

- Let $X_i \times t(X_i)$ and $X_j \times t(X_j)$ be any two members of a class $[p]$, with $X_i \leq_f X_j$, where f is a total order. The following four properties hold:
  - 1. If $t(X_i) = t(X_j)$, then $c(X_i) = c(X_j) = c(X_i \cup X_j)$
  - 2. If $t(X_i) \subset t(X_j)$, then $c(X_i) \neq c(X_j)$, but $c(X_i) = c(X_i \cup X_j)$
  - 3. If $t(X_i) \supset t(X_j)$, then $c(X_i) \neq c(X_j)$, but $c(X_j) = c(X_i \cup X_j)$
  - 4. If $t(X_i) \neq t(X_j)$, then $c(X_i) \neq c(X_j) \neq c(X_i \cup X_j)$

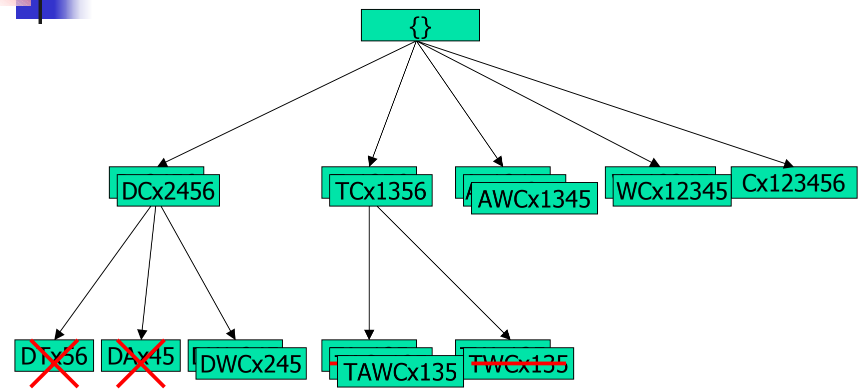
CHARM algorithm

CHARM ($\mathcal{D}$, min_sup):
[P] $= \{X_i \times t(X_i) : X_i \in \mathcal{I} \wedge \sigma(X_i) \geq min\_sup\}$
CHARM-EXTEND ([P], $\mathcal{C} = \emptyset$)
return $\mathcal{C}$ //all closed sets

CHARM-EXTEND ([P], $\mathcal{C}$):
for each $X_i \times t(X_i)$ in $[P]$
  $[P_i] = \emptyset$ and $\mathbf{X} = X_i$
  for each $X_j \times t(X_j)$ in $[P]$, with $X_j \geq_f X_i$
    $\mathbf{X} = \mathbf{X} \cup X_j$ and $\mathbf{Y} = t(X_i) \cap t(X_j)$
    CHARM-PROPERTY([P], $[P_i]$)
  if ($[P_i] \neq \emptyset$) **then** CHARM-EXTEND ($[P_i]$, $\mathcal{C}$)
  delete $[P_i]$
  $\mathcal{C} = \mathcal{C} \cup \mathbf{X}$ //if $\mathbf{X}$ is not subsumed

CHARM-PROPERTY ([P], $[P_i]$):
if ($\sigma(\mathbf{X}) \geq minsup$) **then**
  if $t(X_i) = t(X_j)$ **then** //Property 1
    Remove X_j from $[P]$
    Replace all X_i with $\mathbf{X}$
  else if $t(X_i) \subset t(X_j)$ **then** //Property 2
    Replace all X_i with $\mathbf{X}$
  else if $t(X_i) \supset t(X_j)$ **then** //Property 3
    Remove X_j from $[P]$
    Add $\mathbf{X} \times \mathbf{Y}$ to $[P_i]$ //use ordering f
  else if $t(X_i) \neq t(X_j)$ **then** //Property 4
    Add $\mathbf{X} \times \mathbf{Y}$ to $[P_i]$ //use ordering f

How does CHARM work?



Subsumption Checking

Before add a set X to the current set of closed set, we need check if X is subsumed by some closed sets.

- Comparing X with all closed set is expensive.

Solution: using hash function to retrieve relevant closed sets

Hash function

$$h(X) = \sum_{T \in t(X)} T$$

The sum of the tids in the tidset of an itemset

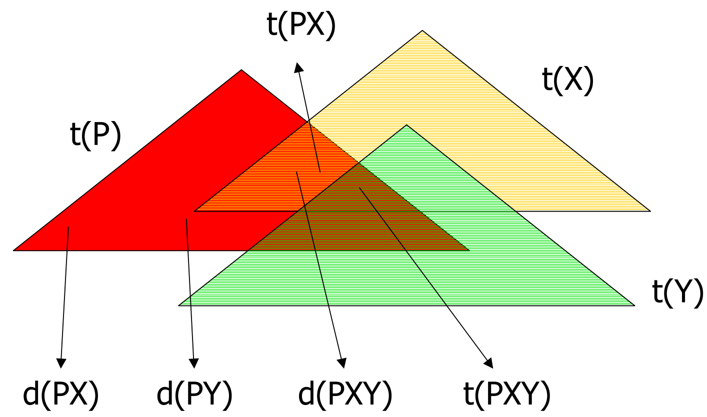
- Assumption: itemsets with the same hash key have different supports.

Complexity issues

- Comparing two itemset's tidsets becomes a time consuming task when tidset gets very large.
- Keeping all tids of itemsets in memory needs lots of space.

Solution: using diffsets

Diffsets



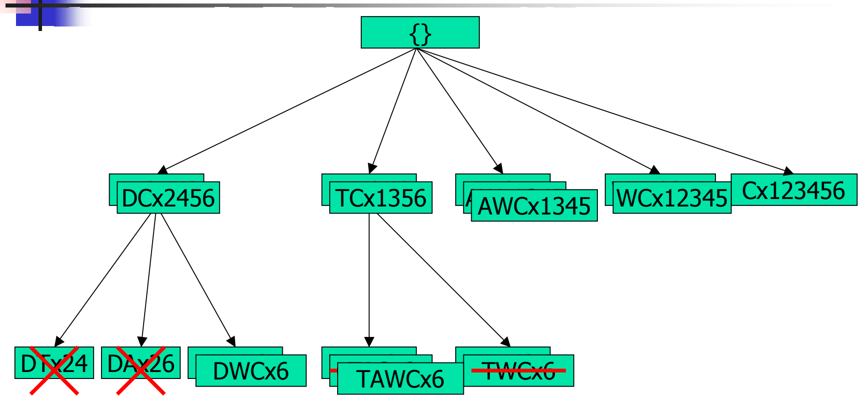
Diffset and Tidset

Let *$m(X_i)$* and *$m(X_j)$* denote the number of mismatches in the diffsets *$d(X_i)$* and *$d(X_j)$*

For example: X_i=D, X_j=T, then $d(X_i)$=2456, $d(X_j)$=1356, $m(X_i)$=|(13)|=2, $m(X_j)$=|(24)|=2

$$\begin{array}{llllll}
m(X_i)=0 & and & m(X_j)=0, & then & d(X_i)=d(X_j) & or & t(X_i)=t(X_j) \\
m(X_i)>0 & and & m(X_j)=0, & then & d(X_i)\supset d(X_j) & or & t(X_i)\subset t(X_j) \\
m(X_i)=0 & and & m(X_j)>0, & then & d(X_i)\subset d(X_j) & or & t(X_i)\supset t(X_j) \\
m(X_i)>0 & and & m(X_j)>0, & then & d(X_i)\neq d(X_j) & or & t(X_i)\neq t(X_j)
\end{array}$$

CHARM using *diffsets*

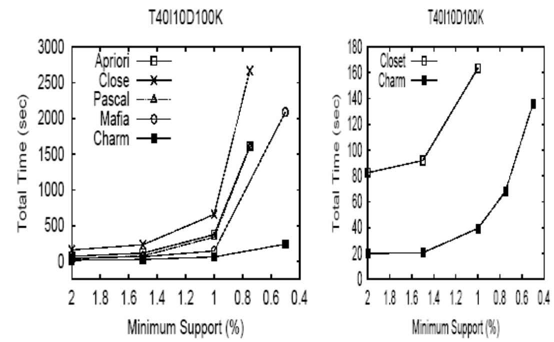


Performance study

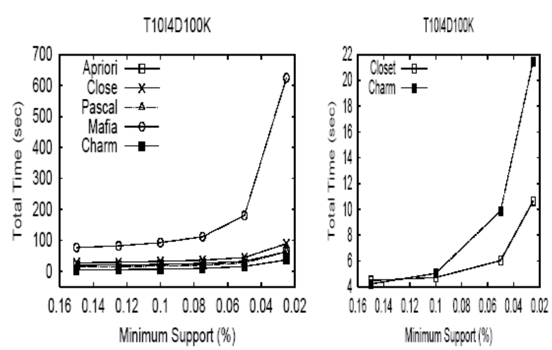
- Datasets

Database	# Items	Avg. Length	Std. Dev.	# Records
chess	76	37	0	3,196
connect	130	43	0	67,557
mushroom	120	23	0	8,124
pumsb*	7117	50	2	49,046
pumsb	7117	74	0	49,046
gazelle	498	2.5	4.9	59,601
T10I4D100K	1000	10	3.7	100,000
T40I10D100K	1000	40	8.5	100,000

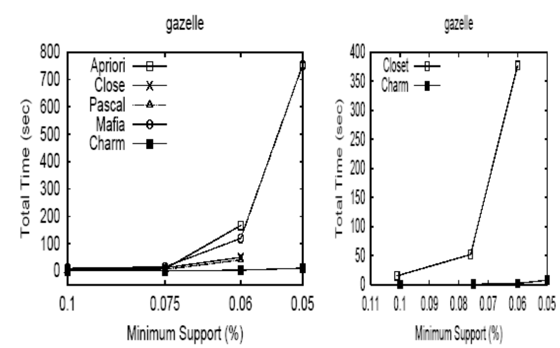
Performance study



Performance study

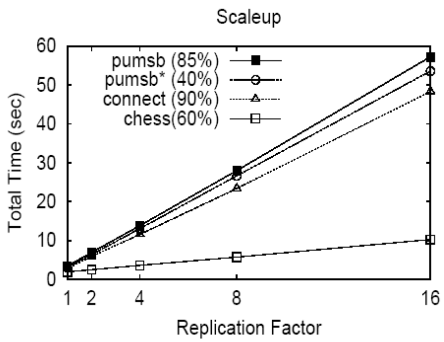


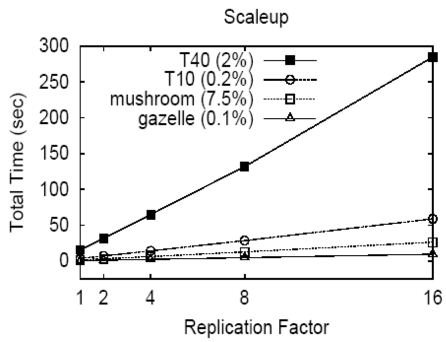
Performance study



Scalability

Linear increasing in the running time with increasing number of transactions at a giving support.





Memory usage

The memory usage is 50 times smaller by using diffsets than using tidsets.

Memory usage (using diffsets)

DB	50%	20%	DB	0.1%	0.05%	DB	1%	0.5%
connect	0.68MB	1.17MB	gazelle	0.13MB	1.24MB	T40I10D100K	0.39MB	0.52MB

Conclusion

- Advantage of CHARM
  - Faster than other algorithm at low support threshold
  - Faster than other algorithm on a database with very long closed patterns
- Disadvantage of CHARM
  - Slower than Closet when most of closed sets are 2-itemset

Comments

- Strength
  - The ideas in the paper are intuitive.
  - The authors first introduced an efficient data structure (IT-tree) for closed itemset mining.
  - The authors demonstrated the algorithm on various datasets.
  - The experimental studies are convincing.
- Weakness
  - The algorithm requires the conversion of database from horizontal format to vertical format.
- Follow-up
  - Closet+ (Wang et al, 2003) beats CHARM one year later.

THANK YOU!

Questions or comments?