



CS 412 Intro. to Data Mining

Chapter 6. Mining Frequent Patterns, Association and Correlations: Basic Concepts and Methods

Jiawei Han, Computer Science, Univ. Illinois at Urbana-Champaign, 2017





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Chapter 6: Mining Frequent Patterns, Association and Correlations: Basic Concepts and Methods

☐ Basic Concepts



การประมวลผลข้อมูลใน Data
↓
ค.แบบที่สนใจ

☐ Efficient Pattern Mining Methods

☐ Pattern Evaluation

☐ Summary

Pattern Discovery: Basic Concepts

- ❑ What Is Pattern Discovery? Why Is It Important?
- ❑ Basic Concepts: Frequent Patterns and Association Rules
- ❑ Compressed Representation: Closed Patterns and Max-Patterns

What Is Pattern Discovery?

- ❑ What are patterns?

- ❑ **Patterns**: A set of items, subsequences, or substructures that occur frequently together (or strongly correlated) in a data set
 - ❑ Patterns represent **intrinsic** and **important properties** of datasets

- ❑ **Pattern discovery**: Uncovering patterns from massive data sets

- ❑ Motivation examples:

- ❑ What products were often purchased together?
 - ❑ What are the subsequent purchases after buying an iPad?
 - ❑ What code segments likely contain copy-and-paste bugs?
 - ❑ What word sequences likely form phrases in this corpus?

Pattern Discovery: Why Is It Important?

- ❑ Finding **inherent regularities** in a data set
- ❑ **Foundation** for many essential data mining tasks
 - ❑ Association, correlation, and causality analysis
 - ❑ Mining sequential, structural (e.g., sub-graph) patterns
 - ❑ Pattern analysis in spatiotemporal, multimedia, time-series, and stream data
 - ❑ Classification: Discriminative pattern-based analysis
 - ❑ Cluster analysis: Pattern-based subspace clustering
- ❑ Broad applications
 - ❑ Market basket analysis, cross-marketing, catalog design, sale campaign analysis, Web log analysis, biological sequence analysis

Basic Concepts: k-Itemsets and Their Supports

Pattern
view data
to find item

- **Itemset**: A set of one or more items
ex. 1-itemset: {Beer, Nuts, Diaper} / 2-itemset: {Beer, Nuts, Diaper}
- **k-itemset**: $X = \{x_1, \dots, x_k\}$

□ Ex. {Beer, Nuts, Diaper} is a 3-itemset

- **(absolute) support (count)** of X , $\text{sup}\{X\}$:
Frequency or the number of occurrences of an itemset X

□ Ex. $\text{sup}\{\text{Beer}\} = 3$

□ Ex. $\text{sup}\{\text{Diaper}\} = 4$

□ Ex. $\text{sup}\{\text{Beer}, \text{Diaper}\} = 3$

□ Ex. $\text{sup}\{\text{Beer}, \text{Eggs}\} = 1$

Tid	Items bought
10	transaction 1: Beer, Nuts, Diaper
20	2: Beer, Coffee, Diaper
30	3: Beer, Diaper, Eggs
40	4: Nuts, Eggs, Milk
50	5: Nuts, Coffee, Diaper, Eggs, Milk

□ **(relative) support**, $s\{X\}$: The fraction of transactions that contains X (i.e., the probability that a transaction contains X)

□ Ex. $s\{\text{Beer}\} = 3/5 = 60\%$

□ Ex. $s\{\text{Diaper}\} = 4/5 = 80\%$

□ Ex. $s\{\text{Beer}, \text{Eggs}\} = 1/5 = 20\%$

Basic Concepts: Frequent Itemsets (Patterns)

☐ An itemset (or a pattern) X is *frequent* if the support of X is no less than a *minsup* threshold σ

minsupport
support \geq minsup
support \geq σ

☐ Let $\sigma = 50\%$ (σ : *minsup* threshold)

For the given 5-transaction dataset

☐ All the frequent 1-itemsets:

☐ Beer: 3/5 (60%); Nuts: 3/5 (60%)

☐ Diaper: 4/5 (80%); Eggs: 3/5 (60%)

☐ All the frequent 2-itemsets:

☐ {Beer, Diaper}: 3/5 (60%)

☐ All the frequent 3-itemsets?

☐ None

why? \rightarrow set min support

$$\frac{6 \times 5}{2} = 15$$

$$\frac{6 \times 5 \times 4}{1 \times 2}$$

Tid	Items bought
10	Beer, Nuts, Diaper
20	Beer, Coffee, Diaper
30	Beer, Diaper, Eggs
40	Nuts, Eggs, Milk
50	Nuts, Coffee, Diaper, Eggs, Milk

☐ Why do these itemsets (shown on the left) form the complete set of frequent k -itemsets (patterns) for any k ?

☐ **Observation:** We may need an efficient method to mine a complete set of frequent patterns

From Frequent Itemsets to Association Rules

- Comparing with itemsets, rules can be more telling

Ex. $Diaper \rightarrow Beer$ *ถ้าซื้อ Diaper มักจะซื้อ Beer*

Buying diapers may likely lead to buying beers

- How strong is this rule? (support, confidence)

Measuring association rules: $X \rightarrow Y (s, c)$

Both X and Y are itemsets

Support, s : The probability that a transaction contains $X \cup Y$

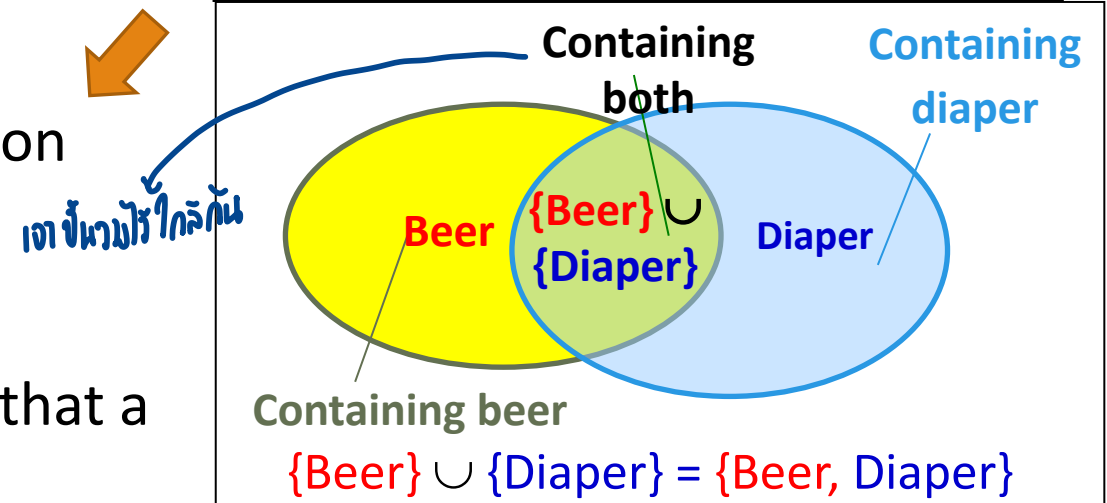
Ex. $s\{Diaper, Beer\} = 3/5 = 0.6$ (i.e., 60%)

Confidence, c : The *conditional probability* that a transaction containing X also contains Y

Calculation: $c = \sup(X \cup Y) / \sup(X)$

Ex. $c = \sup\{Diaper, Beer\} / \sup\{Diaper\} = 3/4 = 0.75$

Tid	Items bought
10	Beer, Nuts, Diaper
20	Beer, Coffee, Diaper
30	Beer, Diaper, Eggs
40	Nuts, Eggs, Milk
50	Nuts, Coffee, Diaper, Eggs, Milk



Note: $X \cup Y$: the union of two itemsets
 ■ The set contains both X and Y

Mining Frequent Itemsets and Association Rules

□ Association rule mining

- Given two thresholds: $minsup$, $minconf$
- Find **all** of the rules, $X \rightarrow Y$ (s, c)
 - such that, $s \geq minsup$ and $c \geq minconf$

□ Let $minsup = 50\%$

- Freq. 1-itemsets: Beer: 3, Nuts: 3, Diaper: 4, Eggs: 3
- Freq. 2-itemsets: {Beer, Diaper}: 3

□ Let $minconf = 50\%$

- $Beer \rightarrow Diaper$ (60%, 100%)
- $Diaper \rightarrow Beer$ (60%, 75%)

(Q: Are these all rules?)

Tid	Items bought
10	Beer, Nuts, Diaper
20	Beer, Coffee, Diaper
30	Beer, Diaper, Eggs
40	Nuts, Eggs, Milk
50	Nuts, Coffee, Diaper, Eggs, Milk

□ Observations:

- Mining association rules and mining frequent patterns are very close problems
- Scalable methods are needed for mining large datasets



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Challenge: There Are Too Many Frequent Patterns!

- A long pattern contains a combinatorial number of sub-patterns
- How many frequent itemsets does the following TDB₁ contain?

□ TDB₁: T₁: {a₁, ..., a₅₀}; T₂: {a₁, ..., a₁₀₀}

□ Assuming (absolute) *minsup* = 1

□ Let's have a try

1-itemsets: {a₁}: 2, {a₂}: 2, ..., {a₅₀}: 2, {a₅₁}: 1, ..., {a₁₀₀}: 1,

2-itemsets: {a₁, a₂}: 2, ..., {a₁, a₅₀}: 2, {a₁, a₅₁}: 1 ..., ..., {a₉₉, a₁₀₀}: 1,

..., ..., ..., ...

99-itemsets: {a₁, a₂, ..., a₉₉}: 1, ..., {a₂, a₃, ..., a₁₀₀}: 1

100-itemset: {a₁, a₂, ..., a₁₀₀}: 1

- The total number of frequent itemsets:

$$\binom{100}{1} + \binom{100}{2} + \binom{100}{3} + \cdots + \binom{100}{100} = 2^{100} - 1$$

A too huge set for any one to compute or store!



Expressing Patterns in Compressed Form: Closed Patterns

- ❑ How to handle such a challenge?
- ❑ Solution 1: **Closed patterns**: A pattern (itemset) X is **closed** if X is *frequent*, and there exists *no super-pattern* $Y \supset X$, with the same support as X
 - ❑ Let Transaction DB TDB_1 : $T_1: \{a_1, \dots, a_{50}\}$; $T_2: \{a_1, \dots, a_{100}\}$
 - ❑ Suppose $minsup = 1$. How many closed patterns does TDB_1 contain?
 - ❑ Two: $P_1: \{\{a_1, \dots, a_{50}\}: 2\}$; $P_2: \{\{a_1, \dots, a_{100}\}: 1\}$
- ❑ **Closed pattern** is a **lossless compression** of frequent patterns
 - ❑ Reduces the # of patterns but does not lose the support information!
 - ❑ You will still be able to say: $\{\{a_2, \dots, a_{40}\}: 2\}$, $\{\{a_5, a_{51}\}: 1\}$

Expressing Patterns in Compressed Form: Max-Patterns

- ❑ Solution 2: **Max-patterns**: A pattern X is a **max-pattern** if X is frequent and there exists no frequent super-pattern $Y \supset X$
- ❑ Difference from close-patterns?
 - ❑ Do not care the real support of the sub-patterns of a max-pattern
 - ❑ Let Transaction DB TDB_1 : $T_1: \{a_1, \dots, a_{50}\}$; $T_2: \{a_1, \dots, a_{100}\}$
 - ❑ Suppose $minsup = 1$. How many max-patterns does TDB_1 contain?
 - ❑ One: $P: \{\{a_1, \dots, a_{100}\}: 1\}$
- ❑ **Max-pattern** is a **lossy compression**!
 - ❑ We only know $\{a_1, \dots, a_{40}\}$ is frequent
 - ❑ But we do not know the real support of $\{a_1, \dots, a_{40}\}$, ..., any more!
- ❑ Thus in many applications, mining close-patterns is more desirable than mining max-patterns

Chapter 6: Mining Frequent Patterns, Association and Correlations: Basic Concepts and Methods

- ☐ Basic Concepts
- ☐ Efficient Pattern Mining Methods
- ☐ Pattern Evaluation
- ☐ Summary



Efficient Pattern Mining Methods

নতুন ও উন্নত পদ্ধতি

- ❑ The Downward Closure Property of Frequent Patterns
- ❑ The Apriori Algorithm
- ❑ Extensions or Improvements of Apriori
- ❑ Mining Frequent Patterns by Exploring Vertical Data Format
- ❑ FPGrowth: A Frequent Pattern-Growth Approach
- ❑ Mining Closed Patterns

The Downward Closure Property of Frequent Patterns

- Observation: From $TDB_1: T_1: \{a_1, \dots, a_{50}\}; T_2: \{a_1, \dots, a_{100}\}$
 - We get a frequent itemset: $\{a_1, \dots, a_{50}\}$
 - Also, its subsets are all frequent: $\{a_1\}, \{a_2\}, \dots, \{a_{50}\}, \{a_1, a_2\}, \dots, \{a_1, \dots, a_{49}\}, \dots$
 - There must be some hidden relationships among frequent patterns!


- The **downward closure (also called “Apriori”)** property of frequent patterns

- If **{beer, diaper, nuts}** is frequent, so is **{beer, diaper}**
- Every transaction containing {beer, diaper, nuts} also contains {beer, diaper}

Algorithm

- Apriori: Any subset of a frequent itemset must be frequent *any subset of frequent ex. 10*
subset is frequent
10 itemset is frequent
10 itemset is frequent
$$\begin{array}{l} A \times \rightarrow A \cup B \cup C \checkmark \\ A \cup B \cup C \checkmark \end{array}$$

- Efficient mining methodology

- If **any subset of an itemset S** is infrequent, then there is no chance for S to be frequent—why do we even have to consider S!?  A sharp knife for pruning!

Apriori Pruning and Scalable Mining Methods

- ❑ Apriori pruning principle: If there is any itemset which is infrequent, its superset should not even be generated! (Agrawal & Srikant @VLDB'94, Mannila, et al. @ KDD' 94)
- ❑ Scalable mining Methods: Three major approaches
 - ❑ Level-wise, join-based approach: Apriori (Agrawal & Srikant@VLDB'94)
 - ❑ Vertical data format approach: Eclat (Zaki, Parthasarathy, Ogihara, Li @KDD'97)
 - ❑ Frequent pattern projection and growth: FPgrowth (Han, Pei, Yin @SIGMOD'00)

Apriori: A Candidate Generation & Test Approach

- Outline of Apriori (level-wise, candidate generation and test)

- Initially, scan DB once to get frequent 1-itemset

scan 1-itemset
down 1-itemset candidate (frequent)

- Repeat

- Generate length-(k+1) candidate itemsets from length-k frequent itemsets

generate length-k+1 candidate itemsets

- Test the candidates against DB to find frequent (k+1)-itemsets

- Set $k := k + 1$

- Until no frequent or candidate set can be generated

- Return all the frequent itemsets derived

The Apriori Algorithm (Pseudo-Code)

C_k : Candidate itemset of size k

F_k : Frequent itemset of size k

$K := 1$;

$F_k := \{\text{frequent items}\}$; // frequent 1-itemset

While ($F_k \neq \emptyset$) **do** { // when F_k is non-empty

$C_{k+1} := \text{candidates generated from } F_k$; // candidate generation

 Derive F_{k+1} by counting candidates in C_{k+1} with respect to TDB at minsup;

$k := k + 1$

}

return $\cup_k F_k$ // return F_k generated at each level

ฐานข้อมูลธุรกรรม

Transaction ID	Items Purchased
1	A B C Milk, Bread, Butter
2	A D Milk, Eggs
3	B C E Bread, Butter, Jam
4	A D C Milk, Eggs, Butter
5	B C E A Bread, Butter, Jam, Milk

Minimum Support (minsup) = 2 (หมายถึงรายการต้องปรากฏใน ≥ 2 ธุรกรรม)

ขั้นตอนที่ 1: สร้าง Candidate Itemsets (C1)

Itemset	Support	Frequent (\geq minsup)
{Milk}	4	✓
{Bread}	3	✓
{Butter}	4	✓
{Eggs}	2	✓
{Jam}	2	✓

Frequent Itemsets (F1): {Milk}, {Bread}, {Butter}, {Eggs}, {Jam}

ขั้นตอนที่ 2: สร้าง Candidate Itemsets (C2)

Itemset	Support	Frequent (\geq minsup)
{Milk, Bread}	2	✓
{Milk, Butter}	3	✓
{Milk, Eggs}	2	✓
{Milk, Jam}	1	✗
{Bread, Butter}	3	✓
{Bread, Eggs}	0	✗
{Bread, Jam}	2	✓
{Butter, Eggs}	2	✓
{Butter, Jam}	2	✓
{Eggs, Jam}	0	✗

Frequent Itemsets (F2):

{Milk, Bread}, {Milk, Butter}, {Milk, Eggs}, {Bread, Butter}, {Bread, Jam}, {Butter, Eggs}, {Butter, Jam}



ขั้นตอนที่ 3: สร้าง Candidate Itemsets (C3)

Itemset	Support	Frequent (\geq minsup)
{Milk, Bread, Butter}	2	✓
{Milk, Bread, Eggs}	0	✗
{Milk, Bread, Jam}	1	✗
{Milk, Butter, Eggs}	2	✓
{Milk, Butter, Jam}	1	✗
{Bread, Butter, Jam}	2	✓

Frequent Itemsets (F3):

{Milk, Bread, Butter}, {Milk, Butter, Eggs}, {Bread, Butter, Jam}



สรุป Frequent Itemsets

ชั้น	Frequent Itemsets
F1	{Milk}, {Bread}, {Butter}, {Eggs}, {Jam}
F2	{Milk, Bread}, {Milk, Butter}, {Milk, Eggs}, {Bread, Butter}, {Bread, Jam}, {Butter, Eggs}, {Butter, Jam}
F3	{Milk, Bread, Butter}, {Milk, Butter, Eggs}, {Bread, Butter, Jam}

Association Rules

จาก Frequent Itemsets ข้างต้น สามารถสร้างกฎความสัมพันธ์ (Association Rules) ได้ เช่น:

- Rule: {Milk} \rightarrow {Butter}
 - Support: $3/5 = 0.6$
 - Confidence: $3/4 = 0.75$
- Rule: {Bread, Butter} \rightarrow {Jam}
 - Support: $2/5 = 0.4$
 - Confidence: $2/3 \approx 0.67$

Apriori: Implementation Tricks

□ How to generate candidates?

□ Step 1: self-joining F_k

□ Step 2: pruning

□ Example of candidate-generation

□ $F_3 = \{abc, abd, acd, ace, bcd\}$

□ Self-joining: $F_3 * F_3$

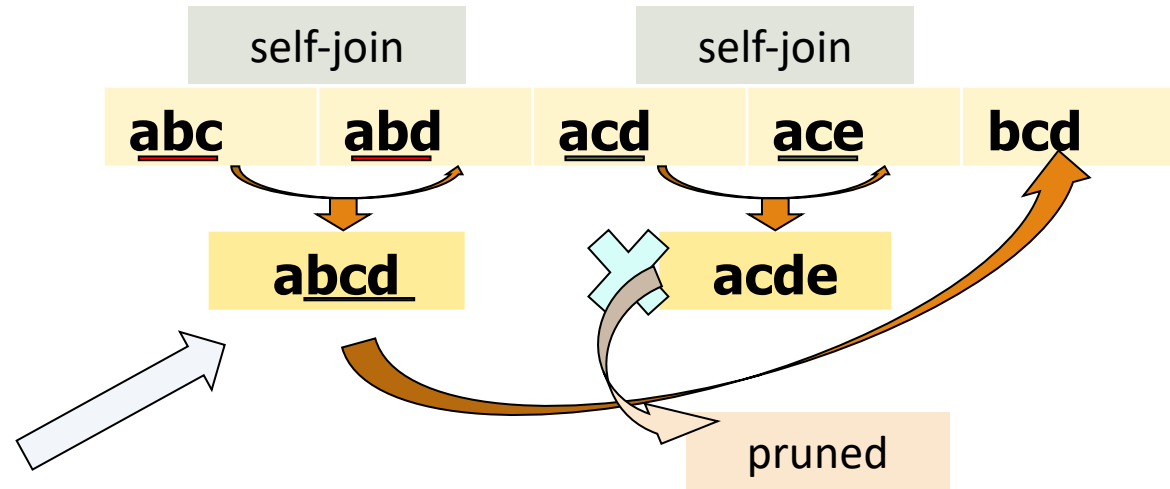
□ $abcd$ from abc and abd

□ $acde$ from acd and ace

□ Pruning:

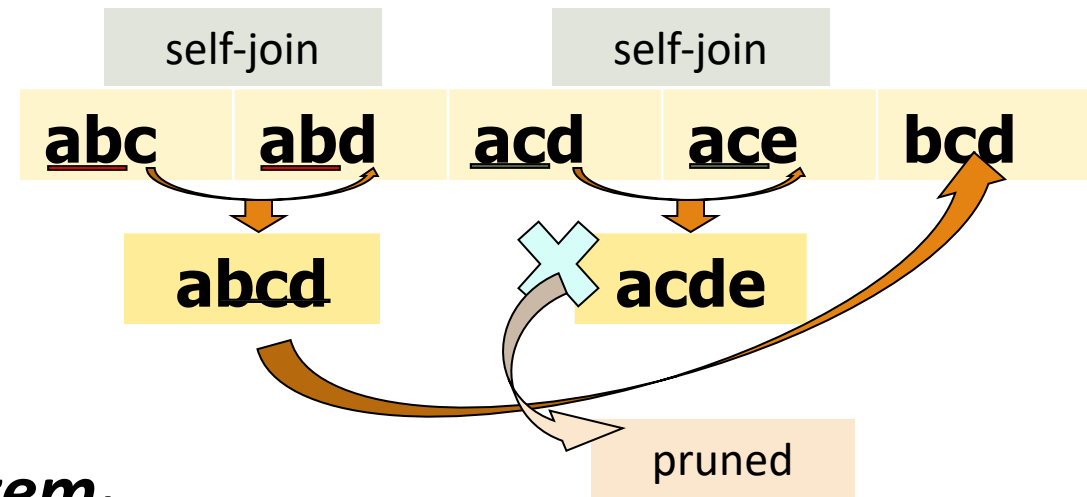
□ $acde$ is removed because ade is not in F_3

□ $C_4 = \{abcd\}$





Candidate Generation: An SQL Implementation

- Suppose the items in F_{k-1} are listed in an order
- Step 1: self-joining F_{k-1}
insert into C_k
select $p.item_1, p.item_2, \dots, p.item_{k-1}, q.item_{k-1}$
from F_{k-1} as p, F_{k-1} as q
where $p.item_1 = q.item_1, \dots, p.item_{k-2} = q.item_{k-2}, p.item_{k-1} < q.item_{k-1}$
- Step 2: pruning
for all *itemsets* c in C_k do
for all $(k-1)$ -subsets s of c do
if (s is not in F_{k-1}) then delete c from C_k



Apriori: Improvements and Alternatives

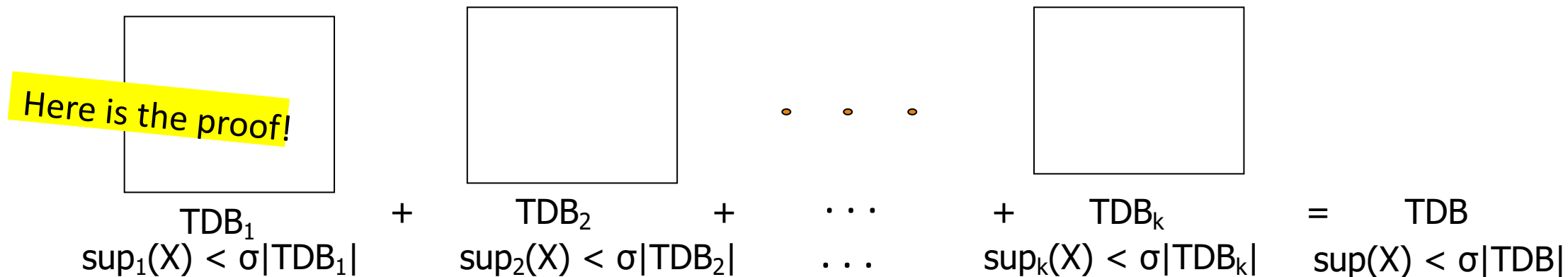
- ❑ Reduce passes of transaction database scans
 - ❑ Partitioning (e.g., Savasere, et al., 1995) 
 - ❑ Dynamic itemset counting (Brin, et al., 1997)
- ❑ Shrink the number of candidates
 - ❑ Hashing (e.g., DHP: Park, et al., 1995) 
 - ❑ Pruning by support lower bounding (e.g., Bayardo 1998)
 - ❑ Sampling (e.g., Toivonen, 1996)
- ❑ Exploring special data structures
 - ❑ Tree projection (Agarwal, et al., 2001)
 - ❑ H-miner (Pei, et al., 2001)
 - ❑ Hypercube decomposition (e.g., LCM: Uno, et al., 2004)

To be discussed in
subsequent slides

To be discussed in
subsequent slides

Partitioning: Scan Database Only Twice

- Theorem: *Any itemset that is potentially frequent in TDB must be frequent in at least one of the partitions of TDB*



- Method: Scan DB twice (A. Savasere, E. Omiecinski and S. Navathe, *VLDB'95*)
 - Scan 1: Partition database so that each partition can fit in main memory (why?)
 - Mine local frequent patterns in this partition
 - Scan 2: Consolidate global frequent patterns
 - Find global frequent itemset candidates (those frequent in at least one partition)
 - Find the true frequency of those candidates, by scanning TDB_i one more time

Direct Hashing and Pruning (DHP)

- ❑ DHP (Direct Hashing and Pruning): (J. Park, M. Chen, and P. Yu, SIGMOD'95)
- ❑ Hashing: Different itemsets may have the same hash value: $v = \text{hash}(\text{itemset})$
- ❑ 1st scan: When counting the 1-itemset, hash 2-itemset to calculate the bucket count
- ❑ Observation: A k -itemset cannot be frequent if its corresponding hashing bucket count is below the *minsup* threshold

- ❑ Example: At the 1st scan of TDB, count 1-itemset, and

Itemsets	Count
{ab, ad, ce}	35
{bd, be, de}	298
.....	...
{yz, qs, wt}	58

Hash Table

- ❑ Hash 2-itemsets in the transaction to its bucket

- ❑ {ab, ad, ce}

- ❑ {bd, be, de}

- ❑ ...

- ❑ At the end of the first scan,

- ❑ if $\text{minsup} = 80$, remove *ab, ad, ce*, since $\text{count}\{ab, ad, ce\} < 80$

Exploring Vertical Data Format: ECLAT

- ❑ ECLAT (Equivalence Class Transformation): A depth-first search algorithm using set intersection [Zaki et al. @KDD'97]
- ❑ Tid-List: List of transaction-ids containing an itemset
- ❑ Vertical format: $t(e) = \{T_{10}, T_{20}, T_{30}\}$; $t(a) = \{T_{10}, T_{20}\}$; $t(ae) = \{T_{10}, T_{20}\}$
- ❑ Properties of Tid-Lists
 - ❑ $t(X) = t(Y)$: X and Y always happen together (e.g., $t(ac) = t(d)$)
 - ❑ $t(X) \subset t(Y)$: transaction having X always has Y (e.g., $t(ac) \subset t(ce)$)
- ❑ Deriving frequent patterns based on vertical intersections
- ❑ Using **diffset** to accelerate mining
 - ❑ Only keep track of differences of tids
 - ❑ $t(e) = \{T_{10}, T_{20}, T_{30}\}$, $t(ce) = \{T_{10}, T_{30}\} \rightarrow \text{Diffset}(ce, e) = \{T_{20}\}$

A transaction DB in Horizontal Data Format

Tid	Itemset
10	a, c, d, e
20	a, b, e
30	b, c, e

The transaction DB in Vertical Data Format

Item	TidList
a	10, 20
b	20, 30
c	10, 30
d	10
e	10, 20, 30

Why Mining Frequent Patterns by Pattern Growth?

- ❑ Apriori: A *breadth-first search* mining algorithm
 - ❑ First find the complete set of frequent k -itemsets
 - ❑ Then derive frequent $(k+1)$ -itemset candidates
 - ❑ Scan DB again to find true frequent $(k+1)$ -itemsets
- ❑ Motivation for a different mining methodology
 - ❑ Can we develop a *depth-first search* mining algorithm?
 - ❑ For a frequent itemset p , can subsequent search be confined to only those transactions that containing p ?
- ❑ Such thinking leads to a frequent pattern growth approach:
 - ❑ FPGrowth (J. Han, J. Pei, Y. Yin, “Mining Frequent Patterns without Candidate Generation,” SIGMOD 2000)

Example: Construct FP-tree from a Transaction DB

TID	Items in the Transaction	Ordered, frequent itemlist
100	{f, a, c, d, g, i, m, p}	f, c, a, m, p
200	{a, b, c, f, l, m, o}	f, c, a, b, m
300	{b, f, h, j, o, w}	f, b
400	{b, c, k, s, p}	c, b, p
500	{a, f, c, e, l, p, m, n}	f, c, a, m, p

After inserting the 1st frequent Itemlist: "f, c, a, m, p"

1. Scan DB once, find single item frequent pattern:

Let min_support = 3

f:4, a:3, c:4, b:3, m:3, p:3

2. Sort frequent items in frequency descending order, f-list

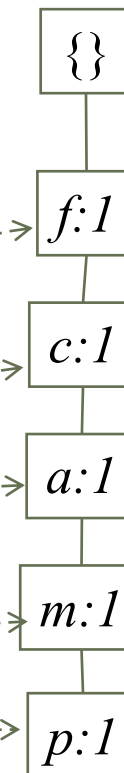
F-list = f-c-a-b-m-p

3. Scan DB again, construct FP-tree

- The frequent itemlist of each transaction is inserted as a branch, with shared sub-branches merged, counts accumulated

Header Table

Item	Frequency	header
f	4	
c	4	
a	3	
b	3	
m	3	
p	3	



Example: Construct FP-tree from a Transaction DB

TID	Items in the Transaction	Ordered, frequent itemlist
100	{f, a, c, d, g, i, m, p}	f, c, a, m, p
200	{a, b, c, f, l, m, o}	f, c, a, b, m
300	{b, f, h, j, o, w}	f, b
400	{b, c, k, s, p}	c, b, p
500	{a, f, c, e, l, p, m, n}	f, c, a, m, p

After inserting the 2nd frequent itemlist "f, c, a, b, m"

1. Scan DB once, find single item frequent pattern:

Let min_support = 3

f:4, a:3, c:4, b:3, m:3, p:3

2. Sort frequent items in frequency descending order, f-list

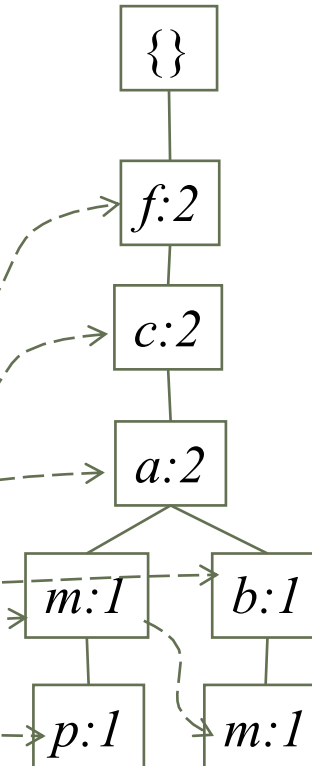
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Example: Construct FP-tree from a Transaction DB

TID	Items in the Transaction	Ordered, frequent itemlist
100	{f, a, c, d, g, i, m, p}	f, c, a, m, p
200	{a, b, c, f, l, m, o}	f, c, a, b, m
300	{b, f, h, j, o, w}	f, b
400	{b, c, k, s, p}	c, b, p
500	{a, f, c, e, l, p, m, n}	f, c, a, m, p

1. Scan DB once, find single item frequent pattern:

Let min_support = 3

f:4, a:3, c:4, b:3, m:3, p:3

2. Sort frequent items in frequency descending order, f-list

F-list = f-c-a-b-m-p

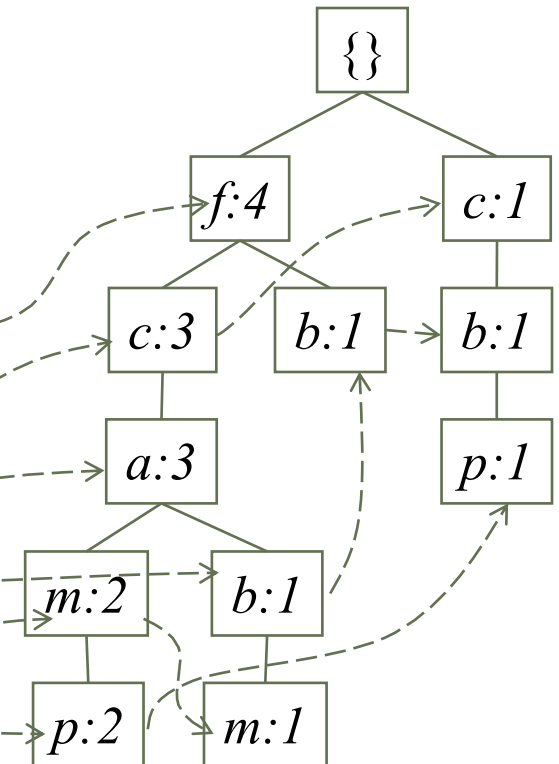
3. Scan DB again, construct FP-tree

- The frequent itemlist of each transaction is inserted as a branch, with shared sub-branches merged, counts accumulated

Header Table

Item	Frequency	header
f	4	
c	4	
a	3	
b	3	
m	3	
p	3	

After inserting all the frequent itemlists

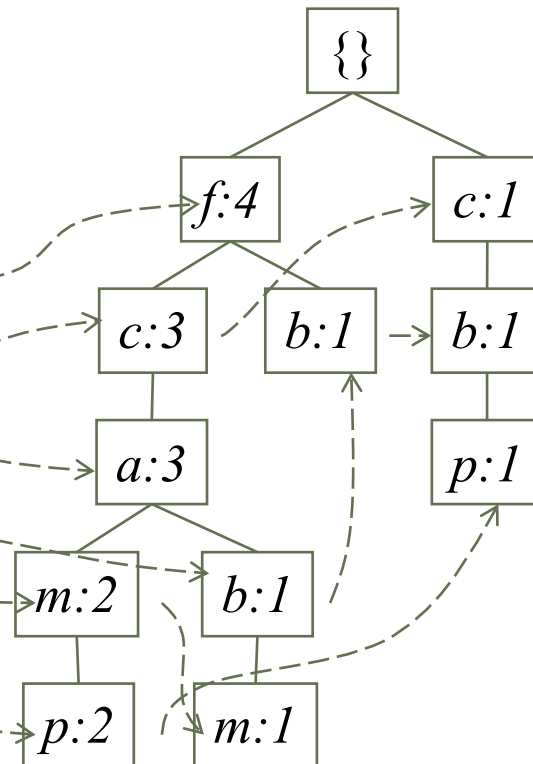


Mining FP-Tree: Divide and Conquer Based on Patterns and Data

- Pattern mining can be partitioned according to current patterns
 - Patterns containing p : p 's conditional database: $fcam:2, cb:1$
 - p 's conditional database (i.e., the database under the condition that p exists):
 - *transformed prefix paths* of item p
 - Patterns having m but no p : m 's conditional database: $fca:2, fcab:1$
 -

min_support = 3

Item	Frequency	Header
f	4	
c	4	
a	3	
b	3	
m	3	
p	3	



Conditional database of each pattern

<u>Item</u>	<u>Conditional database</u>
<i>c</i>	<i>f:3</i>
<i>a</i>	<i>fc:3</i>
<i>b</i>	<i>fca:1, f:1, c:1</i>
<i>m</i>	<i>fca:2, fcab:1</i>
<i>p</i>	<i>fcam:2, cb:1</i>

Mine Each Conditional Database Recursively

min_support = 3

Conditional Data Bases

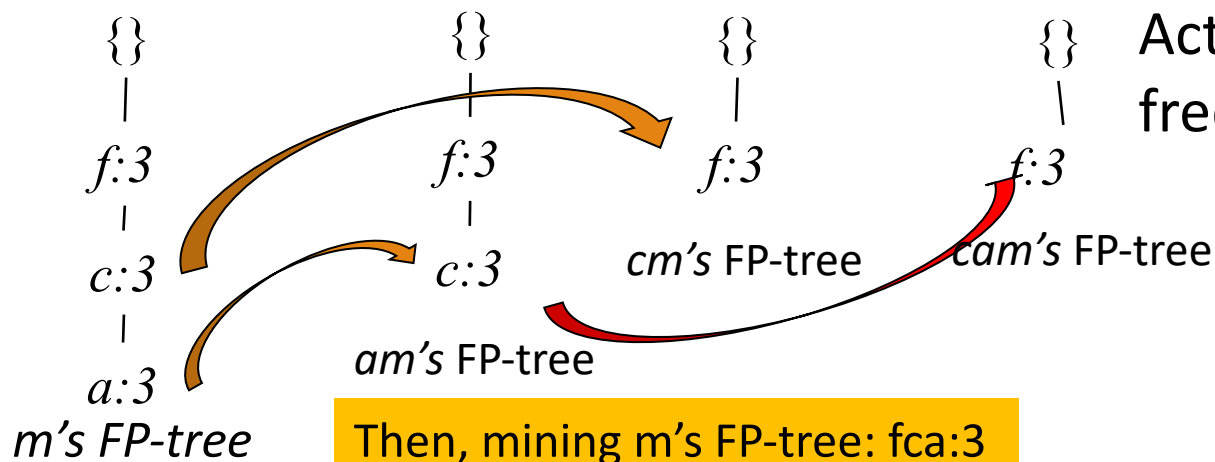
<i>item</i>	<i>cond. data base</i>
<i>c</i>	<i>f:3</i>
<i>a</i>	<i>fc:3</i>
<i>b</i>	<i>fca:1, f:1, c:1</i>
<i>m</i>	<i>fca:2, fcab:1</i>
<i>p</i>	<i>fcam:2, cb:1</i>

- For each conditional database
 - Mine single-item patterns
 - Construct its FP-tree & mine it

p's conditional DB: *fcam:2, cb:1* → *c: 3*

m's conditional DB: *fca:2, fcab:1* → *fca: 3*

b's conditional DB: *fca:1, f:1, c:1* → ϕ

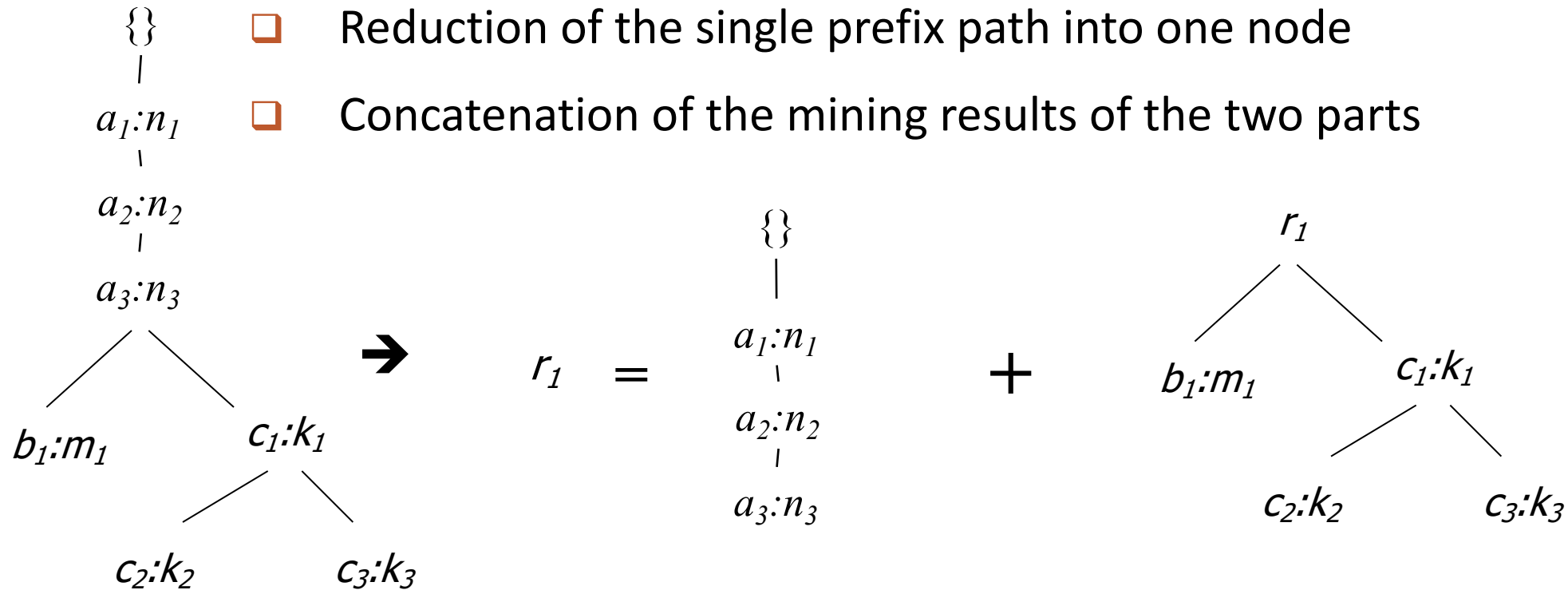


Actually, for single branch FP-tree, all the frequent patterns can be generated in one shot

m: 3
fm: 3, cm: 3, am: 3
fcm: 3, fam:3, cam: 3
fcam: 3

A Special Case: Single Prefix Path in FP-tree

- Suppose a (conditional) FP-tree T has a shared single prefix-path P
- Mining can be decomposed into two parts

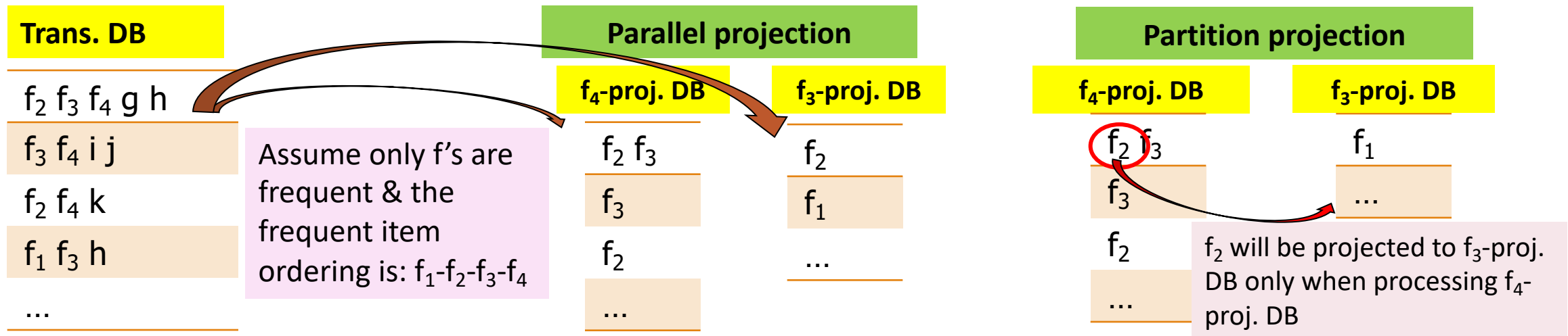


FPGrowth: Mining Frequent Patterns by Pattern Growth

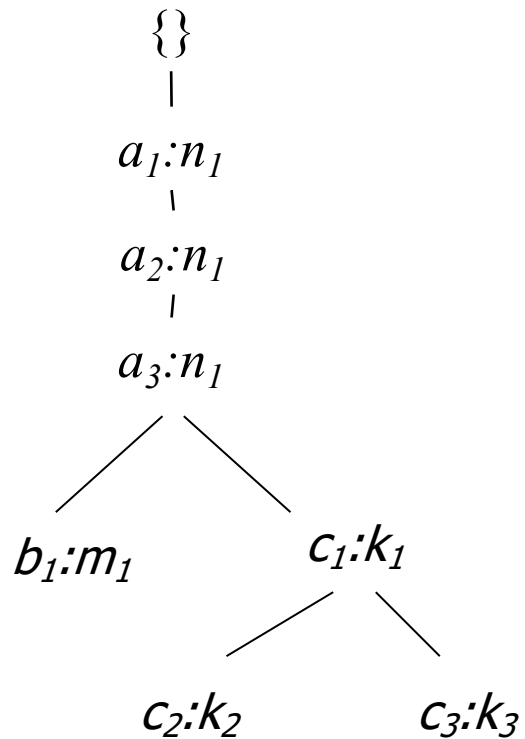
- ❑ Essence of frequent pattern growth (FPGrowth) methodology
 - ❑ Find frequent single items and partition the database based on each such single item pattern
 - ❑ Recursively grow frequent patterns by doing the above for each *partitioned database* (also called the pattern's *conditional database*)
 - ❑ To facilitate efficient processing, an efficient data structure, FP-tree, can be constructed
- ❑ Mining becomes
 - ❑ Recursively construct and mine (conditional) FP-trees
 - ❑ Until the resulting FP-tree is empty, or until it contains only one path—single path will generate all the combinations of its sub-paths, each of which is a frequent pattern

Scaling FP-growth by Item-Based Data Projection

- ❑ What if FP-tree cannot fit in memory?—Do not construct FP-tree
 - ❑ “Project” the database based on frequent single items
 - ❑ Construct & mine FP-tree for each projected DB
- ❑ **Parallel projection** vs. **partition projection**
 - ❑ Parallel projection: Project the DB on each frequent item
 - ❑ Space costly, all partitions can be processed in parallel
 - ❑ Partition projection: Partition the DB in order
 - ❑ Passing the unprocessed parts to subsequent partitions



CLOSET+: Mining Closed Itemsets by Pattern-Growth



- ❑ Efficient, *direct* mining of closed itemsets
- ❑ Intuition:
 - ❑ If an FP-tree contains a single branch as shown left
 - ❑ “a₁, a₂, a₃” should be merged
- ❑ Itemset merging: If Y appears in every occurrence of X, then Y is merged with X
 - ❑ *d*-proj. db: {acef, acf} → *acfd*-proj. db: {e}
 - ❑ Final closed itemset: *acfd*:2
- ❑ There are many other tricks developed
 - ❑ For details, see J. Wang, et al., “CLOSET+: Searching for the Best Strategies for Mining Frequent Closed Itemsets”, KDD'03


TID	Items
1	acdef
2	abe
3	cefg
4	acdf

Let minsupport = 2

a:3, c:3, d:2, e:3, f:3

F-List: a-c-e-f-d

Chapter 6: Mining Frequent Patterns, Association and Correlations: Basic Concepts and Methods

- ☐ Basic Concepts
- ☐ Efficient Pattern Mining Methods
- ☐ Pattern Evaluation 
- ☐ Summary

Pattern Evaluation

- ❑ Limitation of the Support-Confidence Framework
- ❑ Interestingness Measures: Lift and χ^2
- ❑ Null-Invariant Measures
- ❑ Comparison of Interestingness Measures

How to Judge if a Rule/Pattern Is Interesting?

- ❑ Pattern-mining will generate a large set of patterns/rules
 - ❑ Not all the generated patterns/rules are interesting
- ❑ Interestingness measures: Objective vs. subjective
 - ❑ Objective interestingness measures
 - ❑ Support, confidence, correlation, ...
 - ❑ Subjective interestingness measures:
 - ❑ Different users may judge interestingness differently
 - ❑ Let a user specify
 - ❑ Query-based: Relevant to a user's particular request
 - ❑ Judge against one's knowledge-base
 - ❑ unexpected, freshness, timeliness

Limitation of the Support-Confidence Framework

- Are s and c interesting in association rules: " $A \Rightarrow B$ " [s , c]? **Be careful!**
- Example: Suppose one school may have the following statistics on # of students who may play basketball and/or eat cereal:

	play-basketball	not play-basketball	sum (row)
eat-cereal	400	350	750
not eat-cereal	200	50	250
sum(col.)	600	400	1000

2-way contingency table

- Association rule mining may generate the following:
 - $\text{play-basketball} \Rightarrow \text{eat-cereal}$ [40% , 66.7%] (higher s & c)
- But this strong association rule is misleading: The overall % of students eating cereal is $75\% > 66.7\%$, a more telling rule:
 - $\neg \text{play-basketball} \Rightarrow \text{eat-cereal}$ [35% , 87.5%] (high s & c)

$\text{not eat cereal} \rightarrow 35\%$

$75\% \rightarrow \text{eat cereal} \rightarrow \text{lift}$

$\text{not play basketball} \rightarrow \text{eat cereal}$

Interestingness Measure: Lift

- Measure of dependent/correlated events: **lift**

$$lift(B, C) = \frac{c(B \rightarrow C)^{0.667}}{s(C)} = \frac{s(B \cup C)}{s(B) \times s(C)}$$

Lift is more telling than s & c

	B	¬B	Σ _{row}
C	400	350	750
¬C	200	50	250
Σ _{col.}	600	400	1000

- Lift(B, C) may tell how B and C are correlated

- Lift(B, C) = 1: B and C are independent
- > 1: positively correlated
- < 1: negatively correlated

- For our example,

$$lift(B, C) = \frac{400/1000}{600/1000 \times 750/1000} = 0.89$$

$$lift(B, \neg C) = \frac{200/1000}{600/1000 \times 250/1000} = 1.33$$

- Thus, B and C are negatively correlated since lift(B, C) < 1;
 - B and ¬C are positively correlated since lift(B, ¬C) > 1

Interestingness Measure: χ^2

- Another measure to test correlated events: χ^2

$$\chi^2 = \sum \frac{(Observed - Expected)^2}{Expected}$$

- For the table on the right,

	B	$\neg B$	Σ_{row}
C	400 (450)	350 (300)	750
$\neg C$	200 (150)	50 (100)	250
Σ_{col}	600	400	1000

$$\chi^2 = \frac{(400 - 450)^2}{450} + \frac{(350 - 300)^2}{300} + \frac{(200 - 150)^2}{150} + \frac{(50 - 100)^2}{100} = 55.56$$

Expected value

Observed value

- By consulting a table of critical values of the χ^2 distribution, one can conclude that the chance for B and C to be independent is very low (< 0.01)
- χ^2 -test shows B and C are negatively correlated since the expected value is 450 but the observed is only 400
- Thus, χ^2 is also more telling than the support-confidence framework

Lift and χ^2 : Are They Always Good Measures?

- ❑ Null transactions: Transactions that contain neither B nor C
- ❑ Let's examine the new dataset D
 - ❑ BC (100) is much rarer than B¬C (1000) and ¬BC (1000), but there are many ¬B¬C (100000)
 - ❑ Unlikely B & C will happen together!
- ❑ But, $\text{Lift}(B, C) = 8.44 \gg 1$ (Lift shows B and C are strongly positively correlated!)
- ❑ $\chi^2 = 670$: Observed(BC) \gg expected value (11.85)
- ❑ *Too many null transactions may "spoil the soup"!*



	B	¬B	Σ_{row}
C	100	1000	1100
¬C	1000	100000	101000
$\Sigma_{\text{col.}}$	1100	101000	102100

null transactions

Contingency table with expected values added

	B	¬B	Σ_{row}
C	100 (11.85)	1000	1100
¬C	1000 (988.15)	100000	101000
$\Sigma_{\text{col.}}$	1100	101000	102100

Interestingness Measures & Null-Invariance

- ❑ **Null invariance**: Value does not change with the # of null-transactions
- ❑ A few interestingness measures: Some are null invariant

Measure	Definition	Range	Null-Invariant?
$\chi^2(A, B)$	$\sum_{i,j} \frac{(e(a_i, b_j) - o(a_i, b_j))^2}{e(a_i, b_j)}$	$[0, \infty]$	No
$Lift(A, B)$	$\frac{s(A \cup B)}{s(A) \times s(B)}$	$[0, \infty]$	No
$Allconf(A, B)$	$\frac{s(A \cup B)}{\max\{s(A), s(B)\}}$	$[0, 1]$	Yes
$Jaccard(A, B)$	$\frac{s(A \cup B)}{s(A) + s(B) - s(A \cup B)}$	$[0, 1]$	Yes
$Cosine(A, B)$	$\frac{s(A \cup B)}{\sqrt{s(A) \times s(B)}}$	$[0, 1]$	Yes
$Kulczynski(A, B)$	$\frac{1}{2} \left(\frac{s(A \cup B)}{s(A)} + \frac{s(A \cup B)}{s(B)} \right)$	$[0, 1]$	Yes
$MaxConf(A, B)$	$\max\left\{ \frac{s(A \cup B)}{s(A)}, \frac{s(A \cup B)}{s(B)} \right\}$	$[0, 1]$	Yes

χ^2 and lift are not null-invariant

Jaccard, cosine, AllConf, MaxConf, and Kulczynski are null-invariant measures

Null Invariance: An Important Property

□ Why is null invariance crucial for the analysis of massive transaction data?

□ Many transactions may contain neither milk nor coffee!

milk vs. coffee contingency table

	<i>milk</i>	$\neg milk$	Σ_{row}
<i>coffee</i>	<i>mc</i>	$\neg mc$	<i>c</i>
$\neg coffee$	<i>m</i> $\neg c$	$\neg m$ $\neg c$	$\neg c$
Σ_{col}	<i>m</i>	$\neg m$	Σ

□ Lift and χ^2 are not null-invariant: not good to evaluate data that contain too many or too few null transactions!

□ Many measures are not null-invariant!

Null-transactions
w.r.t. *m* and *c*

Data set	<i>mc</i>	$\neg mc$	<i>m</i> $\neg c$	$\neg m$ $\neg c$	χ^2	<i>Lift</i>
<i>D</i> ₁	10,000	1,000	1,000	100,000	90557	9.26
<i>D</i> ₂	10,000	1,000	1,000	100	0	1
<i>D</i> ₃	100	1,000	1,000	100,000	670	8.44
<i>D</i> ₄	1,000	1,000	1,000	100,000	24740	25.75
<i>D</i> ₅	1,000	100	10,000	100,000	8173	9.18
<i>D</i> ₆	1,000	10	100,000	100,000	965	1.97

Comparison of Null-Invariant Measures

- ❑ Not all null-invariant measures are created equal
- ❑ Which one is better?
 - ❑ D_4 — D_6 differentiate the null-invariant measures
 - ❑ Kulc (Kulczynski 1927) holds firm and is in balance of both directional implications

2-variable contingency table

	<i>milk</i>	$\neg milk$	Σ_{row}
<i>coffee</i>	<i>mc</i>	$\neg mc$	<i>c</i>
$\neg coffee$	$m\neg c$	$\neg m\neg c$	$\neg c$
Σ_{col}	<i>m</i>	$\neg m$	Σ

All 5 are null-invariant

Data set	<i>mc</i>	$\neg mc$	$m\neg c$	$\neg m\neg c$	<i>AllConf</i>	Jaccard	<i>Cosine</i>	<i>Kulc</i>	<i>MaxConf</i>
D_1	10,000	1,000	1,000	100,000	0.91	0.83	0.91	0.91	0.91
D_2	10,000	1,000	1,000	100	0.91	0.83	0.91	0.91	0.91
D_3	100	1,000	1,000	100,000	0.09	0.05	0.09	0.09	0.09
D_4	1,000	1,000	1,000	100,000	0.5	0.33	0.5	0.5	0.5
D_5	1,000	100	10,000	100,000	0.09	0.09	0.29	0.5	0.91
D_6	1,000	10	100,000	100,000	0.01	0.01	0.10	0.5	0.99

Subtle: They disagree on those cases

Analysis of DBLP Coauthor Relationships

- DBLP: Computer science research publication bibliographic database
 - > 3.8 million entries on authors, paper, venue, year, and other information

ID	Author <i>A</i>	Author <i>B</i>	$s(A \cup B)$	$s(A)$	$s(B)$	Jaccard	<i>Cosine</i>	<i>Kulc</i>
1	Hans-Peter Kriegel	Martin Ester	28	146	54	0.163 (2)	0.315 (7)	0.355 (9)
2	Michael Carey	Miron Livny	26	104	58	0.191 (1)	0.335 (4)	0.349 (10)
3	Hans-Peter Kriegel	Joerg Sander	24	146	36	0.152 (3)	0.331 (5)	0.416 (8)
4	Christos Faloutsos	Spiros Papadimitriou	20	162	26	0.119 (7)	0.308 (10)	0.446 (7)
5	Hans-Peter Kriegel	Martin Pfeifle	18	146	18	0.123 (6)	0.351 (2)	0.562 (2)
6	Hector Garcia-Molina	Wilburt Labio	16	144	18	0.110 (9)	0.314 (8)	0.500 (4)
7	Divyakant Agrawal	Wang Hsiung	16	120	16	0.133 (5)	0.365 (1)	0.567 (1)
8	Elke Rundensteiner	Murali Mani	16	104	20	0.148 (4)	0.351 (3)	0.477 (6)
9	Divyakant Agrawal	Oliver Po	12	120	12	0.100 (10)	0.316 (6)	0.550 (3)
10	Gerhard Weikum	Martin Theobald	12	106	14	0.111 (8)	0.312 (9)	0.485 (5)

Advisor-advisee relation: Kulc: high, Jaccard: low, cosine: middle

- Which pairs of authors are strongly related?
 - Use Kulc to find Advisor-advisee, close collaborators

Imbalance Ratio with Kulczynski Measure

- IR (Imbalance Ratio): measure the imbalance of two itemsets A and B in rule implications:

$$IR(A, B) = \frac{|s(A) - s(B)|}{s(A) + s(B) - s(A \cup B)}$$


- Kulczynski and Imbalance Ratio (IR) together present a clear picture for all the three datasets D_4 through D_6
 - D_4 is neutral & balanced; D_5 is neutral but imbalanced
 - D_6 is neutral but very imbalanced

Data set	mc	$\neg mc$	$m\neg c$	$\neg m\neg c$	Jaccard	Cosine	Kulc	IR
D_1	10,000	1,000	1,000	100,000	0.83	0.91	0.91	0
D_2	10,000	1,000	1,000	100	0.83	0.91	0.91	0
D_3	100	1,000	1,000	100,000	0.05	0.09	0.09	0
D_4	1,000	1,000	1,000	100,000	0.33	0.5	0.5	0
D_5	1,000	100	10,000	100,000	0.09	0.29	0.5	0.89
D_6	1,000	10	100,000	100,000	0.01	0.10	0.5	0.99

What Measures to Choose for Effective Pattern Evaluation?

- ❑ Null value cases are predominant in many large datasets
 - ❑ Neither milk nor coffee is in most of the baskets; neither Mike nor Jim is an author in most of the papers;
- ❑ *Null-invariance* is an important property
- ❑ Lift, χ^2 and cosine are good measures if null transactions are not predominant
 - ❑ Otherwise, *Kulczynski + Imbalance Ratio* should be used to judge the interestingness of a pattern
- ❑ Exercise: Mining research collaborations from research bibliographic data
 - ❑ Find a group of frequent collaborators from research bibliographic data (e.g., DBLP)
 - ❑ Can you find the likely advisor-advisee relationship and during which years such a relationship happened?
 - ❑ Ref.: C. Wang, J. Han, Y. Jia, J. Tang, D. Zhang, Y. Yu, and J. Guo, "Mining Advisor-Advisee Relationships from Research Publication Networks", KDD'10

Chapter 6: Mining Frequent Patterns, Association and Correlations: Basic Concepts and Methods

- ❑ Basic Concepts
- ❑ Efficient Pattern Mining Methods
- ❑ Pattern Evaluation
- ❑ Summary 

Summary

- ❑ Basic Concepts
 - ❑ What Is Pattern Discovery? Why Is It Important?
 - ❑ Basic Concepts: Frequent Patterns and Association Rules
 - ❑ Compressed Representation: Closed Patterns and Max-Patterns
- ❑ Efficient Pattern Mining Methods
 - ❑ The Downward Closure Property of Frequent Patterns
 - ❑ The Apriori Algorithm
 - ❑ Extensions or Improvements of Apriori
 - ❑ Mining Frequent Patterns by Exploring Vertical Data Format
 - ❑ FPGrowth: A Frequent Pattern-Growth Approach
 - ❑ Mining Closed Patterns
- ❑ Pattern Evaluation
 - ❑ Interestingness Measures in Pattern Mining
 - ❑ Interestingness Measures: Lift and χ^2
 - ❑ Null-Invariant Measures
 - ❑ Comparison of Interestingness Measures

Recommended Readings (Basic Concepts)

- ❑ R. Agrawal, T. Imielinski, and A. Swami, “Mining association rules between sets of items in large databases”, in Proc. of SIGMOD'93
- ❑ R. J. Bayardo, “Efficiently mining long patterns from databases”, in Proc. of SIGMOD'98
- ❑ N. Pasquier, Y. Bastide, R. Taouil, and L. Lakhal, “Discovering frequent closed itemsets for association rules”, in Proc. of ICDT'99
- ❑ J. Han, H. Cheng, D. Xin, and X. Yan, “Frequent Pattern Mining: Current Status and Future Directions”, Data Mining and Knowledge Discovery, 15(1): 55-86, 2007

Recommended Readings (Efficient Pattern Mining Methods)

- ❑ R. Agrawal and R. Srikant, “Fast algorithms for mining association rules”, VLDB'94
- ❑ A. Savasere, E. Omiecinski, and S. Navathe, “An efficient algorithm for mining association rules in large databases”, VLDB'95
- ❑ J. S. Park, M. S. Chen, and P. S. Yu, “An effective hash-based algorithm for mining association rules”, SIGMOD'95
- ❑ S. Sarawagi, S. Thomas, and R. Agrawal, “Integrating association rule mining with relational database systems: Alternatives and implications”, SIGMOD'98
- ❑ M. J. Zaki, S. Parthasarathy, M. Ogihara, and W. Li, “Parallel algorithm for discovery of association rules”, Data Mining and Knowledge Discovery, 1997
- ❑ J. Han, J. Pei, and Y. Yin, “Mining frequent patterns without candidate generation”, SIGMOD'00
- ❑ M. J. Zaki and Hsiao, “CHARM: An Efficient Algorithm for Closed Itemset Mining”, SDM'02
- ❑ J. Wang, J. Han, and J. Pei, “CLOSET+: Searching for the Best Strategies for Mining Frequent Closed Itemsets”, KDD'03
- ❑ C. C. Aggarwal, M.A., Bhuiyan, M. A. Hasan, “Frequent Pattern Mining Algorithms: A Survey”, in Aggarwal and Han (eds.): Frequent Pattern Mining, Springer, 2014

Recommended Readings (Pattern Evaluation)

- ❑ C. C. Aggarwal and P. S. Yu. A New Framework for Itemset Generation. PODS'98
- ❑ S. Brin, R. Motwani, and C. Silverstein. Beyond market basket: Generalizing association rules to correlations. SIGMOD'97
- ❑ M. Klemettinen, H. Mannila, P. Ronkainen, H. Toivonen, and A. I. Verkamo. Finding interesting rules from large sets of discovered association rules. CIKM'94
- ❑ E. Omiecinski. Alternative Interest Measures for Mining Associations. TKDE'03
- ❑ P.-N. Tan, V. Kumar, and J. Srivastava. Selecting the Right Interestingness Measure for Association Patterns. KDD'02
- ❑ T. Wu, Y. Chen and J. Han, Re-Examination of Interestingness Measures in Pattern Mining: A Unified Framework, Data Mining and Knowledge Discovery, 21(3):371-397, 2010

