



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





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

- Basic Concepts 
- 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?

↳ ការការពិនិត្យ search នៃ Google ក្នុង Pattern

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 *glove, VDO*
 - Market basket analysis, cross-marketing, catalog design, sale campaign analysis, Web log analysis, biological sequence analysis

Basic Concepts: k-Itemsets and Their Supports

- **Itemset:** A set of one or more items
- **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. $\text{sup}\{\text{Beer, Diaper}\} = 3$
 - Ex. $\text{sup}\{\text{Beer, Eggs}\} = 1$

Transaction ID (ກະລຸນາຕາງໜີໃບຕົວລາຍລະອຽດ)

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

- **(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. $s\{\text{Beer, Eggs}\} = 1/5 = 20\%$

5 11ຄວ

ຈຳກວດ transaction
ທີ່ support (Beer, Eggs)

ໄປຮູ້ຮ່າງສາມາດແນ່ວ່າຫຼຸດ
ເກືອບເກີນເພື່ອຫຼຸດ

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 *ຈະ ບໍລິສັດໃນນີ້ແລ້ວ?*
- ❑ 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

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

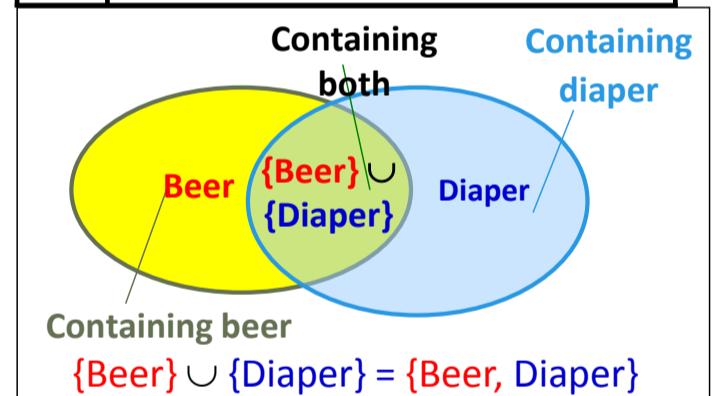
- ❑ Why do these itemsets (shown on the left) form the complete set of frequent k-itemsets (patterns) for any k ?
- ❑ **Observation:** We may need an efficient method to mine a complete set of frequent patterns

From Frequent Itemsets to Association Rules

- Comparing with itemsets, rules can be more telling
 - Ex. $\text{Diaper} \rightarrow \text{Beer}$
 - *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. $s\{\text{Diaper}, \text{Beer}\} = 3/5 = 0.6$ (i.e., 60%)
 - **Confidence**, c: The *conditional probability* that a transaction containing X also contains Y
 - Calculation: $c = \text{sup}(X \cup Y) / \text{sup}(X) \leq \frac{3/5}{4/5} = \frac{3}{4} = 0.75$
 - Ex. $c = \text{sup}\{\text{Diaper}, \text{Beer}\}/\text{sup}\{\text{Diaper}\} = \frac{3}{4} = 0.75$

S x, g { / {x} wso 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?)

Item 1 မျှနဲ့
Minsup ကို 50% မျှော်လဲ။



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

ကျေစွဲ Beer သွေစွဲ Diaper ပေါ်
ကျေအေကြတ် Diaper ပျော်စွဲတဲ့ Beer

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:

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

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 $\{a_1, \dots, a_{40}\}, \dots$, 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

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

The Downward Closure Property of Frequent Patterns

- Observation: From TDB₁: T₁: {a₁, ..., a₅₀}; T₂: {a₁, ..., a₁₀₀}
 - We get a frequent itemset: {a₁, ..., a₅₀}
 - Also, its subsets are all frequent: {a₁}, {a₂}, ..., {a₅₀}, {a₁, a₂}, ..., {a₁, ..., a₄₉}, ...
 - 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}
 - Apriori: Any subset of a frequent itemset must be frequent
- 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, Ogihsara, 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
 - **Repeat**
 - Generate length-($k+1$) candidate itemsets from length- k frequent 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 := {frequent items}; // frequent 1-itemset

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

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

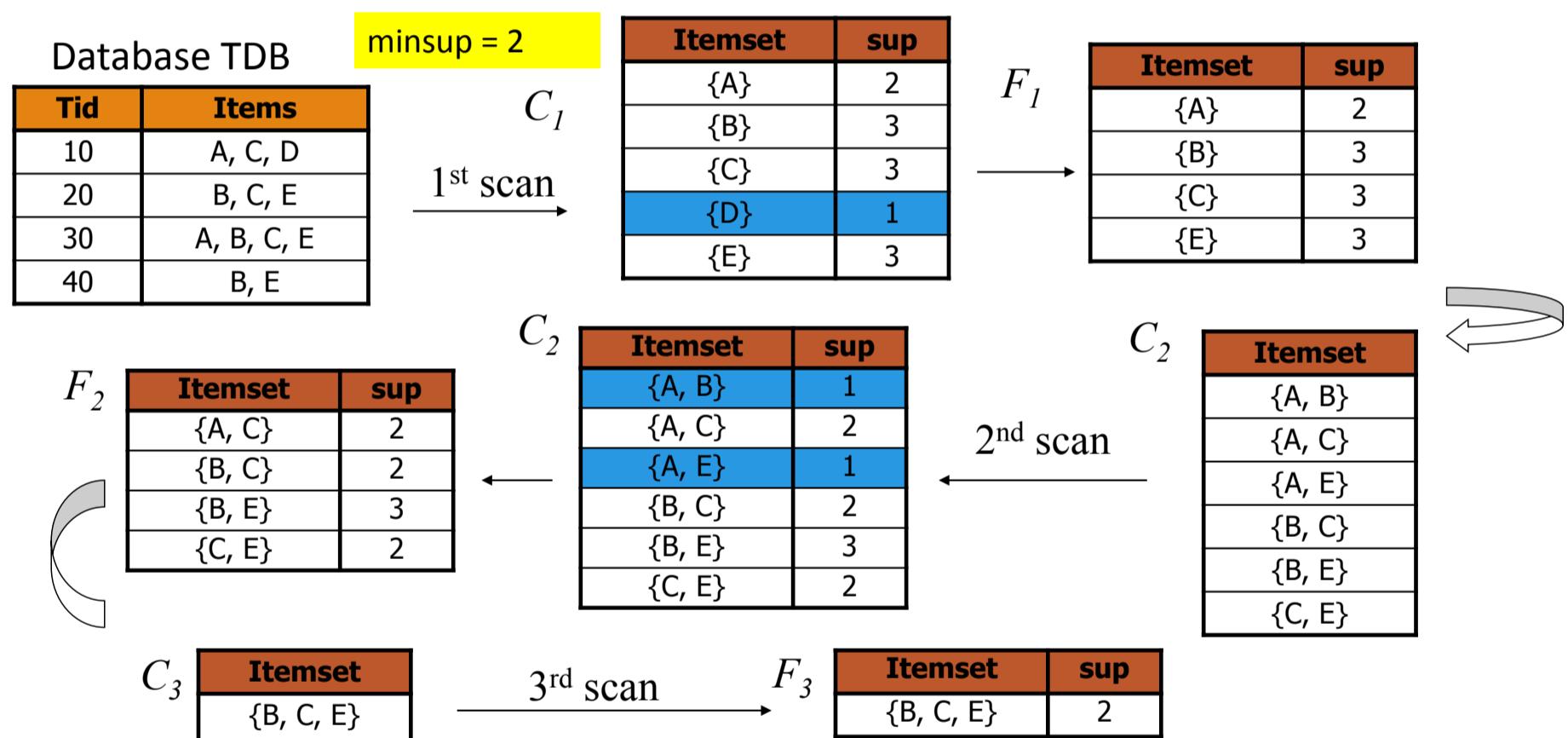
Derive F_{k+1} by counting candidates in C_{k+1} with respect to TDB at minsup;

k := k + 1

}

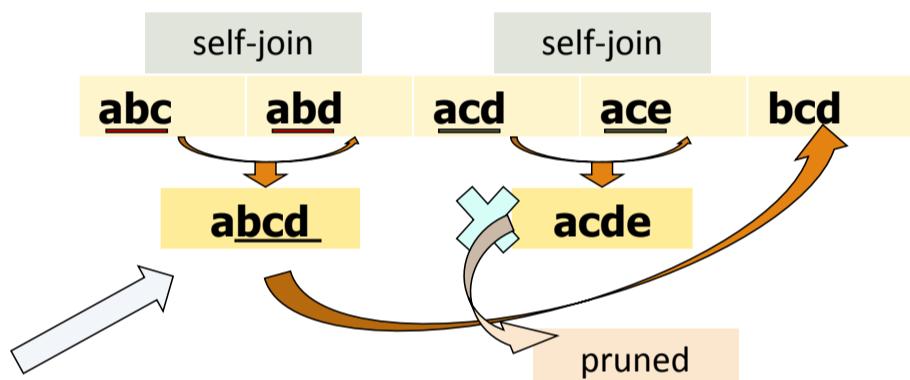
return $\cup_k F_k$ // return F_k generated at each level

The Apriori Algorithm—An Example



Apriori: Implementation Tricks

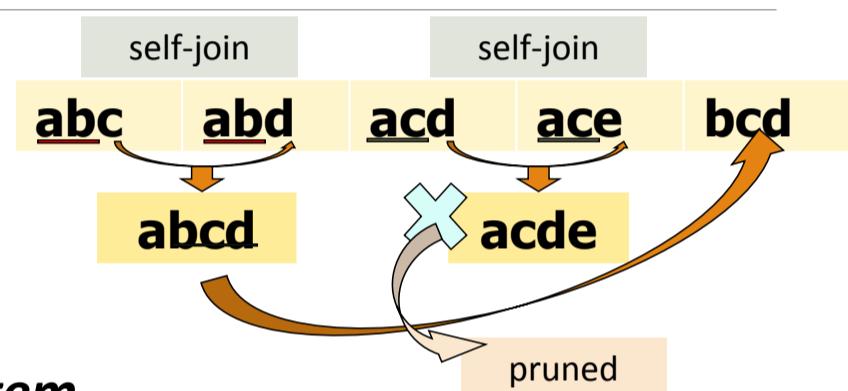
- How to generate candidates?
 - Step 1: self-joining F_k
 - Step 2: pruning
- Example of candidate-generation
 - $F_3 = \{abc, abd, acd, ace, bcd\}$
 - Self-joining: $F_3 * F_3$
 - $abcd$ from abc and abd
 - $acde$ from acd and ace
 - Pruning:
 - $acde$ is removed because ade is not in F_3
 - $C_4 = \{abcd\}$



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.item1, p.item2, ..., p.itemk-1, q.itemk-1
from Fk-1 as p, Fk-1 as q
where p.item1=q.item1, ..., p.itemk-2=q.itemk-2, p.itemk-1< q.itemk-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)  To be discussed in subsequent slides
 - Dynamic itemset counting (Brin, et al., 1997)
- Shrink the number of candidates
 - Hashing (e.g., DHP: Park, et al., 1995)  To be discussed in subsequent slides
 - 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)
 - Hypocube decomposition (e.g., LCM: Uno, et al., 2004)

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

The diagram illustrates the decomposition of a database TDB into k partitions. It shows a large rectangle labeled TDB on the right, preceded by a plus sign. To its left is a sequence of k smaller rectangles, each labeled TDB_i below it. Between the first two rectangles is another plus sign. Ellipses between the second and third rectangles indicate intermediate partitions, and ellipses below the third partition indicate additional partitions up to k . Below the first partition is the condition $\text{sup}_1(X) < \sigma|TDB_1|$. Below the second partition is the condition $\text{sup}_2(X) < \sigma|TDB_2|$. Below the third partition is the condition \dots . Below the k -th partition is the condition $\text{sup}_k(X) < \sigma|TDB_k|$. Below the entire sum is the final condition $\text{sup}(X) < \sigma|TDB|$. A yellow box containing the text "Here is the proof!" is positioned to the left of the first partition.

- 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
 - ❑ 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 $\text{count}\{\text{ab, ad, ce}\} < 80$

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

Hash Table

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: $t(e) = \{T_{10}, T_{20}, T_{30}\}$; $t(a) = \{T_{10}, T_{20}\}$; $t(ce) = \{T_{10}, T_{20}\}$
- ❑ 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 ρ , can subsequent search be confined to only those transactions that containing ρ ?
- ❑ Such thinking leads to a frequent pattern growth approach:
 - ❑ FP-Growth (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"

- Scan DB once, find single item frequent pattern:

Let min_support = 3

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

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

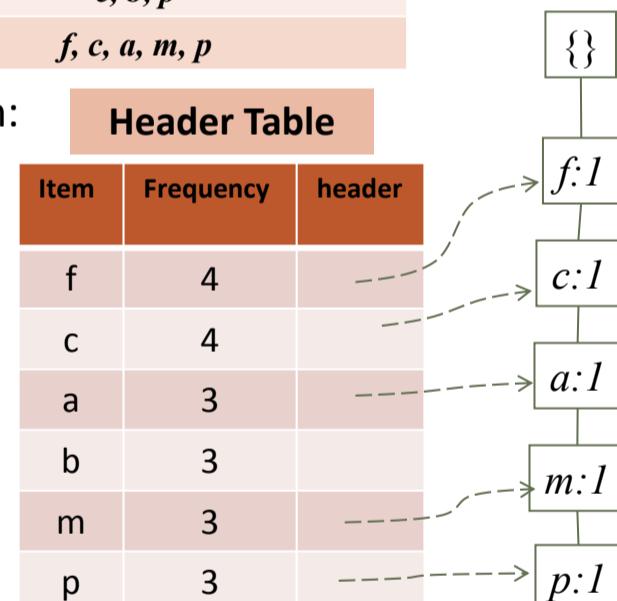
F-list = f-c-a-b-m-p

- 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"

- Scan DB once, find single item frequent pattern:

Let min_support = 3

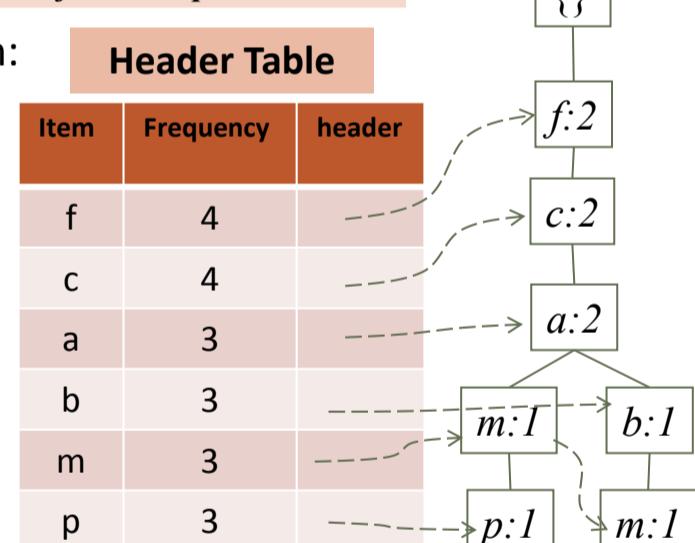
f:4, a:3, c:4, b:3, m:3, p:3

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

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

- Scan DB again, construct FP-tree

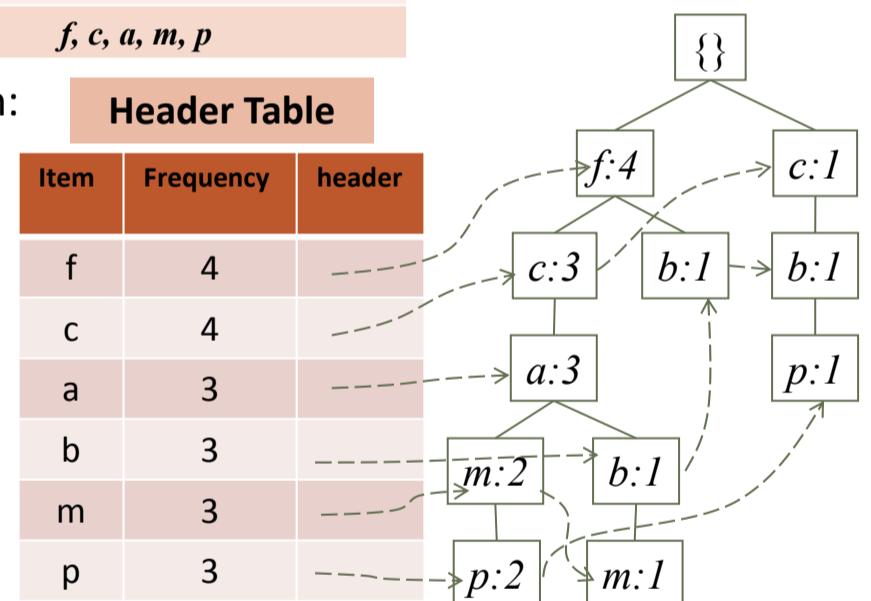
The frequent itemlist of each transaction is inserted as a branch, with shared sub-branches merged, counts accumulated



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 all the frequent itemlists



- Scan DB once, find single item frequent pattern:

Let min_support = 3

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

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

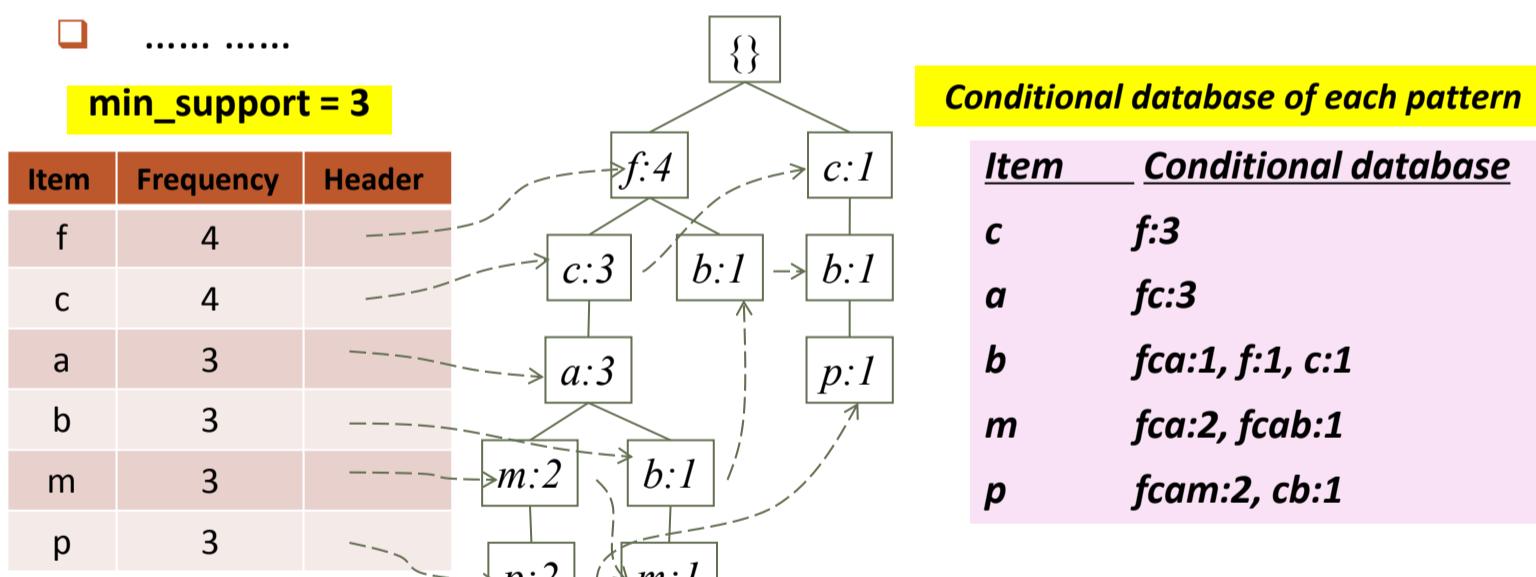
F-list = f-c-a-b-m-p

- Scan DB again, construct FP-tree

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

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: $fca:2, fcab:1$
 -



Mine Each Conditional Database Recursively

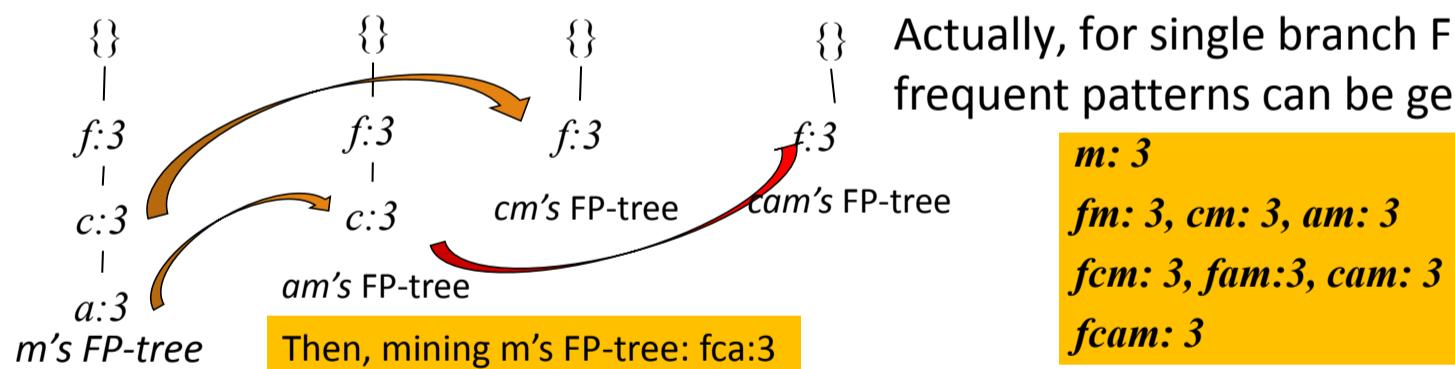
min_support = 3	
Conditional Data Bases	
item	cond. data base
c	f:3
a	fc:3
b	fca:1, f:1, c:1
m	fca:2, fcab:1
p	fcam:2, cb:1

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

p's conditional DB: $fcam:2, cb:1 \rightarrow c: 3$

m's conditional DB: $fca:2, fcab:1 \rightarrow fca: 3$

b's conditional DB: $fca:1, f:1, c:1 \rightarrow \phi$

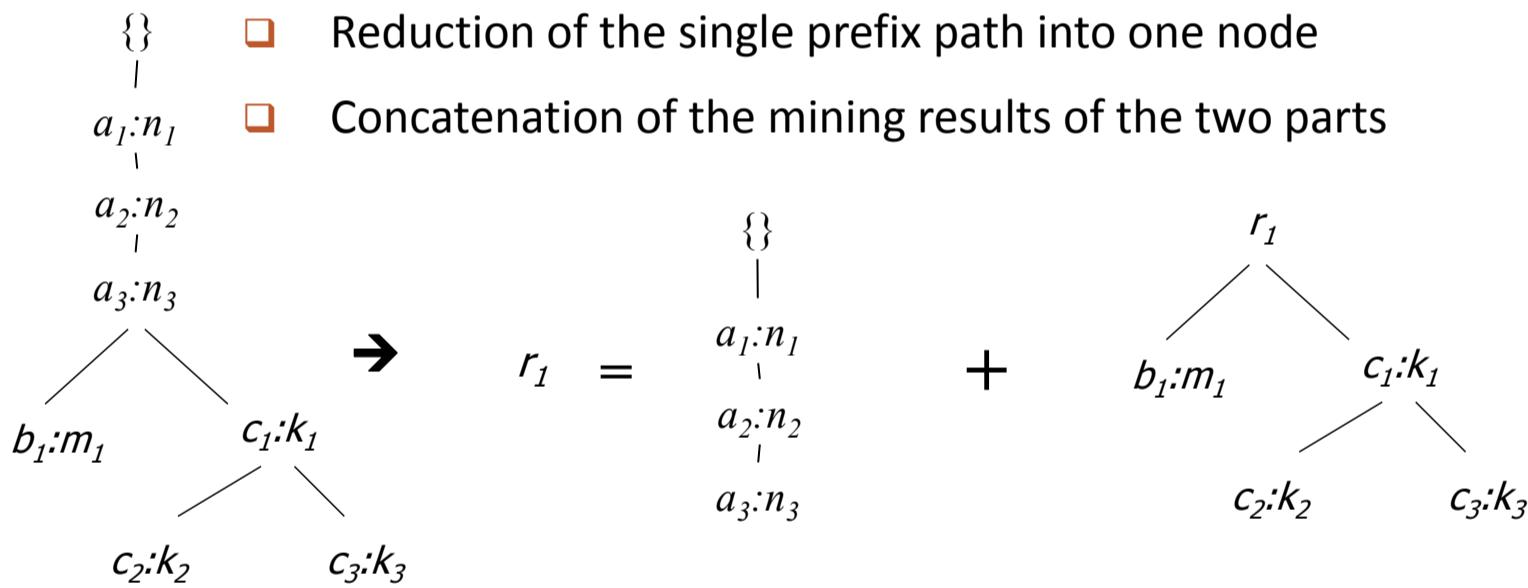


Actually, for single branch FP-tree, all the frequent patterns can be generated in one shot

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

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

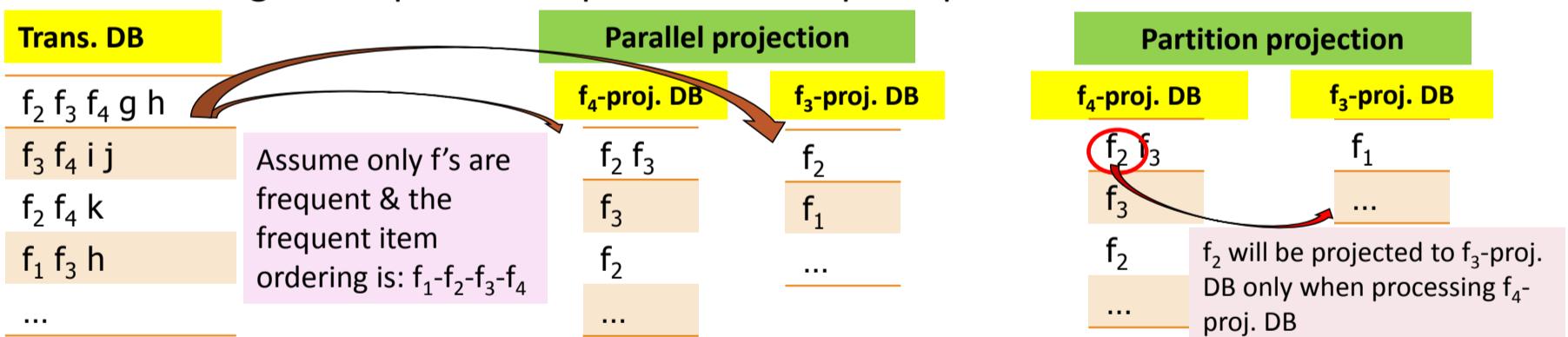


FPGrowth: Mining Frequent Patterns by Pattern Growth

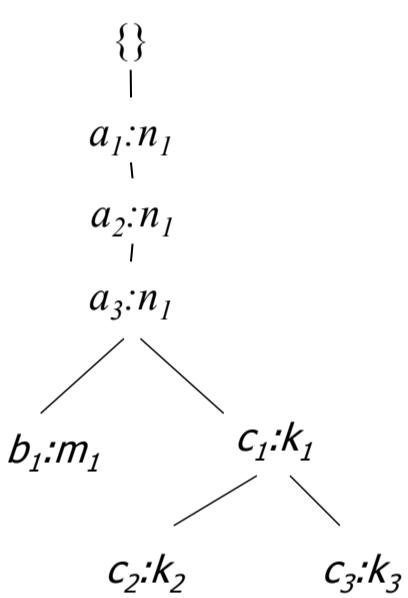
- Essence of frequent pattern growth (FPGrowth) methodology
 - Find frequent single items and partition the database based on each such single item pattern
 - Recursively grow frequent patterns by doing the above for each *partitioned database* (also called the pattern's *conditional database*)
 - To 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
 - ❑ “ a_1, a_2, a_3 ” should be merged
- ❑ Itemset merging: If Y appears in every occurrence of X, then Y is merged with X
 - ❑ $d\text{-proj. db: } \{acef, acf} \rightarrow acfd\text{-proj. db: } \{e\}$
 - ❑ 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:
 - $play\text{-}basketball \Rightarrow eat\text{-}cereal$ [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:
 - $\neg play\text{-}basketball \Rightarrow eat\text{-}cereal$ [35%, 87.5%] (high s & c)

Interestingness Measure: Lift

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

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

- 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 $\neg C$ are positively correlated since lift(B, $\neg C$) > 1

Lift is more telling than s & c

	B	$\neg B$	Σ_{row}
C	400	350	750
$\neg C$	200	50	250
$\Sigma_{\text{col.}}$	600	400	1000

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,

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

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

Observed value

Expected 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, Lift(B, C) = 8.44 >> 1 (Lift shows B and C are strongly positively correlated!)
 - $\chi^2 = 670$: Observed(BC) >> expected value (11.85)
 - *Too many null transactions may “spoil the soup”!*



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

null transactions

Contingency table with expected values added

	B	$\neg B$	Σ_{row}
C	100 (11.85)	1000	1100
$\neg C$	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>	$\neg\text{milk}$	Σ_{row}
<i>coffee</i>	<i>mc</i>	$\neg\text{mc}$	<i>c</i>
$\neg\text{coffee}$	$m\neg c$	$\neg m\neg c$	$\neg c$
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>	$\neg\text{mc}$	$m\neg c$	$\neg m\neg c$	χ^2	Lift
D_1	10,000	1,000	1,000	100,000	90557	9.26
D_2	10,000	1,000	1,000	100	0	1
D_3	100	1,000	1,000	100,000	670	8.44
D_4	1,000	1,000	1,000	100,000	24740	25.75
D_5	1,000	100	10,000	100,000	8173	9.18
D_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>	$\neg\text{milk}$	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

All 5 are null-invariant

Data set	<i>mc</i>	$\neg mc$	<i>m</i> $\neg c$	$\neg m$ $\neg c$	<i>AllConf</i>	Jaccard	Cosine	Kulc	MaxConf
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 A	Author B	$s(A \cup B)$	$s(A)$	$s(B)$	Jaccard	Cosine	Kulc
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	Wilbert 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 D₄ through D₆
 - D₄ is neutral & balanced; D₅ is neutral but imbalanced
 - D₆ is neutral but very imbalanced

Data set	<i>mc</i>	$\neg mc$	<i>m</i> $\neg c$	$\neg m$ $\neg c$	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
 - ❑ FP-Growth: 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. Ogihsara, 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

