

Frequent Itemsets

The Market-Basket Model

Association Rules

A-Priori Algorithm

Other Algorithms

Jeffrey D. Ullman
Stanford University



More Administrivia

- 2% of your grade will be for answering other students' questions on Piazza.
 - 18% for Gradiance.
- Piazza code is **mmds**.
- Please use only one Gradiance account.
- Review sessions the next two Fridays, from 4:30-6PM, in B01 Gates.
 - This Friday: Statistics.
 - Next Friday: Linear Algebra.

The Market-Basket Model

- A large set of *items*, e.g., things sold in a supermarket.
- A large set of *baskets*, each of which is a **small** set of the items, e.g., the things one customer buys on one day.

Support

- Simplest question: find sets of items that appear “frequently” in the baskets.
- *Support* for itemset I = the number of baskets containing all items in I .
 - Sometimes given as a percentage of the baskets.
- Given a *support threshold* s , a set of items appearing in at least s baskets is called a *frequent itemset*.

Example: Frequent Itemsets

- Items={milk, coke, pepsi, beer, juice}.
- Support = 3 baskets.

$$B_1 = \{m, c, b\}$$

$$B_2 = \{m, p, j\}$$

$$B_3 = \{m, b\}$$

$$B_4 = \{c, j\}$$

$$B_5 = \{m, p, b\}$$

$$B_6 = \{m, c, b, j\}$$

$$B_7 = \{c, b, j\}$$

$$B_8 = \{b, c\}$$

- Frequent itemsets: $\{m\}$, $\{c\}$, $\{b\}$, $\{j\}$,
 $\{m, b\}$, $\{b, c\}$, $\{c, j\}$.

Applications

- “Classic” application was analyzing what people bought together in a brick-and-mortar store.
 - Apocryphal story of “diapers and beer” discovery.
 - Used to position potato chips between diapers and beer to enhance sales of potato chips.
- Many other applications, including plagiarism detection; see MMDS.

Association Rules

- If-then rules about the contents of baskets.
- $\{i_1, i_2, \dots, i_k\} \rightarrow j$ means: “if a basket contains all of i_1, \dots, i_k then it is *likely* to contain j .”
- *Confidence* of this association rule is the probability of j given i_1, \dots, i_k .
 - That is, the fraction of the baskets with i_1, \dots, i_k that also contain j .
- Generally want both high confidence and high support for the set of items involved.
- We’ll worry about support and itemsets, not association rules.

Example: Confidence

- + $B_1 = \{m, c, b\}$
- $B_3 = \{m, b\}$
- $B_5 = \{m, p, b\}$
- $B_7 = \{c, b, j\}$
- $B_2 = \{m, p, j\}$
- $B_4 = \{c, j\}$
- + $B_6 = \{m, c, b, j\}$
- $B_8 = \{b, c\}$

- An association rule: $\{m, b\} \rightarrow c$.
 - Confidence = $2/4 = 50\%$.

Computation Model

- Typically, data is kept in flat files.
- Stored on disk.
- Stored basket-by-basket.
- Expand baskets into pairs, triples, etc. as you read baskets.
 - Use k nested loops to generate all sets of size k .

Computation Model – (2)

- The true cost of mining disk-resident data is usually the **number of disk I/O's**.
- In practice, algorithms for finding frequent itemsets read the data in *passes* – all baskets read in turn.
- Thus, we measure the cost by the **number of passes** an algorithm takes.

Main-Memory Bottleneck

- For many frequent-itemset algorithms, main memory is the critical resource.
- As we read baskets, we need to count something, e.g., occurrences of pairs of items.
- The number of different things we can count is limited by main memory.
- Swapping counts in/out is a disaster.

Finding Frequent Pairs

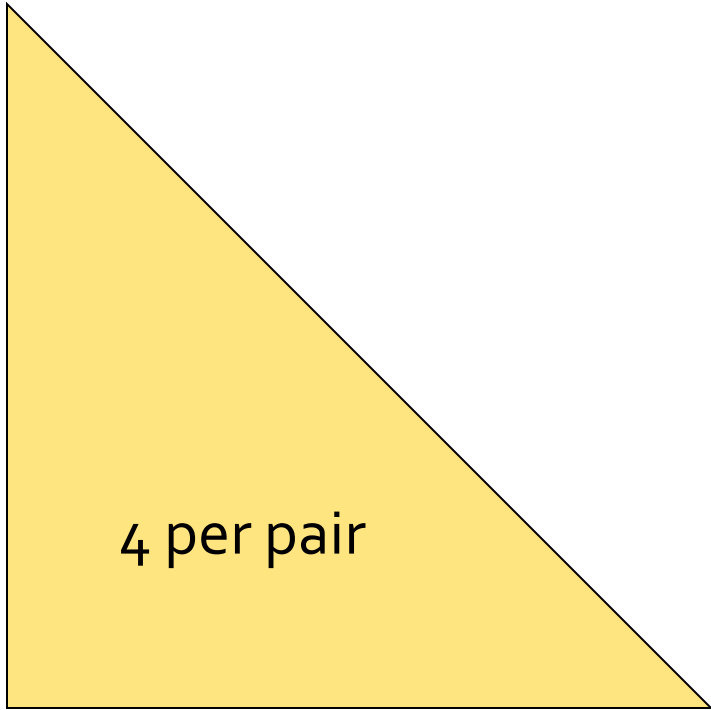
- The hardest problem often turns out to be finding the frequent pairs.
 - **Why?** Often frequent pairs are common, frequent triples are rare.
 - **Why?** Support threshold is usually set high enough that you don't get too many frequent itemsets.
- We'll concentrate on pairs, then extend to larger sets.

Naïve Algorithm

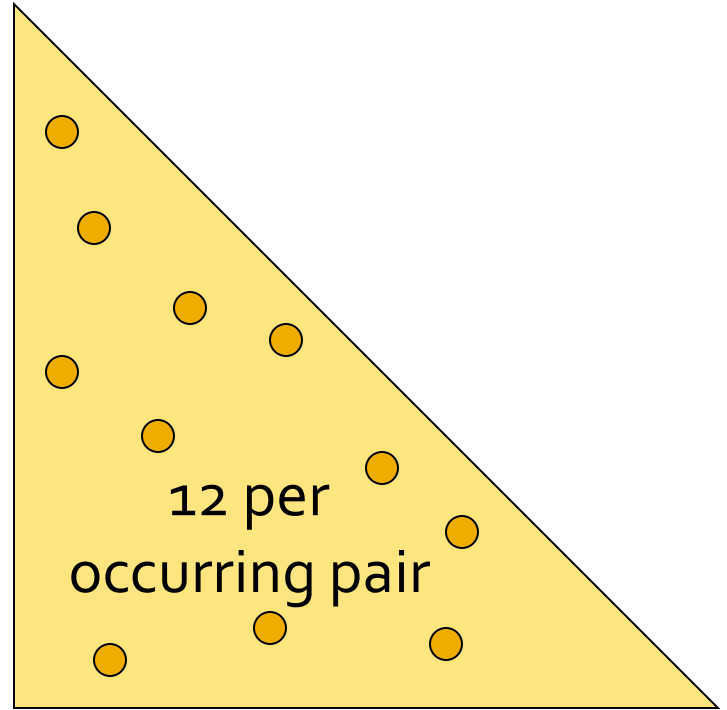
- Read file once, counting in main memory the occurrences of each pair.
 - From each basket of n items, generate its $n(n-1)/2$ pairs by two nested loops.
- Fails if $(\#items)^2$ exceeds main memory.
 - **Example:** Walmart sells 100K items, so probably OK.
 - **Example:** Web has 100B pages, so definitely not OK.

Details of Main-Memory Counting

- Two approaches:
 1. Count all pairs, using a triangular matrix.
 2. Keep a table of triples $[i, j, c]$ = “the count of the pair of items $\{i, j\}$ is c .”
- (1) requires only 4 bytes/pair.
 - **Note:** always assume integers are 4 bytes.
- (2) requires 12 bytes, but only for those pairs with count > 0 .



Triangular matrix



Tabular method

Triangular-Matrix Approach

- Number items $1, 2, \dots, n$.
 - Requires table of size $O(n)$ to convert item names to consecutive integers.
- Count $\{i, j\}$ only if $i < j$.
- Keep pairs in the order $\{1,2\}, \{1,3\}, \dots, \{1,n\}, \{2,3\}, \{2,4\}, \dots, \{2,n\}, \{3,4\}, \dots, \{3,n\}, \dots, \{n-1,n\}$.
- Find pair $\{i, j\}$, where $i < j$, at the position:
$$(i-1)(n-i/2) + j - i$$
- Total number of pairs $n(n-1)/2$; total bytes about $2n^2$.

Details of Tabular Approach

- Total bytes used is about $12p$, where p is the number of pairs that actually occur.
 - Beats triangular matrix if at most $1/3$ of possible pairs actually occur.
- May require extra space for retrieval structure, e.g., a hash table.

The A-Priori Algorithm

Monotonicity of “Frequent”

Candidate Pairs

Extension to Larger Itemsets

A-Priori Algorithm

- A two-pass approach called *a-priori* limits the need for main memory.
- Key idea: *monotonicity*: if a set of items appears at least s times, so does every subset of the set.
- **Contrapositive for pairs**: if item i does not appear in s baskets, then no pair including i can appear in s baskets.

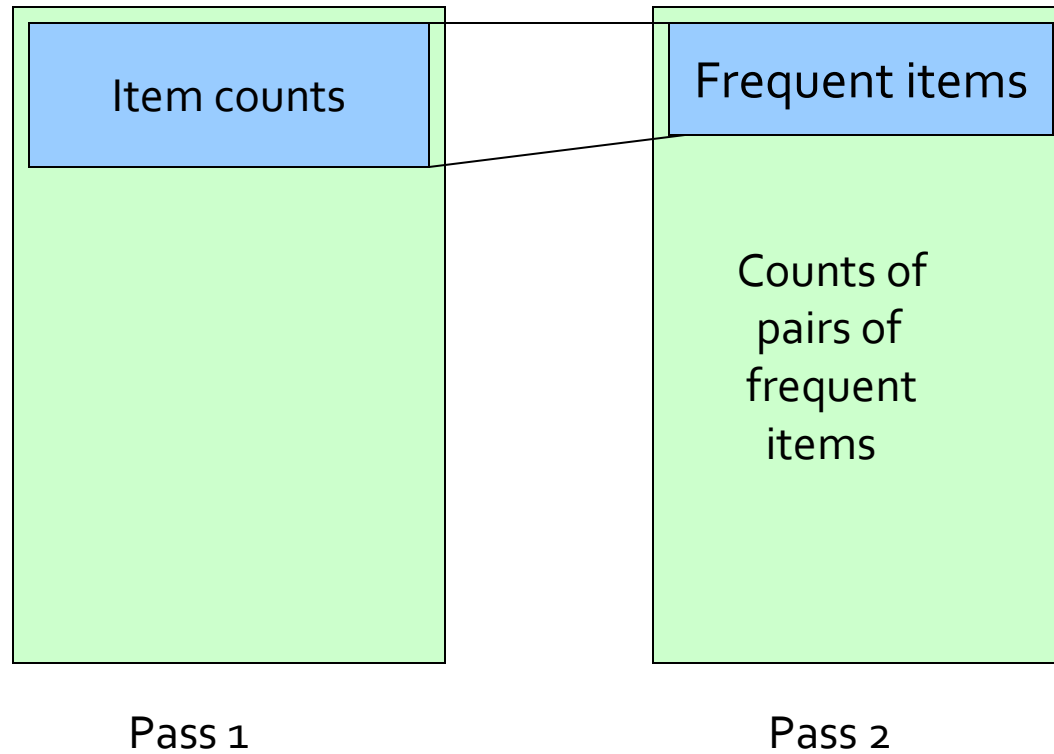
A-Priori Algorithm – (2)

- **Pass 1:** Read baskets and count in main memory the occurrences of each item.
 - Requires only memory proportional to #items.
- Items that appear at least s times are the *frequent items*.

A-Priori Algorithm – (3)

- **Pass 2:** Read baskets again and count in main memory only those pairs both of which were found in Pass 1 to be frequent.
- Requires memory proportional to square of *frequent* items only (for counts), plus a list of the frequent items (so you know what must be counted).

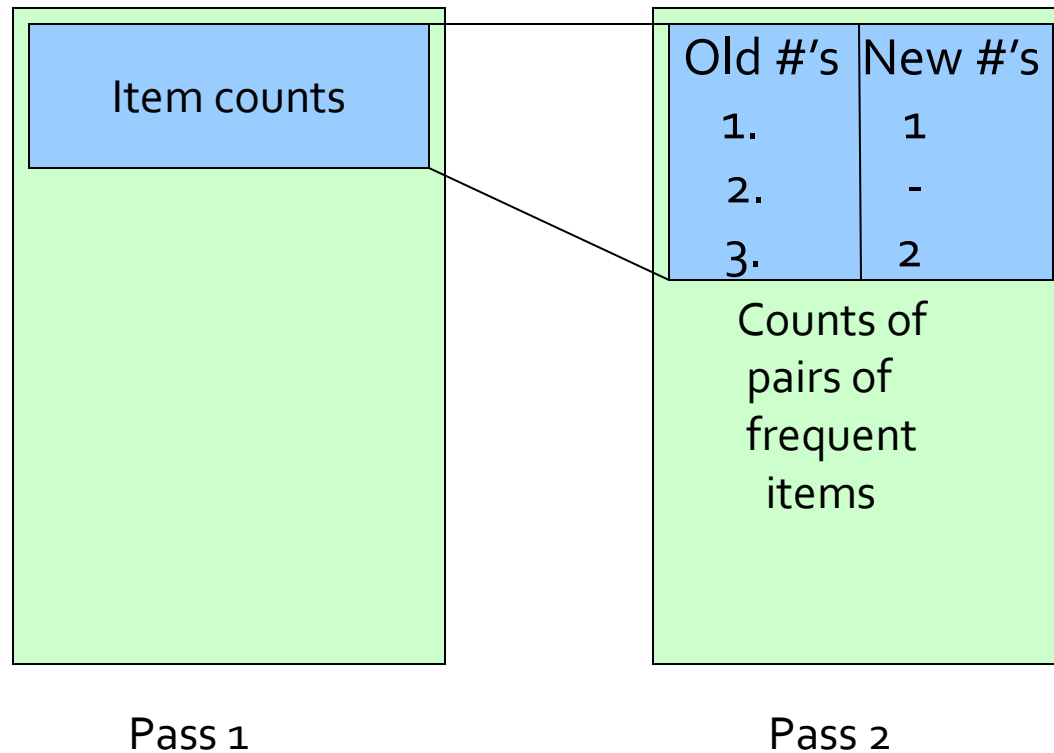
Picture of A-Priori



Detail for A-Priori

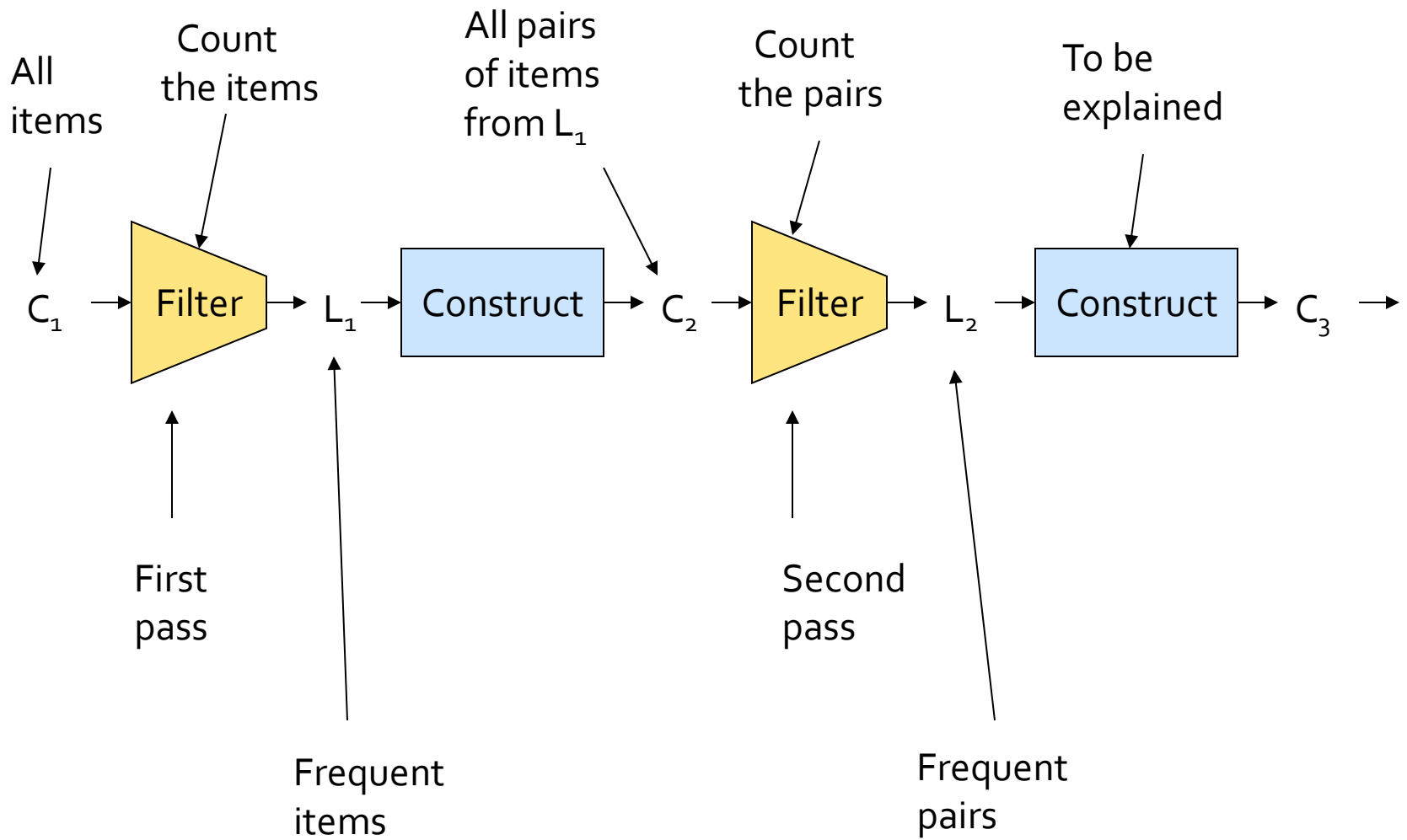
- You can use the triangular matrix method with $n =$ number of frequent items.
 - May save space compared with storing triples.
- **Trick:** number frequent items 1, 2,... and keep a table relating new numbers to original item numbers.

A-Priori Using Triangular Matrix



Frequent Triples, Etc.

- For each size of itemsets k , we construct two sets of *k -sets* (sets of size k):
 - $C_k = \text{candidate } k\text{-sets}$ = those that might be frequent sets (support $\geq s$) based on information from the pass for itemsets of size $k - 1$.
 - $L_k = \text{the set of truly frequent } k\text{-sets}$.



Passes Beyond Two

- $C_1 =$ all items
- In general, $L_k =$ members of C_k with support $\geq s$.
 - Requires one pass.
- $C_{k+1} = (k+1)$ -sets, each k of which is in L_k .

Memory Requirements

- At the k^{th} pass, you need space to count each member of C_k .
- In realistic cases, because you need fairly high support, the number of candidates of each size drops, once you get beyond pairs.

The PCY (Park-Chen-Yu) Algorithm

Improvement to A-Priori

Exploits Empty Memory on First Pass

Frequent Buckets

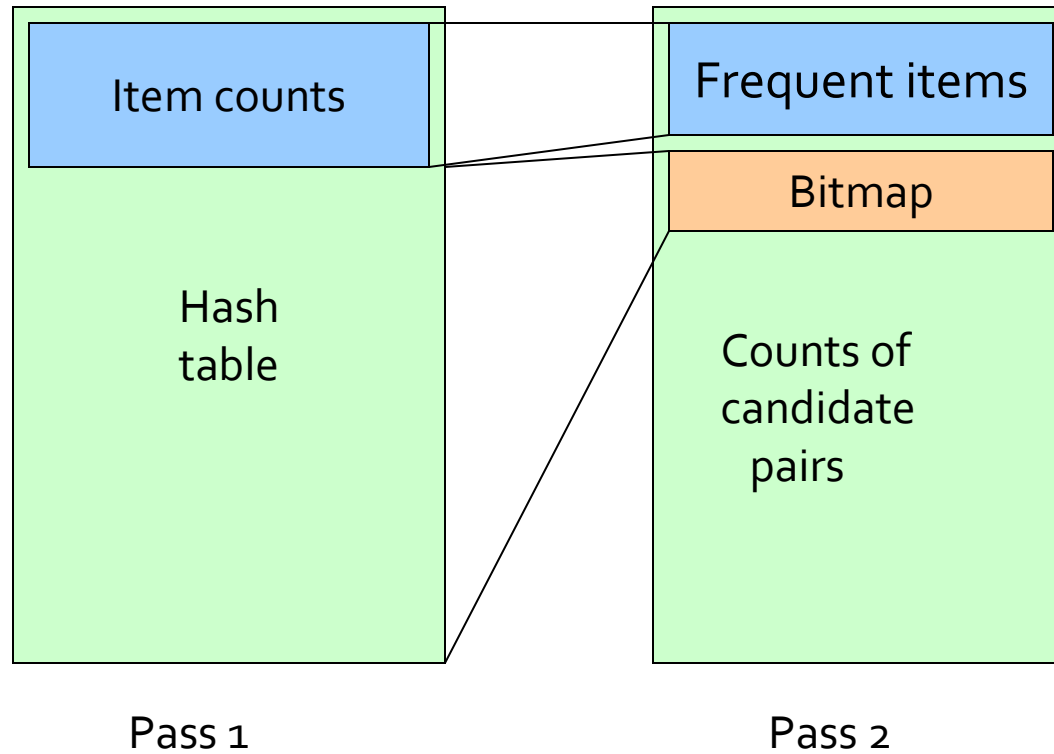
PCY Algorithm

- During Pass 1 of A-priori, most memory is idle.
- Use that memory to keep counts of buckets into which pairs of items are hashed.
 - Just the count, not the pairs themselves.
- For each basket, enumerate all its pairs, hash them, and increment the resulting bucket count by 1.

PCY Algorithm – (2)

- A bucket is *frequent* if its count is at least the support threshold.
- If a bucket is not frequent, no pair that hashes to that bucket could possibly be a frequent pair.
- On Pass 2, we only count pairs of frequent items that *also* hash to a frequent bucket.
- A *bitmap* tells which buckets are frequent, using only one bit per bucket (i.e., 1/32 of the space used on Pass 1).

Picture of PCY



Pass 1: Memory Organization

- Space to count each item.
 - One (typically) 4-byte integer per item.
- Use the rest of the space for as many integers, representing buckets, as we can.

PCY Algorithm – Pass 1

```
FOR (each basket) {  
    FOR (each item in the basket)  
        add 1 to item's count;  
    FOR (each pair of items) {  
        hash the pair to a bucket;  
        add 1 to the count for that bucket  
    }  
}
```

Observations About Buckets

1. A bucket that a frequent pair hashes to is surely frequent.
 - We cannot use the hash table to eliminate any member of this bucket.
2. Even without any frequent pair, a bucket can be frequent.
 - Again, nothing in the bucket can be eliminated.

Observations – (2)

3. But in the best case, the count for a bucket is less than the support s .
 - Now, all pairs that hash to this bucket can be eliminated as candidates, even if the pair consists of two frequent items.

PCY Algorithm – Between Passes

- Replace the buckets by a bit-vector (the “**bitmap**”):
 - 1 means the bucket is frequent; 0 means it is not.
- Also, decide which items are frequent and list them for the second pass.

PCY Algorithm – Pass 2

- Count all pairs $\{i, j\}$ that meet the conditions for being a **candidate pair**:
 1. Both i and j are frequent items.
 2. The pair $\{i, j\}$, hashes to a bucket number whose bit in the bit vector is 1.

Memory Details

- Buckets require a few bytes each.
 - **Note**: we don't have to count past s .
 - # buckets is $O(\text{main-memory size})$.
- On second pass, a table of **(item, item, count)** triples is essential.
 - Thus, hash table on Pass 1 must eliminate 2/3 of the candidate pairs for PCY to beat a-priori.

More Extensions to A-Priori

- The MMDS book covers several other extensions beyond the PCY idea: “Multistage” and “Multihash.”
- For reading on your own.

All (Or Most) Frequent Itemsets In ≤ 2 Passes

Simple Algorithm

Savasere-Omiecinski- Navathe
(SON) Algorithm

Toivonen's Algorithm

Simple Algorithm

- Take a random sample of the market baskets.
- Run a-priori or one of its improvements (for sets of all sizes, not just pairs) in main memory, so you don't pay for disk I/O each time you increase the size of itemsets.
- Use as your support threshold a suitable, scaled-back number.
 - **Example:** if your sample is $1/100$ of the baskets, use $s/100$ as your support threshold instead of s .

Simple Algorithm – Option

- Optionally, verify that your guesses are truly frequent in the entire data set by a second pass.
- But you don't catch sets frequent in the whole but not in the sample.
 - Smaller threshold, e.g., $s/125$ instead of $s/100$, helps catch more truly frequent itemsets.
 - But requires more space.

SON Algorithm

- Partition the baskets into small subsets.
- Read each subset into main memory and perform the first pass of the simple algorithm on each subset.
 - Parallel processing of the subsets a good option.
- An itemset becomes a candidate if it is found to be frequent (with support threshold suitably scaled down) in *any* one or more subsets of the baskets.

SON Algorithm – Pass 2

- On a second pass, count all the candidate itemsets and determine which are frequent in the entire set.
- Key “monotonicity” idea: an itemset cannot be frequent in the entire set of baskets unless it is frequent in at least one subset.

Toivonen's Algorithm

- Start as in the simple algorithm, but lower the threshold slightly for the sample.
 - **Example:** if the sample is 1% of the baskets, use $s/125$ as the support threshold rather than $s/100$.
 - Goal is to avoid missing any itemset that is frequent in the full set of baskets.

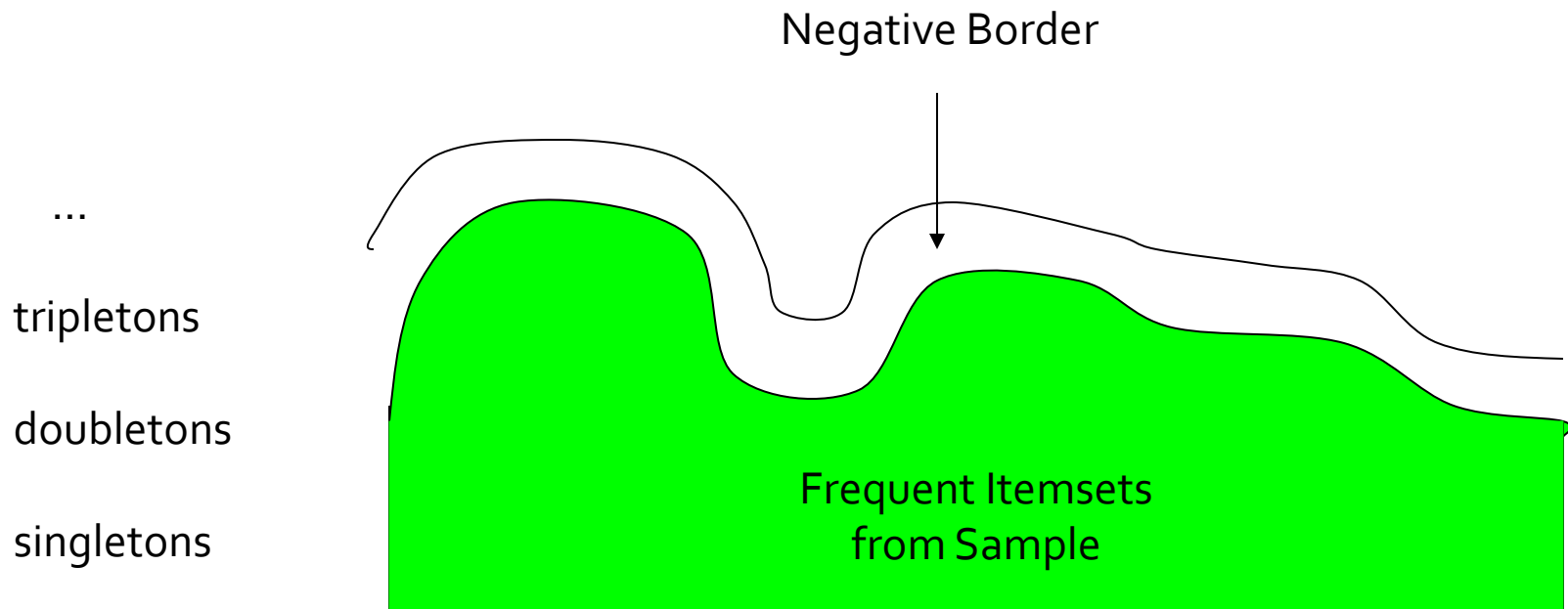
Toivonen's Algorithm – (2)

- Add to the itemsets that are frequent in the sample the *negative border* of these itemsets.
- An itemset is in the negative border if it is not deemed frequent in the sample, but *all* its immediate subsets are.
 - *Immediate* = “delete exactly one element.”

Example: Negative Border

- $\{A,B,C,D\}$ is in the negative border if and only if:
 1. It is not frequent in the sample, but
 2. All of $\{A,B,C\}$, $\{B,C,D\}$, $\{A,C,D\}$, and $\{A,B,D\}$ are.
- $\{A\}$ is in the negative border if and only if it is not frequent in the sample.
 - Because the empty set is always frequent.
 - Unless there are fewer baskets than the support threshold (silly case).

Picture of Negative Border



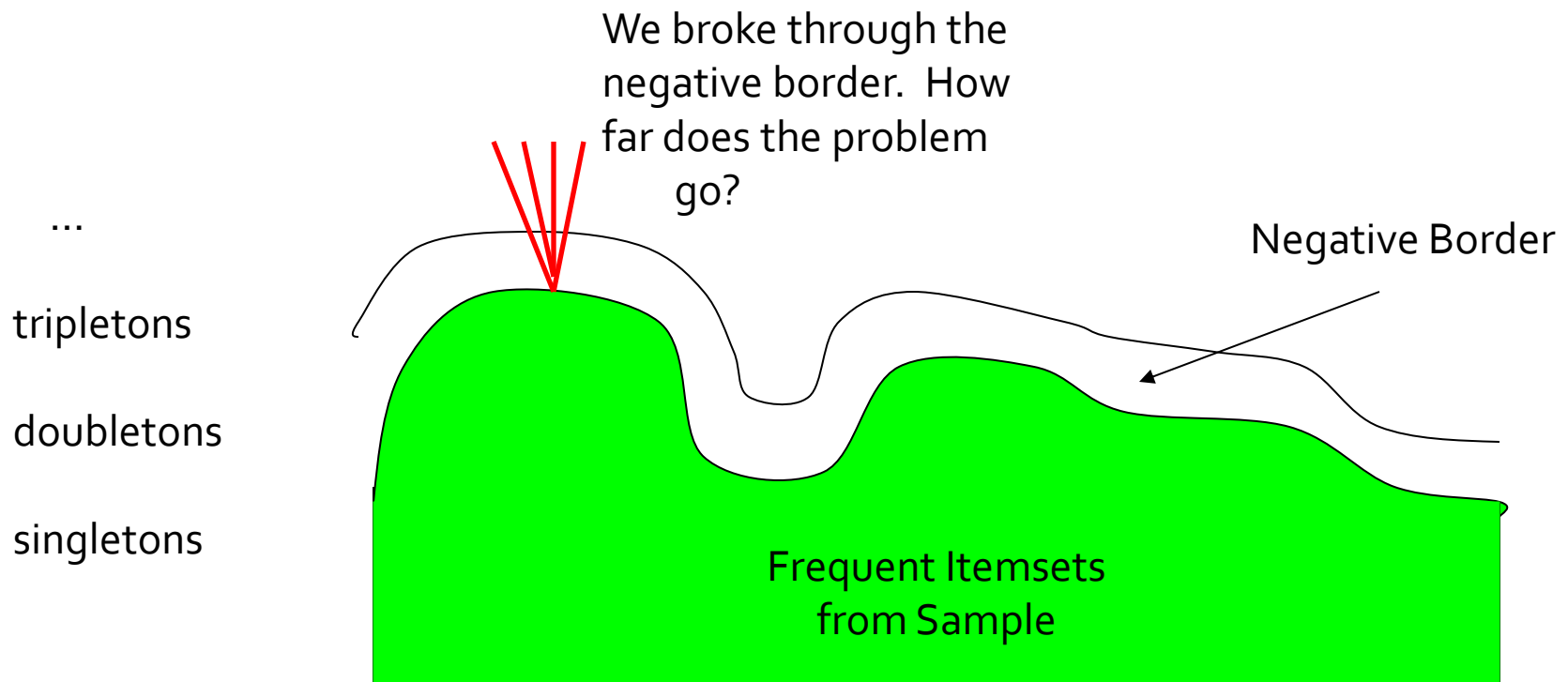
Toivonen's Algorithm – (3)

- In a second pass, count all candidate frequent itemsets from the first pass, and also count their negative border.
- If no itemset from the negative border turns out to be frequent, then the candidates found to be frequent in the whole data are *exactly* the frequent itemsets.

Toivonen's Algorithm – (4)

- What if we find that something in the negative border is actually frequent?
- We must start over again with another sample!
- Try to choose the support threshold so the probability of failure is low, while the number of itemsets checked on the second pass fits in main-memory.

If Something in the Negative Border Is Frequent . . .



Theorem:

- If there is an itemset that is frequent in the whole, but not frequent in the sample, then there is a member of the negative border for the sample that is frequent in the whole.

Proof:

- Suppose not; i.e.;
 1. There is an itemset S frequent in the whole but not frequent in the sample, and
 2. Nothing in the negative border is frequent in the whole.
- Let T be a **smallest** subset of S that is not frequent in the sample.
- T is frequent in the whole (S is frequent + monotonicity).
- T is in the negative border (else not “smallest”).

Cool Idea Provided by a Student

- If you execute a-priori on the sample, in main memory, then every candidate k-set is either a frequent k-set or it is in the negative border.
- And the entire negative border can be found this way.
- So you get the negative border “for free.”