Aggregation Computation Over Distributed Data Streams

(partial content)

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What's Different: Distributed, Continuous Monitoring of Duplicate-Resilient Aggregates on Data Streams
- Published in ICDE, 2006
- Cited by 61 times
- By Graham Cormode, S. Muthukrishnan etc.

I think it’s a good reading suitable for freshmen on distributed data streams
Background

- Distributed Data Streams
  - Where and why?
    - Large scale monitoring applications
    - Many sensors distributed over a wide area

- Distributed Streaming Model

- What do we research? → Query paradigm
  - Centralized vs Decentralized
Constraints and Features

- **Constraints**
  - **Space**
    - Embedded equipments don't have enough memory
  - **Processing power**
    - The same reason
  - **Communication capability**
    - Unreliable, spotty and sporadic

- **Features**
  - Different from *ad hoc* queries in DBMS, but continuous
  - *Continuous* is one of core characteristics in queries over data streams
Trouble

- Dduplication → Why?
  Wide scale monitoring invariably encounters the same events at different points

- Instances
  - The same flow will be observed in different routers
  - The same individual will be observed by several mobile sensors

- Requirement
  - Duplicate-resilient aggregate

- Two vital questions
  - What is the amount of duplication in the network?
  - What are the versions of classical aggregates in the presence of duplicates?
What kind of topics are researchers interested in?
- Aggregation computation
- Routing algorithms
- ...

What is the aggregation?
Summarization, namely a statistical variable computed from the original data sets
- Examples
  - min, max, quantile, heavy hitter
  - distinct counts, average, sum
  - ...

Mirror the topic in data base
Why only aggregation?
→ transaction
Not strange contacting with data streams
Problems and Concerns

- **Distinct count**
  
  To obtain the number of distinct data (item, record, etc) in multi-sets, namely the cardinality

- **Distinct sample**
  
  Important, but I’m sorry that I haven’t finished this part 😞

- **What does this paper concern about?**
  
  - Priority: correctness, communication cost
  - Computational cost, space cost

- **What do we concern about dealing with aggregation computation?**
  
  - Space complexity may be more attention-getting than time complexity
Distinct Counting: Flajolet-Martin Sketch

- Flajolet-Martin Sketch
  - Goal: To estimate the cardinalities of multi-sets of data using relative small space by one pass scan
  - The sketch is a kind of data structure, which is the way to obtain the aggregation results. → aggregation
  - I think this method can be regarded as the classical application of probability without complexity.

- Give a question: How about you dealing with this problem?
  - The computing paradigm of sketching
  - Space complexity
Flajolet-Martin Sketch (Cont.)

- Preliminary \(\rightarrow\) what do we need?
  - the Multi-set \(M\), containing all items/records, and \(|M| = n\)
  - the upper bound on the number of distinct items/records \(U\), which is more than \(n\)
  - one bitmap, consisting of \(L\) elements, and \(2^L = U\)
  - the hash function \(h(x: \text{item/record})\), transforming each item into a binary string distributed uniformly over the range of \([1 \ldots 2^L]\), just like \(b_1b_2\ldots b_L\), in which \(b_1\) is the lowest digit, and \(b_L\) is the highest
  - the \(p(x)\), attaining the left most position of ‘1’

\[
\begin{array}{cccccc}
0 & 1 & 1 & \ldots & 0 \\
\end{array}
\]

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PPT vs Whiteboard?
The algorithm itself

- the core task: remarking the position of which the leftmost ‘1’ of the hash value recorded by p(x) in bitmap B

```plaintext
for i:=1 to L do bitmap[i] := 0
for all x in M do
    begin
        index := p(hash(x));
        if bitmap[index] = the bitmap[index] := 1;
    end
```

Why?

```
1 | 1 | 0 | ... | 0
-------------------
Bitmap
```
Flajolet-Martin Sketch(Cont.)

- The explanation
  - The fact: bitmap[k] equals to 1 iff after execution a pattern of the form $0^{k-1}1$ has appeared amongst hashed values of records in M
  - The probability: the occurrence probability of the pattern $0^{k-1}1$ is $1/2^k$
  - Occurrence times: so if $|M| = n$, then bitmap[1] is accessed approximately $n/2$ times, bitmap[2] approximately $n/4$ times
  - Extension: bitmap[k] will almost certainly be zero if $k >> \log_2(n)$ and one if $k << \log_2(n)$ with a fringe of 0 and 1 for $k \approx \log_2(n)$
  - Selection: the leftmost 0, the rightmost 1 or something else

The most practical part is over, and the left is very complicated taken for proving and error analysis, namely all about mathematic
Flajolet-Martin Sketch (Cont.)

- Conclusion
  - Analysis
    - Bit-based, reducing the space complexity by constant level
    - Space complexity $O(\log(n)) \rightarrow O(\log(\log(n)))$
    - Duplicate-insensitive $\rightarrow$ duplicate-resilient and flexible
    - Order-insensitive $\rightarrow$ stable and robust
    - Additivity $\rightarrow$ The ability to merge two FM sketches together, and the merger is simply the bitwise-or of each pair of corresponding bitmaps

- Questions
  - How to make the value of $U$?
  - What's the relationship of $U$ and $n$?
  - How to make the analysis to the error? $\rightarrow \log(\alpha n)$
  - ...
Question

- Is the CFV in my last report a kind of sketch?
  - Yes, I think so

- What’s the relationship between sketch and skyline?
  - Are they the same? No, just trust me
  - I hold the opposite opinion

- Does the *aggregation computation* belong to the research fields of *data mining*?
  - No, I suppose it doesn’t and I don’t care
Q&A