Views and Incremental View Maintenance

CSE 4/562: Database Systems | Lecture 17

Repeat Queries


```
SELECT l.partkey
FROM lineitem l, orders o
WHERE l.orderkey = o.orderkey AND o.orderdate > DATE(NOW() - '1 Month')
ORDER BY l.shipdate DESC LIMIT 10
```

—

```
SELECT l.suppkey, COUNT(*)
FROM lineitem l, orders o
WHERE l.orderkey = o.orderkey AND o.orderdate > DATE(NOW() - '1 Month')
GROUP BY l.suppkey
```

—

```
SELECT l.partkey, COUNT(*)
FROM lineitem l, orders o
WHERE l.orderkey = o.orderkey AND o.orderdate > DATE(NOW() - '1 Month')
GROUP BY l.partkey
```

Views

```
CREATE VIEW salesSinceLastMonth AS
  SELECT l.*
  FROM lineitem l, orders o
  WHERE l.orderkey = o.orderkey
  AND o.orderdate > DATE(NOW() - '1 Month')
```

—

```
SELECT l.partkey FROM salesSinceLastMonth
ORDER BY l.shipdate DESC LIMIT 10
```

```
SELECT l.suppkey, COUNT(*) FROM salesSinceLastMonth
GROUP BY l.suppkey
```

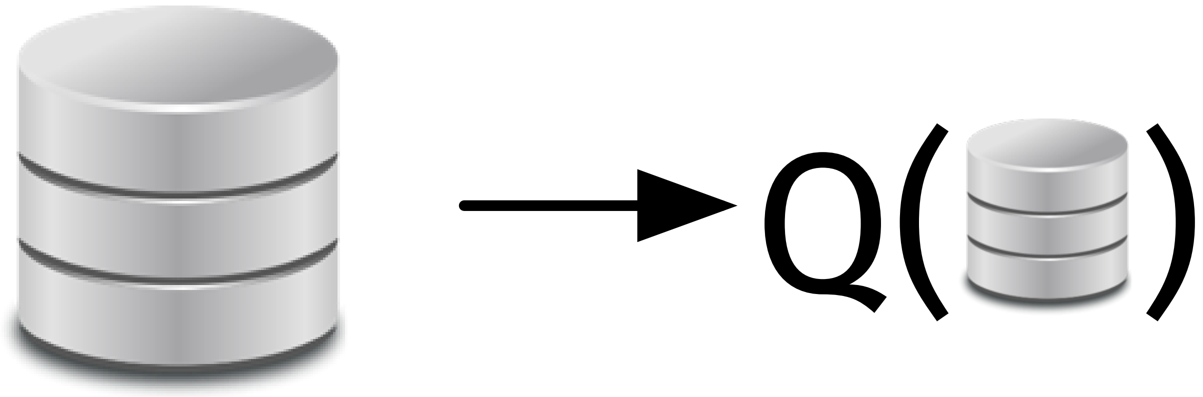
```
SELECT l.partkey, COUNT(*) FROM salesSinceLastMonth
GROUP BY l.partkey
```

Views exist to be queried frequently

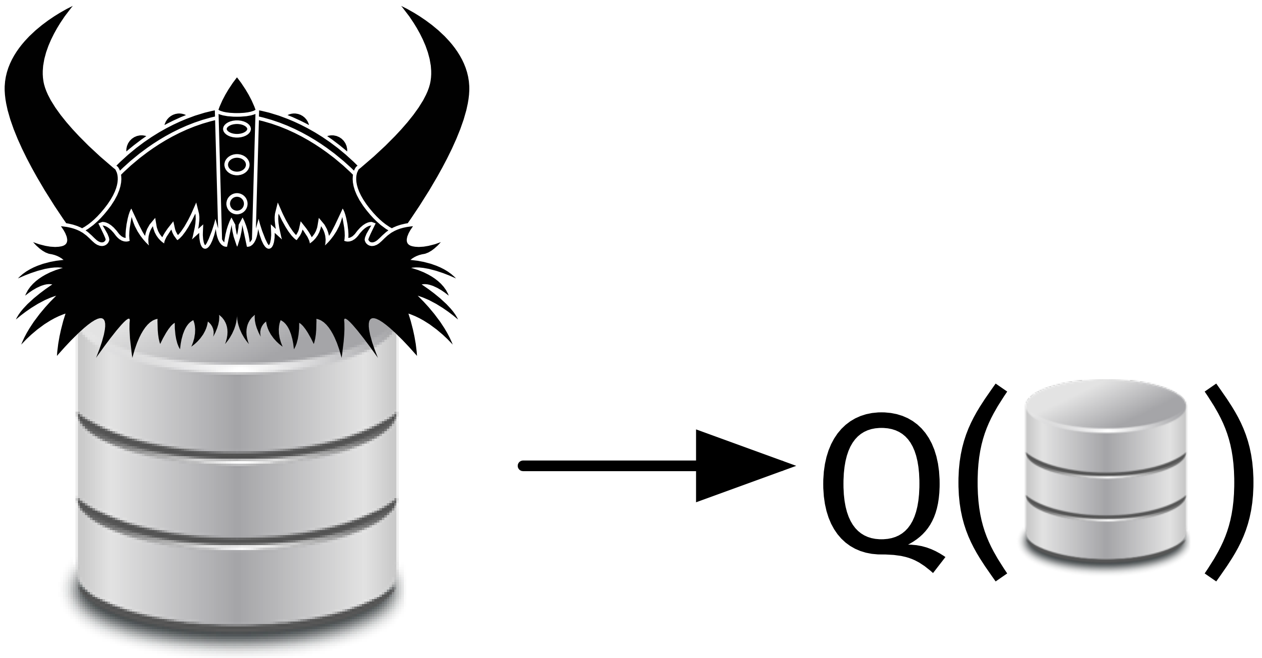
Idea: Pre-compute and save the view's contents

(like an index)

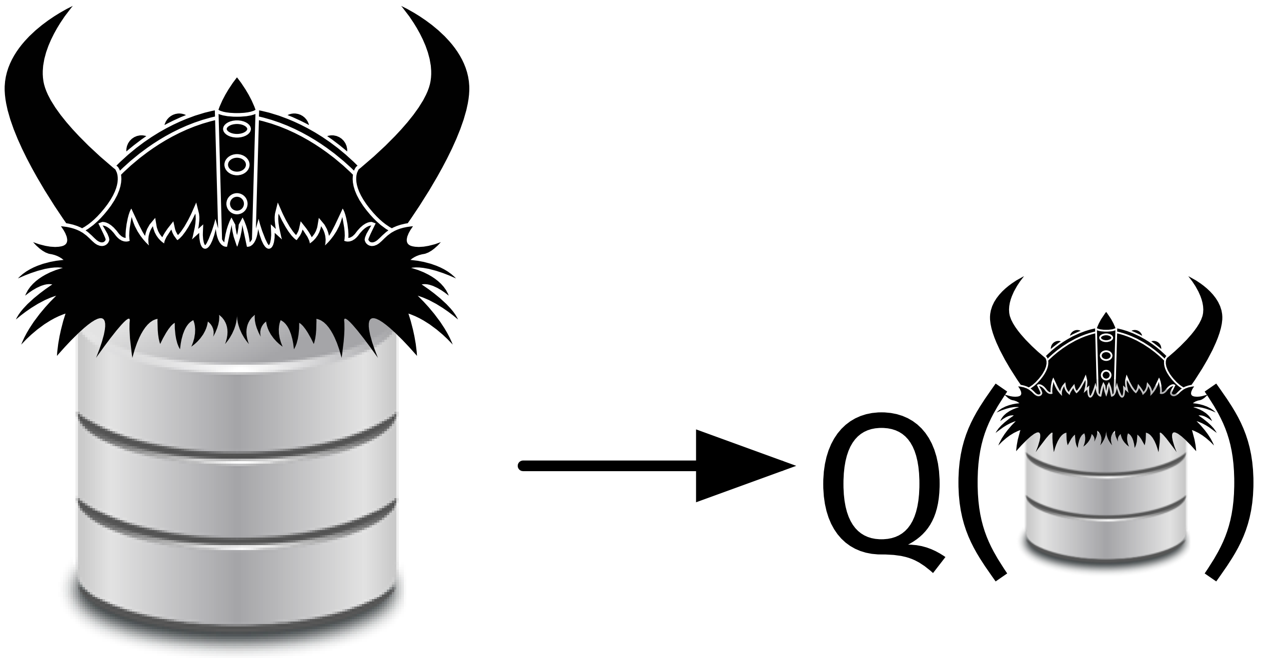
View Changes


Q( )

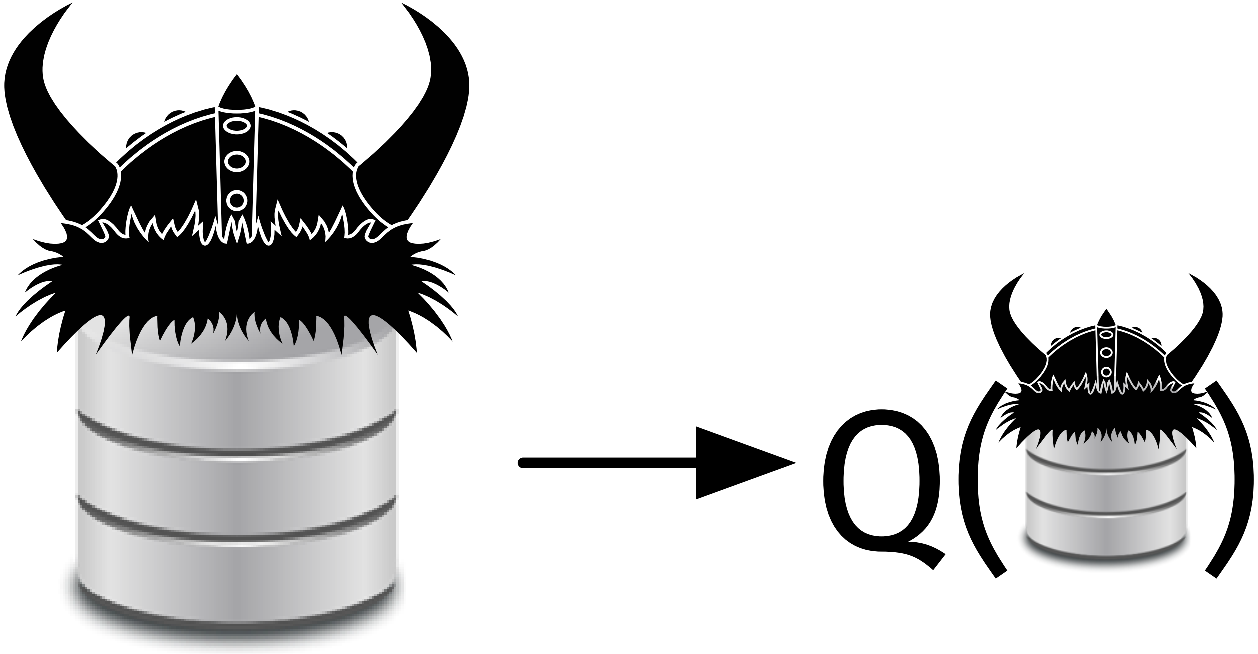
View Changes



View Changes



View Changes



When the base data changes, the view needs to be updated too!

Initial Setup

Given: D_0

Initial Setup

Given: D_0

Compute: $\texttt{VIEW}_0 \leftarrow Q(D_0)$

Initial Setup

Given: D_0

Compute: $\texttt{VIEW}_0 \leftarrow Q(D_0)$

After an update

Given: D_1

Initial Setup

Given: D_0

Compute: $\texttt{VIEW}_0 \leftarrow Q(D_0)$

After an update

Given: D_1

Idea 1: Recompute the view.

Initial Setup

Given: D_0

Compute: $\texttt{VIEW}_0 \leftarrow Q(D_0)$

After an update

Given: D_1

Compute: $\texttt{VIEW}_1 \leftarrow Q(D_1)$

Idea 1: Recompute the view.

$Q(D_0)$ and $Q(D_1)$ are doing (mostly) the same work

Initial Setup

Given: D_0

Initial Setup

Given: D_0

Compute: $\texttt{VIEW}_0 \leftarrow Q(D_0)$

Initial Setup

Given: D_0

Compute: $\texttt{VIEW}_0 \leftarrow Q(D_0)$

After an update

Given: δ_1 such that $D_1 = D_0 + \delta_1$

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Given: δ_1 such that $D_1 = D_0 + \delta_1$

Compute: $\texttt{VIEW}_1 \leftarrow Q(D_1)$

Initial Setup

Given: D_0

Compute: $\texttt{VIEW}_0 \leftarrow Q(D_0)$

After an update

Given: δ_1 such that $D_1 = D_0 + \delta_1$

Compute: $\texttt{VIEW}_1 \leftarrow$ ~~$Q(D_1)$~~ $Q(D_0 + \delta_1)$

Initial Setup

Given: D_0

Compute: $\texttt{VIEW}_0 \leftarrow Q(D_0)$

After an update

Given: δ_1 such that $D_1 = D_0 + \delta_1$

Compute: $\texttt{VIEW}_1 \leftarrow$ ~~$Q(D_1)$~~ ~~$Q(D_0 + \delta_1)$~~ $\Delta Q(D_0, \delta_1)$

View Maintenance

Is there an operation "+" and a function $\Delta Q(D, \delta)$ such that...

1. $Q(D + \delta) = Q(D) + \Delta Q(D, \delta)$
2. $\Delta(D, \delta)$ is "cheap"
3. '+' is "cheap"

Intuition

Given

- $D = \{1, 2, 3, 4\}$
- $\delta = \{5\}$
- $Q(D) = \texttt{SUM(D)}$

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Naive Approach

$\texttt{SUM(}D \cup \delta\texttt{)} = 1 + 2 + 3 + 4 + 5$

Intuition

Given

- $D = \{1, 2, 3, 4\}$
- $\delta = \{5\}$
- $Q(D) = \texttt{SUM(D)}$

Naive Approach

$\texttt{SUM(}D \cup \delta\texttt{)} = 1 + 2 + 3 + 4 + 5$ $O(|D| + |\delta|)$

Given

- $D = \{1, 2, 3, 4\}$
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- $Q(D) = \texttt{SUM(D)}$

Naive Approach

$\texttt{SUM(}D \cup \delta\texttt{)} = 1 + 2 + 3 + 4 + 5$ $O(|D| + |\delta|)$

Incremental Approach

$\texttt{SUM(}D \cup \delta\texttt{)} = \texttt{SUM(}D\texttt{)} + 5 = 10 + 5$

Given

- $D = \{1, 2, 3, 4\}$
- $\delta = \{5\}$
- $Q(D) =$ `SUM(D)`

Naive Approach

$\texttt{SUM(}D \cup \delta\texttt{)} = 1 + 2 + 3 + 4 + 5$ $O(|D| + |\delta|)$

Incremental Approach

$\texttt{SUM(}D \cup \delta\texttt{)} = \texttt{SUM(}D\texttt{)} + 5 = 10 + 5$ $O(|\delta|)$

Intuition

Given

- $R = \{A, B, C\}$ $S = \{X, Y\}$
- $\delta_R = \{D\}$
- $Q(D) = \texttt{COUNT(}R \times S\texttt{)}$

Intuition

Given

- $R = \{A, B, C\}$ $\qquad$ $S = \{X, Y\}$
- $\delta_R = \{D\}$
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Naive Approach

$\texttt{COUNT(}D \cup \delta\texttt{)} = \texttt{COUNT(}AX, AY, BX, BY, CX, CY, \underline{DX, DY}\texttt{)}$

Given

- $R = \{A, B, C\}$ $\quad\quad S = \{X, Y\}$
- $\delta_R = \{D\}$
- $Q(D) = \texttt{COUNT(}R \times S\texttt{)}$

Naive Approach

$\texttt{COUNT(}D \cup \delta\texttt{)} = \texttt{COUNT(}AX, AY, BX, BY, CX, CY, \underline{DX, DY}\texttt{)}$ $\quad\quad O((|R| + |\delta_R|) \cdot |S|)$

Given

- $R = \{A, B, C\}$ $\quad\quad S = \{X, Y\}$
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- $Q(D) = \texttt{COUNT(}R \times S\texttt{)}$

Naive Approach

$\texttt{COUNT(}D \cup \delta\texttt{)} = \texttt{COUNT(}AX, AY, BX, BY, CX, CY, \underline{DX, DY}\texttt{)} \quad\quad O((|R| + |\delta_R|) \cdot |S|)$

Incremental Approach

$\texttt{COUNT(}D \cup \delta\texttt{)} = \texttt{COUNT(}D\texttt{)} + \texttt{COUNT(}\delta\texttt{)} = 6 + \texttt{COUNT(}\underline{DX, DY}\texttt{)}$

Intuition

Given

- $R = \{A, B, C\}$ $\qquad S = \{X, Y\}$
- $\delta_R = \{D\}$
- $Q(D) = \texttt{COUNT}(R \times S)$

Naive Approach

$\texttt{COUNT}(D \cup \delta) = \texttt{COUNT}(AX, AY, BX, BY, CX, CY, \underline{DX, DY}) \qquad O((|R| + |\delta_R|) \cdot |S|)$

Incremental Approach

$\texttt{COUNT}(D \cup \delta) = \texttt{COUNT}(D) + \texttt{COUNT}(\delta) = 6 + \texttt{COUNT}(\underline{DX, DY}) \qquad O(|\delta_R| \cdot S)$

Intuition

$+$ is like $\cup$

$\times$ is like $\bowtie$

Intuition

Are these types of pattern common?

Semiring: $\langle \mathbb{S}, +, \times, 0, 1 \rangle$

Any set of ‘things’ $\mathbb{S}$ (where $a, b, c \in \mathbb{S}$) such that...

$$a + b = c \qquad a + 0 = a$$

$$a \times b = c \qquad a \times 1 = a$$

$$a \times 0 = 0$$

$$a \times (b + c) = (a \times b) + (a \times c)$$

Semiring: $\langle \mathbb{S}, +, \times, 0, 1 \rangle$

Any set of 'things' $\mathbb{S}$ (where $a, b, c \in \mathbb{S}$) such that...

"Closed"

$$a + 0 = a$$

$$a + b = c$$

$$a \times 1 = a$$

$$a \times b = c$$

$$a \times 0 = 0$$

$$a \times (b + c) = (a \times b) + (a \times c)$$

Semiring: $\langle \mathbb{S}, +, \times, 0, 1 \rangle$

Any set of 'things' $\mathbb{S}$ (where $a, b, c \in \mathbb{S}$) such that...

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$$a + b = c$$

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Additive, Multiplicative Identities

$$a + 0 = a$$

$$a \times 1 = a$$

$$a \times 0 = 0$$

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Rings/Semirings

Semiring: $\langle \mathbb{S}, +, \times, 0, 1 \rangle$

Any set of 'things' $\mathbb{S}$ (where $a, b, c \in \mathbb{S}$) such that...

"Closed"

$$a + b = c$$

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Additive, Multiplicative Identities

$$a + 0 = a$$

$$a \times 1 = a$$

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$$a \times (b + c) = (a \times b) + (a \times c)$$

Addition distributes over multiplication

Rings/Semirings

Ring: $\langle \mathbb{S}, +, \times, 0, 1, - \rangle$

A semiring with an additive inverse

$a + (-a) = 0$

THE TANGENT ENDS NOW!

Image credit: Futurama is ©20th Century Fox

Initial Setup

Given: D_0

Compute: $\texttt{VIEW}_0 \leftarrow Q(D_0)$

After an update

Given: D_1

Compute: $\texttt{VIEW}_1 \texttt{ += } \Delta Q(D_0, \delta)$

What are “+”, δ, and ΔQ?

Defining the Problem

What is δ_R?

Defining the Problem

What is δ_R?

- Insertions
- Deletions
- Updates

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What is δ_R?

- Insertions
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What is δ_R?

- Insertions
- Deletions
- Updates

δ_R is a set/bag of insertions and a set/bag of deletions

Defining the Problem

$$R_i = R_{i-1} - (\delta_{R-}) \cup (\delta_{R+})$$

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Caveats

- '-' needs to account for multiplicities
- Generally we compute insertions and deletions separately

Defining the Problem

Let’s focus on insertions for now.

Given

$\texttt{VIEW} = Q(R, S, ...)$

We want...

ΔQ such that... $\texttt{VIEW}_i = \texttt{VIEW}_{i-1} \cup \Delta Q\big(R_{i-1},\ \delta_{R,i},\ S_{i-1},\ \delta_{S,i},\ ...\big)$

Defining the Problem

Given

$\texttt{VIEW} = Q(R, S, ...)$

We want...

ΔQ such that... $\texttt{VIEW}_i = \texttt{VIEW}_{i-1} \cup \Delta Q\big(R_{i-1},\ \delta_{R,i},\ S_{i-1},\ \delta_{S,i},\ ...\big)$

We want to compute $\delta_{\texttt{VIEW}}$ in terms of Q

Suppose that $Q = \sigma(R)$

Also suppose that we know δ_R

The Delta Transform - Selection

Suppose that $Q = \sigma(R)$

Also suppose that we know δ_R

—

... then we want

$\sigma(R) \cup ??? = \sigma(R \cup \delta_R)$

The Delta Transform - Selection

Suppose that $Q = \sigma(R)$

Also suppose that we know δ_R

—

... then we want

$$\sigma(R) \cup \sigma(\delta_R) = \sigma(R \cup \delta_R)$$

The Delta Transform - Selection

Suppose that $Q = \sigma(R)$

Also suppose that we know δ_R

—

... then we want

$$\sigma(R) \cup \sigma(\delta_R) = \sigma(R \cup \delta_R)$$

—

$$\Delta\sigma(R) = \sigma(\delta_R)$$

The Delta Transform - Selection

Suppose that $Q = \sigma(Q'(...))$

Also suppose that we know $\Delta Q'(...)$

—

... then we want

$\sigma(R) \cup \sigma(\Delta Q'(...)) = \sigma(R \cup \Delta Q'(...))$

—

$\Delta\sigma(Q'(...)) = \sigma(\Delta Q'(...))$

Suppose that $Q = \pi(R)$

Also suppose that we know δ_R

—

... then we want

$\pi(R) \cup ??? = \pi(R \cup \delta_R)$

The Delta Transform - Projection

Suppose that $Q = \pi(R)$

Also suppose that we know δ_R

—

... then we want

$$\pi(R) \cup \pi(\delta_R) = \pi(R \cup \delta_R)$$

—

$$\Delta\pi(R) = \pi(\delta_R)$$

The Delta Transform - Union

Suppose that $Q = R \cup S$

Also suppose that we know δ_R, δ_S

—

... then we want

$(R \cup S) \cup ??? = (R \cup \delta_R) \cup (S \cup \delta_S)$

The Delta Transform - Union

Suppose that $Q = R \cup S$

Also suppose that we know δ_R, δ_S

—

… then we want

$$(R \cup S) \cup (\delta_R \cup \delta_S) = (R \cup \delta_R) \cup (S \cup \delta_S)$$

—

$$\Delta(R \cup S) = \delta_R \cup \delta_S$$

The Delta Transform - Join

Suppose that $Q = R \bowtie S$

Also suppose that we know δ_R, δ_S

—

The Delta Transform - Join

Suppose that $Q = R \bowtie S$

Also suppose that we know δ_R, δ_S

—

$(R \cup \delta_R) \bowtie (S \cup \delta_S)$

The Delta Transform - Join

Suppose that $Q = R \bowtie S$

Also suppose that we know δ_R, δ_S

—

$(R \cup \delta_R) \bowtie (S \cup \delta_S)$

$(R \bowtie (S \cup \delta_S)) \cup (\delta_R \bowtie (S \cup \delta_S))$

The Delta Transform - Join

Suppose that $Q = R \bowtie S$

Also suppose that we know δ_R, δ_S

—

$(R \cup \delta_R) \bowtie (S \cup \delta_S)$

$(R \bowtie (S \cup \delta_S)) \cup (\delta_R \bowtie (S \cup \delta_S))$

$((R \bowtie S) \cup (R \bowtie \delta_S)) \cup (\delta_R \bowtie (S \cup \delta_S))$

Suppose that $Q = R \bowtie S$

Also suppose that we know δ_R, δ_S

—

$(R \cup \delta_R) \bowtie (S \cup \delta_S)$

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The Delta Transform - Join

Suppose that $Q = R \bowtie S$

Also suppose that we know δ_R, δ_S

—

$(R \cup \delta_R) \bowtie (S \cup \delta_S)$

$(R \bowtie (S \cup \delta_S)) \cup (\delta_R \bowtie (S \cup \delta_S))$

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$(R \bowtie S) \cup (R \bowtie \delta_S) \cup (\delta_R \bowtie S) \cup (\delta_R \bowtie \delta_S)$

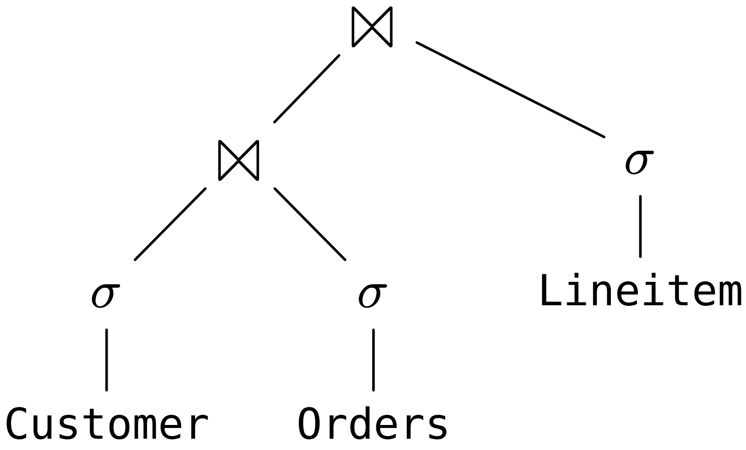
—

$\Delta(R \bowtie S) = (R \bowtie \delta_S) \cup (\delta_R \bowtie S) \cup (\delta_R \bowtie \delta_S)$

Example

Example

What is ΔQ with respect to a change in `Lineitem`?



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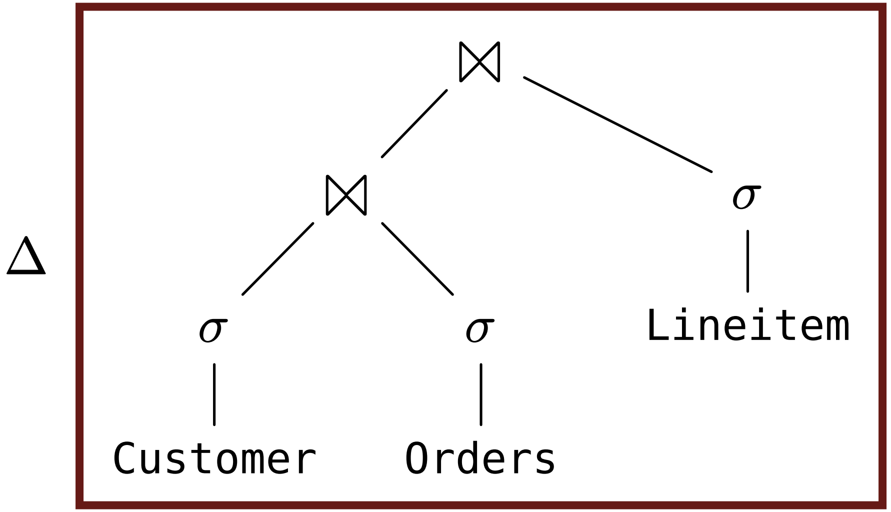

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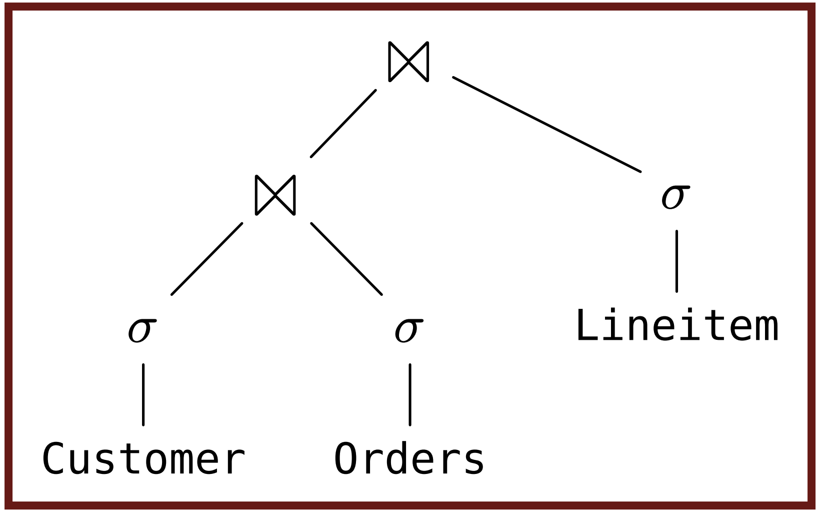
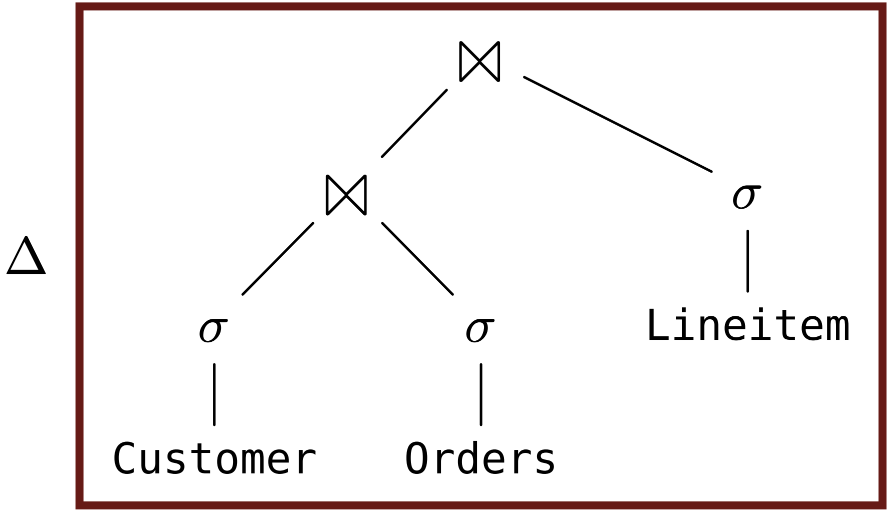
Δ 

$$\Delta[(\sigma(C) \bowtie \sigma(O)) \bowtie \sigma(L)]$$

Example

What is ΔQ with respect to a change in `Lineitem`?



$$\Delta[(\sigma(C) \bowtie \sigma(O))] \bowtie \sigma(L) \cup (\sigma(C) \bowtie \sigma(O)) \bowtie \Delta[\sigma(L)] \cup \Delta[(\sigma(C) \bowtie \sigma(O))] \bowtie \Delta[\sigma(L)]$$

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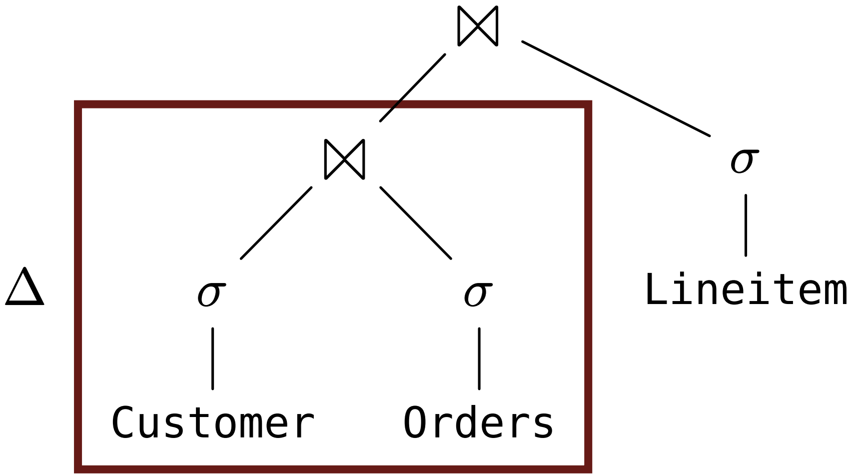

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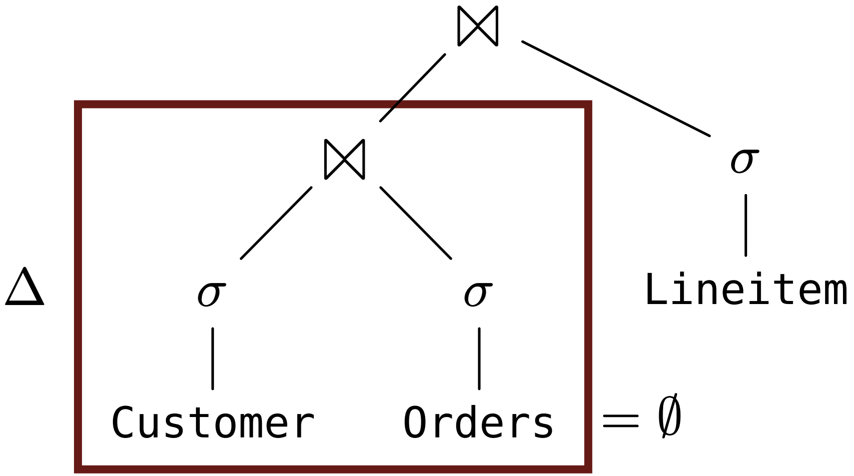
Example

What is ΔQ with respect to a change in `Lineitem`?



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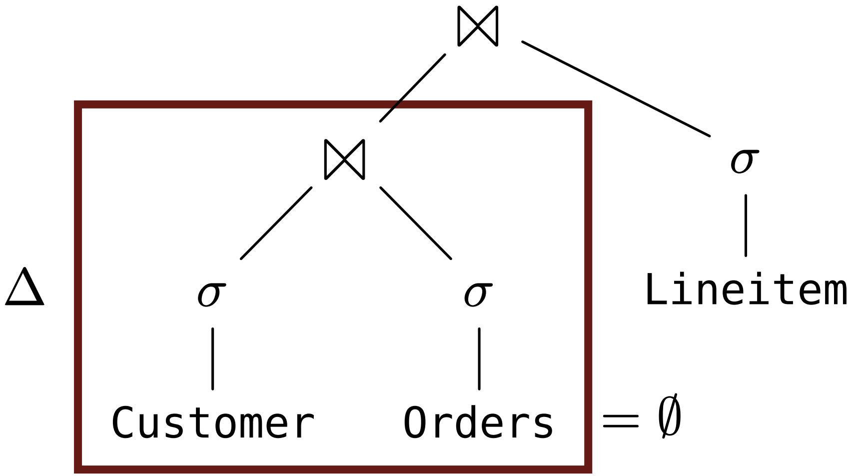
Example

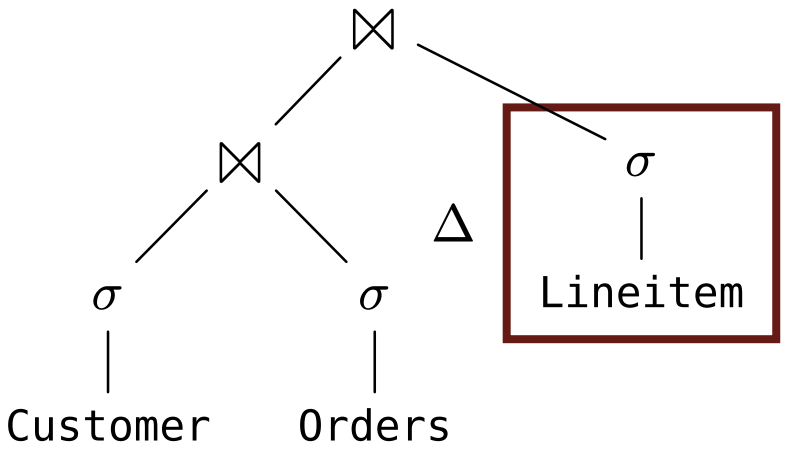
What is ΔQ with respect to a change in `Lineitem`?



$(\sigma(C) \bowtie \sigma(O)) \bowtie \Delta[\sigma(L)]$

Example

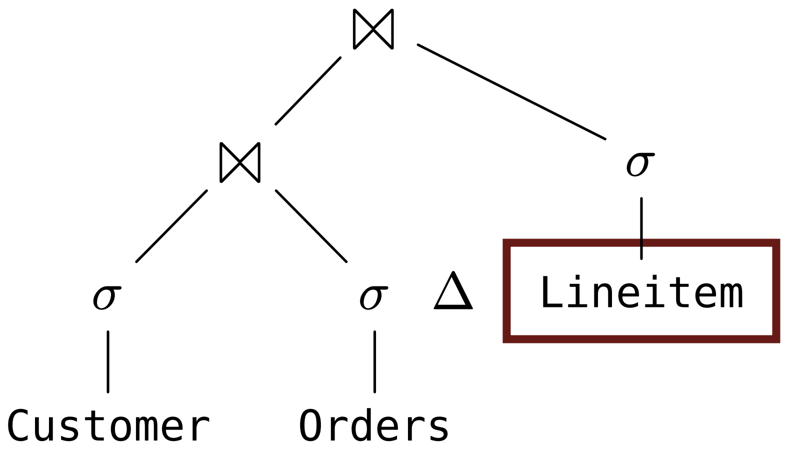
What is ΔQ with respect to a change in `Lineitem`?



$(\sigma(C) \bowtie \sigma(O)) \bowtie \sigma(\Delta[L])$

Example

What is ΔQ with respect to a change in `Lineitem`?



$(\sigma(C) \bowtie \sigma(O)) \bowtie \sigma(\delta_L)$

Multisets

Multisets

$$\{1, 1, 1, 2, 2, 2, 2, 2, 3, 3, 4, 4, 4, 4, 4, 4, 5\}$$

Multisets

$\{1, 1, 1, 2, 2, 2, 2, 2, 3, 3, 4, 4, 4, 4, 4, 4, 5\}$

(not compact)

Multisets

$\{1, 1, 1, 2, 2, 2, 2, 2, 3, 3, 4, 4, 4, 4, 4, 4, 5\}$

(not compact)

$\{1 \to 3; 2 \to 5; 3 \to 2; 4 \to 6; 5 \to 1\}$

$\{1, 1, 1, 2, 2, 2, 2, 2, 3, 3, 4, 4, 4, 4, 4, 4, 5\}$

(not compact)

$\{1 \to 3; 2 \to 5; 3 \to 2; 4 \to 6; 5 \to 1\}$

Multiset Representation: Tuple $\to$ # of occurrences

Multisets

$$\{1, 1, 1, 2, 2, 2, 2, 2, 3, 3, 4, 4, 4, 4, 4, 4, 5\}$$

(not compact)

$$\{1 \rightarrow 3; 2 \rightarrow 5; 3 \rightarrow 2; 4 \rightarrow 6; 5 \rightarrow 1\}$$

Multiset Representation: Tuple $\rightarrow$ ~~# of occurrences~~ multiplicity

Multiset Deltas

How does union work with multisets?

$$\{\langle A\rangle \to 1, \langle B\rangle \to 3\} \cup \{\langle B\rangle \to 2, \langle C\rangle \to 4\} =$$

Multiset Deltas

How does union work with multisets?

$$\{\langle A\rangle \rightarrow 1, \langle B\rangle \rightarrow 3\} \cup \{\langle B\rangle \rightarrow 2, \langle C\rangle \rightarrow 4\} =$$

$$\{\langle A\rangle \rightarrow ???, \langle B\rangle \rightarrow ???, \langle C\rangle \rightarrow ???\}$$

Multiset Deltas

How does union work with multisets?

$$\{\langle A \rangle \to 1, \langle B \rangle \to 3\} \cup \{\langle B \rangle \to 2, \langle C \rangle \to 4\} =$$

$$\{\langle A \rangle \to 1 + 0, \langle B \rangle \to \texttt{???}, \langle C \rangle \to \texttt{???}\}$$

Multiset Deltas

How does union work with multisets?

$\{\langle A\rangle \rightarrow 1, \langle B\rangle \rightarrow 3\} \cup \{\langle B\rangle \rightarrow 2, \langle C\rangle \rightarrow 4\} =$

$\{\langle A\rangle \rightarrow 1 + 0, \langle B\rangle \rightarrow 3 + 2, \langle C\rangle \rightarrow \text{???}\}$

Multiset Deltas

How does union work with multisets?

$$\{\langle A \rangle \to 1, \langle B \rangle \to 3\} \cup \{\langle B \rangle \to 2, \langle C \rangle \to 4\} =$$

$$\{\langle A \rangle \to 1 + 0, \langle B \rangle \to 3 + 2, \langle C \rangle \to 0 + 4\}$$

Multiset Deltas

How does union work with multisets?

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$$\{\langle A\rangle \to 1+0, \langle B\rangle \to 3+2, \langle C\rangle \to 0+4\}$$

—

$$\{\langle A\rangle \to 1\} \cup \{\langle A\rangle \to -1\} =$$

Multiset Deltas

How does union work with multisets?

$\{\langle A\rangle \rightarrow 1, \langle B\rangle \rightarrow 3\} \cup \{\langle B\rangle \rightarrow 2, \langle C\rangle \rightarrow 4\} =$

$\{\langle A\rangle \rightarrow 1+0, \langle B\rangle \rightarrow 3+2, \langle C\rangle \rightarrow 0+4\}$

—

$\{\langle A\rangle \rightarrow 1\} \cup \{\langle A\rangle \rightarrow -1\} = \{\langle A\rangle \rightarrow 0\}$

Multiset Deltas

How does union work with multisets?

$$\{\langle A\rangle \to 1, \langle B\rangle \to 3\} \cup \{\langle B\rangle \to 2, \langle C\rangle \to 4\} =$$

$$\{\langle A\rangle \to 1+0, \langle B\rangle \to 3+2, \langle C\rangle \to 0+4\}$$

—

$$\{\langle A\rangle \to 1\} \cup \{\langle A\rangle \to -1\} = \{\langle A\rangle \to 0\} = \{\}$$

How does cross-product work with multisets?

$$\{\langle A\rangle \to 1, \langle B\rangle \to 3\} \cup \{\langle C\rangle \to 4\} =$$

Multiset Deltas

How does cross-product work with multisets?

$\{\langle A\rangle \to 1, \langle B\rangle \to 3\} \cup \{\langle C\rangle \to 4\} =$

$\{\langle A, C\rangle \to ???, \langle B, C\rangle \to ???\}$

Multiset Deltas

How does cross-product work with multisets?

$$\{\langle A \rangle \to 1, \langle B \rangle \to 3\} \cup \{\langle C \rangle \to 4\} =$$

$$\{\langle A, C \rangle \to 1 \times 4, \langle B, C \rangle \to ???\}$$

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How does projection work with multisets?

$$\pi_{\#1}\{\langle A, X\rangle \to 1, \langle A, Y\rangle \to 2, \langle B, Z\rangle \to 5\} =$$

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How does selection work with multisets?

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Multiset Deltas

How does selection work with multisets?

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$\{\langle A, X\rangle \to 1, \langle A, Y\rangle \to 2, \langle B, Z\rangle \to 0\}$ $\{\langle A, X\rangle \to 1, \langle A, Y\rangle \to 2\}$

Rings strike again

$$\bowtie = \times$$

$$\pi, \cup = +$$