Toward Building Deletion Compliant Data Systems

Subhadeep Sarkar
IoT, edge computing, autonomous vehicles, smart city, and smart healthcare are all examples of exponential data growth that are enabled by 5G technology.
fast writes

fast reads
Out-of-place paradigm

Relational & Array-based

NoSQL

- SciDB
- VERTICA
- SQLite
- [tile]DB

- Bigtable
- Cassandra
- HBase
- RocksDB
- WT

- monetdb
- influxdb
- DynamoDB
- levelDB
- Scylla

- SAP HANA
- QuasarDB
- riak
- tarantool

BOSTON UNIVERSITY
Out-of-place paradigm

Out-of-place updates/deletes

Merge updates/deletes lazily

BetrFS

Vertica

RocksDB
Out-of-place paradigm

Out-of-place updates/deletes

Merge updates/deletes lazily

Does Not Scale with Deletes!
Some items will also be deleted from 11 albums.

Delete 6,447 Items

Cancel

Large-scale production
Internal DB ops
Privacy
Table drop
data migration
Periodic cleanup
CCPA (California)
GDPR (EU, UK)
VCDPA (Virginia)
ZippyDB
25.2M deletes / day
UP2X
100M merge via deletes / day
<table>
<thead>
<tr>
<th>Large-scale production</th>
<th>Internal DB ops</th>
<th>Privacy</th>
</tr>
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<tr>
<td><strong>ZippyDB</strong></td>
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MANDATES

- GDPR (EU, UK)
- CCPA (California)
- VCPDA (Virginia)

- Persistent deletes
- Timely deletes
Our Vision

PRIVACY-THROUGH-DELETION

- Navigate deletion requirements
- Translate the requirements
- Realize efficient deletes
- Scale with data
Right to be forgotten

Right to delete

Deletion right
Right to be forgotten
Right to delete
Deletion right

on-demand
retention-based

Extracting Requirements

Regulations
Right to be forgotten
Right to delete
Deletion right

Extracting Requirements
- on-demand
- retention-based

Query Language Support
- requirement translation

Regulations

Extracting Requirements

Query Language Support
SQL-support for deletes

CREATE TABLE R (column1 type1, column2 type2, ...) WITH RET_DUR
  {ARBITRARY|FIXED (t1 <ret1>, t1 <ret1>, ...)}
WITH DPT
  {ARBITRARY|FIXED (d1 <dpt1>, d1 <dpt1>, ...)};

INSERT INTO R (val1, val2, ...) WITH RET_DUR
  {<t>|t<i>};

DELETE FROM R
  WHERE (...)
WITH DPT
  {<d>|d<i>};
CREATE TABLE R (...
  WITH RET_DUR
  {ARBITRARY | FIXED(...)}
  WITH DPT
  {ARBITRARY | FIXED(...)};

INSERT INTO R (...)  
  WITH RET_DUR {<t>|t<i>};

DELETE FROM R  
  WHERE (...)  
  WITH DPT {<d>|d<i>};
Regulations

- Right to be forgotten
- Right to delete
- Deletion right

Extracting Requirements

- on-demand
- retention-based

Query Language Support

CREATE TABLE R (...) 
WITH RET_DUR 
{ARBITRARY | FIXED(...)}
WITH DPT 
{ARBITRARY | FIXED(...)};

INSERT INTO R (...) 
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DELETE FROM R 
WHERE (...) 
WITH DPT {<d>|d<i>};

System Support
On-demand Deletes
Retention-based Deletes
Persisting Updates
Delete from File System
Timely Deletes from B-e trees
Timely deletes from B-e trees
Regulation Compliance as a System Feature
Secure Deletes from Hardware
Delete from Archive
Delete from View & Snapshots
On-demand Deletes

Retention-based Deletes

Persisting Updates

Range Deletes

Secured Deletes from Hardware

Delete from File System

Deletion from File System

Regulation Compliance as a System Feature

Timely deletes from B-e trees

Timely Deletes from B-e trees

Delete from View & Snapshots

Delete from Archive

Persisting Updates

Deletion from File System
On-demand Deletes
Retention-based Deletes

- Range Deletes
- Persisting Updates
- Deletion from File System
- On-demand Deletes
- Secure Deletes from Hardware

- Timely Deletes from B-e trees
- Deletion in Distributed Frameworks
- Deletion from File System

- Delete from View & Snapshots
- Regulation Compliance as a System Feature
- Secure Deletes from Hardware
- Deletion from Archive

Secure Deletes from Hardware
Log-Structured Merge-tree
key  value

RID  address  name  department  ...  location
Realizing **Retention-Based Deletes**

delete all entries older than: $TS_x$

key

<table>
<thead>
<tr>
<th>RID</th>
<th>attr-1</th>
<th>attr-2</th>
<th>attr-3</th>
<th>...</th>
<th>attr-n</th>
</tr>
</thead>
</table>

sort key = delete key
Realizing **Retention-Based Deletes**

Delete all entries older than: $TS_x$
Realizing Retention-Based Deletes

delete all entries older than: $T{S_x}$

<table>
<thead>
<tr>
<th>key</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RID</td>
<td>timestamp attr-2 attr-3 ... attr-n</td>
</tr>
</tbody>
</table>

sort key ≠ delete key

scattered occurrences
Realizing **Retention-Based Deletes**

delete all entries older than: $TS_x$

<table>
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<th>RID</th>
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<th>attr-2</th>
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<th>...</th>
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**sort key** ≠ **delete key**

scattered occurrences
Realizing Retention-Based Deletes

delete all entries older than: $TS_x$

latency spikes
superfluous I/Os

sort key ≠ delete key
Realizing Retention-Based Deletes

delete all entries older than <= 65\textsubscript{D}

S\textsubscript{min}=1 :: S\textsubscript{max}=99
D\textsubscript{min}=1\textsubscript{D} :: D\textsubscript{max}=90\textsubscript{D}

S\textsubscript{min}=1 :: S\textsubscript{max}=24
D\textsubscript{min}=3\textsubscript{D} :: D\textsubscript{max}=80\textsubscript{D}

S\textsubscript{min}=29 :: S\textsubscript{max}=60
D\textsubscript{min}=9\textsubscript{D} :: D\textsubscript{max}=90\textsubscript{D}

S\textsubscript{min}=61 :: S\textsubscript{max}=79
D\textsubscript{min}=1\textsubscript{D} :: D\textsubscript{max}=89\textsubscript{D}

S\textsubscript{min}=80 :: S\textsubscript{max}=99
D\textsubscript{min}=7\textsubscript{D} :: D\textsubscript{max}=85\textsubscript{D}

page 1
1 4 9 14 15 19 20 24
34\textsubscript{D} 69\textsubscript{D} 3\textsubscript{D} 79\textsubscript{D} 8\textsubscript{D} 80\textsubscript{D} 23\textsubscript{D} 24\textsubscript{D}

page 2
29 32 33 40 44 52 56 60
88\textsubscript{D} 90\textsubscript{D} 28\textsubscript{D} 74\textsubscript{D} 9\textsubscript{D} 76\textsubscript{D} 81\textsubscript{D} 64\textsubscript{D}

page 3
61 63 67 71 72 73 78 79
75\textsubscript{D} 82\textsubscript{D} 1\textsubscript{D} 67\textsubscript{D} 77\textsubscript{D} 89\textsubscript{D} 65\textsubscript{D} 12\textsubscript{D}

page 4
80 84 86 87 91 94 95 99
70\textsubscript{D} 41\textsubscript{D} 62\textsubscript{D} 7\textsubscript{D} 25\textsubscript{D} 85\textsubscript{D} 59\textsubscript{D} 19\textsubscript{D}

SST file
Realizing **Retention-Based Deletes**

delete all entries older than \( \leq 65_D \)

<table>
<thead>
<tr>
<th>SST file</th>
<th>page 1</th>
<th>page 2</th>
<th>page 3</th>
<th>page 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_{\text{min}}=1 :: S_{\text{max}}=99 )</td>
<td>1 4 9 14 15 19 20 24</td>
<td>29 32 33 40 44 52 56 60</td>
<td>61 63 67 71 72 73 78 79</td>
<td>80 84 86 87 91 94 95 99</td>
</tr>
<tr>
<td>( D_{\text{min}}=1D :: D_{\text{max}}=90_D )</td>
<td>( 34_D ) ( 69_D ) ( 3_D ) ( 79_D ) ( 8_D ) ( 80_D ) ( 23_D ) ( 24_D )</td>
<td>( 88_D ) ( 90_D ) ( 28_D ) ( 74_D ) ( 9_D ) ( 76_D ) ( 81_D ) ( 64_D )</td>
<td>( 75_D ) ( 82_D ) ( 1_D ) ( 67_D ) ( 77_D ) ( 89_D ) ( 65_D ) ( 12_D )</td>
<td>( 70_D ) ( 41_D ) ( 62_D ) ( 7_D ) ( 25_D ) ( 85_D ) ( 59_D ) ( 19_D )</td>
</tr>
</tbody>
</table>
Realizing **Retention-Based Deletes**

delete all entries older than \( \leq 65_D \)

Data Layout holds the key!
Realizing Retention-Based Deletes

KiWi
Key Weaving storage layout
Key Weaving storage layout

delete all entries older than <= $65_D$
Key Weaving storage layout

delete all entries older than $\leq 65_D$

SST file

partitioned on $S$
Key Weaving storage layout

delete all entries older than <= \(65_D\)

partitioned on \(S\)
Key Weaving storage layout

delete all entries older than \( \leq 65_D \)

SST file

partitioned on \( S \)
Key Weaving storage layout

delete all entries older than $\leq 65_D$

partitioned on $S$
Key Weaving storage layout

delete all entries older than $\leq 65_D$

SST file

partitioned on $D$

partitioned on $S$
Key Weaving storage layout

delete all entries older than \( \leq 65_D \)

<table>
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<th>SST file</th>
<th>partitioned on ( D )</th>
<th>partitioned on ( S )</th>
</tr>
</thead>
</table>

**page 1**

| \( S_{\text{min}}=1 :: S_{\text{max}}=99 \) | \( D_{\text{min}}=1_D :: D_{\text{max}}=90_D \) |

| \( S_{\text{min}}=1 :: S_{\text{max}}=60 \) | \( D_{\text{min}}=3_D :: D_{\text{max}}=90_D \) |

| \( S_{\text{min}}=1 :: S_{\text{max}}=60 \) | \( D_{\text{min}}=3_D :: D_{\text{max}}=64_D \) |

**page 2**

| \( S_{\text{min}}=1 :: S_{\text{max}}=60 \) | \( D_{\text{min}}=3_D :: D_{\text{max}}=64_D \) |

| \( S_{\text{min}}=4 :: S_{\text{max}}=56 \) | \( D_{\text{min}}=9_D :: D_{\text{max}}=90_D \) |

| \( S_{\text{min}}=4 :: S_{\text{max}}=56 \) | \( D_{\text{min}}=69_D :: D_{\text{max}}=90_D \) |

**Drop page**

| \( 3_D \) | \( 8_D \) | \( 9_D \) | \( 23_D \) | \( 24_D \) | \( 28_D \) | \( 34_D \) | \( 64_D \) |

| \( 4 \) | \( 40 \) | \( 52 \) | \( 14 \) | \( 19 \) | \( 56 \) | \( 29 \) | \( 32 \) |

| \( 69_D \) | \( 74_D \) | \( 76_D \) | \( 79_D \) | \( 80_D \) | \( 81_D \) | \( 88_D \) | \( 90_D \) |
Key Weaving storage layout

delete all entries older than $\leq 65_D$

SST file

page 1

page 2

page 3

page 4

partitioned on $D$
sorted on $S$

drop page

delete tile 1

delete tile 2
Key Weaving storage layout

delete all entries older than $\leq 65_D$

partitioned on $D$
sorted on $S$

$S_{\text{min}} = 1 :: S_{\text{max}} = 99$
$D_{\text{min}} = 1_D :: D_{\text{max}} = 90_D$

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Key Weaving storage layout

delete all entries older than <= 65\(_D\)

SST file

partitioned on \(S\)

sorted on \(S\)

partitioned on \(D\)

sorted on \(D\)

drop page

drop page

1 I/O
Key Weaving storage layout

SST file

partitioned on S

partitioned on D

sorted on S

get(14)
Kiwi navigates deletion performance vs. lookup performance.
KiWi navigates lookup performance retention-based delete performance

\[ h^* = \sqrt{\frac{f_{\text{SRD}} \cdot \frac{N}{B}}{\phi \cdot L \cdot (f_{\text{EPQ}} + f_{\text{PQ}})} + L \cdot f_{\text{SRQ}}} \]

workload data structure
On-demand Deletes

Range Deletes
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https://disc.bu.edu/persistent-deletes
My Amazing Collaborators

Thank You!

https://disc.bu.edu/persistent-deletes