Fast Compaction Algorithms for NoSQL Databases

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July 2, 2015

Big Data is Everywhere

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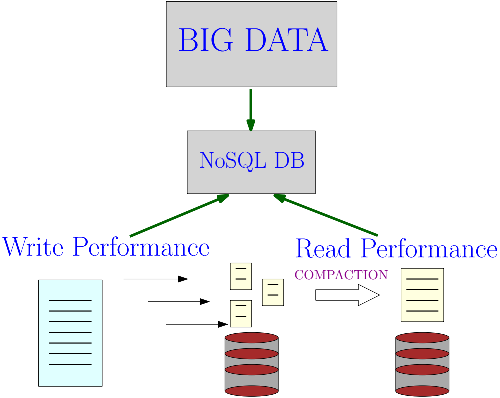
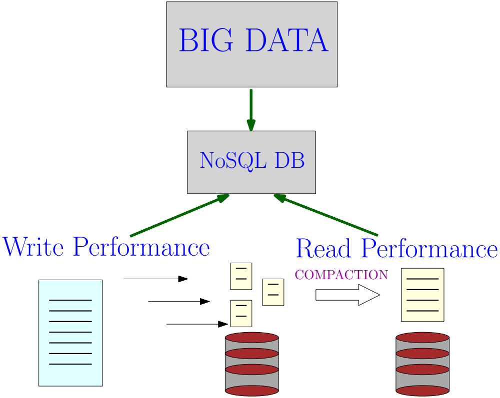
Systems experts have to cope with Big Data

Online shopping, content management, finance, education

Big Data, NoSQL and Compaction



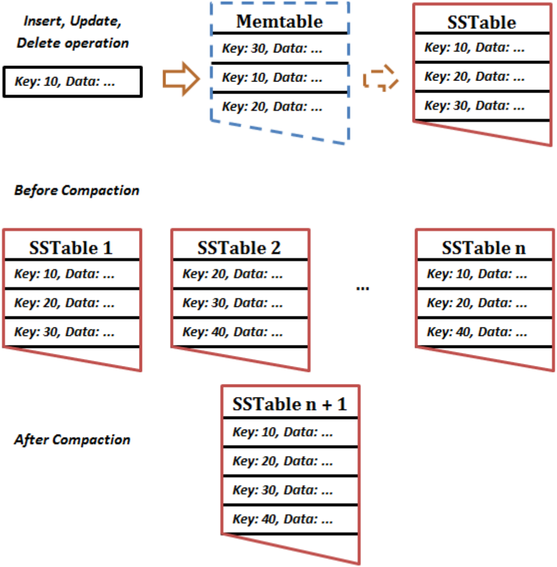
Big Data, NoSQL and Compaction



We provide algorithms with provable guarantees for compaction

Use algorithm : Balanced Tree with Smallest Input

A day in the life of a NoSQL DB



Outline

- Compaction - the problem
- Compaction - our approach
- Greedy algorithms for Compaction
- Experimental results

Compaction - so why is it a problem?

Strategy A

S_1	S_2	S_3	S_4
1	2	3	1,2,3

Compaction - so why is it a problem?

Strategy A

$S_1 \cup S_2$	S_3	S_4
1,2	3	1,2,3

$$\text{Cost} = |S_1| + |S_2| + |S_1 \cup S_2| = 4$$

Compaction - so why is it a problem?

Strategy A

$S_1 \cup S_2 \cup S_3$ $\quad\quad$ S_4

$\boxed{1,2,3}$ $\quad\quad$ $\boxed{1,2,3}$

$$\text{Cost} = |S_1| + |S_2| + |S_1 \cup S_2| = 4$$

$$\text{Cost} = |S_1 \cup S_2| + |S_3| + |S_1 \cup S_2 \cup S_3| = 6$$

Compaction - so why is it a problem?

Strategy A

$$S_1 \cup S_2 \cup S_3 \cup S_4$$

$$\boxed{1,2,3}$$

$$\text{Cost} = |S_1| + |S_2| + |S_1 \cup S_2| = 4$$

$$\text{Cost} = |S_1 \cup S_2| + |S_3| + |S_1 \cup S_2 \cup S_3| = 6$$

$$\text{Cost} = |S_1 \cup S_2 \cup S_3| + |S_4| + |S_1 \cup S_2 \cup S_3 \cup S_4| = 9$$

Compaction - so why is it a problem?

OR ...

Compaction - so why is it a problem?

Strategy B

S_1	S_2	S_3	S_4
1	2	3	1,2,3

Compaction - so why is it a problem?

Strategy B

S_1	S_2	$S_3 \cup S_4$
$\boxed{1}$	$\boxed{2}$	$\boxed{1,2,3}$

$$\text{Cost} = |S_3| + |S_4| + |S_3 \cup S_4| = 7$$

Compaction - so why is it a problem?

Strategy B

S_1 $\boxed{1}$

$S_2 \cup S_3 \cup S_4$ $\boxed{1,2,3}$

$$\text{Cost} = |S_3| + |S_4| + |S_3 \cup S_4| = 7$$

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Compaction - so why is it a problem?

Strategy B

$$S_1 \cup S_2 \cup S_3 \cup S_4$$

$$\boxed{1,2,3}$$

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Compaction - so why is it a problem?

Which choice is better?

Current approaches to Compaction

- **Merge sstables when their number exceeds a threshold**
  - Bigtable, Cassandra, Riak

Current approaches to Compaction

- **Merge sstables when their number exceeds a threshold**
  - Bigtable, Cassandra, Riak

- **Merge at every Insert, Update, Delete**
  - Optimizes for reads
  - Cassandra, Riak

Current approaches to Compaction

- **Merge sstables of equal size**
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Current approaches to Compaction

- **Merge sstables of equal size**
  - Cassandra, Bigtable

- **Prioritize more recent data**
  - Logs

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Theoretical analysis of compaction

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Formulate as an optimization problem

Study algorithms and their complexity

Theoretical analysis - why?

- **Theoretical analysis will provide new insights**

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- **Better idea about limits of optimization**

Theoretical analysis - why?

- **Theoretical analysis will provide new insights**
- **Better idea about limits of optimization**
- **Past work: Mathieu et. al.**
  - Merge prefix of sets - what prefix?
  - Cost function additive

Compaction as an optimization problem

Given sets $S_1, \ldots, S_n$, merge them to produce a single set

Compaction as an optimization problem

A merge is replacing some sets with their union

Compaction as an optimization problem

How many sets k?

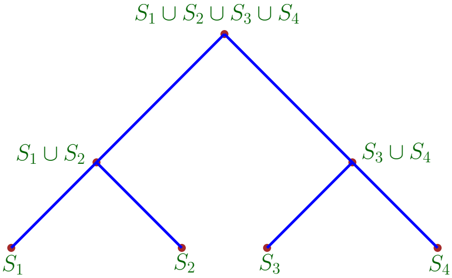
Compaction as an optimization problem

$$\textbf{Cost} = \overbrace{|S_{i_1}| + \ldots + |S_{i_k}|}^{\textbf{Read}} + \overbrace{|S_{i_1} \cup \ldots \cup S_{i_k}|}^{\textbf{Write}}$$

How to do the merge so that overall cost is minimized?

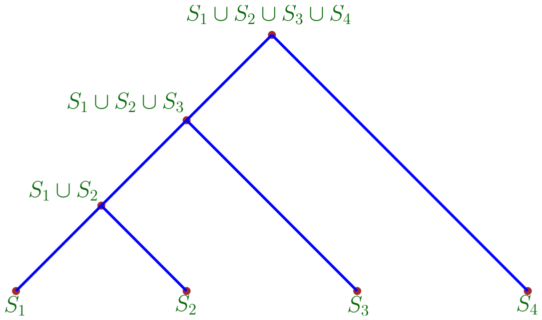
How to select the sets at each merge?

The tree view



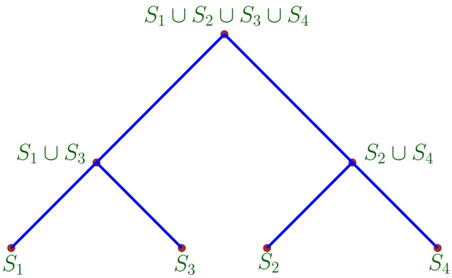
Trees as blueprints for merging algorithms

The tree view



Choice in the merge tree

The tree view



Choice in the ordering of sets on leaves

Hardness result

The compaction problem is NP-hard

Proof in the paper

Hardness result

View - find the tree and the ordering

Hardness result

Fixed tree - choice on ordering. Is this NP hard?

Hardness result

Yes. For some trees we prove NP hardness

Hardness result

Compaction reduces to this problem

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Maintain a collection :

$$S_1, \ldots, S_n$$

We always merge 2 sets at a time

Strategy determines which two we merge

We have $n-1$ merge steps in all

Main intuition : Merge so that larger sets form later

Smallest Output (SO)

Minimize $|S_i \cup S_j|$

Smallest Input (SI)

Choose two smallest sets

Balanced Tree (BT)

Ensure a balanced merge tree

Largest Match (LM)

Maximize $|S_i \cap S_j|$

Balanced Tree, Smallest Input (BT(I))

Combine Balanced Tree with Smallest Input

Approximation guarantee

SI, SO, BT are all $O(\log n)$ approximations

Approximation guarantee

BT is $\Omega(\log n)$ in worst case

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Experimental Setup

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- **Merge sstables in Phase II**

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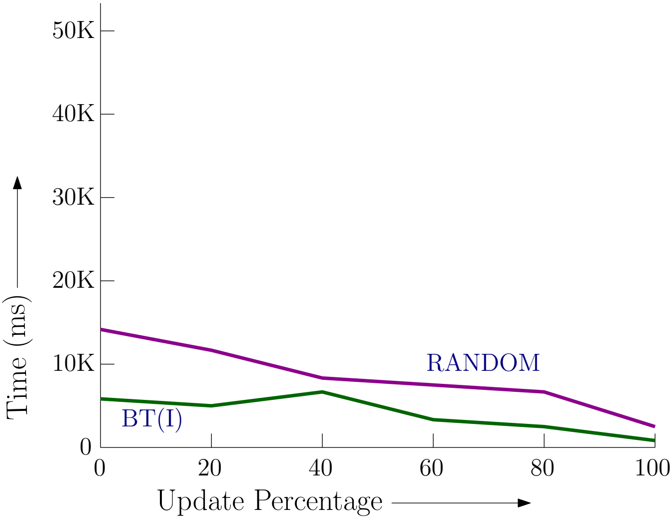
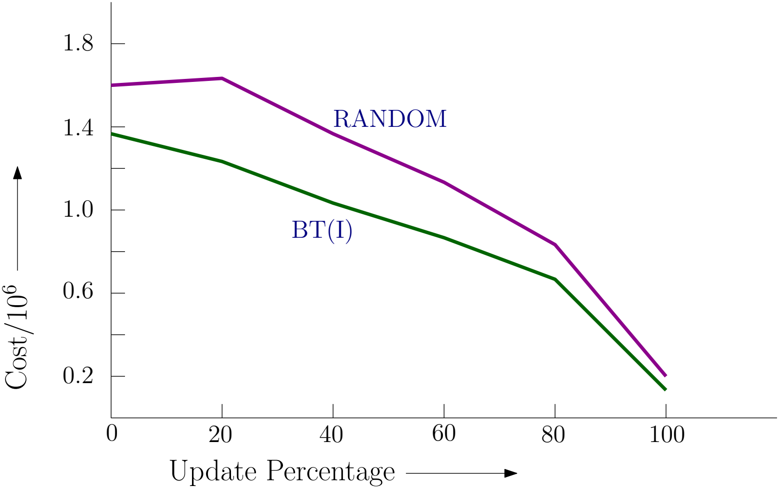
- **Merge sstables in Phase II**
- **Hyperloglog to estimate set sizes with SO (Flajolet et. al.)**

Experimental results



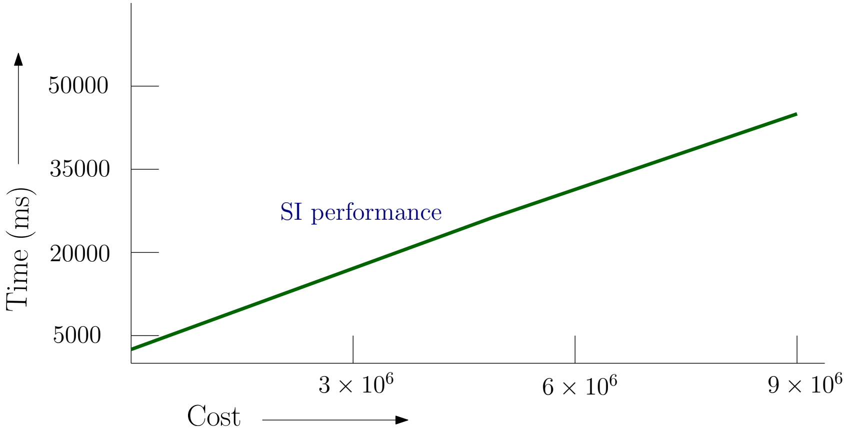
BT(I) is the most efficient in implementation

Experimental results



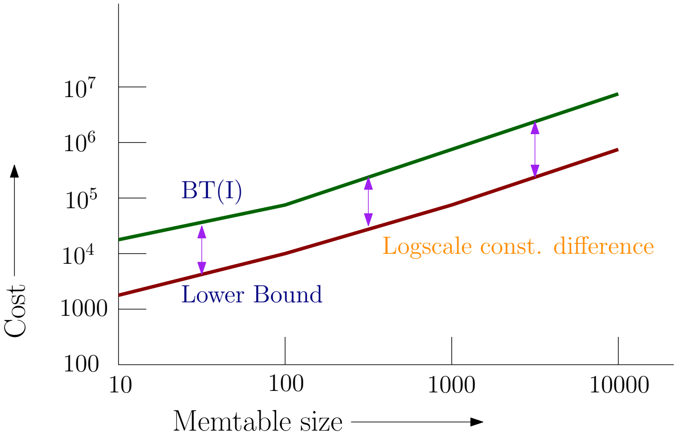
BT(I) is the best cost wise

Experimental results



True cost is modeled accurately by our cost function

Experimental results



Performance within constant factor

SO, SI are better than $O(\log n)$ - proof?

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