Distributed Collaborative Editing

LSEQ: an Adaptive Distributed Sequence Data Structure

On the Fly Order Preserving Object Renaming

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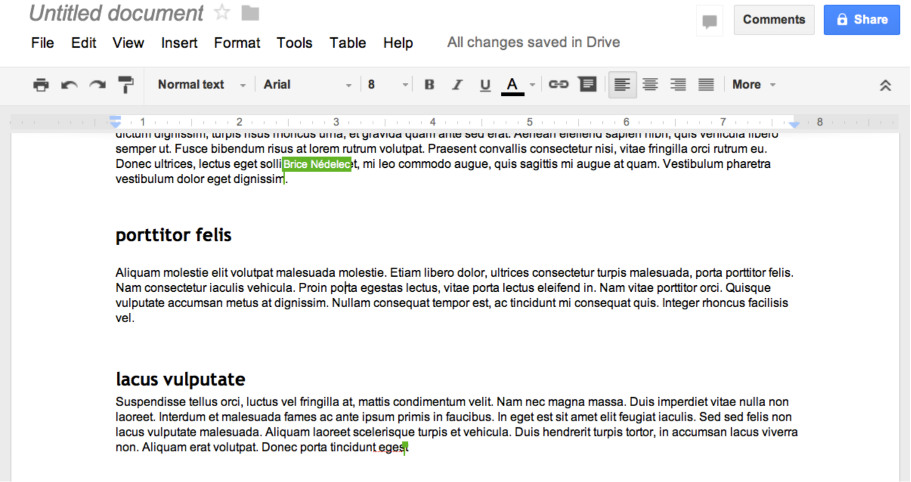
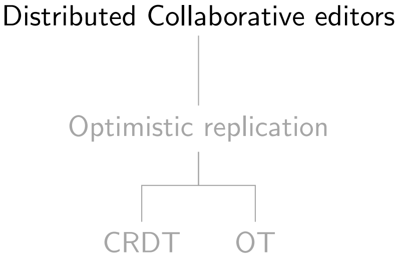
Distributed Collaborative Editors



Distributed Collaborative Editors

1. Across space, time, organizations.



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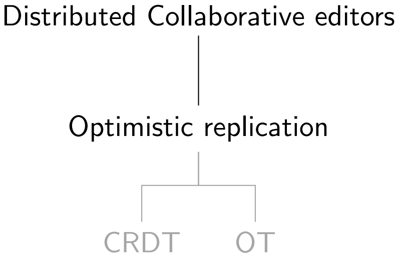
2. Two phases :
   a. locally prepare operations to send
   b. execute remote operations



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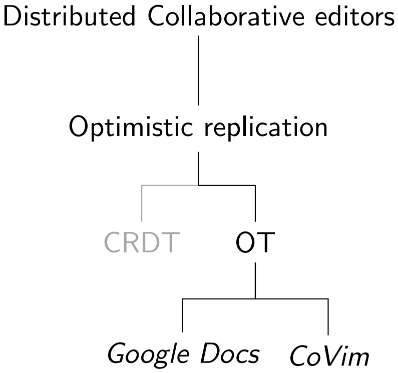
3. Operational transform
   + local operations cheap
   – remote operations complex



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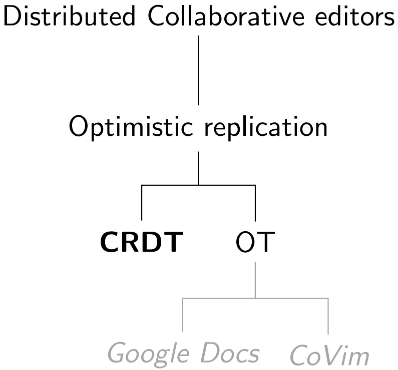
4. Conflict-free Replicated Data Type
    - 2 phases share computational cost



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- Distributed Collaborative editors
  - Optimistic replication
    - **CRDT**
    - OT
      - *Google Docs*
      - *CoVim*

- $\nearrow$ **collaborators** $\Rightarrow$ **quadratic** $\nearrow$ **remote operations**

Distributed Collaborative Editors

A document can be seen as a sequence od basic elements (characters, words, lines, etc.). The problem is non trivial because it is necessary that the edition (updating of the document) ensures the following three properties (CCI) :

1. Convergence : the different copies need to converge to a same copy

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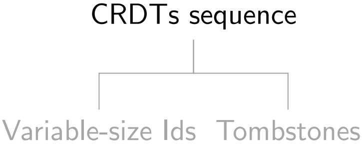
3. Intention : the effect of an operation needs to meet the intention of the user that ordered it

CRDTs for sequences

1. Two commutative operations :
    - Insert / delete
    - **Identify the basic elements**
    - The set of ids is totally ordered
    - The ids make the sequence



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CRDTs sequence

Variable-size Ids Tombstones

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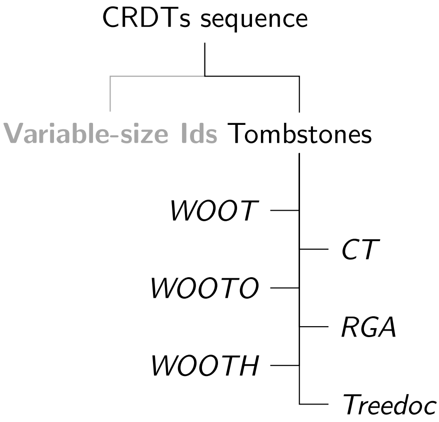

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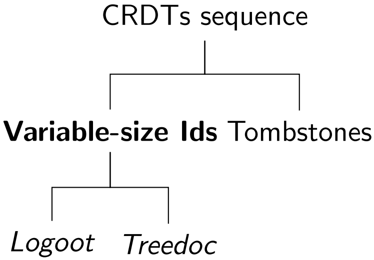
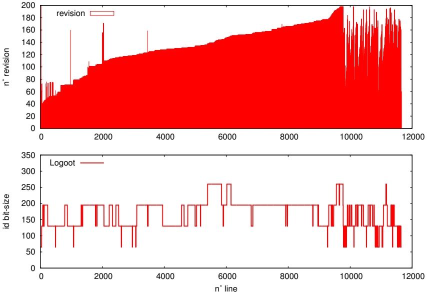
4. The size of identifiers may grow
   - linearly wrt # operations

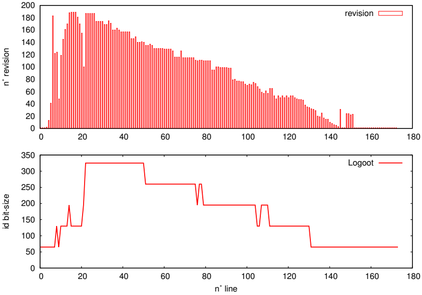


Motivations

Spectrum of two Wikipedia documents.



(a) Page edited in the end. ⇒ 169.7 bits/id.



(b) Page edited in front. ⇒ 172.25 bits/id.

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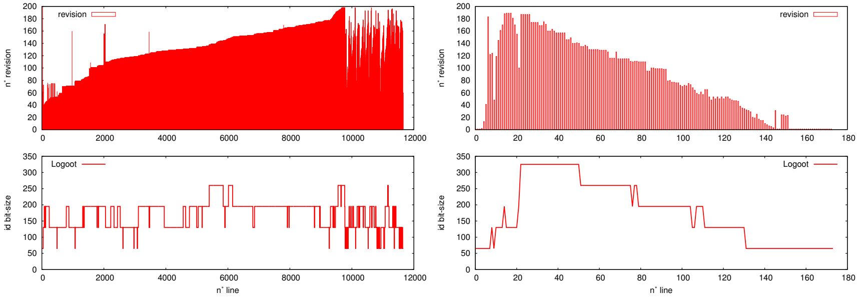
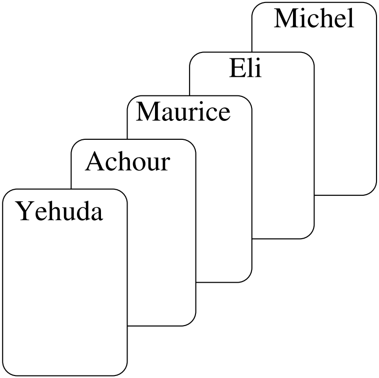


(c) Page edited in the end. ⇒ 169.7 bits/id.

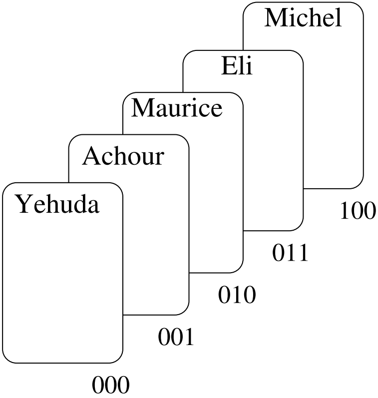
(d) Page edited in front. ⇒ 172.25 bits/id.

⇒ **Allocation strategies are CRUCIAL**

Abstract Problem (1)



Abstract Problem (1)



n cards can be named using ids of size $O(\log n)$

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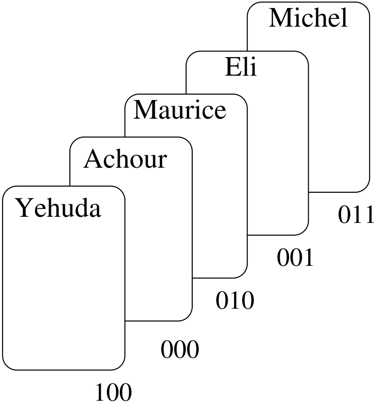
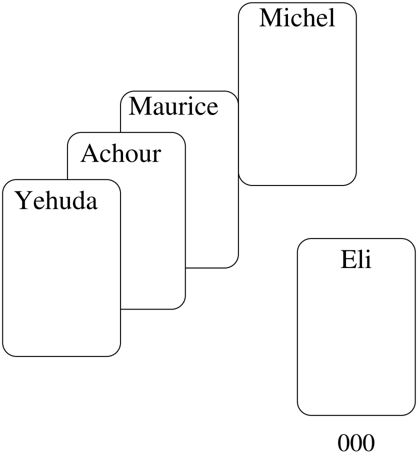


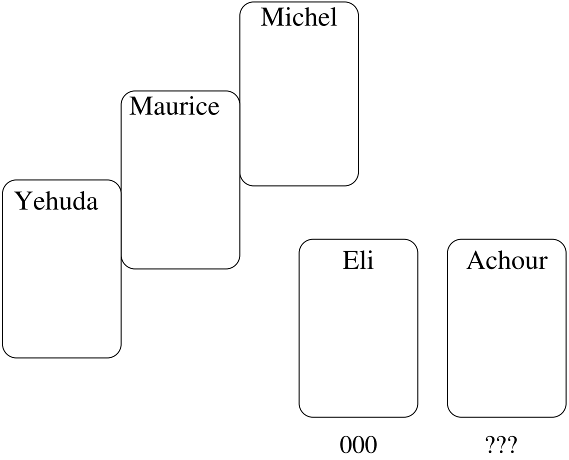
Even if one wants to preserve the order defined by the original names, n cards can be renamed with ids of size $O(\log n)$

Abstract Problem (2)



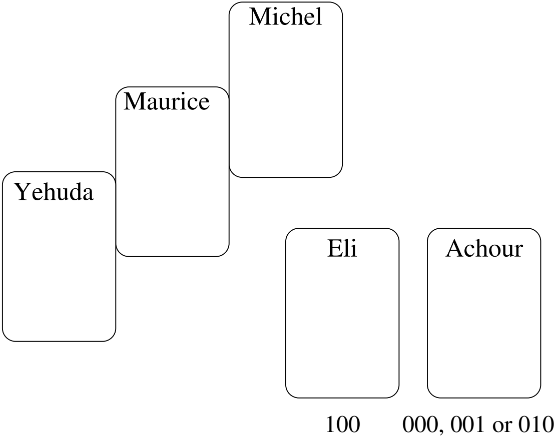
How about if the original names are not a priori known ?

Abstract Problem (2)



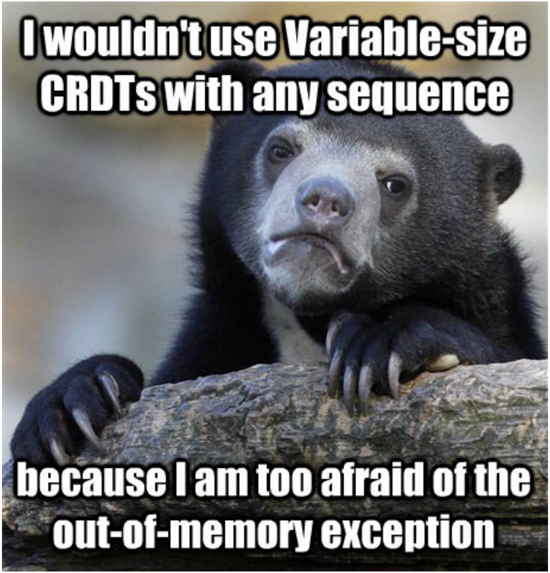
One needs to have spare space (dense set of ids)

Abstract Problem (2)



Is it possible to avoid all this loss of space ?

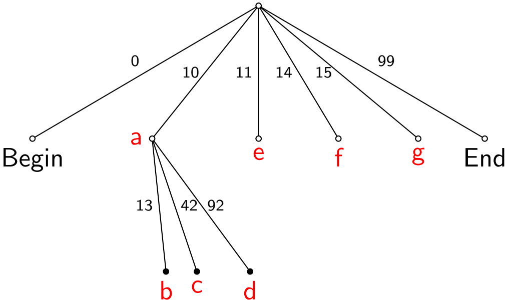
Bear confesses. . .



Problem

Variable-size identifier

A variable-size identifier id is a sequence of numbers $id = [p_1.p_2 \dots p_n]$ which can designate a path in a tree.



Problem statement

Let $\mathcal{D}$ a document on which n insert operations have been performed. Let $\mathcal{I}(\mathcal{D}) = \{id | (\_, id) \in \mathcal{D}\}$. The function $alloc(id_p, id_q)$ should provide identifiers such as :

$$\sum_{id \in \mathcal{I}} \frac{|id|_2}{n} < O(n)$$

$|id|_2$ means $log_2(id)$ aka. bit-length

Proposal : **LSEQ**

Three components :

- base doubling,
- multiple allocation strategies,
- random strategy choice.

Intuition

As it is complex to predict the editing behaviour, some depths of the tree on a given path can be lost if the reward **compensates** the loss.
In other terms, even if LSEQ chooses the wrong strategy at a given time, it will eventually choose the good one, and that choice will **amortize** the cost of all previous lost depths.

Base doubling

Exponential trees :

- Under uniform distribution :
  - Spatial complexity : $O(n\,log\,log\,n)$. Where n the number of Ids.

$[p_1.p_2 \dots p_n] \Rightarrow |p_n|_2 = |p_{n-1}|_2 \mathbf{+1}$. Where $|p_1| = base$

$\mathbf{+1}$ bit $\Rightarrow$ **x2** identifiers

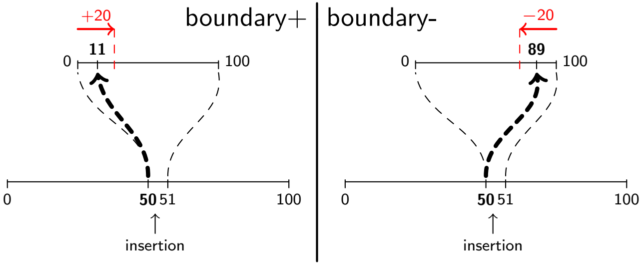
Intuition

If the number of insert operations is **low**, the id bit-length can stay **small**. On the other hand, when the number of insertions **increases**, it is profitable to allocate **larger** identifiers.

Multiple allocation strategies

boundary :

+ Good : page edited in the end.
– Good : page edited in front.



Intuition

The allocation strategy *boundary* is **not sufficient** to be employed as a safe allocation strategy. However, by using its antagonist strategy, each strategy **cancels** the other's **deficiency**.

Random strategy choice

- Unique strategy : not sufficient

$\Rightarrow$ Strategy choice : When ? Which ?

Intuition : When

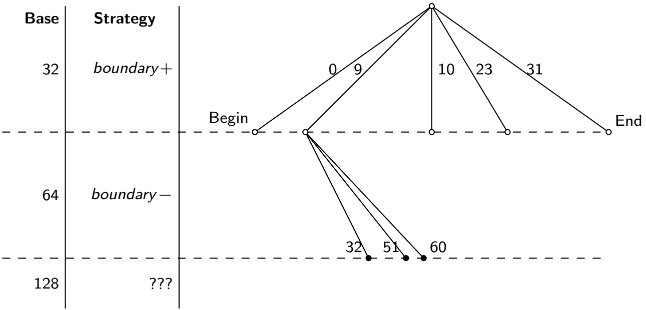
The **opening** of a new space has a major meaning : Either the allocation strategy went wrong, or, on the opposite, a high number of insertions saturated the previous depths, meaning that it requires more space. Therefore, the space opening is an ideal moment to decide which strategy to employ.

Intuition : Which

Since it is impossible to *a priori* know the editing behaviour, the strategy choice should **not favorize any behaviour**. Consequently, the frequency of appearence of each strategies must be equal.

Synthesis : example

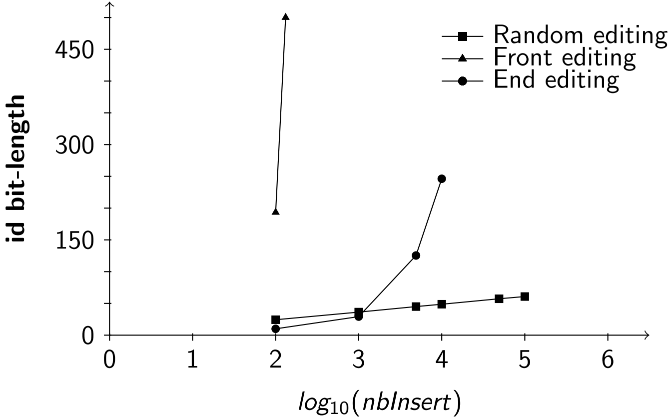
- Exponential tree
- Two allocation strategies : *boundary+* and *boundary–*
- Random strategy choice



Experimentations

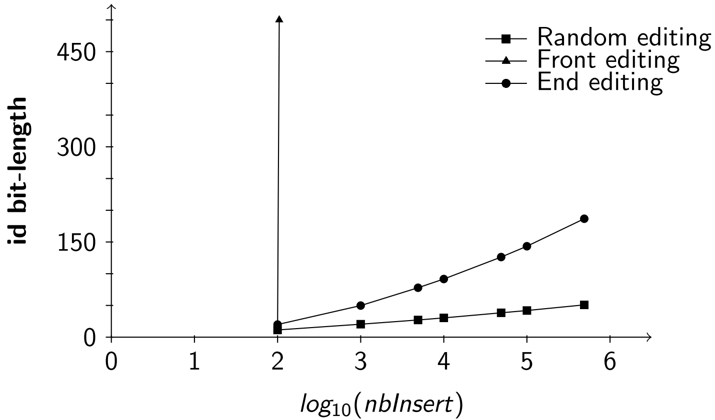
1. Influence of each LSEQ's component
   - $\Rightarrow$ Synthetic documents.
   - $\Rightarrow$ High amount of insertions.
   - $\Rightarrow$ 3 editing behaviour : in the beginning, in the end, random.
2. Comparison with variable-size CRDT.
   - $\Rightarrow$ Real documents : Wikipedia.
   - $\Rightarrow$ 2 editing behaviour : in the beginning, in the end.

Boundary



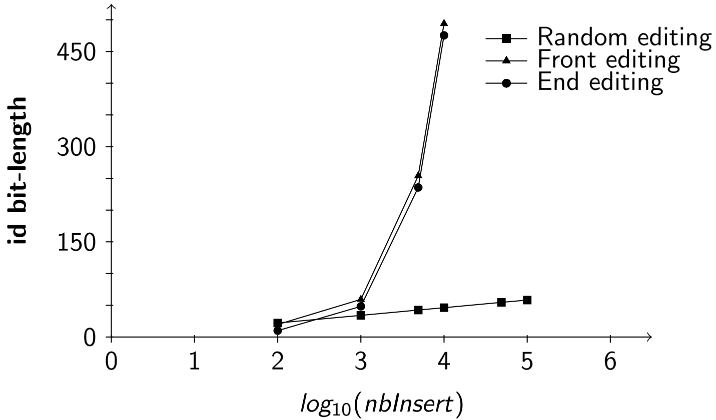
Simple *boundary+* setup with $base = 2^{10}$ and $boundary = 10$

Exponential tree



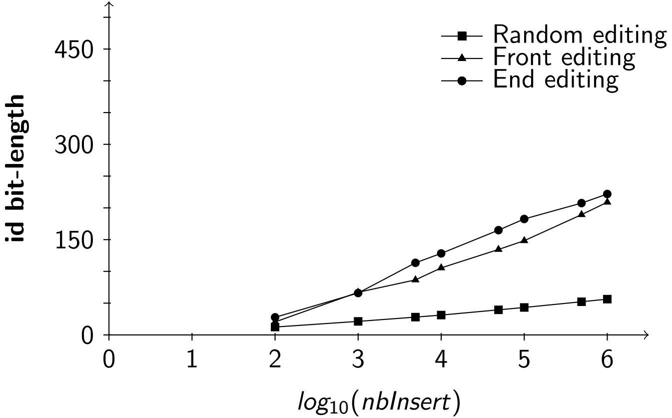
Base doubling setup with $base = 2^{4+id.size}$ and $boundary = 10$

Strategy choice



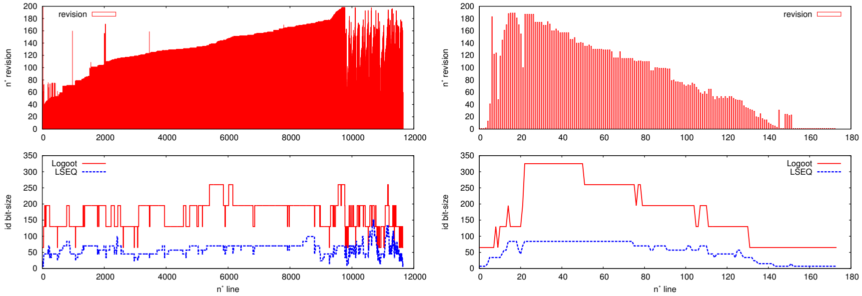
Round-Robin (**RR**) alternation of strategies *boundary+* and *boundary–*
($base = 2^{10}$; $boundary = 10$)

LSEQ



LSEQ randomly alternating *boundary+* and *boundary–* and using the base doubling ($base = 2^{4+id.size}$; $boundary = 10$)

Comparison with Logoot I



Comparison with Logoot II

		L	LSEQ
id-length	avg	2.65	6.25
	max	4	12
id-bit-length	avg	169.7	**61.24**
	max	256	150

Numerical values of a page edited in the end.

		L	LSEQ
id-length	avg	2.69	5.29
	max	5	8
id-bit-length	avg	172.25	**51.99**
	max	320	84

Numerical values on front edited page.

Synthesis : experiments

1. Each component contributes to LSEQ :
   - Exponential tree : sub-linear behaviour
   - Multiple strategies + choice : generic
2. Better than Logoot :
   - On documents edited in the end
   - On documents edited in the beginning

Conclusion and Future Works

- Proof : sub-linear space complexity.
  - n operations : uniform distribution $\Rightarrow O(log\ n)$
  - n operations : monotononic $\Rightarrow O((log\ n)^2)$
  - n operations : worst-case $\Rightarrow O(n^2)$? ? ?
- Proof : worst-case happens with a negligible probability
- Concurrency effect