Distributed Collaborative Editing

LSEQ: an Adaptive Distributed Sequence Data Structure

On the Fly Order Preserving Object Renaming

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Distributed Collaborative Editors

porttitor felis


lacus vulputate

Distributed Collaborative Editors

1. Across space, time, organizations.

Distributed Collaborative editors

Optimistic replication

CRDT OT

Google Docs CoVim
Distributed Collaborative Editors

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

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  - CRDT
  - OT
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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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   ■ 2 phases share computational cost

   ↗ collaborators ⇒ quadratic ↗ remote operations
Distributed Collaborative Editors

A document can be seen as a sequence of 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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1. Convergence: the different copies need to converge to a same copy.
2. Causality: any operation needs to reflect the operations that occurred causally before it.
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

CRDTs sequence

Variable-size Ids  Tombstones
CRDTs for sequences

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   - \(\text{insert}(p, \text{elem}, q)\)
     \(\Rightarrow\) **basic function** \(\text{alloc}(p, q)\)
   - \(\text{delete}(\text{id}_\text{elem})\)
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   - $\Rightarrow$ eventually needs purge
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4. The size of identifiers may grow
   - linearly wrt \# operations
   - very fast depending on the use case
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.
Motivations

Spectrum of two Wikipedia documents.

(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)
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$n$ 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 $O(\log n)$
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...

I wouldn't use Variable-size CRDTs with any sequence

because I am too afraid of the out-of-memory exception
Problem

Variable-size identifier

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

Problem statement

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

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

$|id|_2$ 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.

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

$+ 1$ 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

⇒ 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 appearance of each strategy must be equal.
Synthesis: example

- Exponential tree
- Two allocation strategies: \textit{boundary+} and \textit{boundary–}
- Random strategy choice

<table>
<thead>
<tr>
<th>Base</th>
<th>Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>\textit{boundary+}</td>
</tr>
<tr>
<td>64</td>
<td>\textit{boundary–}</td>
</tr>
<tr>
<td>128</td>
<td>???</td>
</tr>
</tbody>
</table>

```
Begin                  End
\hspace{1cm} 0 \hspace{1cm} 9 \hspace{1cm} 10 \hspace{1cm} 23 \hspace{1cm} 31

\hspace{1cm} 32 \hspace{1cm} 51 \hspace{1cm} 60
```
Experimentations

1. Influence of each LSEQ’s component
   ⇒ Synthetic documents.
   ⇒ High amount of insertions.
   ⇒ 3 editing behaviour: in the beginning, in the end, random.

2. Comparison with variable-size CRDT.
   ⇒ Real documents: Wikipedia.
   ⇒ 2 editing behaviour: in the beginning, in the end.
Boundary

Simple boundary+ setup with $base = 2^{10}$ and $boundary = 10$
Base doubling setup with $base = 2^{4+\text{id.size}}$ and $boundary = 10$
Strategy choice

Round-Robin (RR) alternation of strategies $\text{boundary}+$ and $\text{boundary}−$ ($base = 2^{10}$; $\text{boundary} = 10$)
LSEQ randomly alternating boundary+ and boundary− and using the base doubling (base = \(2^{4+\text{id.size}}\); boundary = 10)
Comparison with Logoot I
Comparison with Logoot II

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>LSEQ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>id-length</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>avg</strong></td>
<td>2.65</td>
<td>6.25</td>
</tr>
<tr>
<td><strong>max</strong></td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td><strong>id-bit-length</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>avg</strong></td>
<td>169.7</td>
<td><strong>61.24</strong></td>
</tr>
<tr>
<td><strong>max</strong></td>
<td>256</td>
<td>150</td>
</tr>
</tbody>
</table>

Numerical values of a page edited in the end.

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>LSEQ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>id-length</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>avg</strong></td>
<td>2.69</td>
<td>5.29</td>
</tr>
<tr>
<td><strong>max</strong></td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td><strong>id-bit-length</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>avg</strong></td>
<td>172.25</td>
<td><strong>51.99</strong></td>
</tr>
<tr>
<td><strong>max</strong></td>
<td>320</td>
<td>84</td>
</tr>
</tbody>
</table>

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