Efficient renaming in Conflict-free Replicated Data Types (CRDTs)

Case Study of a Sequence CRDT : LogootSplit

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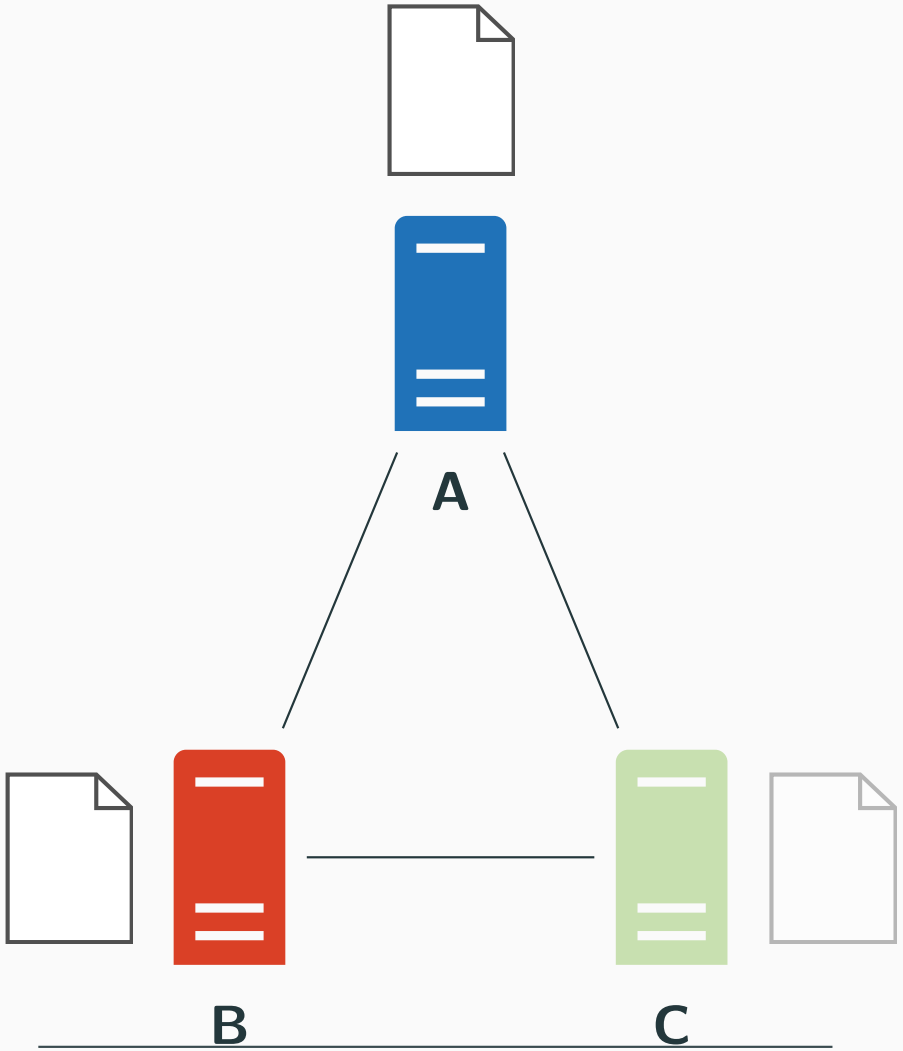
COAST team

December 12, 2021

Conflict-free Replicated Data Types (CRDTs)[1]



- Replicated data structure

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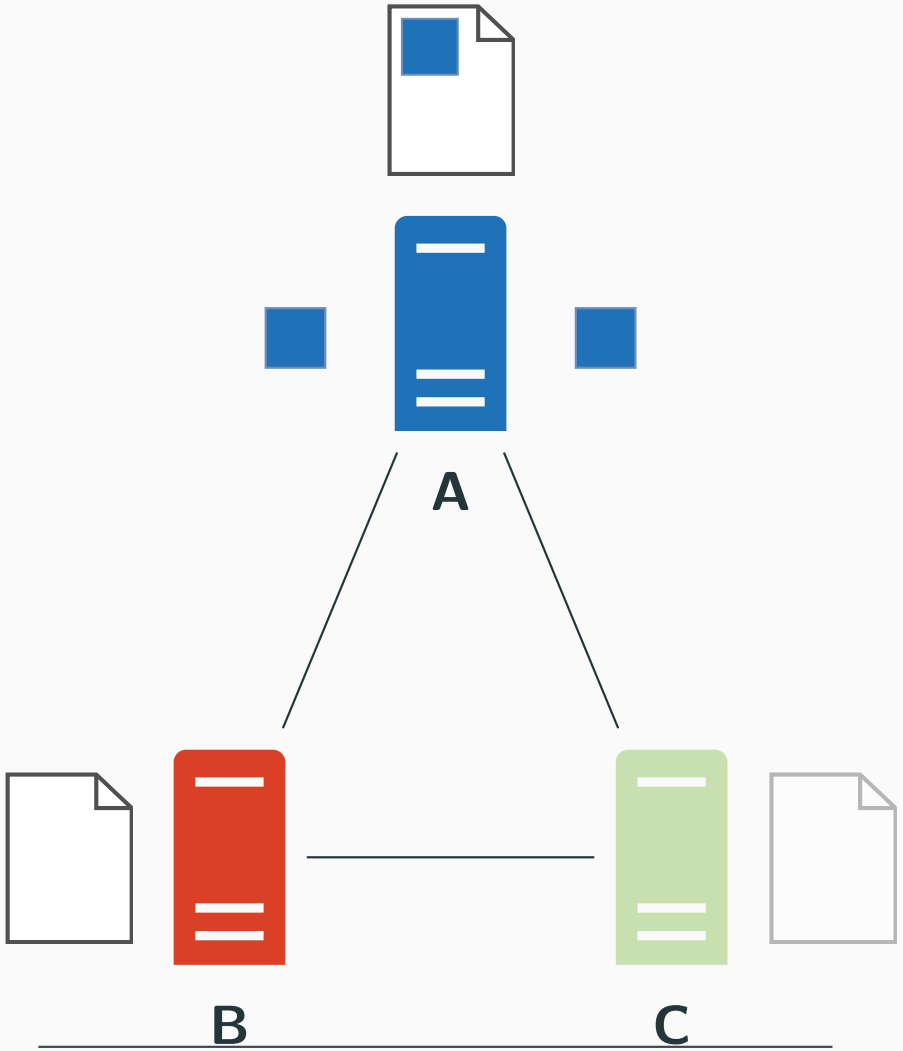

- Replicated data structure
- Updates performed without coordination

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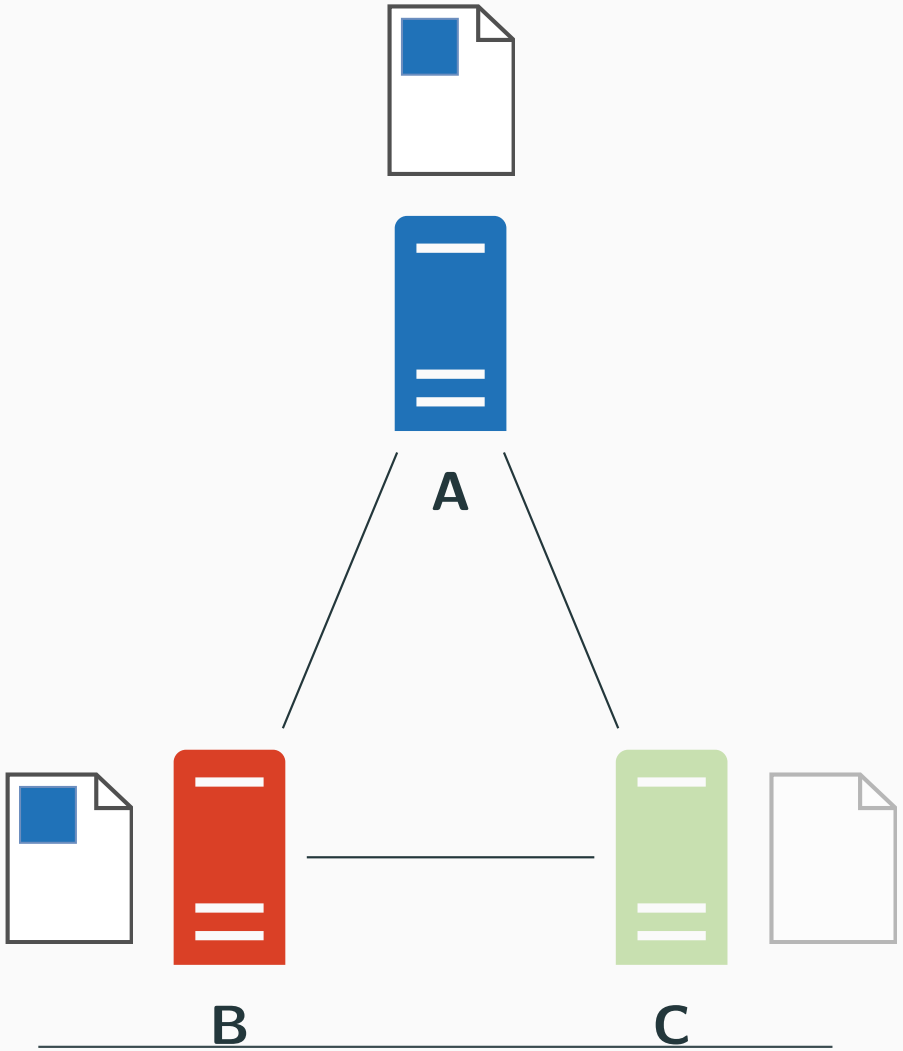

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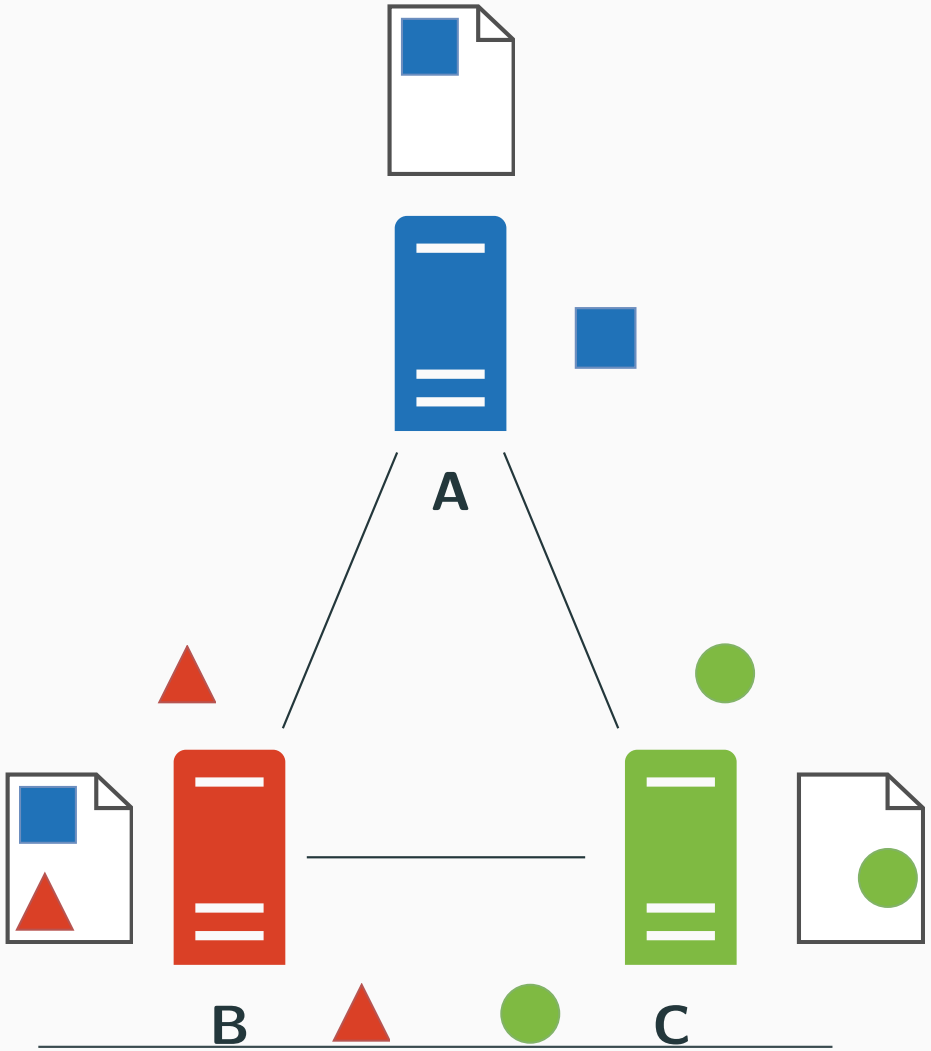

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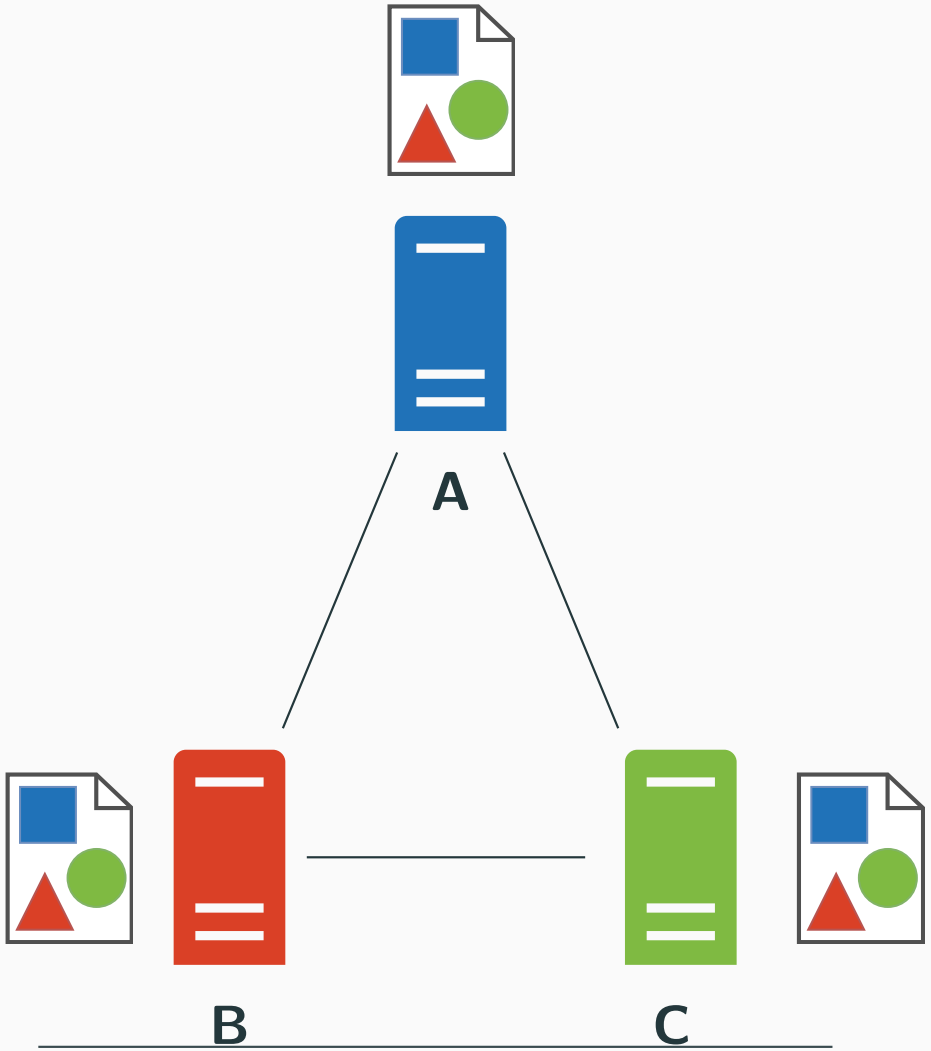

- Replicated data structure
- Updates performed without coordination
- Strong Eventual Consistency

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LogootSplit[2]

- State of the art of *Sequence CRDTs*
- Elements are ordered by their identifier, noted here with the following formalism: $position_{offset}^{node\_id\ \ node\_seq}$

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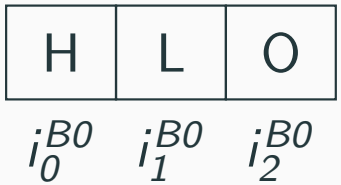

Figure 1: State of a sequence which contains the elements "hlo" and their corresponding identifiers

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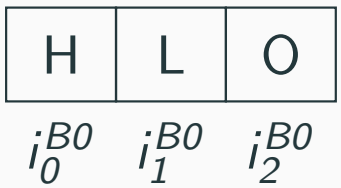

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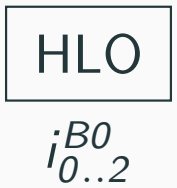

Figure 2: State of a sequence which contains the block "hlo"

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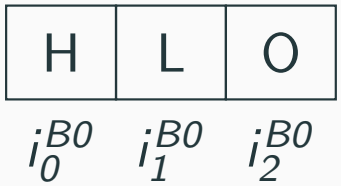

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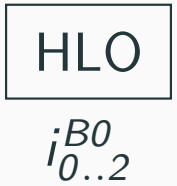

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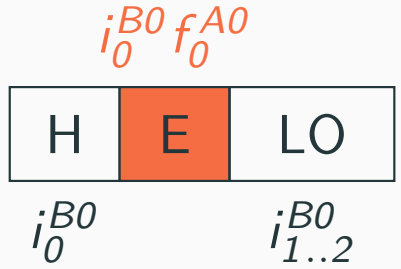

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Research issue

- **Evergrowing overhead:** impacts memory, bandwidth and CPU

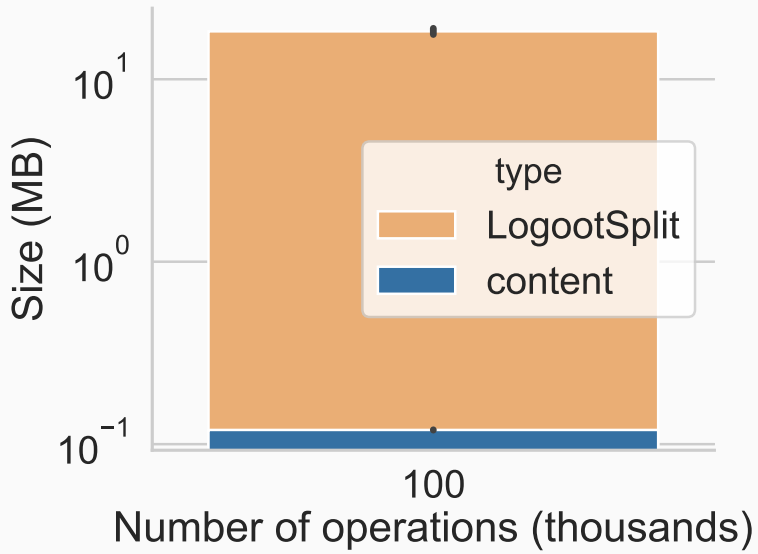


Figure 4: Memory footprint of the data structure

- **Operation count:** 100k
- **Size of content:** 100KB
- **Size of data structure:** 20MB

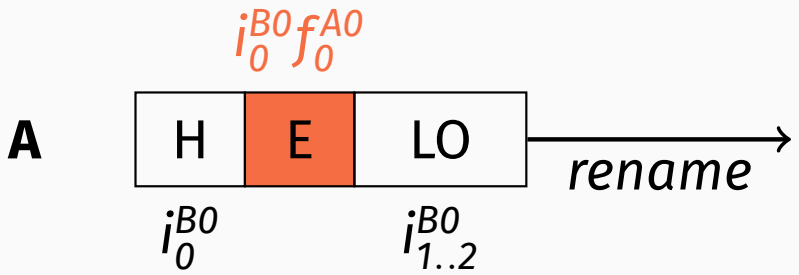
How to reduce the overhead introduced by the data structure?

Our approach

Reassign shorter identifiers and aggregate them into blocks in a fully distributed manner

RenamableLogootSplit

- Propose *RenamableLogootSplit*, *LogootSplit* with a *rename* operation
- Can be performed without coordination



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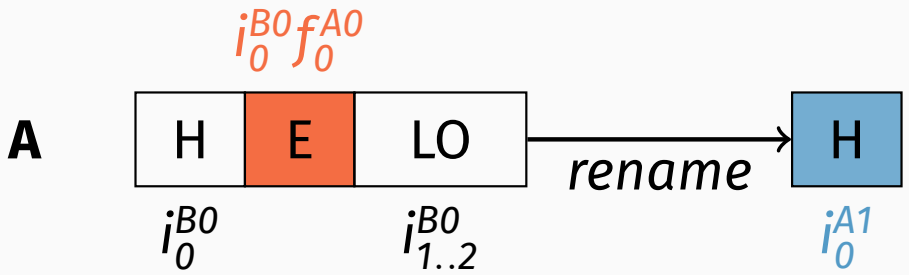

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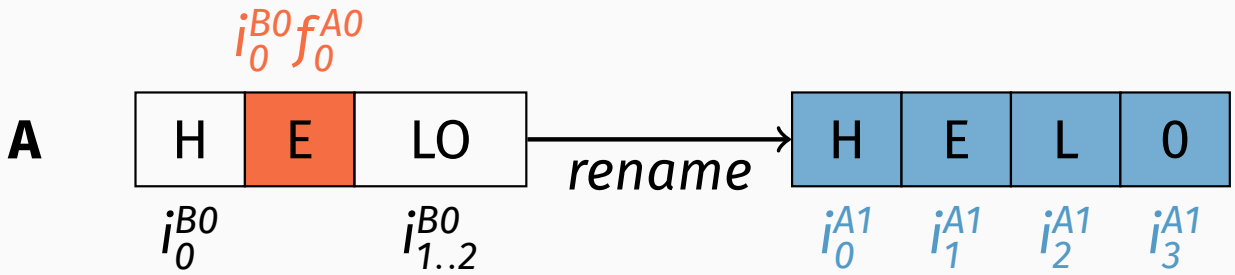

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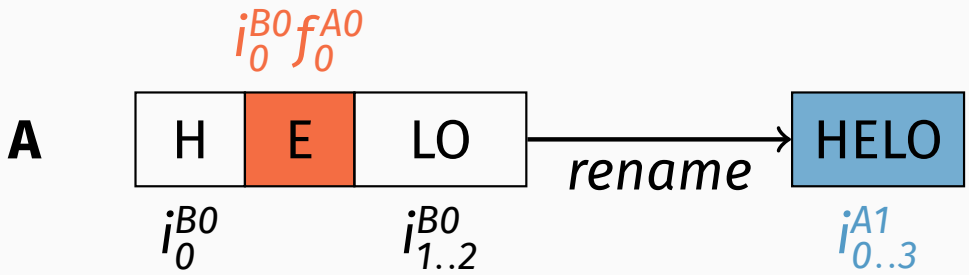

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Handling concurrent operations

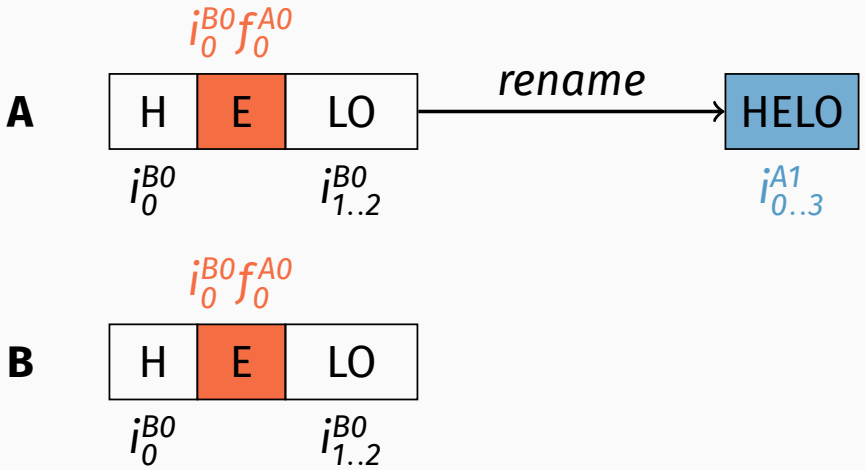

Figure 6: Applying naively concurrent update

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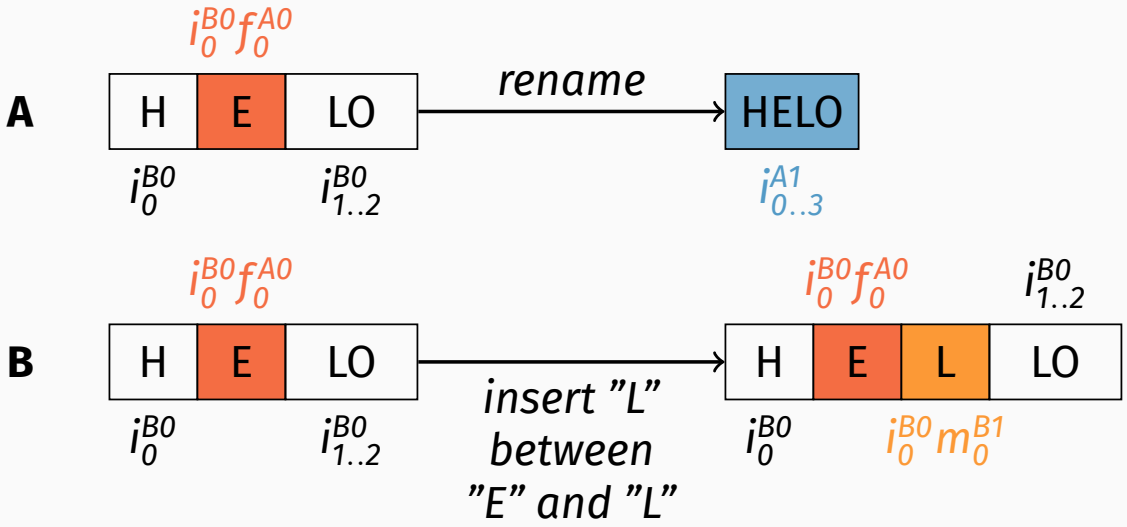

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- Can issue operations concurrently to *rename*

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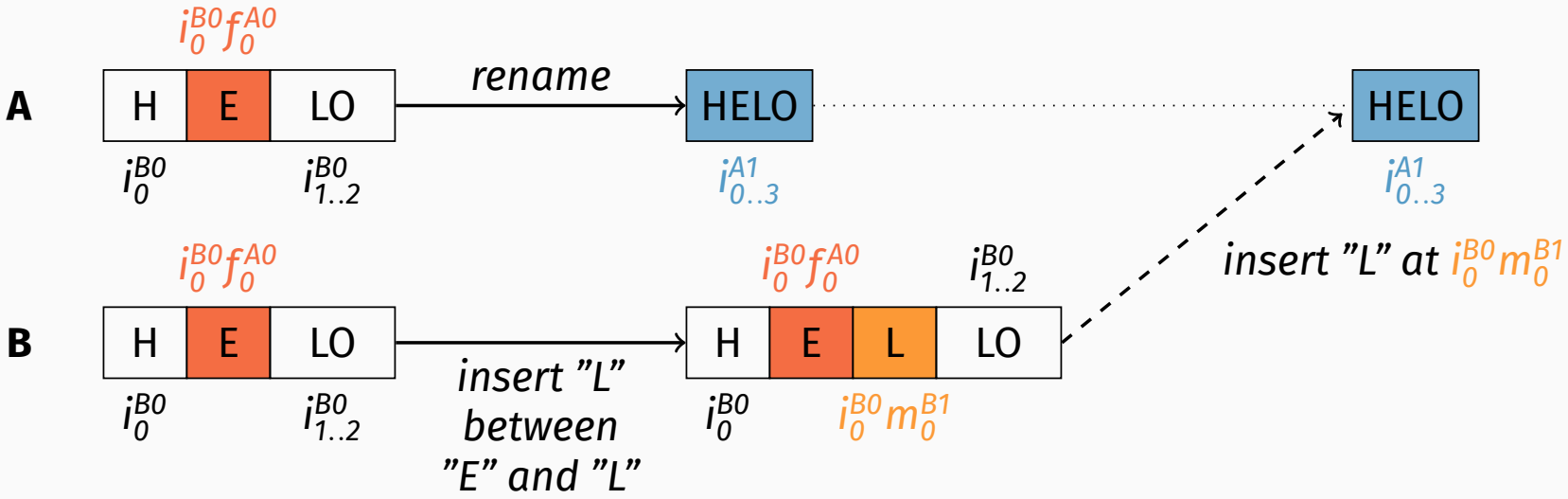

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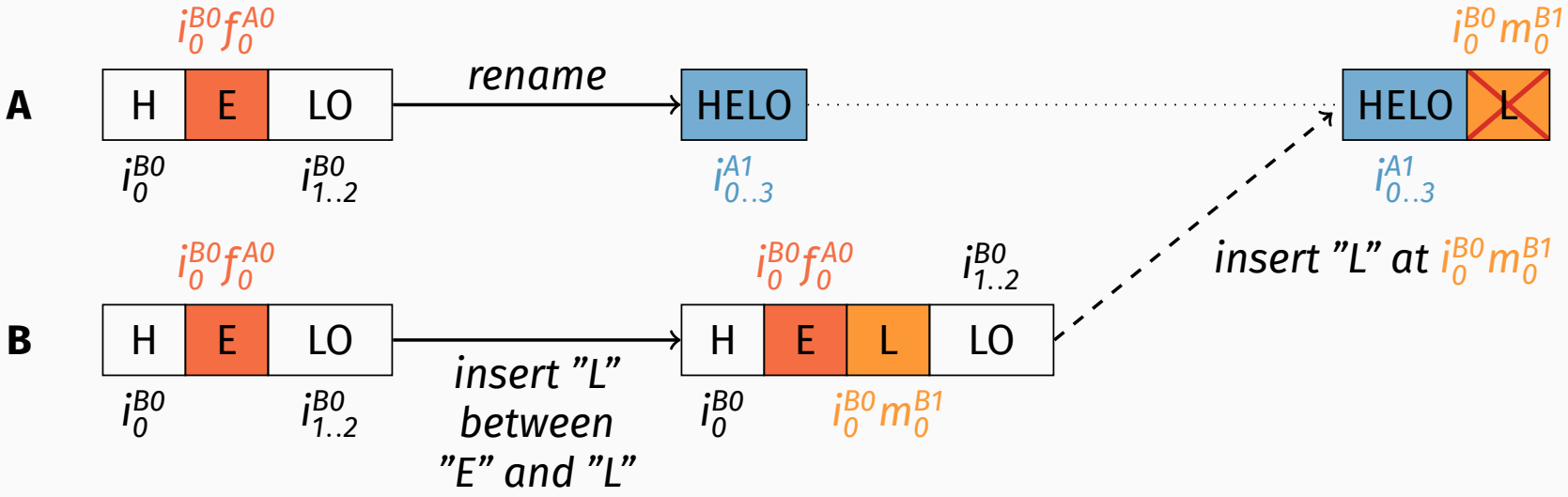

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- Can issue operations concurrently to *rename*
- Produce inconsistencies if applied naively

Fixing handling concurrent operations

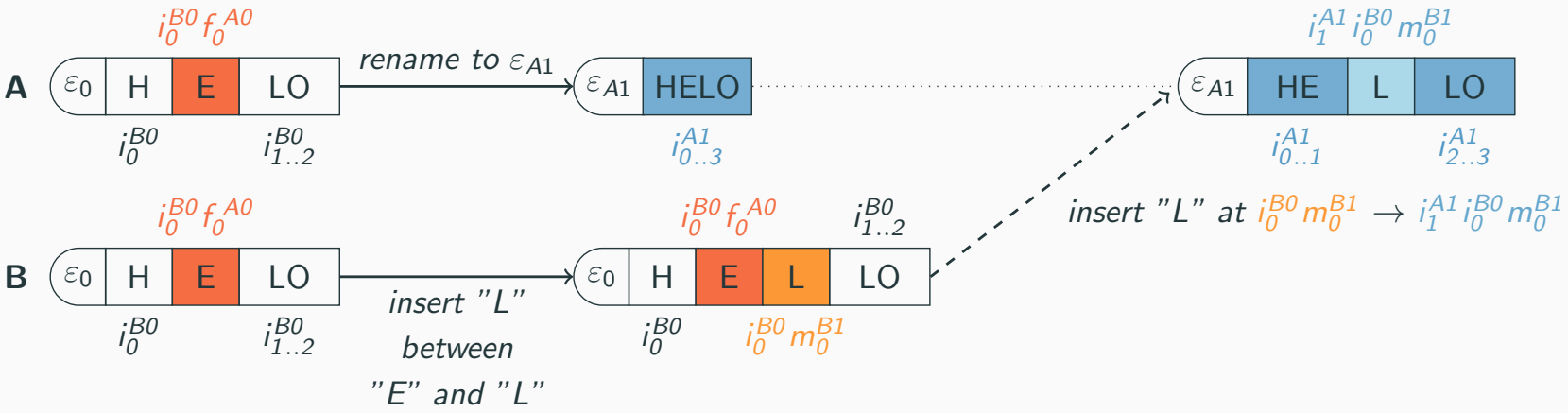

Figure 7: Handling properly concurrent update

- Use *epoch-based* system to track concurrent operations
- Use transform operations against *rename* ones (*OT*)

What about concurrent rename operations ?

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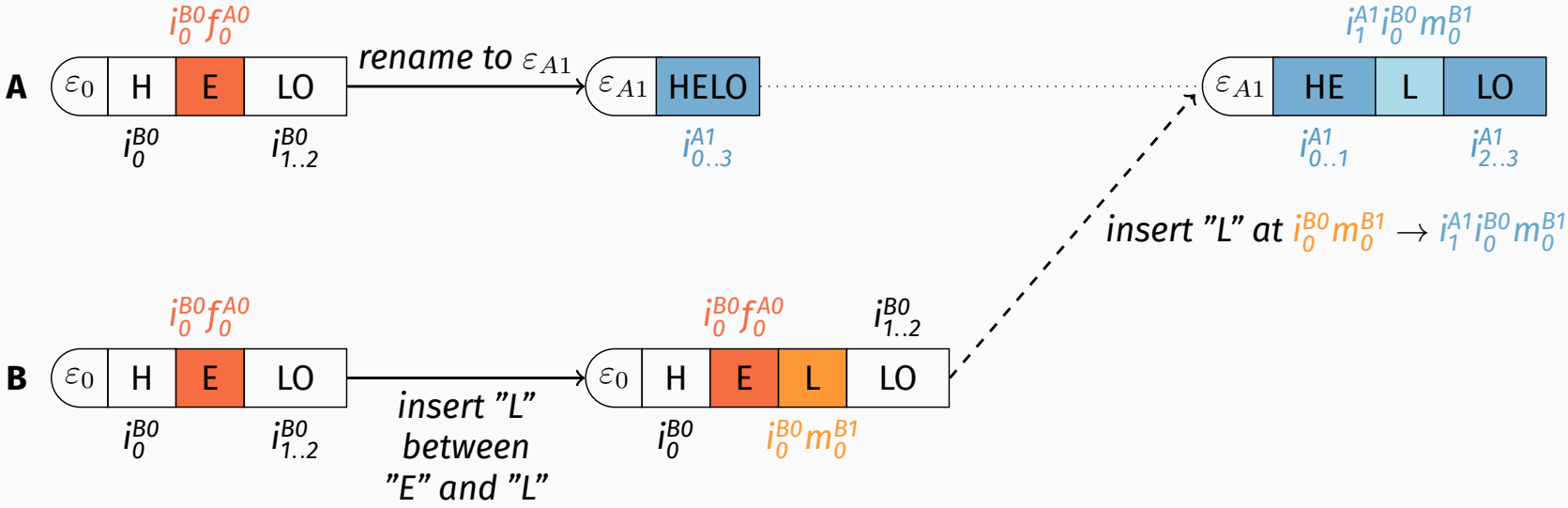

Figure 8: Concurrent *rename* operations leading to divergent states

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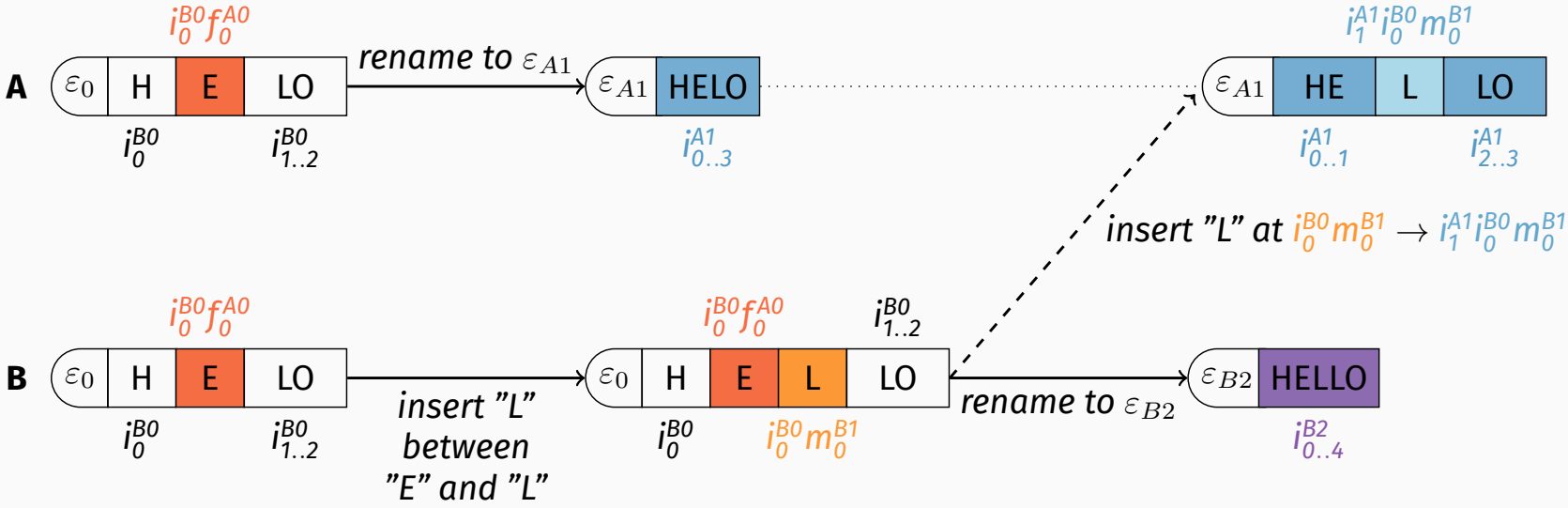

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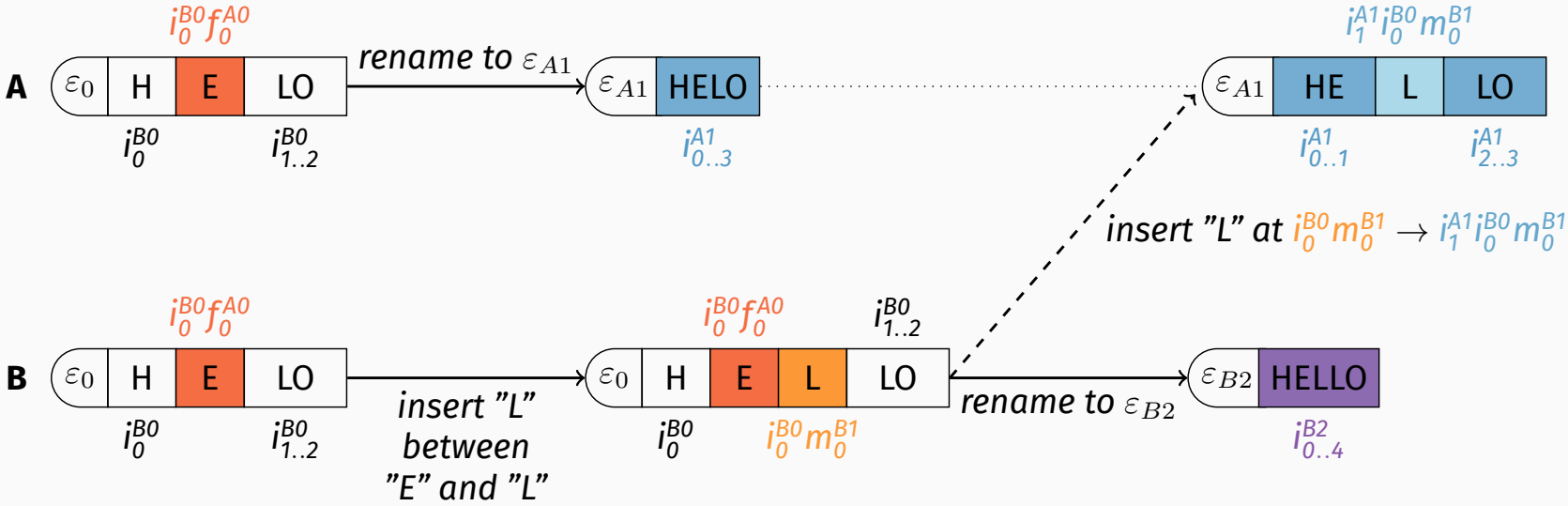

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- *Rename* operations are system operations

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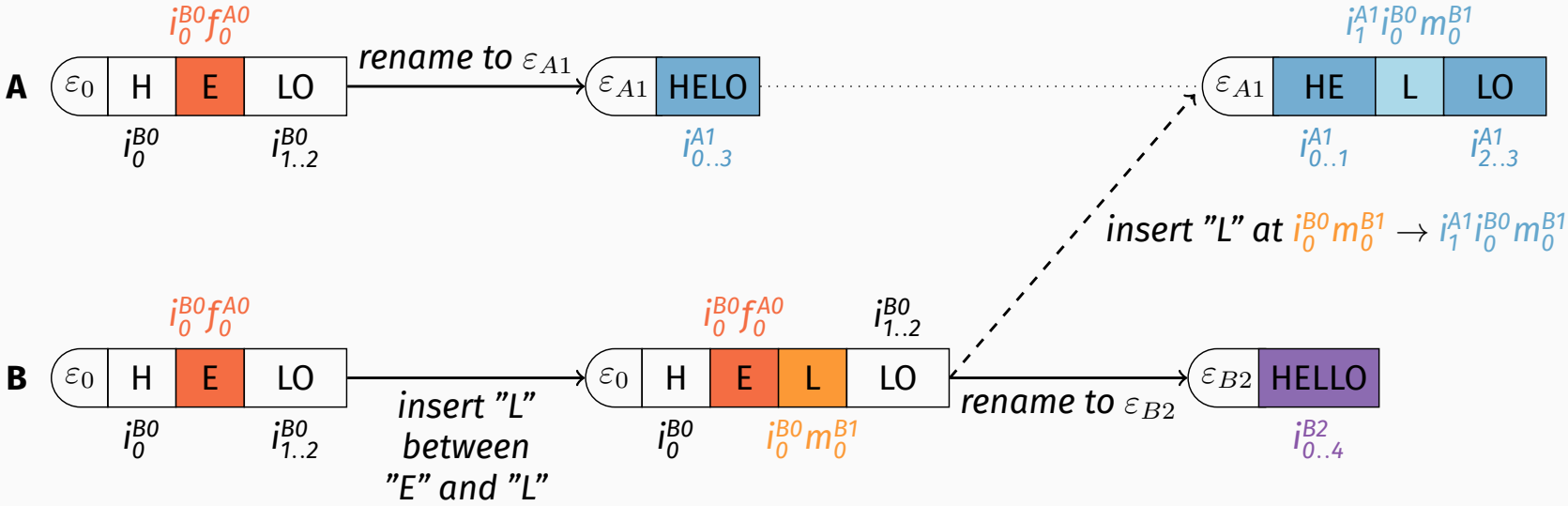

Figure 8: Concurrent *rename* operations leading to divergent states

- *Rename* operations are system operations
- Can resolve conflict by only applying one of them

How to do so ?

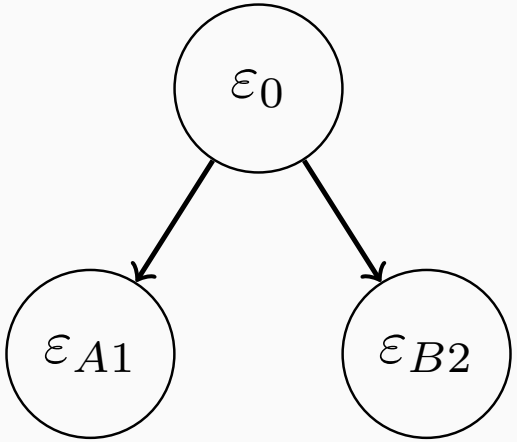

Figure 9: *Epoch tree* corresponding to previous scenario

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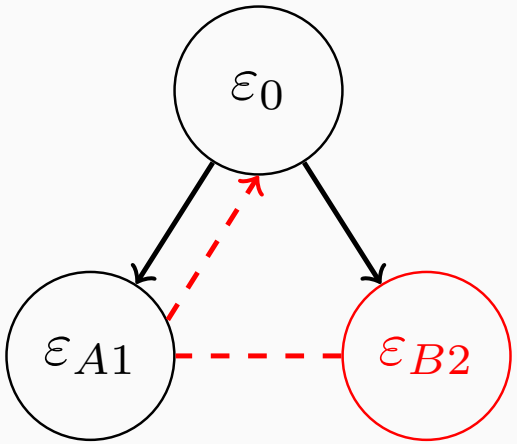

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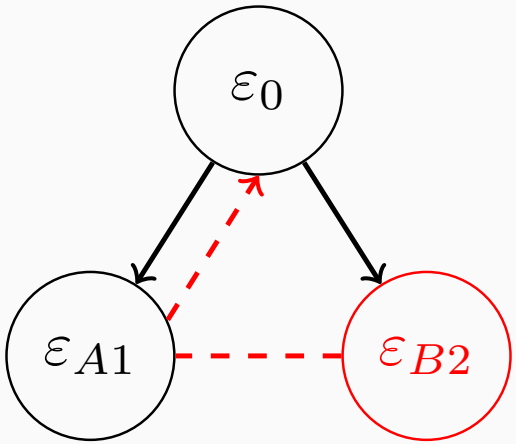

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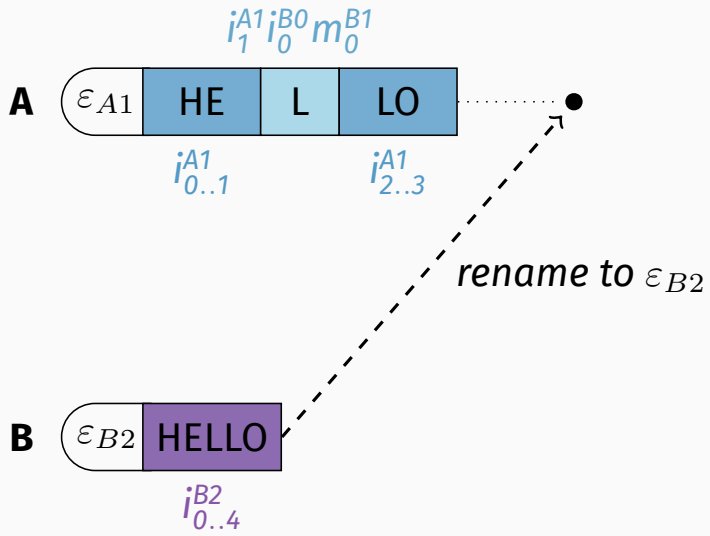
- Define total order on epochs to select target epoch
- Design transformation function to revert *rename* operation

Applying concurrent rename operations



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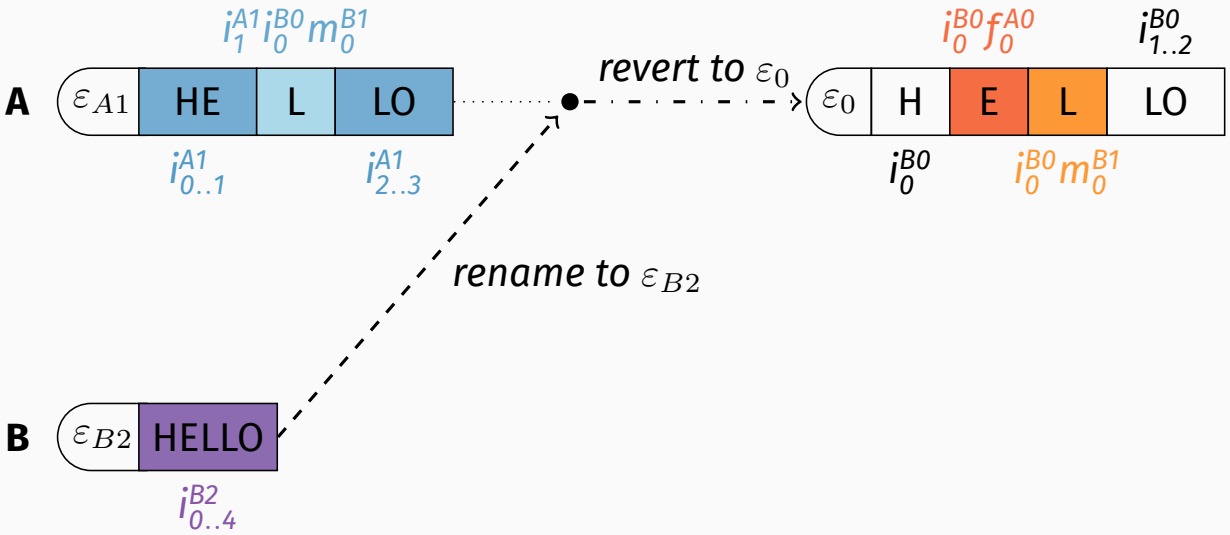

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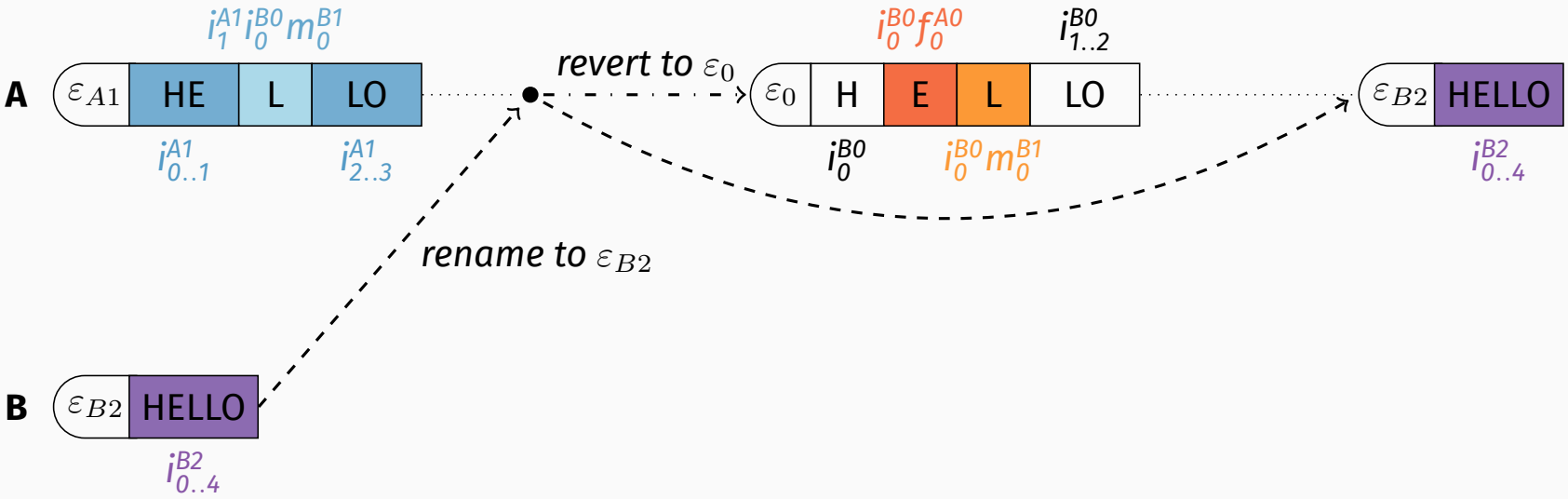

Figure 10: Applying a concurrent *rename* operation

- Revert state to equivalent one at LCA epoch
- Apply then *rename* operations leading to target epoch

Downsides

Need to store former state until no more concurrent operations

- Can garbage collect it once the *rename* operation is causally stable[3]
- Can offload it to the disk meanwhile

Need to propagate former state to other nodes

- Can compress the operation to minimise bandwidth consumption
- Can trigger *rename* operations at a given number of blocks

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[3] Carlos Baquero et al. Making operation-based crdts operation-based. In Kostas Magoutis et al., editors, *Distributed Applications and Interoperable Systems*, pages 126–140, Berlin, Heidelberg. Springer Berlin Heidelberg, 2014 .

Evaluation

Ran simulations to compare performance of RenamableLogootSplit to LogootSplit one

Scenario

- Simulate collaborative editing sessions using either LogootSplit or RenamableLogootSplit
- **Phase 1 (content generation):** 80/20% of *insert*/*remove*
- **Phase 2 (editing):** 50/50% of *insert*/*remove*
- Nodes switch to phase 2 when document reaches critical size (15 pages - 60k elements)

Results - Convergence

- Compared final content of nodes per sessions
- Did not observe any divergence

- Empirical result, not a proof...
- ... but represents first step towards the validation

Results - Memory footprint

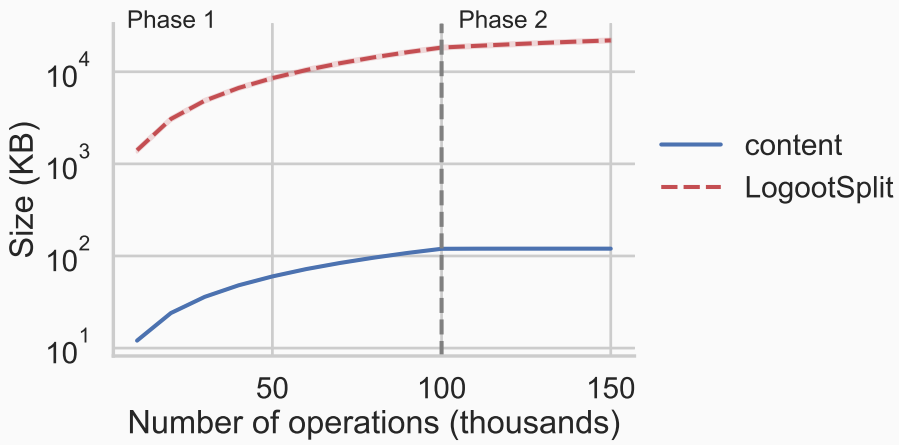
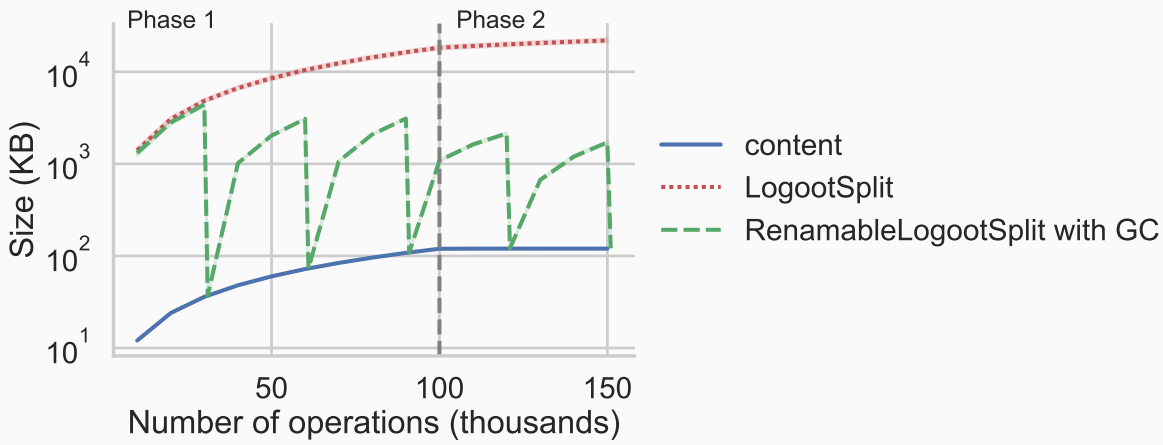


Figure 11: Evolution of the size of the document

Results - Memory footprint



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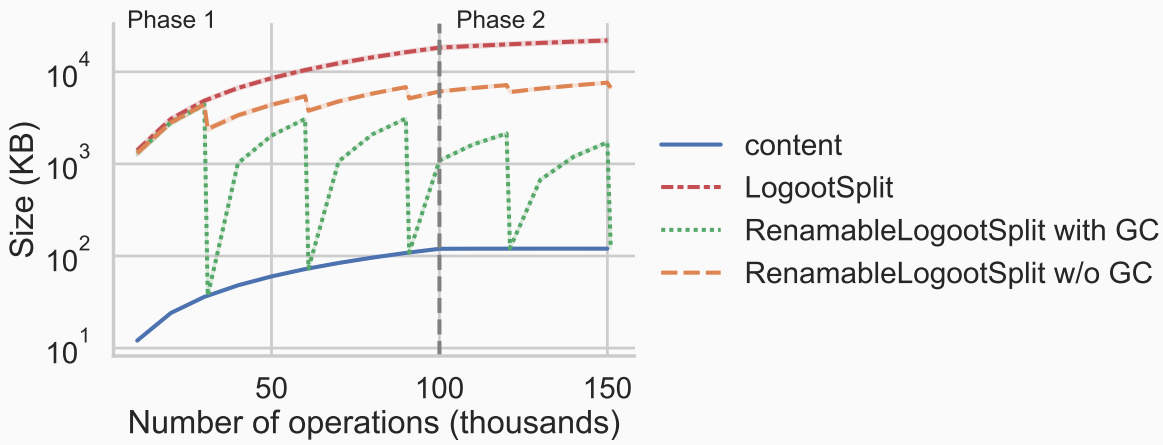

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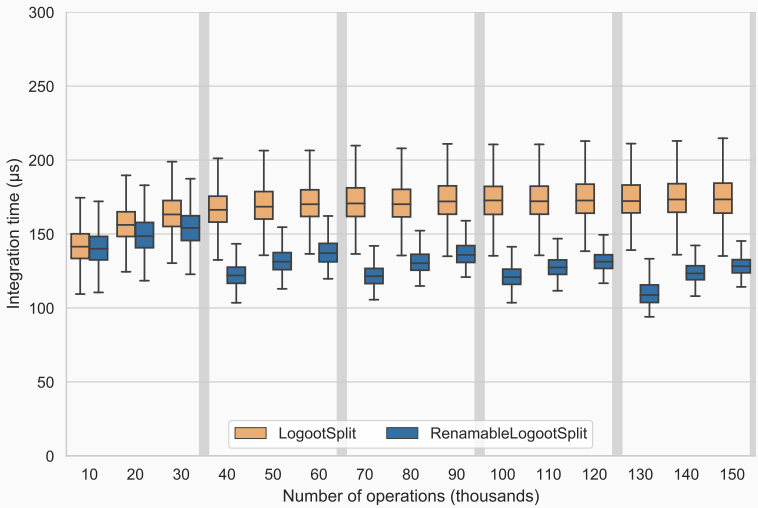
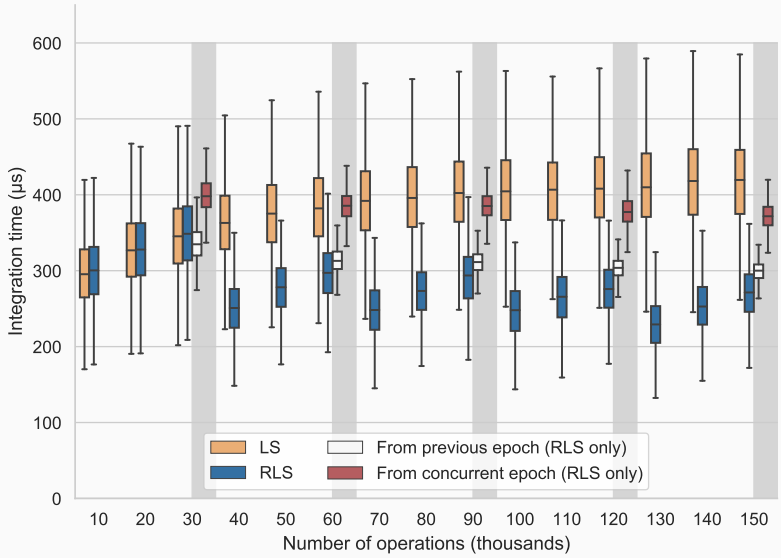
- *Rename* resets the overhead of the CRDT, if can garbage collect
- *Rename* still reduces by 66% the size otherwise

Results - Integration time of insert operations



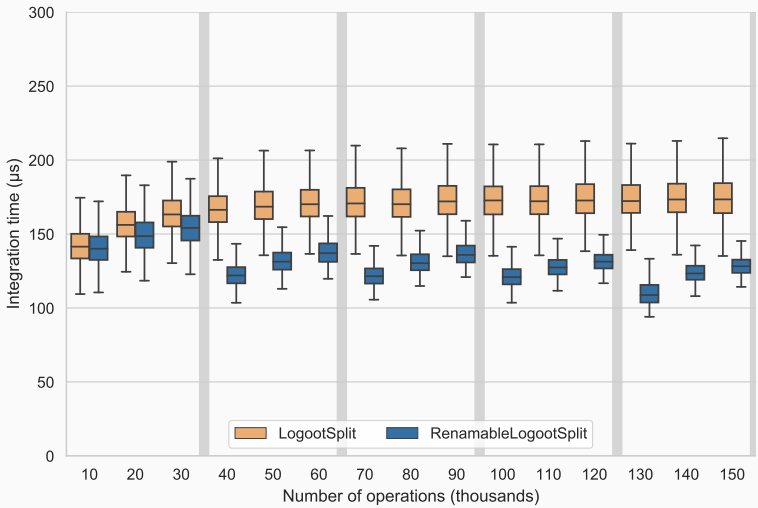
(a) Local operations



(b) Remote operations

Figure 12: Evolution of the integration time of *insert* operations

Results - Integration time of insert operations



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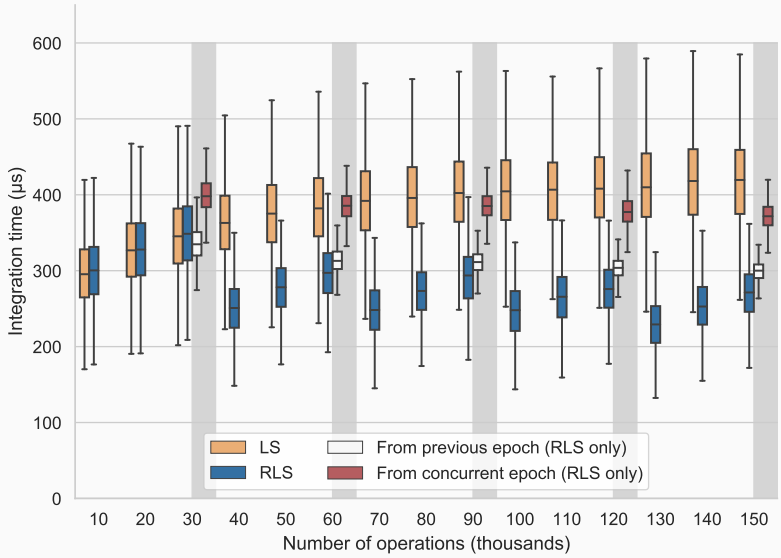

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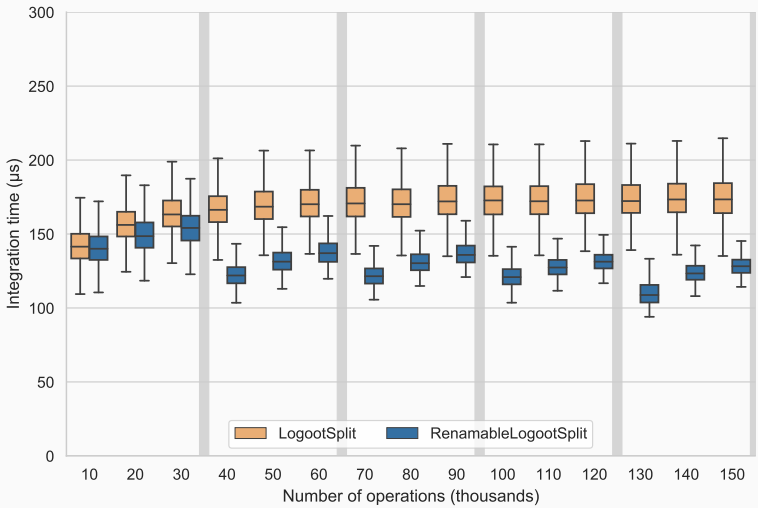

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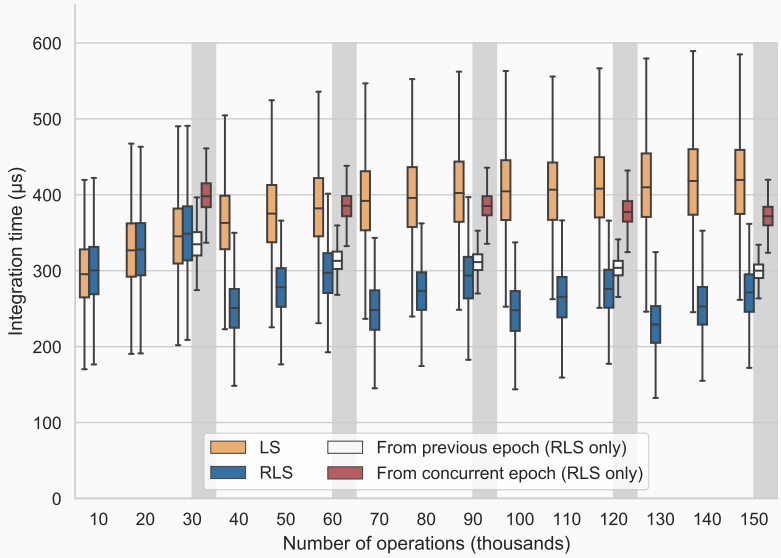

(b) Remote operations

Figure 12: Evolution of the integration time of *insert* operations

- *Rename* reduces integration times of future operations
- Transforming concurrent operations is actually faster than applying them on former state

Results - Integration time of rename operations

Parameters		Integration Time (ms)			
Type	Nb Ops (k)	Mean	Median	99^{th} Quant.	Std
Local	30	41.75	38.74	71.68	6.84
	90	119.19	118.87	124.22	2.49
	150	158.04	157.95	164.38	2.49
Remote	30	481.32	477.13	537.30	17.11
	90	1491.28	1481.83	1657.58	51.10
	150	1694.17	1675.95	1852.55	59.94

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Results - Integration time of rename operations

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	150	158.04	157.95	164.38	2.49
Remote	30	481.32	477.13	537.30	17.11
	90	1491.28	1481.83	1657.58	51.10
	150	1694.17	1675.95	1852.55	59.94

Table 1: Integration time of rename operations

- Noticeable by users if delayed too much

Results - Integration time of rename operations

Parameters		Integration Time (ms)			
Type	Nb Ops (k)	Mean	Median	99^{th} Quant.	Std
Local	30	41.75	38.74	71.68	6.84
	90	119.19	118.87	124.22	2.49
	150	158.04	157.95	164.38	2.49
Remote	30	481.32	477.13	537.30	17.11
	90	1491.28	1481.83	1657.58	51.10
	150	1694.17	1675.95	1852.55	59.94

Table 1: Integration time of rename operations

- Noticeable by users if delayed too much
- Need to improve remote integration time

Conclusion

Done

- Designed a *rename* operation for LogootSplit
- Compared its performance to one of LogootSplit

Conclusion

Done

- Designed a *rename* operation for LogootSplit
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Work in progress

- Publishing it
- Writing the manuscript

Conclusion

Done

- Designed a *rename* operation for LogootSplit
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Work in progress

- Publishing it
- Writing the manuscript

To do

- Prove formally the correctness of the mechanism
- Design better strategies to select the target epoch
- Improve performance of *rename* operations

Thanks for your attention, any questions?

LogootSplit identifiers

- To comply with these constraints, LogootSplit proposes identifiers composed of quadruplets of integers of the following form:

$$position_{offset}^{node\_id \;\; node\_seq}$$

- *position* allows to determine the position of this identifier compared to others
- *node_id* refers to the node's identifier, assumed to be unique
- *node_seq* refers to the node's logical clock, which increases monotonically with local operations
- *offset* refers to the element position in its original block

Identifier constraints

- To fulfill their role, identifiers have to comply to several constraints:

Globally unique

- Identifiers should never be generated twice, neither by different users nor by the same one at different times

Totally ordered

- We should always be able to compare and order two elements using their identifiers

Dense set

- We should always be able to add a new element, and thus a new identifier, between two others

Related work

- Core-nebula approach[4]
  - Reassigns shorter identifiers to elements...
  - ...but requires consensus
- LSEQ[5]
  - Set of strategies to reduce the growth of identifiers ...
  - ...but overhead still proportional to number of elements

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[4] Marek Zawirski et al. Asynchronous rebalancing of a replicated tree. In *Conférence Française en Systèmes d'Exploitation (CFSE)*, page 12, Saint-Malo, France, May 2011. URL: https://hal.inria.fr/hal-01248197 .

[5] Brice Nédelec et al. A scalable sequence encoding for collaborative editing. *Concurrency and Computation: Practice and Experience*:e4108. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/cpe.4108.

Perspectives

Propose a strategy to avoid conflicting rename operations

- How to minimise likelihood of concurrent *rename* operations without coordinating?

Propose a smarter strategy to choose the "winning" renaming

- How to minimise the overall computations?

Results - Integration time of rename operations (complete)

Parameters		Integration Time (ms)			
Type	Nb Ops (k)	Mean	Median	99^{th} Quant.	Std
Local	30	41.75	38.74	71.68	6.84
	90	119.19	118.87	124.22	2.49
	150	158.04	157.95	164.38	2.49
Direct remote	30	481.32	477.13	537.30	17.11
	90	1491.28	1481.83	1657.58	51.10
	150	1694.17	1675.95	1852.55	59.94
Cc. int. greater epoch	30	643.53	643.57	682.80	13.42
	90	1998.23	1994.08	2111.98	45.37
	150	2241.92	2233.61	2351.02	52.20
Cc. int. lesser epoch	30	1.36	1.30	3.53	0.37
	90	4.45	4.23	5.81	0.71
	150	5.53	5.26	8.70	0.79

Table 2: Integration time of rename operations

Experimental settings

- Use Node.js version 13.1.0
- Obtained documents sizes using our fork of *object-sizeof* [6]
- Ran benchmarks on a workstation equipped of a Intel Xeon CPU E5-1620 (10MB Cache, 3.50 GHz) with 16GB of RAM running Fedora 31
- Measured times using `process.hrtime.bigint()`

[6] `https://www.npmjs.com/package/object-sizeof`