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

Case Study of a Sequence CRDT : LogootSplit

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Context

- Working on data replication in Local-first softwares[1]
- Focusing on *Sequence Conflict-free Replicated Data Types (CRDTs)*
  - Real-time collaborative text editing

[1] Martin Kleppmann et al. Local-first software: you own your data, in spite of the cloud. In *Proceedings of the 2019 ACM SIGPLAN International Symposium on New Ideas, New Paradigms, and Reflections on Programming and Software*, Onward! 2019, pages 154–178, Athens, Greece. Association for Computing Machinery, 2019. ISBN: 9781450369954. DOI: 10.1145/3359591.3359737. URL: https://doi.org/10.1145/3359591.3359737 .

LogootSplit[2]

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

[2] Luc André et al. Supporting adaptable granularity of changes for massive-scale collaborative editing. In *International Conference on Collaborative Computing: Networking, Applications and Worksharing - CollaborateCom 2013*, pages 50–59, Austin, TX, USA. IEEE Computer Society, October 2013. DOI: 10.4108/icst.collaboratecom.2013.254123 .

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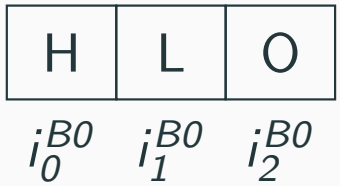

Figure 1: State of a sequence which contains the elements "hlo" and their corresponding identifiers

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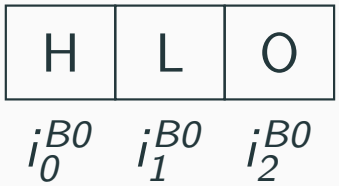

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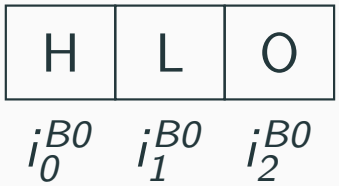

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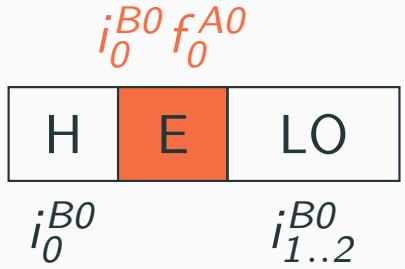

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Research issue

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

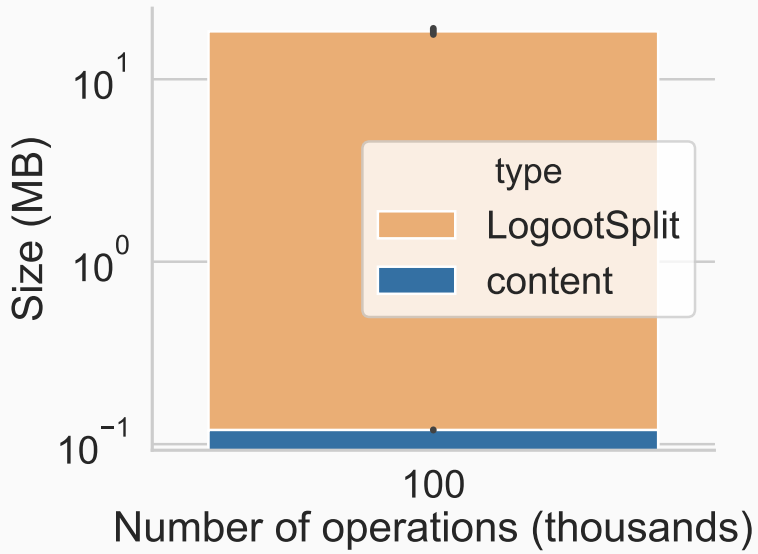

Figure 4: Memory footprint of the data structure

- **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 perform without coordination
- In this talk, focus on scenario without concurrent *rename* operations

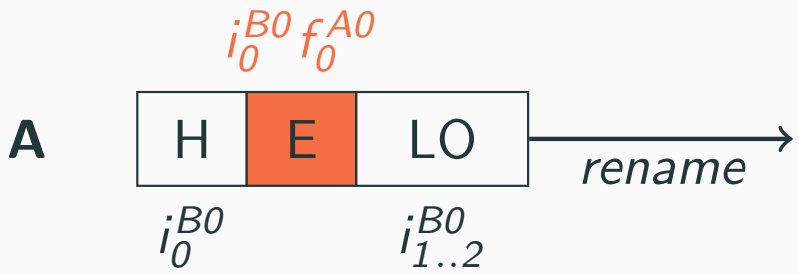

Figure 5: Example of renaming

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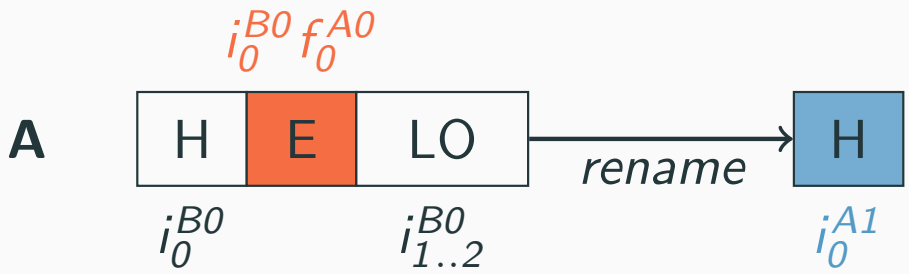

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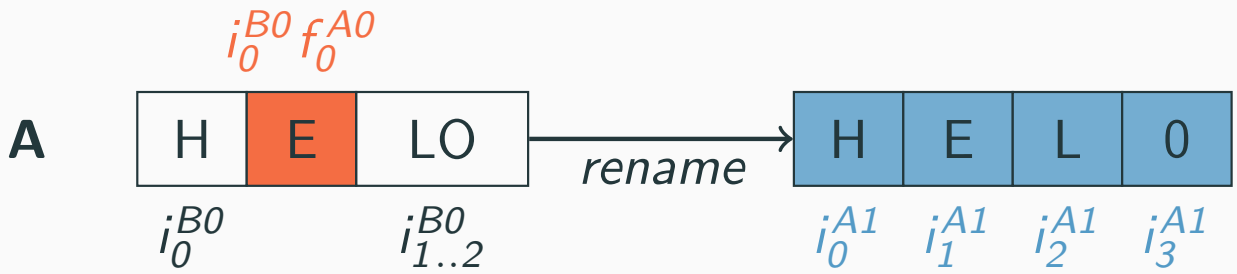

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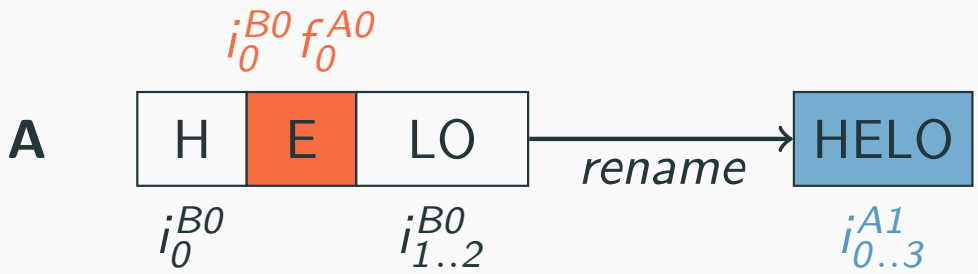

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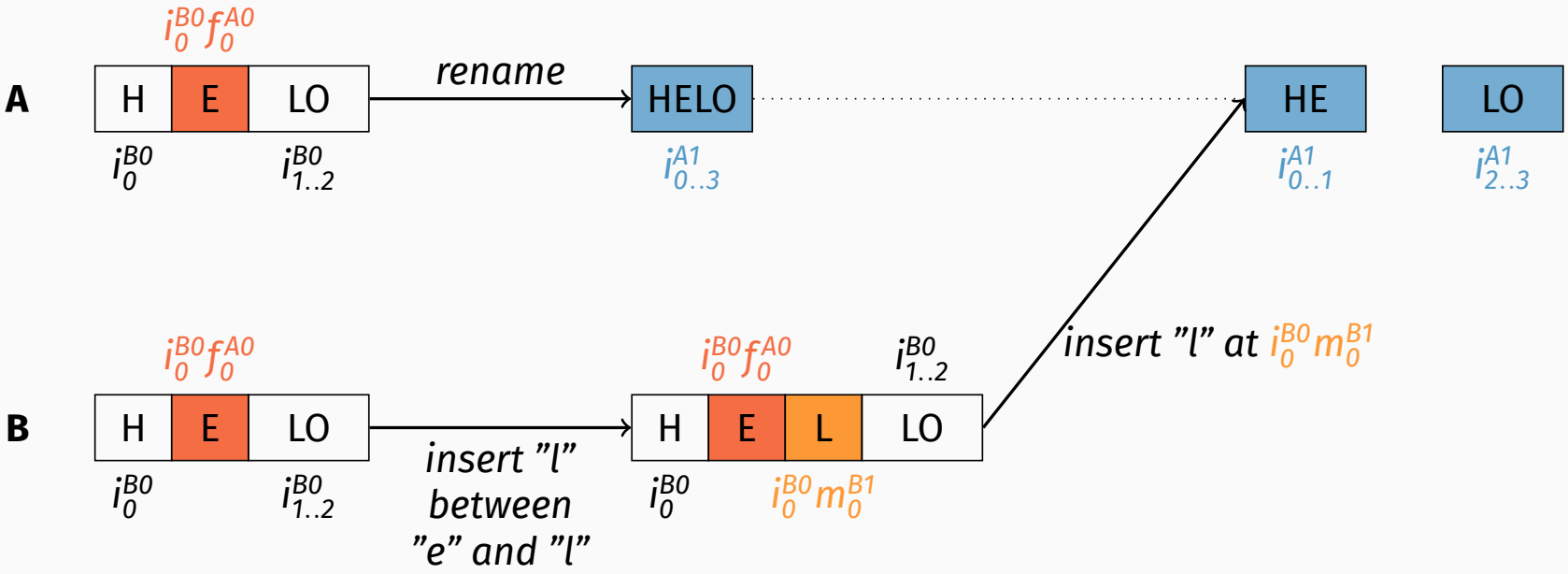

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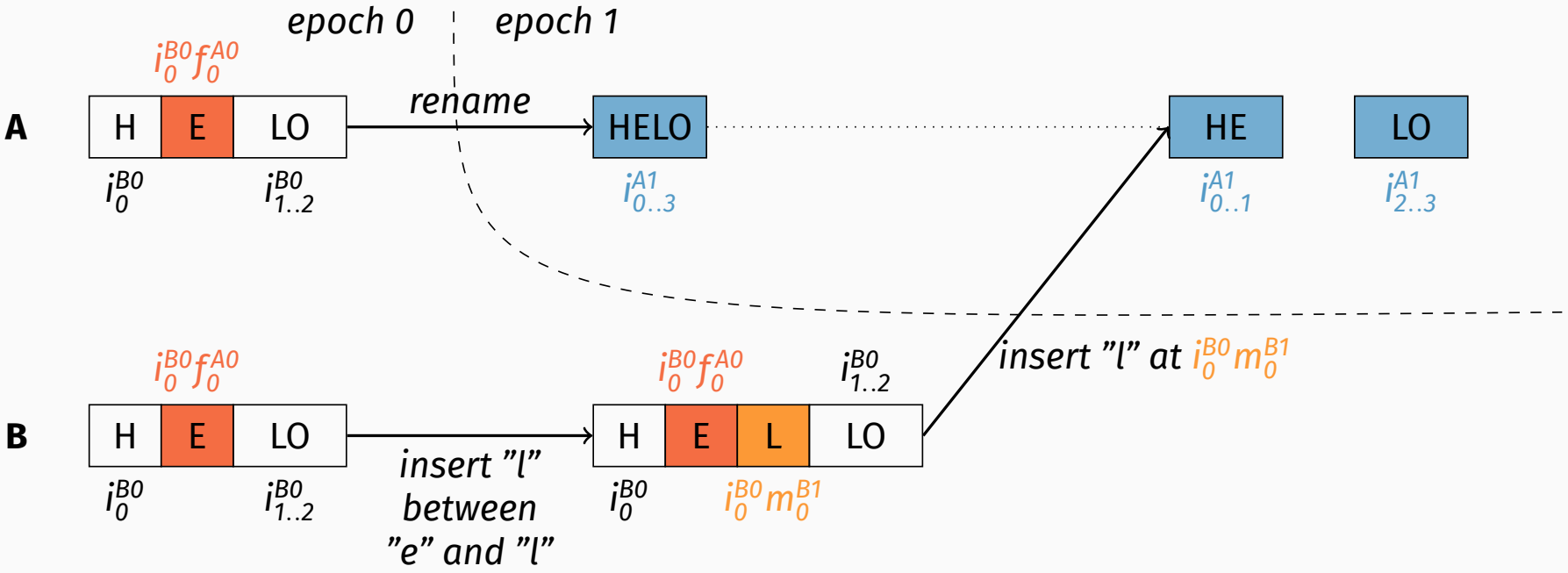
Handling concurrent operations



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- Use *epoch-based* system to track concurrent operations

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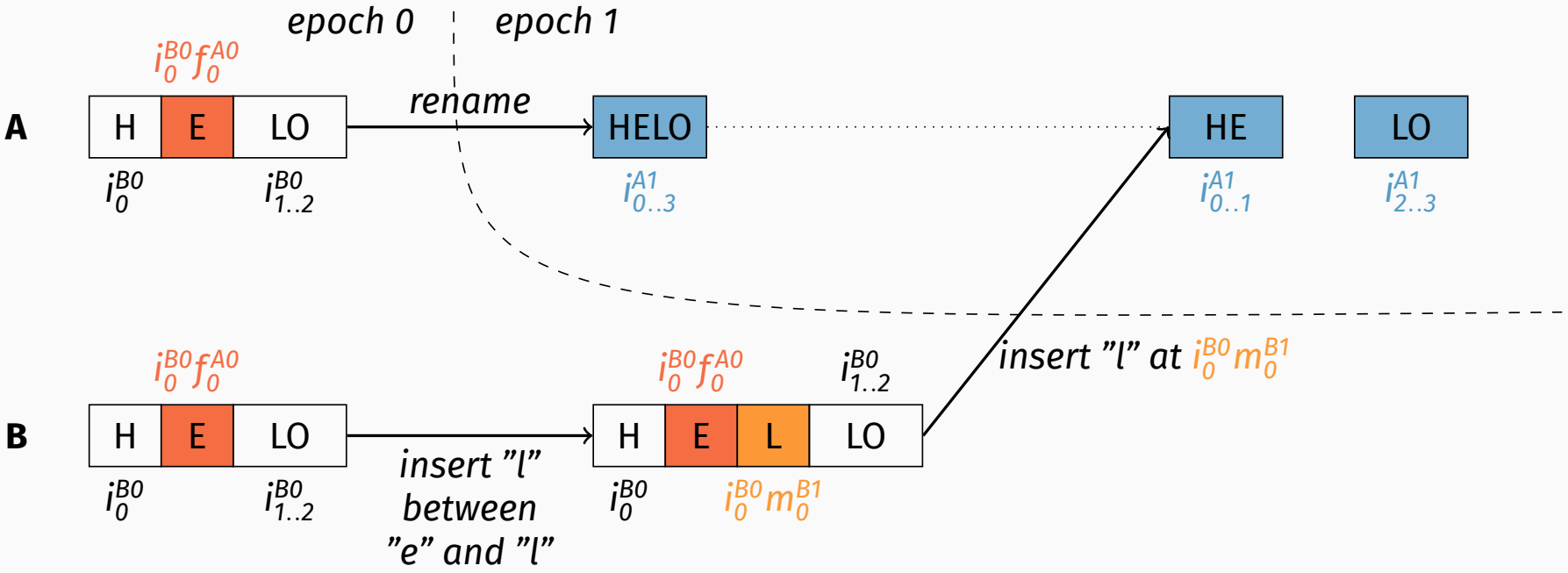

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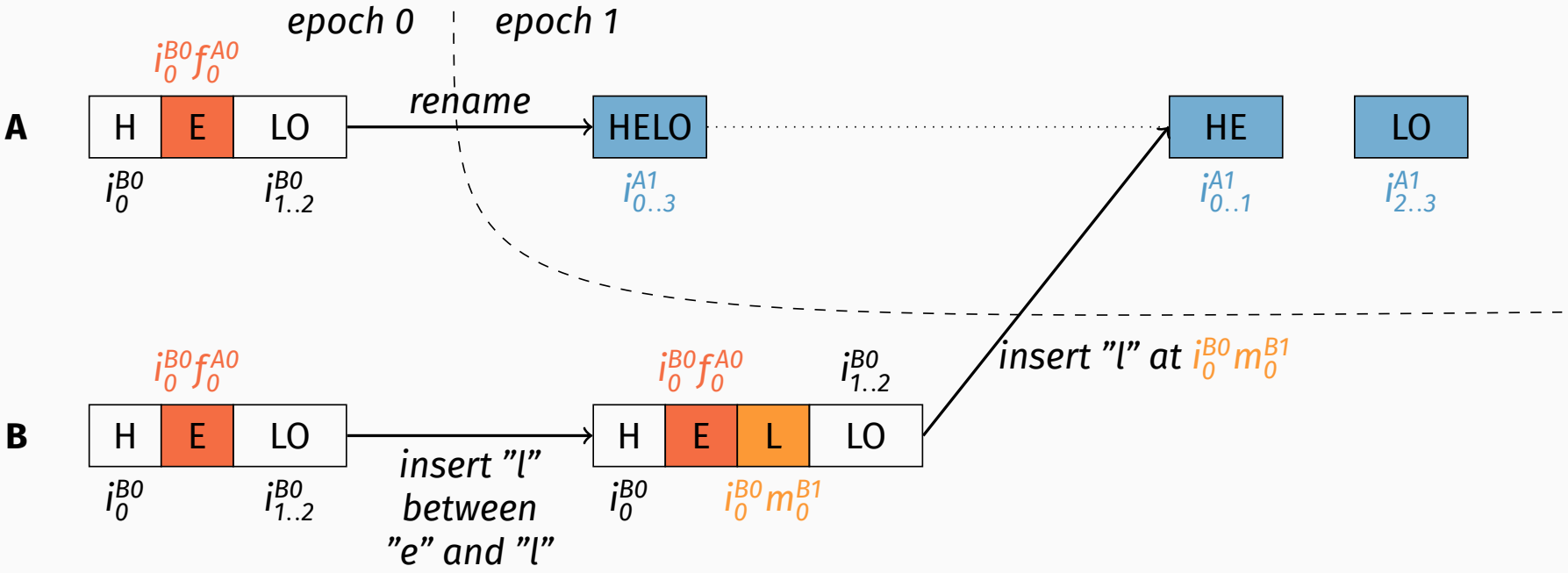

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- Use *epoch-based* system to track concurrent operations
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  1. Find predecessor in former state ($i_0^{B0} f_0^{A0}$)
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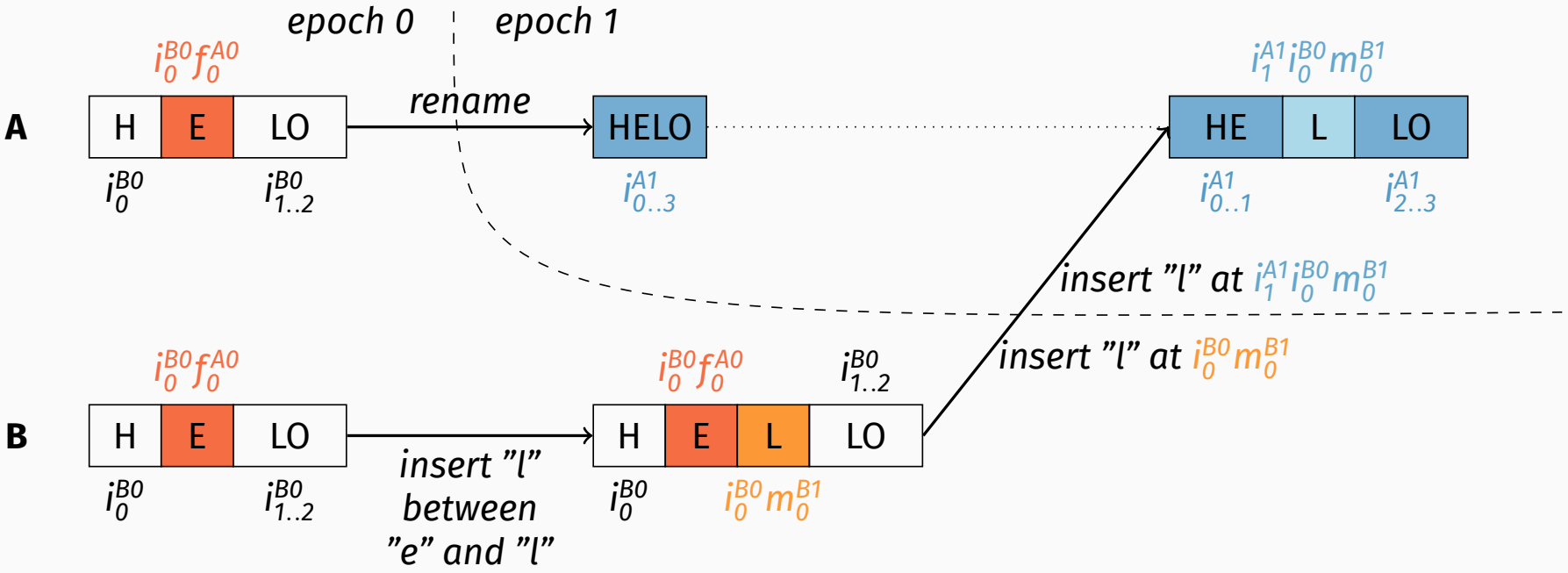

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Evaluation

Ran simulations to compare RenamableLogootSplit performances to LogootSplit ones

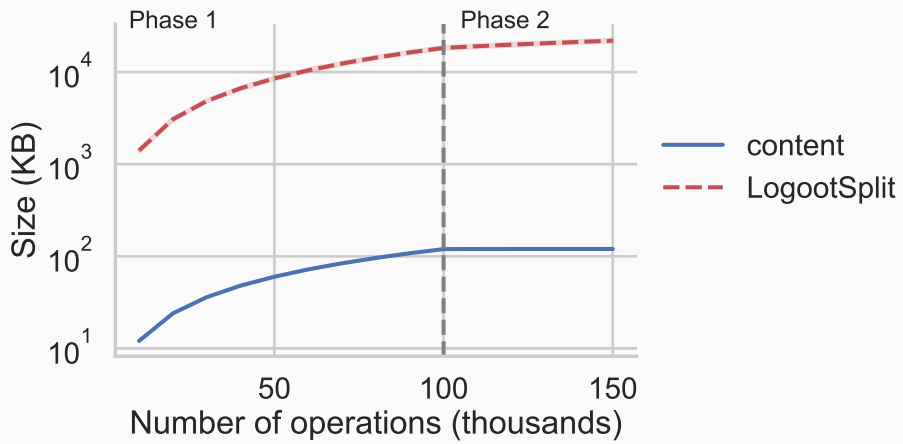
Results - Convergence

- 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

- **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)



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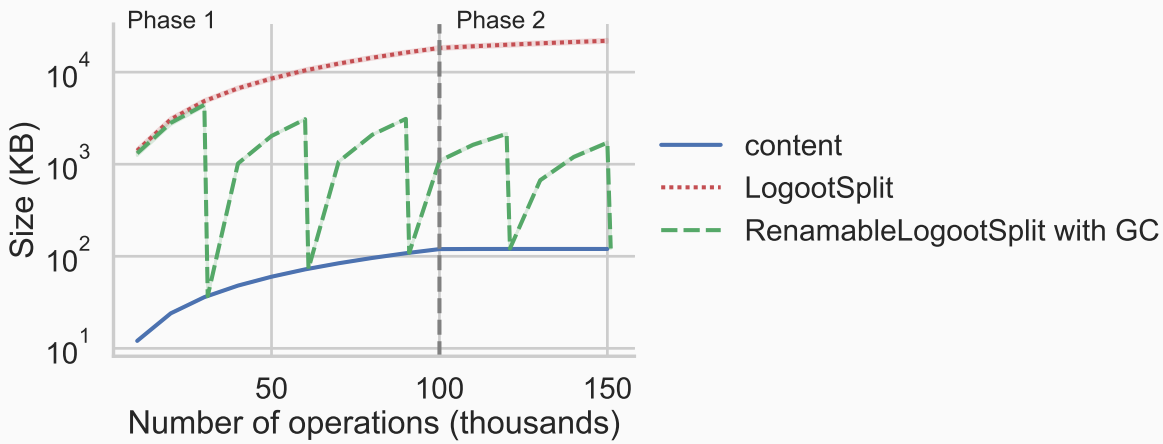

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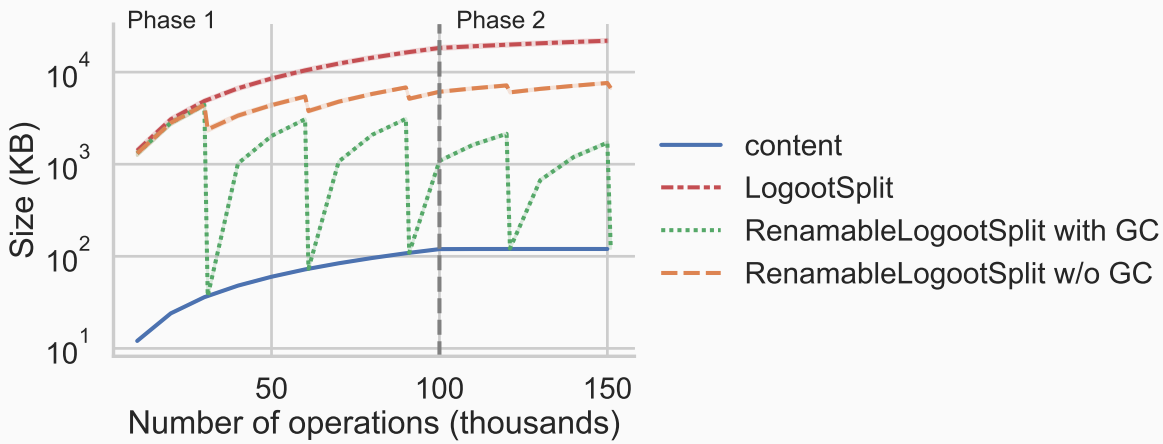

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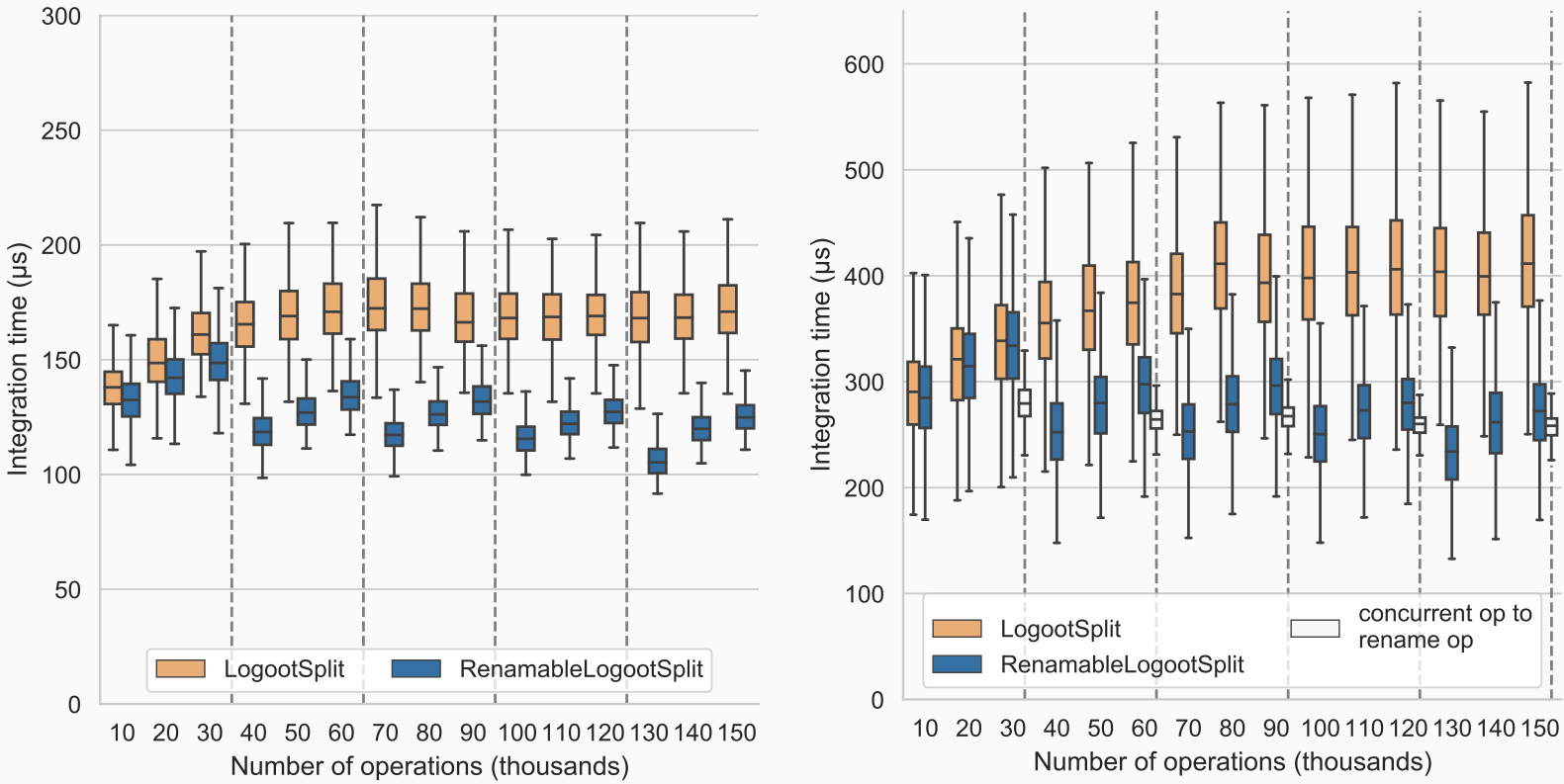
- *Rename* resets the overhead of the CRDT, if can garbage collect
- *Rename* still reduces by 66% the size otherwise

Results - Integration time of insert operations



(a) Local operations

(b) Remote operations

Figure 8: Evolution of the integration time of *insert* operations

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

Results - Integration time of rename operations

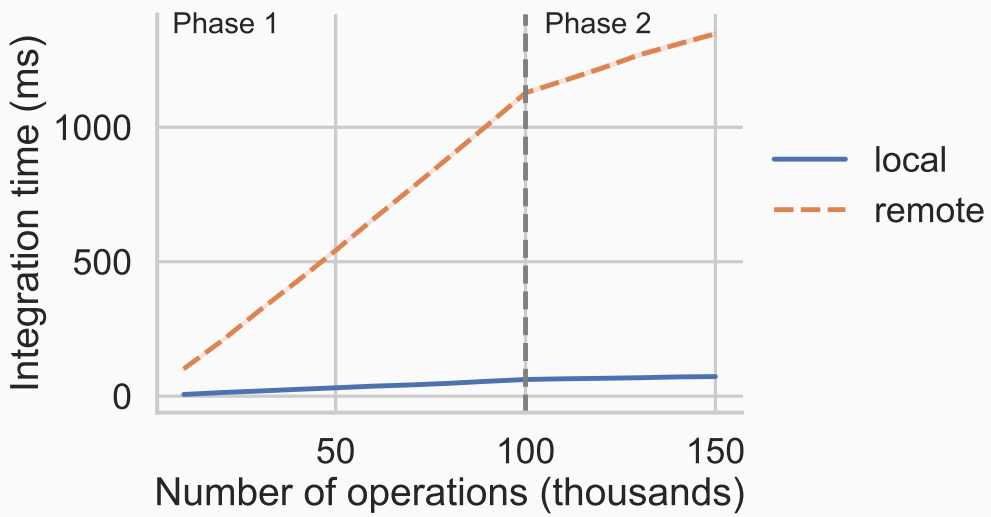


Figure 9: Evolution of the integration time of *rename* operations

- Noticeable by users if delayed too much

Research trail: propose strategies to retain acceptable integration time for *rename* operations

Conclusion

Done

- Designed a *rename* operation for LogootSplit
- Defined transformation functions to deal with concurrent updates

[3]Matthieu Nicolas et al. MUTE: A Peer-to-Peer Web-based Real-time Collaborative Editor. In Proceedings of European Conference on Computer-Supported Cooperative Work - Panels, Posters and Demos, 2017 .

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Work in progress

- Implementing support of concurrent *rename* operations in MUTE[3], our P2P collaborative text editor
- Proceeding to its validation
- Designing the strategy to trigger *rename* operations

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To do

- Prove formally the correctness of the mechanism
- Investigate the combination of OT techniques and CRDTs

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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.

Downsides

Need to store former state until no more concurrent operations

- Can garbage collect it once the *rename* operation is causally stable[6]
- Can offload it to the disk meanwhile

Need to propagate former state to other nodes

- Can compress the operation to minimise bandwidth consumption

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[6] 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 .

Handling concurrent rename

The topic of a later contribution

rename operation not commutative

To fix this:

- Define a total order between *rename* operations
- Pick a "winner" operation between concurrent *renames*
- Define additional transformation functions to *undo* the effect of "losing" ones

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?

Experimental settings

- Use Node.js version 13.1.0
- Obtained documents sizes using our fork of *object-sizeof* [7]
- 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()`

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