Highly Dynamic and Fully Distributed Data Structures

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Introduction

- Real-world networks are dynamic
- Fast evolution
- Nodes continuously join and leave the network (churn)
- The churn can be arbitrarily bad

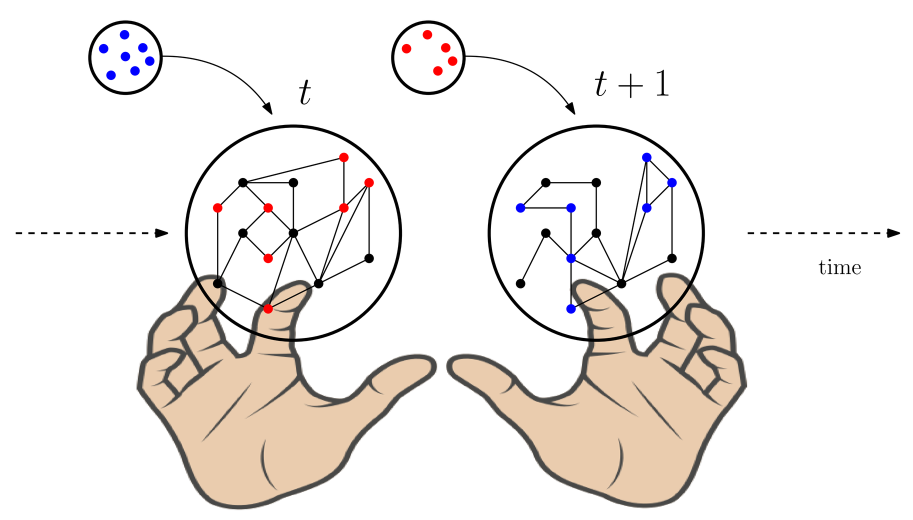

Figure 1. Example of a dynamic graph in which nodes are replaced at each round by an adversary.

- What about maintaining a dynamic distributed data structure?

Challenges

- Classic distributed protocols do not work!
- Powerful (**oblivous**) adversary
- High churn rate (almost linear)
- We need to be **very fast** in updating the data structure!
- We must spend as "little effort as possible" to maintain the data structure!

Some related work

- The Dynamic Network with churn model (survey by Augustine et al. [1]).
- Skip List-like data structures [4, 3, 2].

Problem Definition

We want to maintain a distributed skip list despite an adversarial churn of $\mathcal{O}(n/\log n)$ nodes per rounds where n is the stable network's size. We must:

- Build and maintain a data structure of all the items/nodes in the network
- Ensure that the data structure can be queried at any time
- Update the data structure as fast a possible
- Be *dynamic resource competitive*, i.e., effort paid to maintain the data structure must be proportional to the overall experienced churn.

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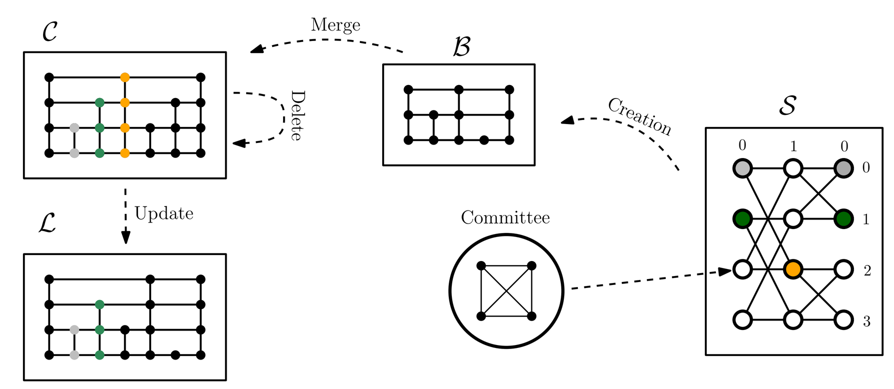
Our Idea

Four networks approach: (1) A churn resilient overlay network $\mathcal{S}$; (2) A **live** queryable network $\mathcal{L}$; (3) A **buffer** network $\mathcal{B}$ of newly added elements; and (4) a **clean** network $\mathcal{C}$ with all the updates.



We propose an $\mathcal{O}(\log n)$ rounds continuous maintenance cycle that preserves the data distributed data structure despite high adversarial churn.

Dealing with removed nodes

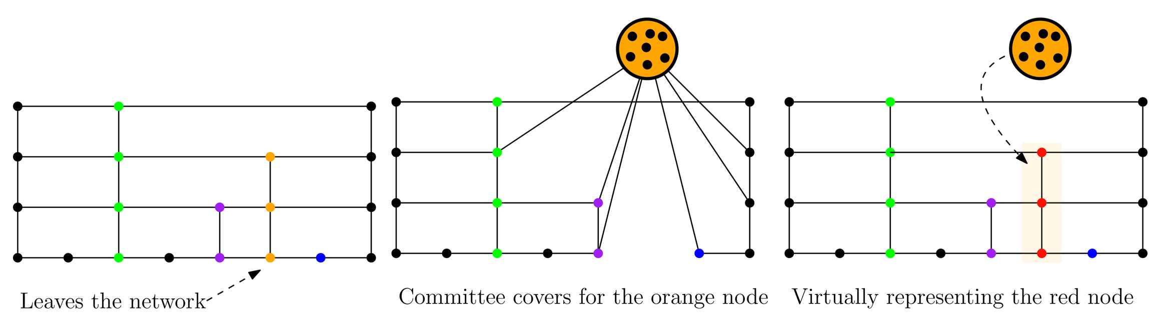


Figure 2. Nodes leave the network are temporarily replaced in $\mathcal{O}(1)$ rounds by committees in the overlay network $\mathcal{S}$.

Deleting virtual nodes in $\mathcal{O}(\log n)$ rounds

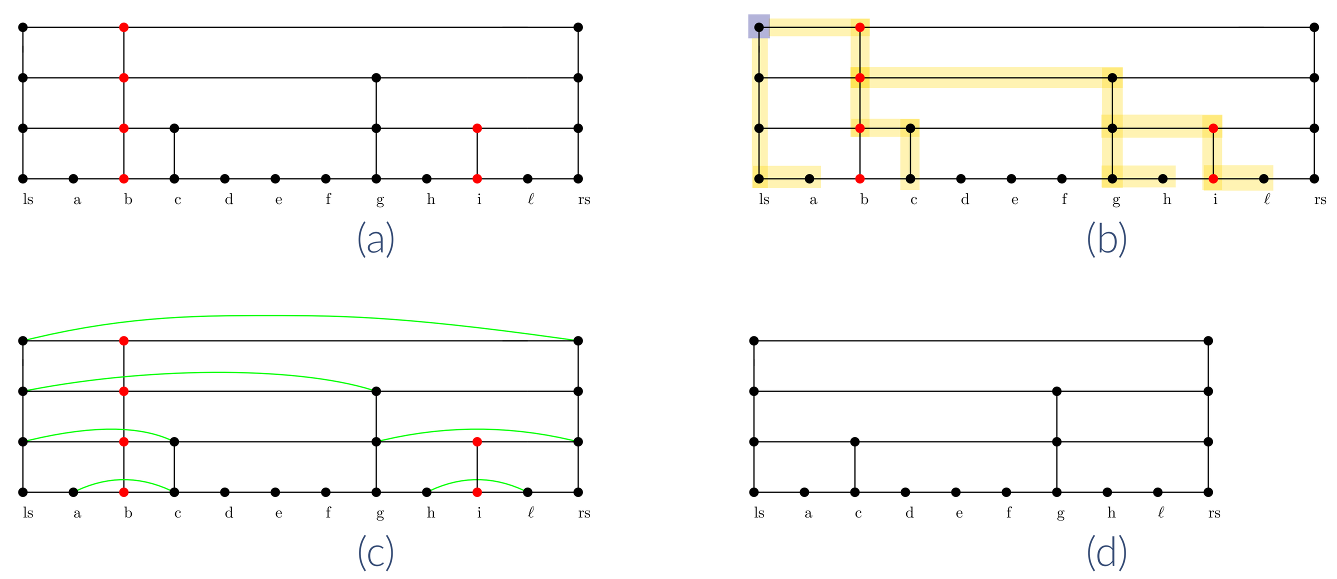


Figure 3. Illustration of our novel distributed and parallel skip list partition algorithm that removes a batch of nodes from a skip list in $\mathcal{O}(\log n)$ rounds with high probability.

Creating the Buffer Network in $\mathcal{O}(\log n)$ rounds

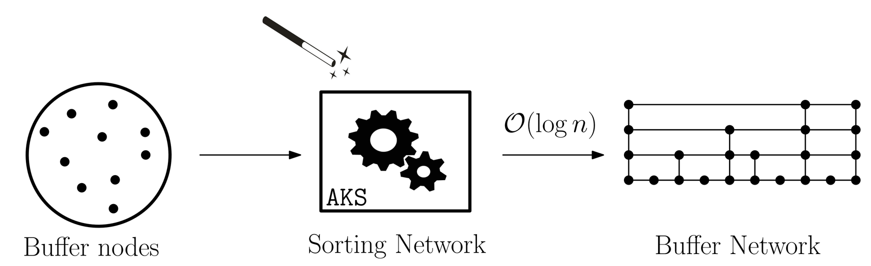


Figure 4. We build a temporary churn resilient sorting network on top of $\mathcal{S}$ and we build the Buffer network using the nodes that have joined the network until this time.

WAVE: An $\mathcal{O}(\log n)$ merge procedure

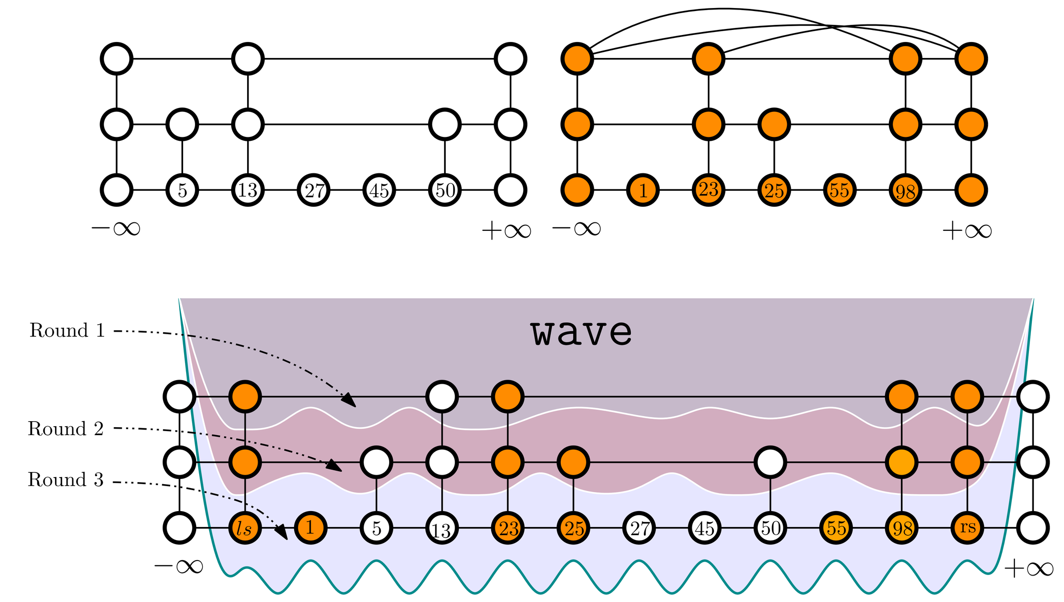
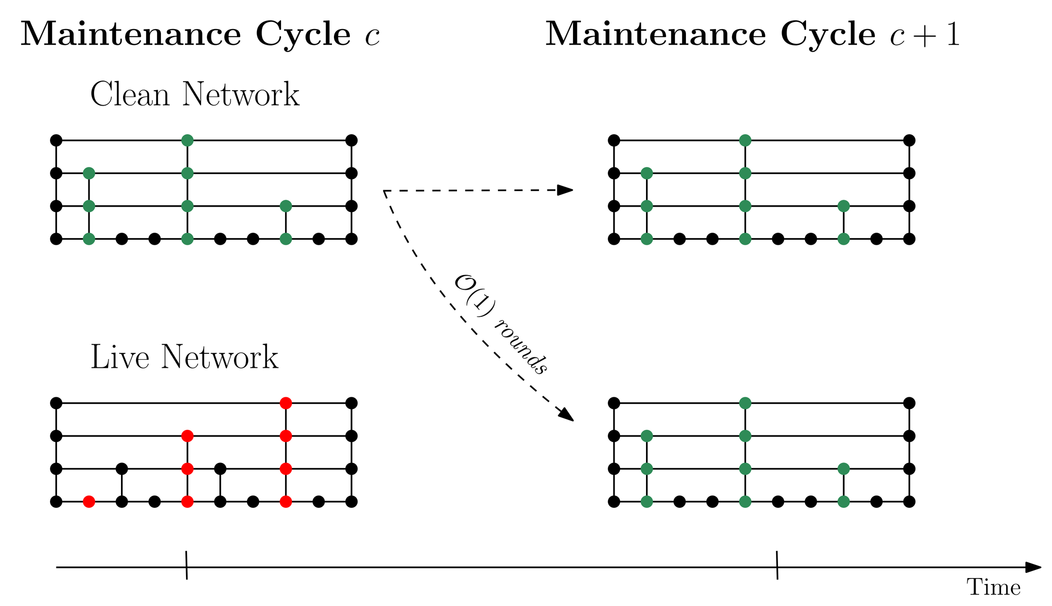


Figure 5. Illustration of our novel merge algorithm that merges two skip list of n elements in $\mathcal{O}(\log n)$ rounds with high probability.

Using the Clean network as the new Live network



Our main result

In this work:

- $\mathcal{O}(\log n)$ round algorithm that builds and maintains a distributed skip list despite an $\mathcal{O}(n/\log n)$ churn rate per round.
- Maintenance protocol the guarantees $\mathcal{O}(\log n)$ rounds insertion/deletion (of a batch of nodes) and query time on the skip list.
- $\mathcal{O}(\text{polylog}(n))$ bits messages and each node sends/receives $\mathcal{O}(\text{polylog}(n))$ messages per round.
- Workload proportional to the churn.
- The skip list is maintained for at least $\text{poly}(n)$ rounds w.h.p.

Our algorithm: (1) can be used to maintain **any** skip list-like data structure (e.g. skip graphs and skip$^+$ [3, 2]); (2) works with any number of data structure's keys per node; and, (3) can be adapted to maintain any distributed pointer-based data structure (e.g. graphs).

[1] J. Augustine, G. Pandurangan, and P. Robinson. Distributed algorithmic foundations of dynamic networks. *SIGACT News*, 2016.

[2] R. Jacob, A. W. Richa, C. Scheideler, S. Schmid, and H. Täubig. Skip$^+$: A self-stabilizing skip graph. *J. ACM*, 2014.

[3] A. James and S. Gauri. Skip graphs. *ACM Trans. Algorithms*, 2007.

[4] P. William. Concurrent maintenance of skip lists. In *Technical Report*, 1998.