RapidCDC: Leveraging Duplicate Locality to Accelerate Chunking in CDC-based Deduplication

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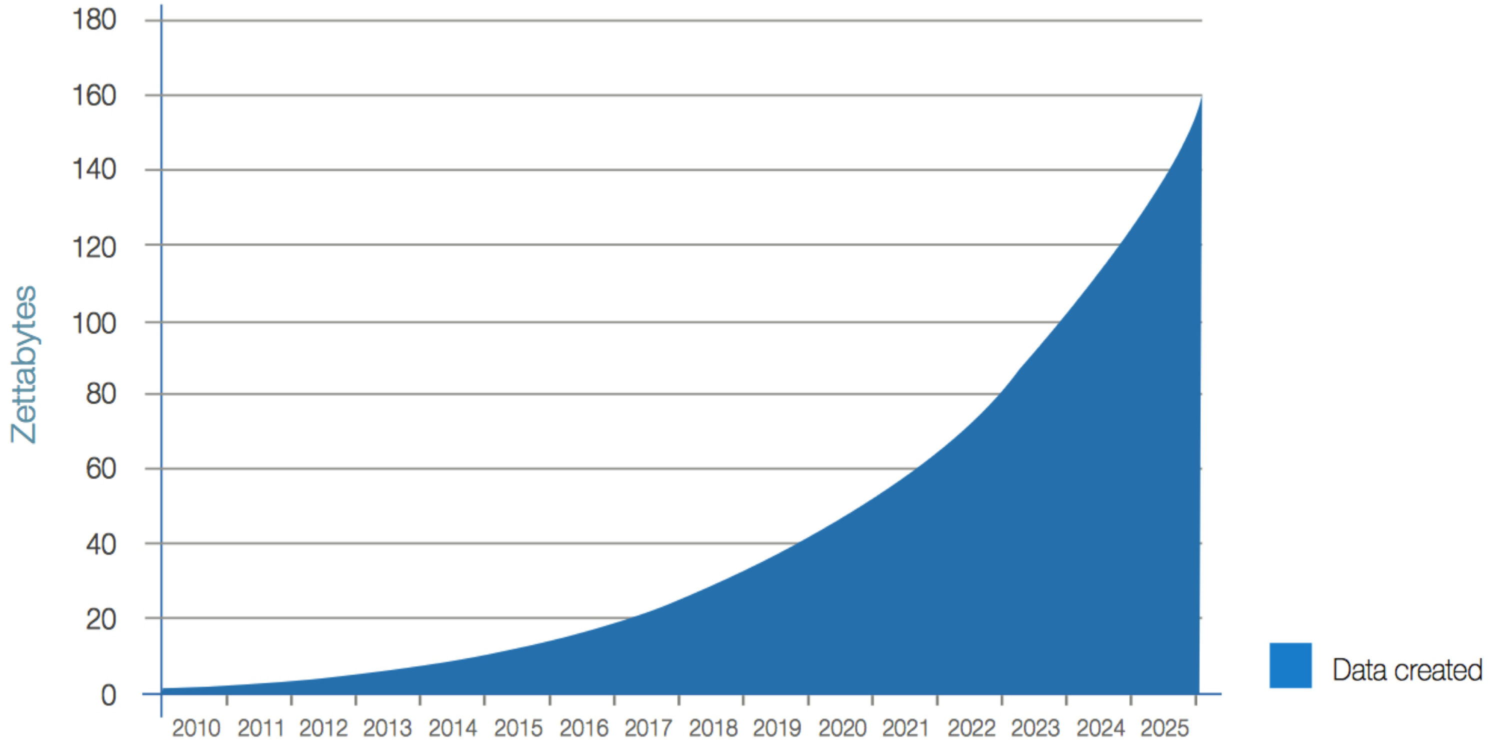
* The work was done when he was a Ph.D. student at UT Arlington

SoCC ACM Symposium on Cloud Computing

Data is Growing Rapidly



From storagenewsletter.com

- Many of the data needs to be stored for preservation and processing.
- **Efficient data storage and management has become a big challenge.**

The Opportunity: Data Duplication is Common

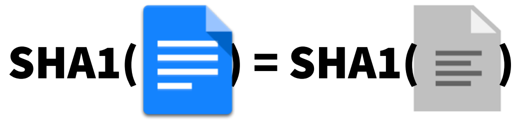
- Sources of duplicate data:
  - The same files are stored by multiple users into the cloud.
  - Continuously updating of files to generate multiple versions.
  - Use of checkpointing and repeated data archiving.
- Significant data duplication has been observed for both backup and primary storage workloads.

The Deduplication Technique can Help

File1

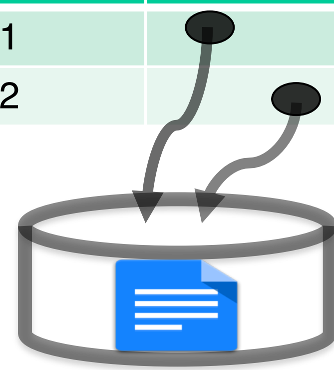
File2

When duplication is detected (using fingerprinting):



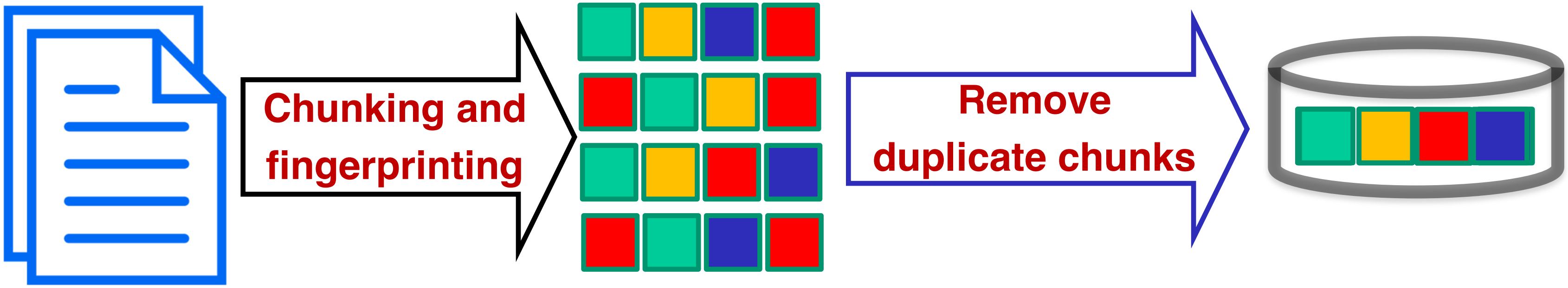
Only one copy is stored:

Logical	Physical
File1	
File2	



- Benefits
  - Storage space
  - I/O bandwidth
  - Network traffic
- An important feature in commercial storage systems.
  - NetApp ONTAP system
  - Dell-EMC Data Domain system
- Two critical issues:
  - **How to deduplicate more data?**
  - **How to deduplicate faster?**

Deduplicate at Smaller Chunks …

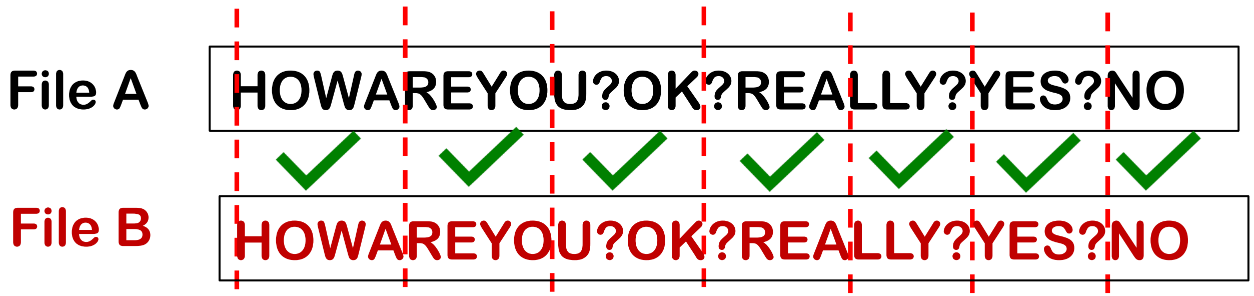


… for higher deduplication ratio

- Two potentially major sources of cost in the deduplication:
  - Chunking
  - Fingerprinting
- **Can chunking be very fast?**

Fixed-Size Chunking (FSC)

- FSC: partition files (or data streams) into equal- and fixed-sized chunks.
  - Very fast!
- But the deduplication ratio can be significantly compromised.
  - **The boundary-shift problem.**



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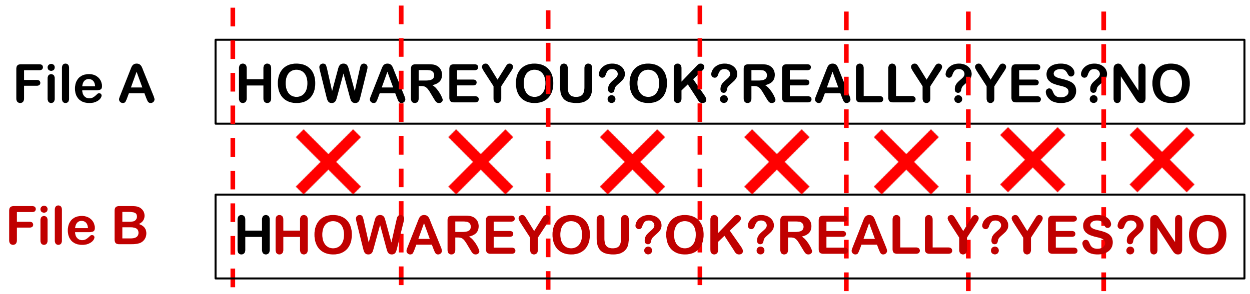
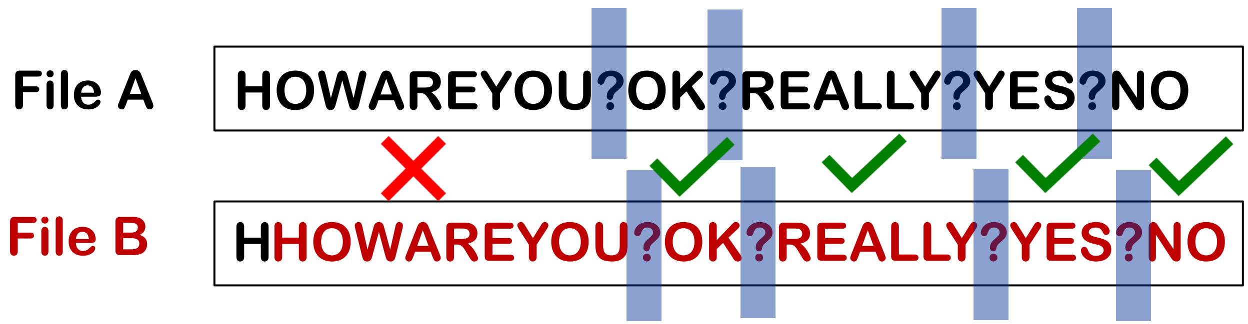


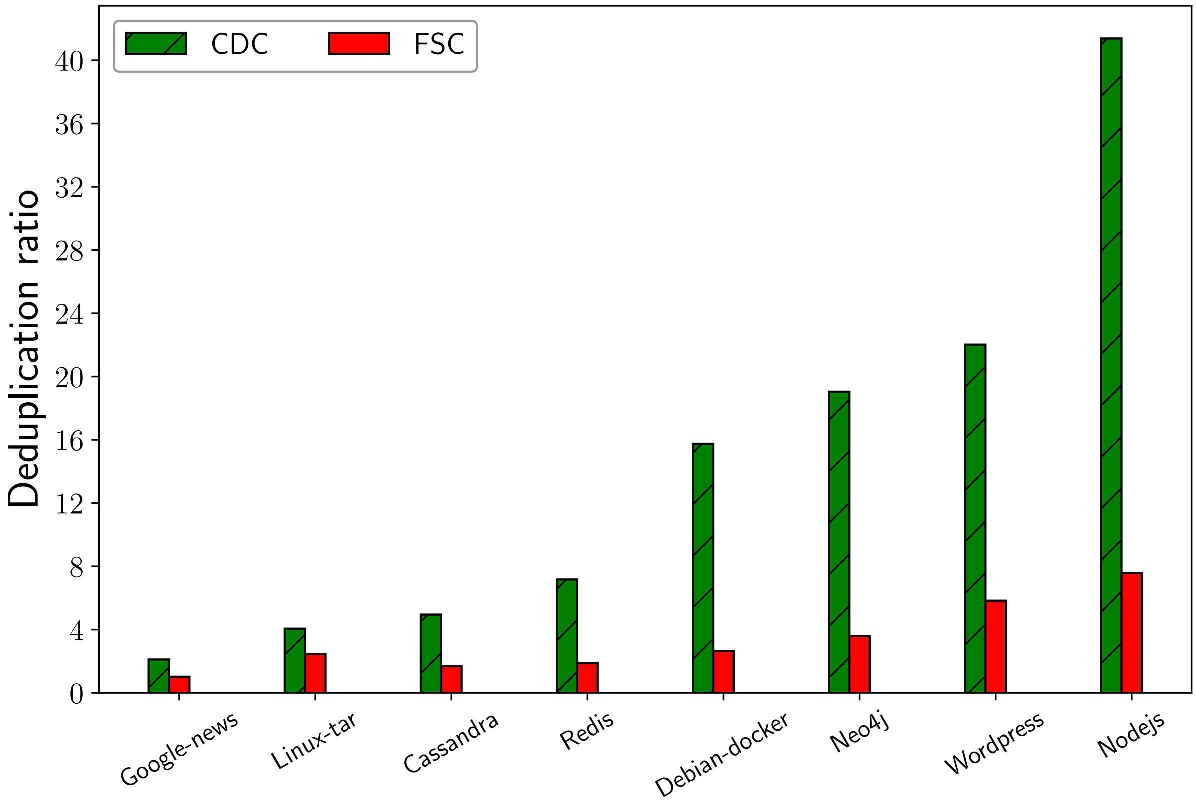
Content-Defined Chunking (CDC)

- CDC: determines chunk boundaries according to contents (a predefined special marker).
  - Variable chunk size.
  - Addresses boundary-shift problem

- Assume the special marker is ‘**?**’



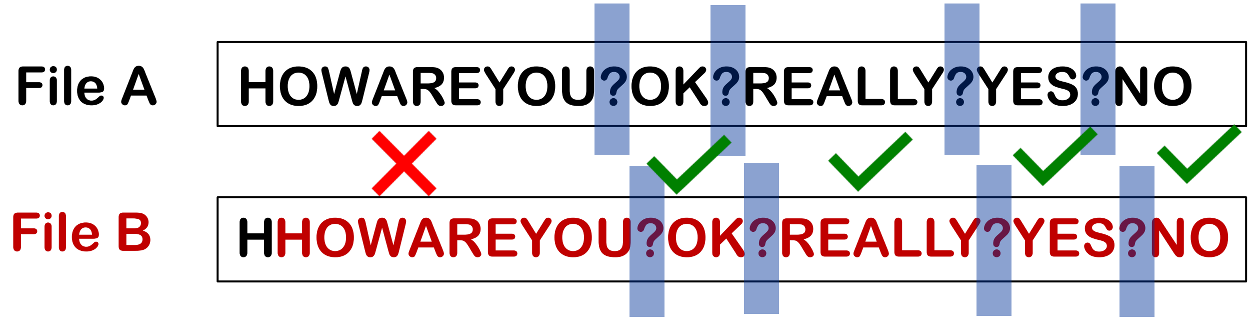
The Advantage of CDC



- Real-world datasets include two-week's google news, Linux kernels, and various Docker images.
- CDC's deduplication ratio is much higher than FSC.
- However, **CDC can be very expensive.**

CDC can be Too Expensive!

Assume the special marker is ‘**?**’



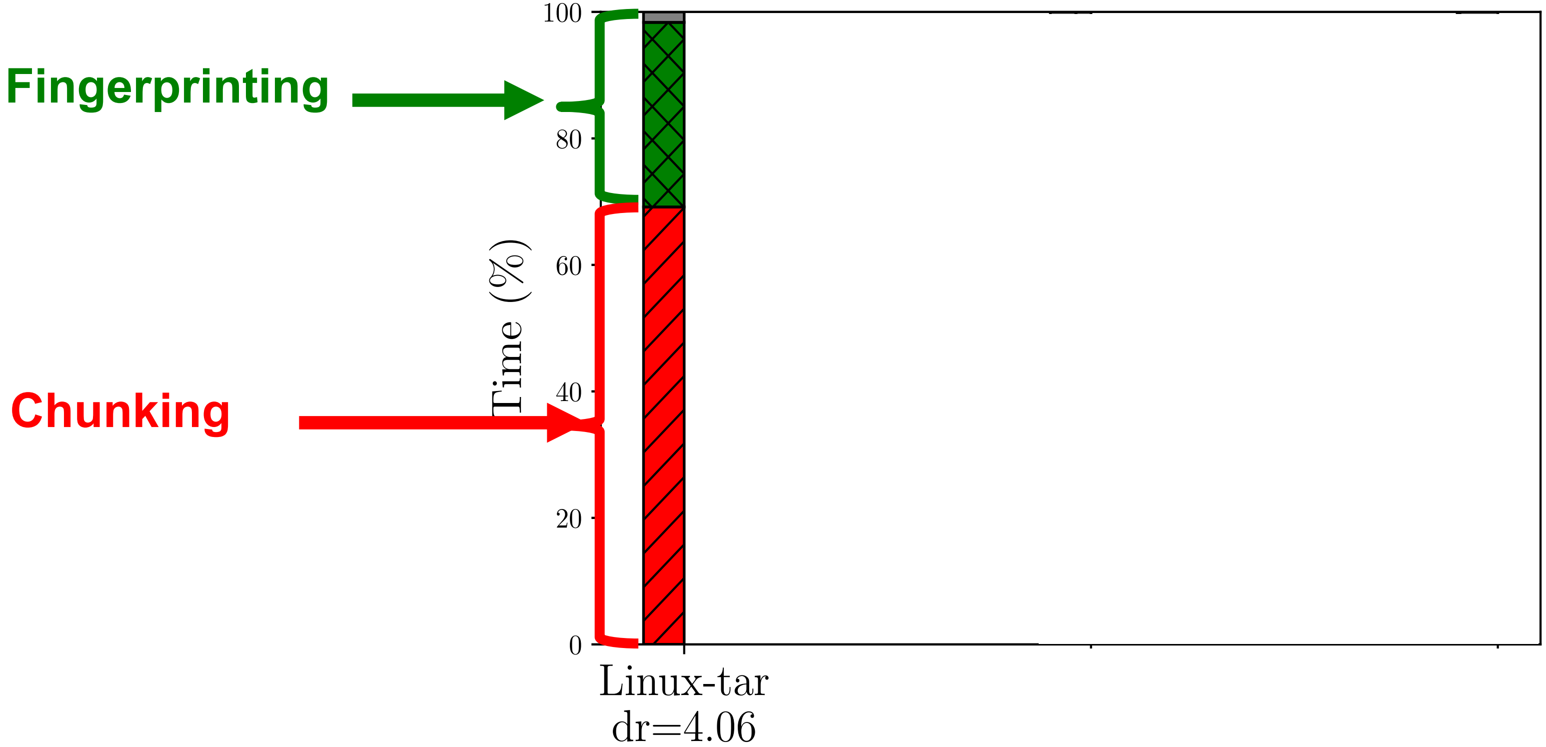
- The marker for identifying chunk boundaries must
  - be evenly spaced out with a controllable distance in between.

- Actually the marker is determined by applying a hash function on a window of bytes.
  - E.g., ***hash(“YOU?”) == pre-defined-value***

- The window rolls forward byte-by-byte and the hashing is applied continuously.

CDC Chunking Becomes a Bottleneck

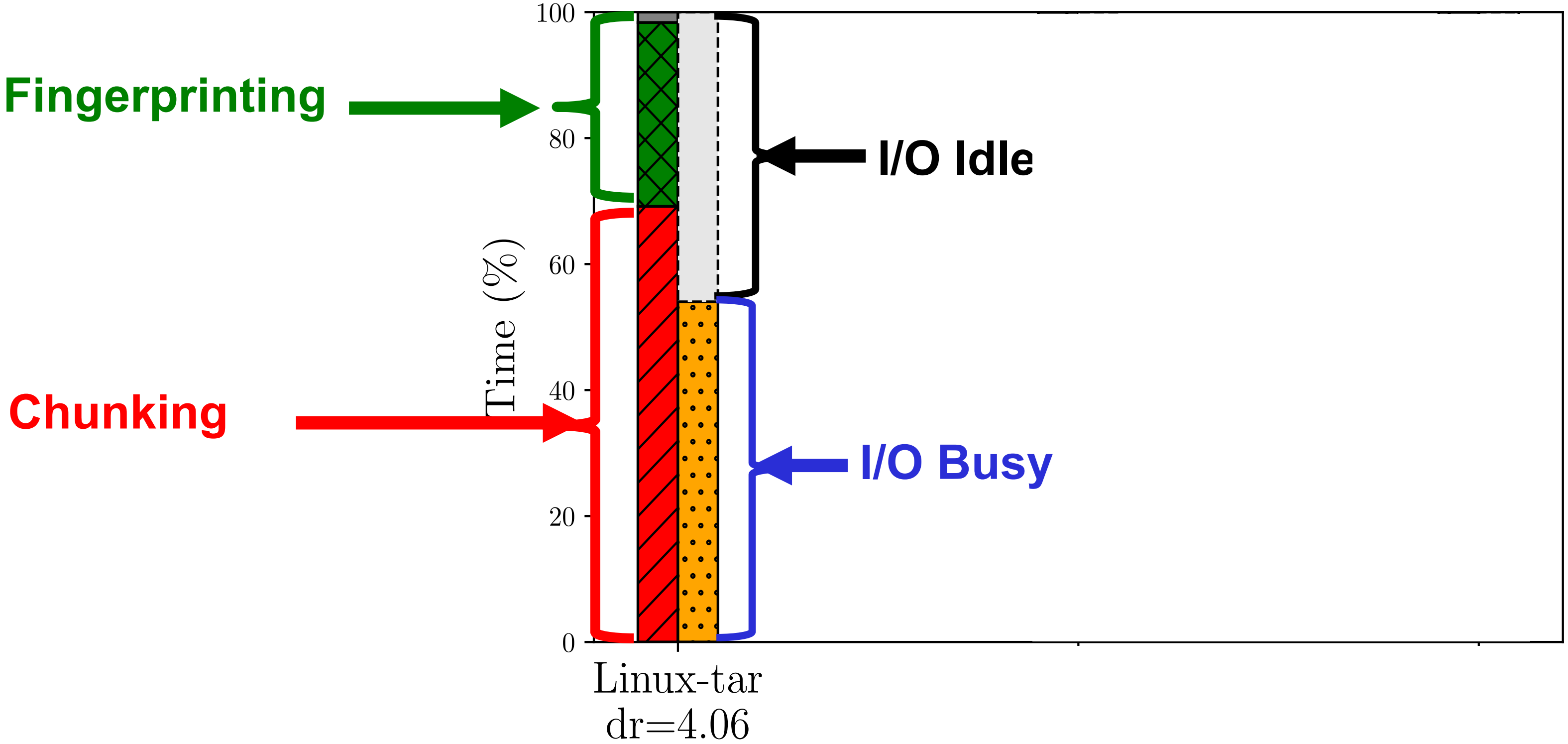
Breakdown of CPU time



- Chunking time > 60% of the CPU time.
- I/O bandwidth is not fully utilized.
- The bottleneck shifts from the disk to CPU.

CDC Chunking Becomes a Bottleneck

Breakdown of CPU time **Breakdown of IO time**



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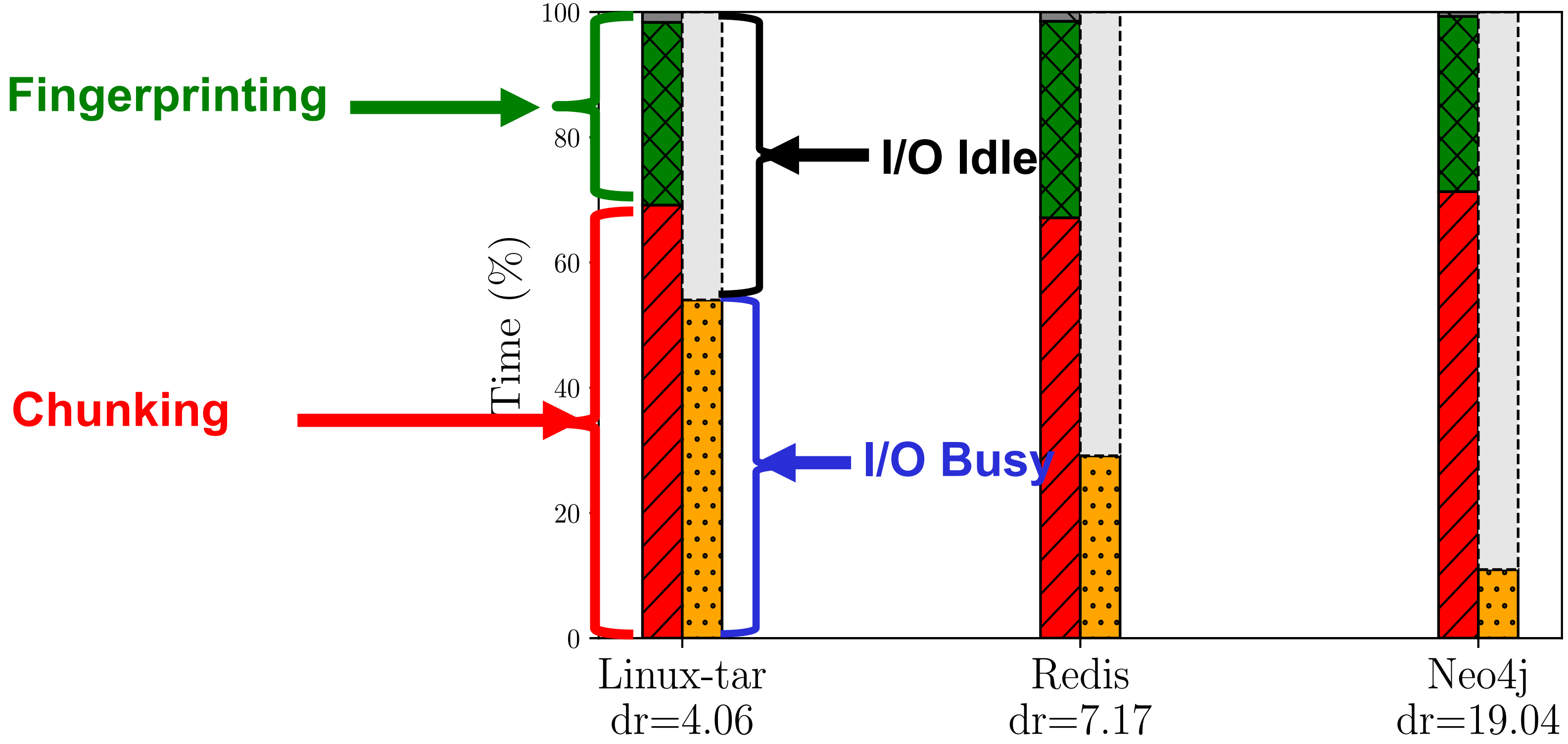

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Efforts on Acceleration of CDC Chunking

- **Make hashing faster**
  – Example functions: SimpleByte, gear, and AE
  – More likely to generate small chunks
    • increasing size of metadata cached in memory for performance

- **Use GPU/multi-core to parallelize the chunking process**
  – Extra hardware cost
  – Substantial efforts to deploy
  – The speedup is bounded by hardware parallelism.

- **Significant software/hardware efforts, but limited performance return**

We proposed RapidCDC that …

- is still **sequential** and doesn’t require additional cores/threads.
- makes the hashing speed **almost irrelevant.**
- accelerates the CDC chunking often by **10-30 times**.
- has a deduplication ratio **the same** as regular CDC methods.
- can be adopted in an existing CDC deduplication system by adding **100~200 LOC** in a few functions.

The Path to the Breakthrough

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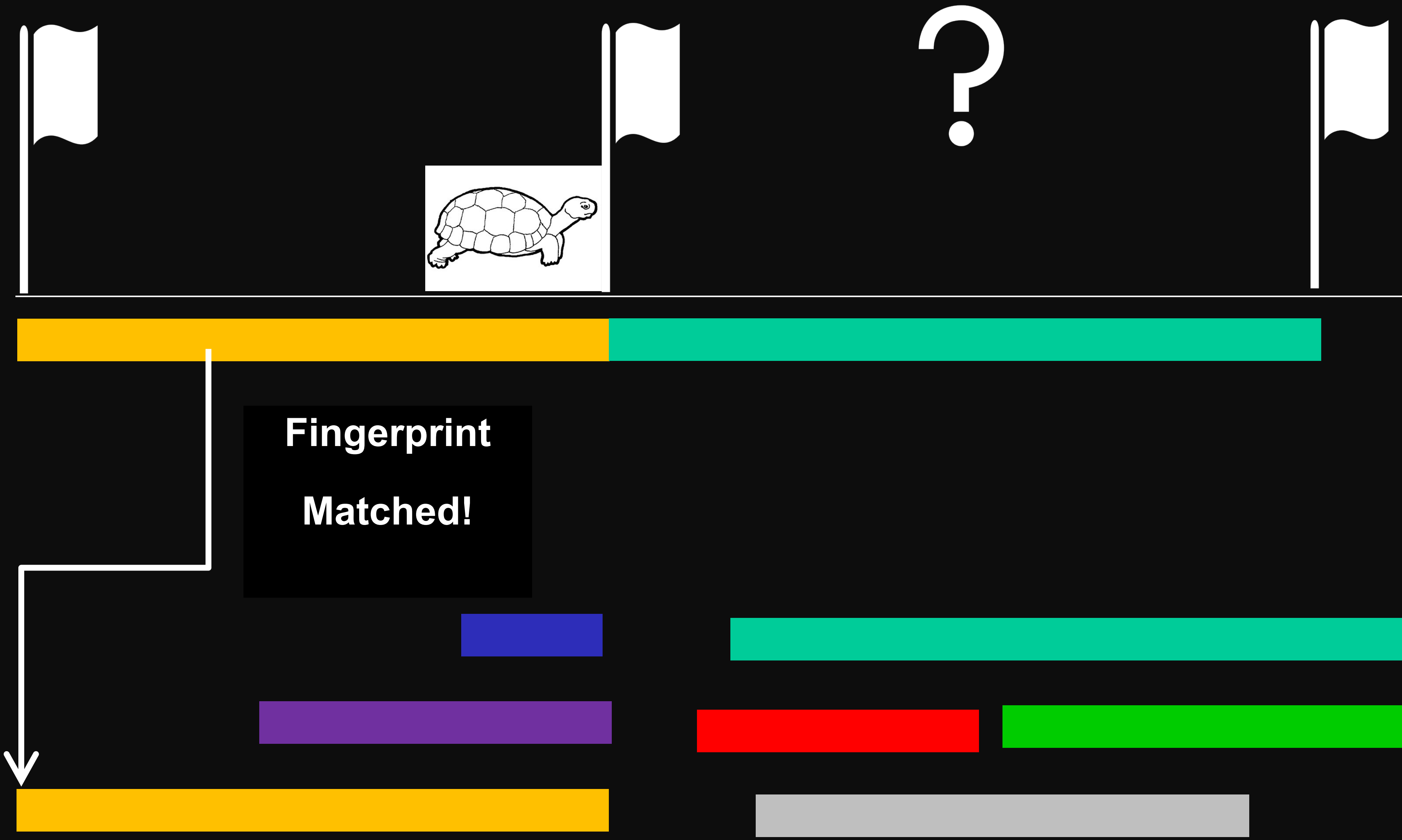

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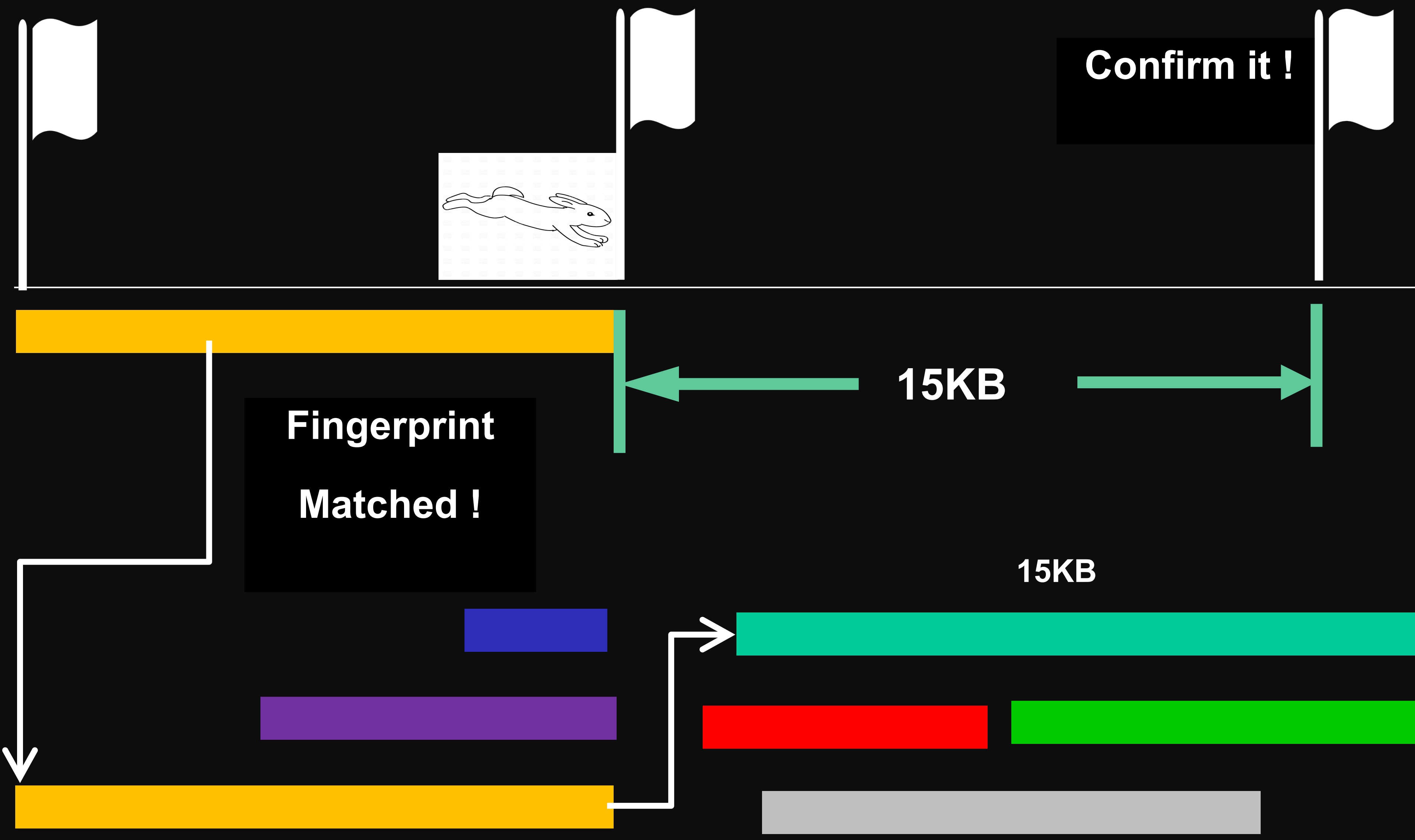

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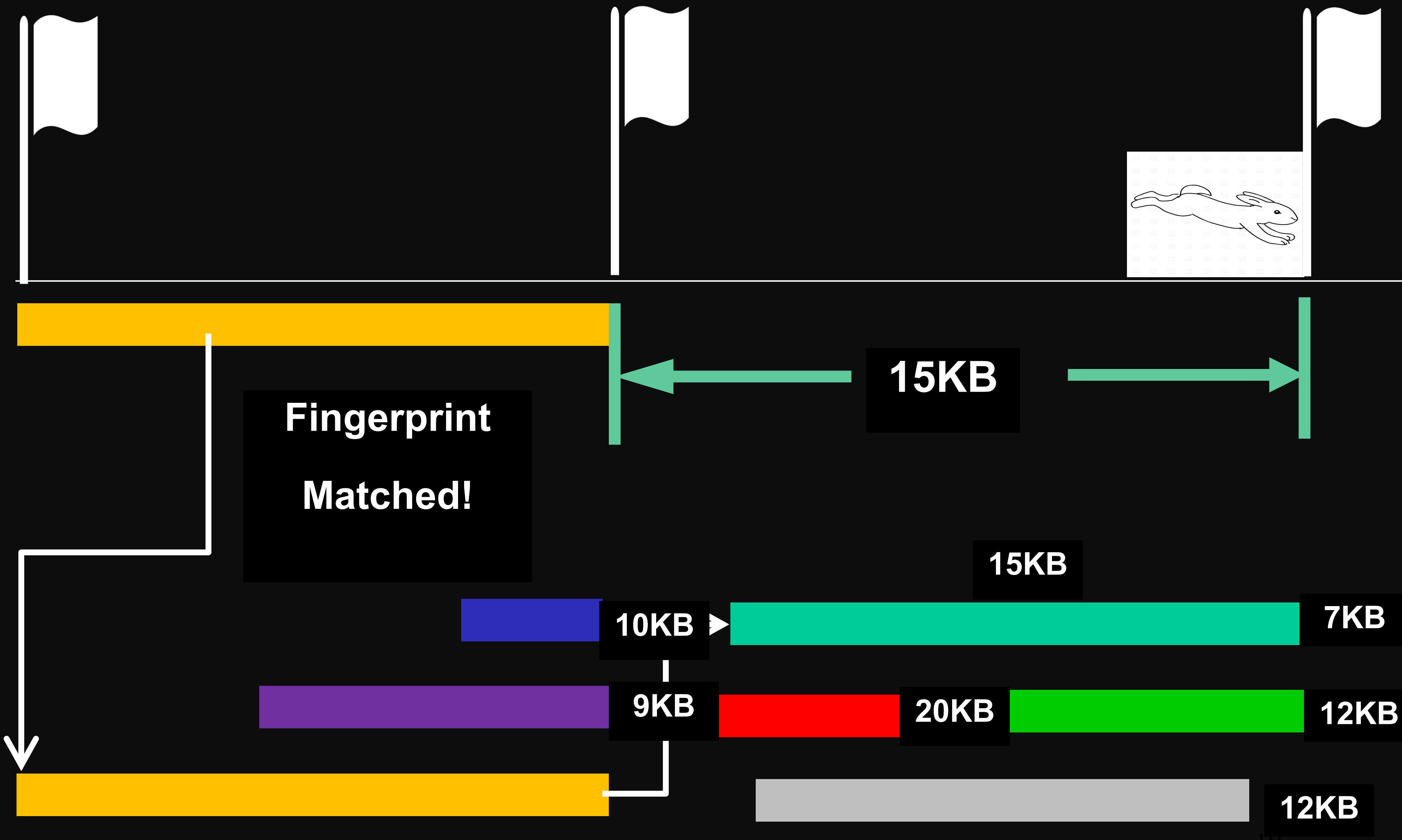

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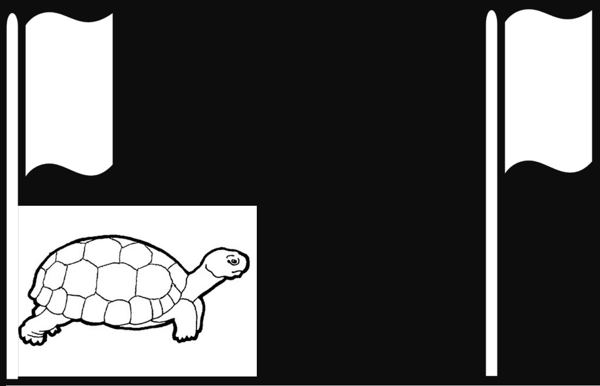
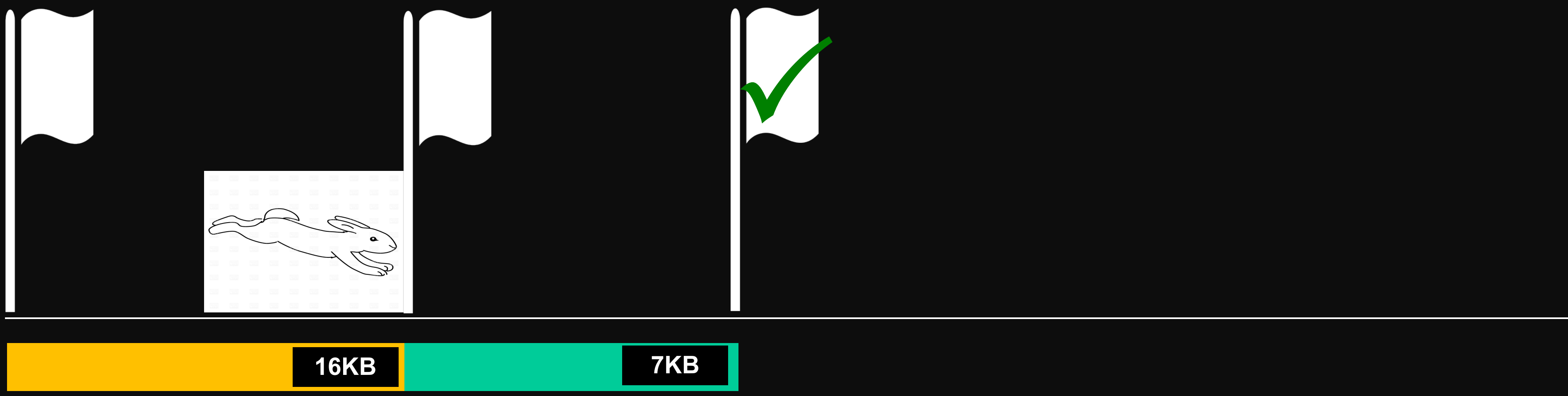


16KB

Fingerprint

Matched !

The Path to the Breakthrough



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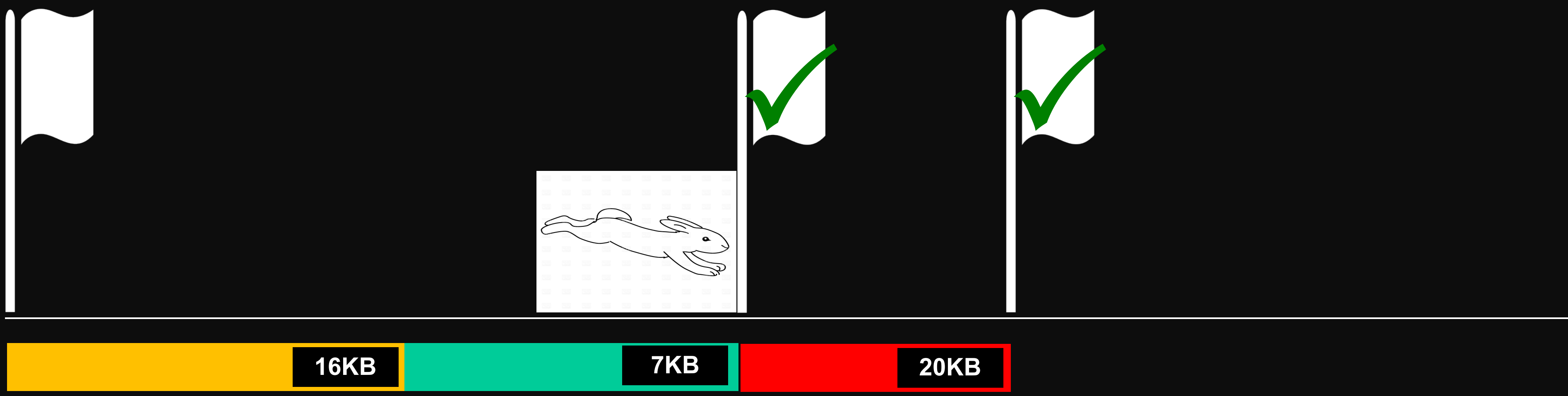

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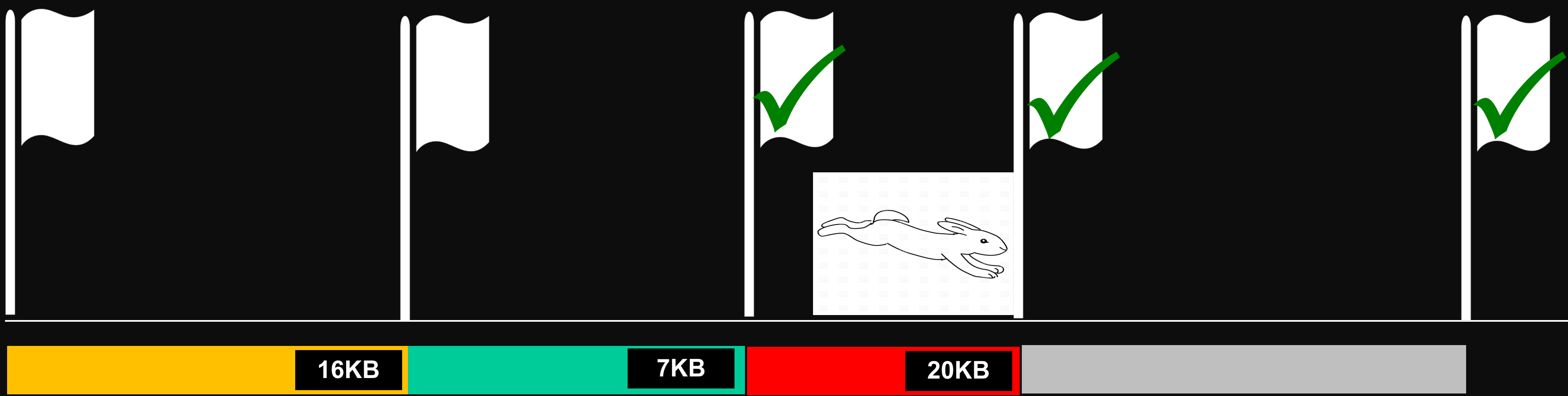

Fingerprint Matched !

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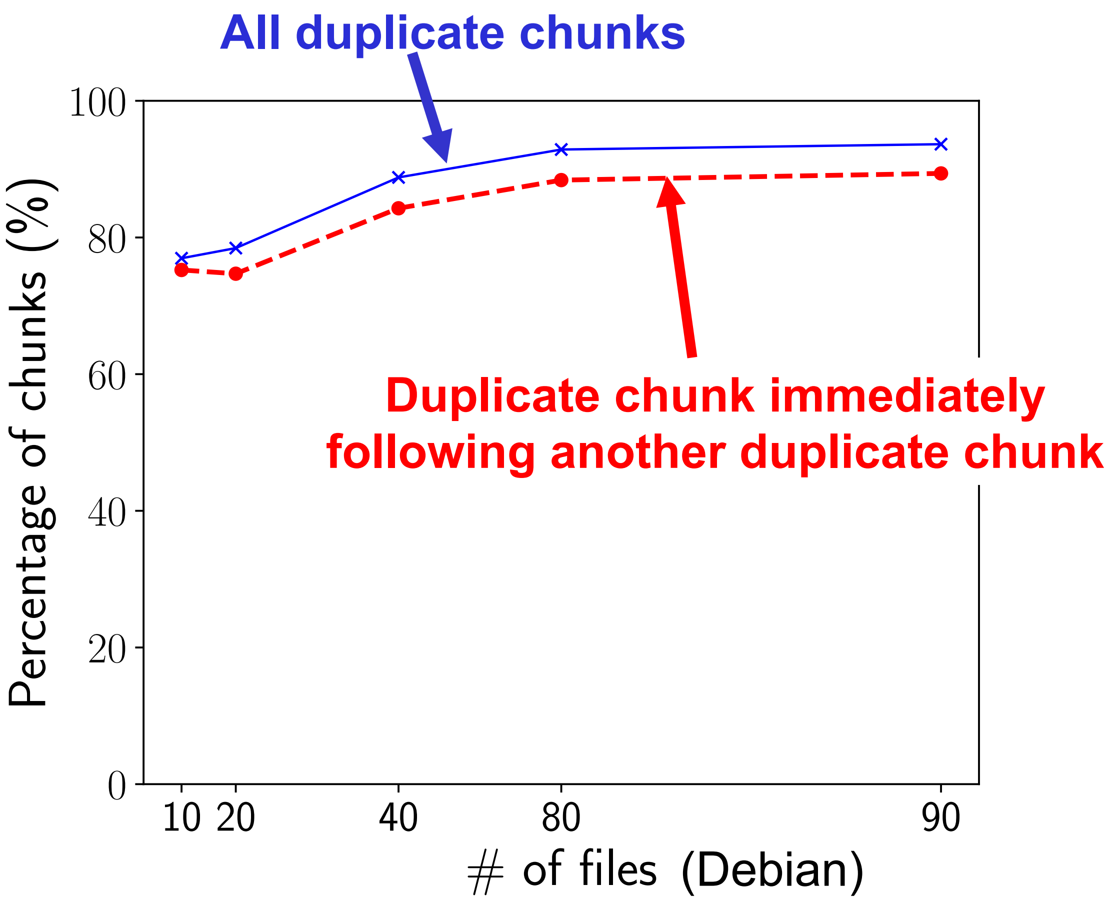
Fingerprint Matched !

Fingerprint Matched !

almost always happens !

Duplicate Locality

- Duplicate locality: if two of chunks are duplicates, their next chunks (in their respective files or data stream) are likely duplicates of each other.
- Duplicate chunks tend to stay together.



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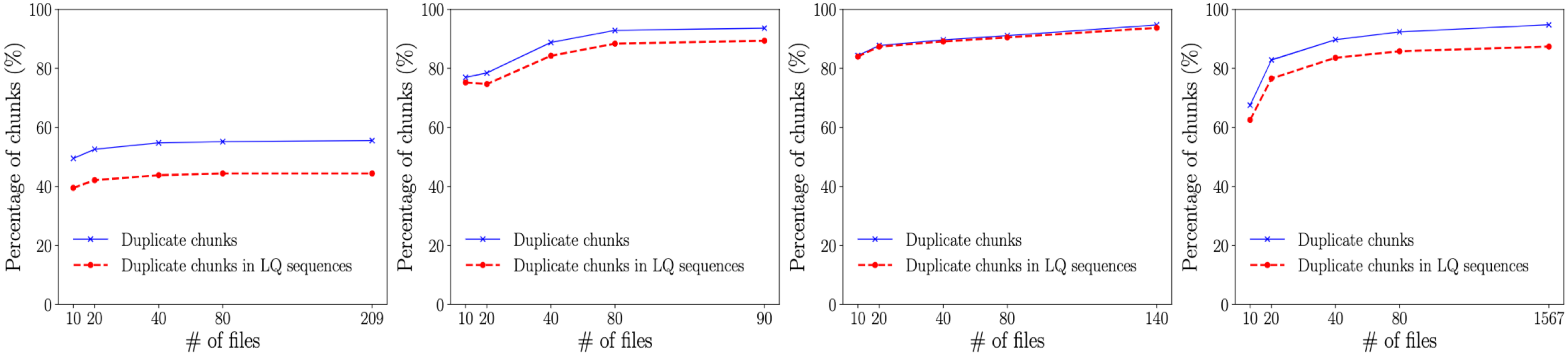
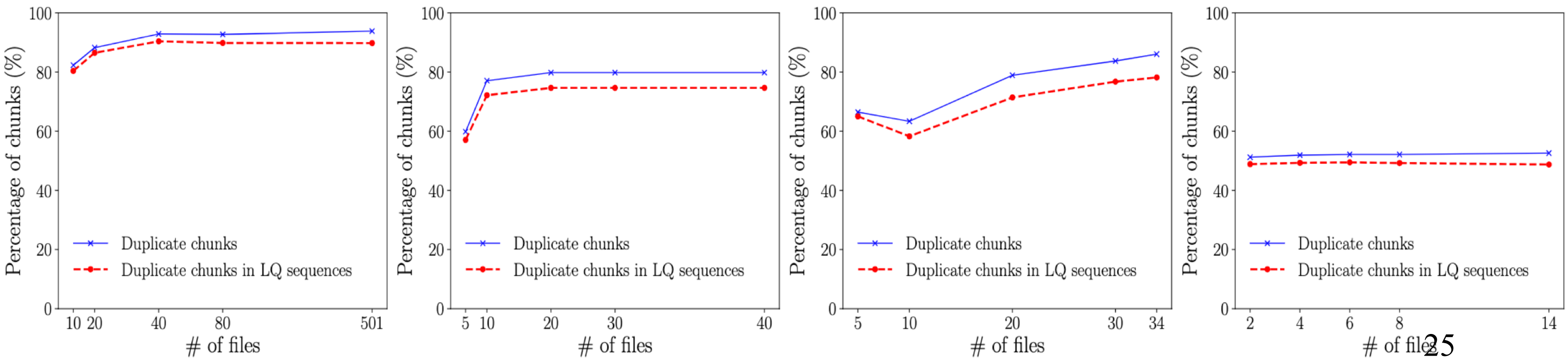


(a) *Linux-tar* (b) *Debian* (c) *Neo4j* (d) *Nodejs*

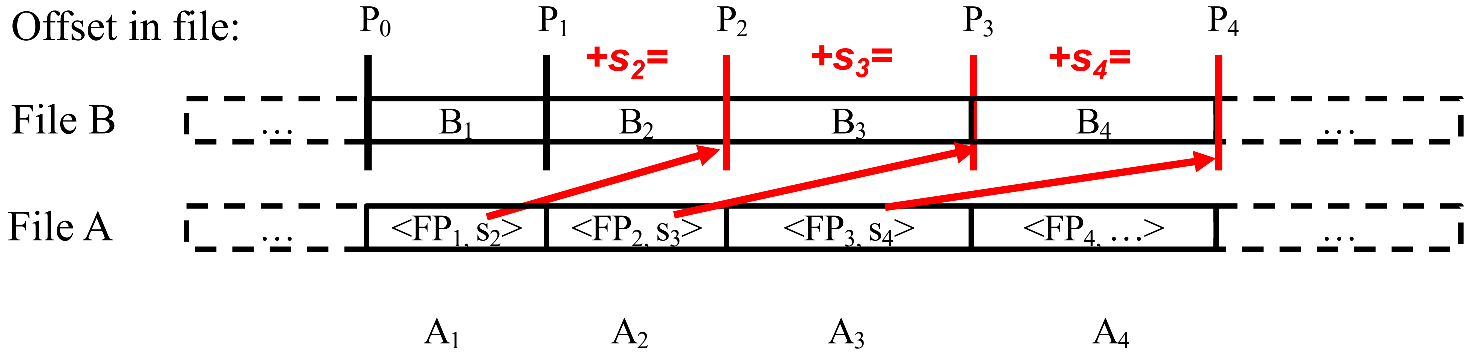


(e) *Wordpress* (f) *Cassandra* (g) *Redis* (h) *Google-news*

RapidCDC: Using Next Chunk in History as a Hint

- History recording: whenever a chunk is detected, its size is attached to its previous chunk (fingerprint);
- Hint-assisted chunking: whenever a duplication is detected, use the history chunk size as a hint for the next chunk boundary.

When FP(B1) == FP(A1):



- **Regular CDC is used for chunking until a duplicate chunk (e.g., B_1) is found**

More Design Considerations …

- A chunk may have been followed with chunks of different sizes
  - Maintain a size list

- Validation of Hinted Next Chunk Boundaries
  - Four alternative criterions with different efficiency and confidences
    - FF (fast-forwarding only)
    - FF+RWT (Rolling window Test)
    - FF+MT (Marker Test)
    - FF+RWT+FPT (Fingerprint Test)

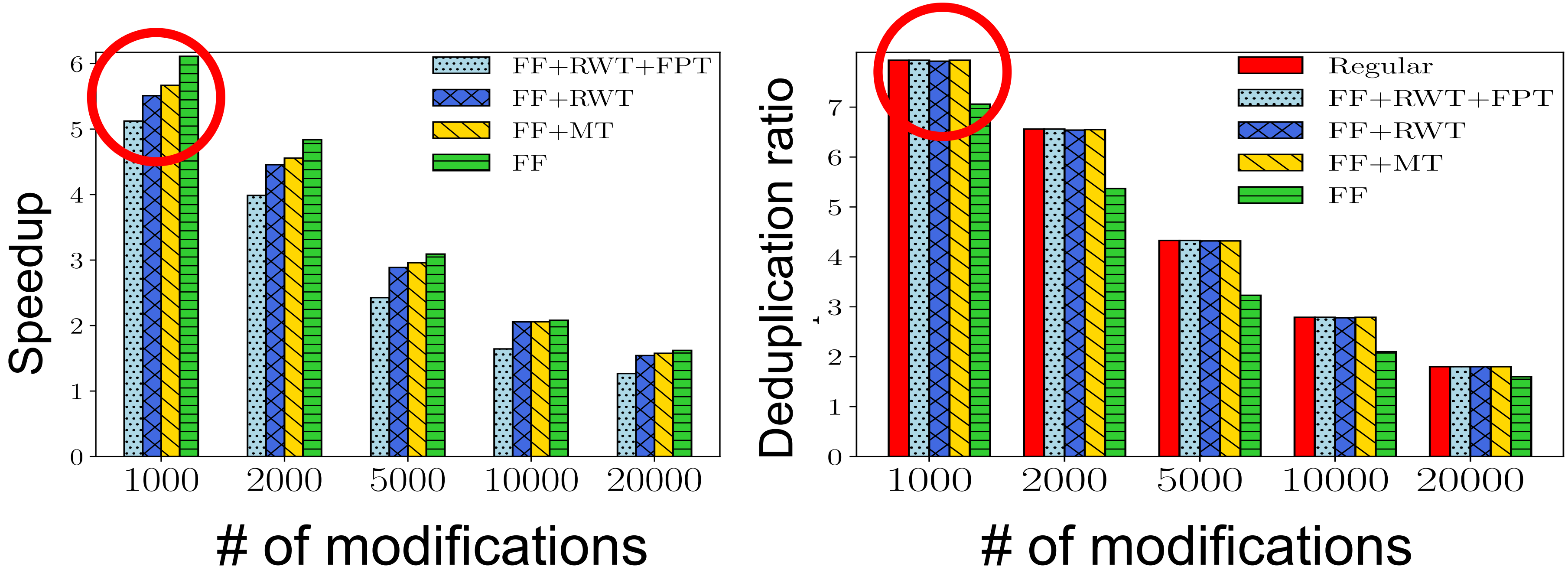
- **Please refer to the paper for detail.**

Evaluation of RapidCDC

- Prototype: based on a rolling-window-based CDC system.
  - Using Rabin/Gear as rolling function for rolling window computation.
  - Using SHA1 to calculate fingerprints.

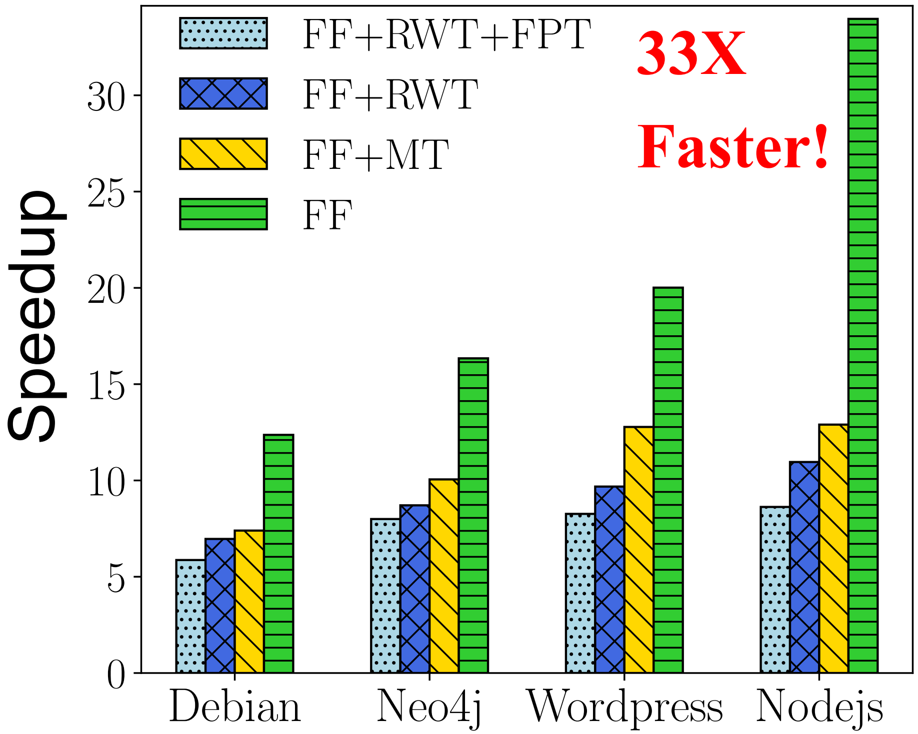
- Three disks with different speed are tested.
  - SATA Hard disk: 138 MB/s and 150MB/s for sequential read/write.
  - SATA SSD: 520 MB/s and 550MB/s for sequential read/write.
  - NVMe SSD: 1.2 GB/s and 2.4G/s for sequential read/write.

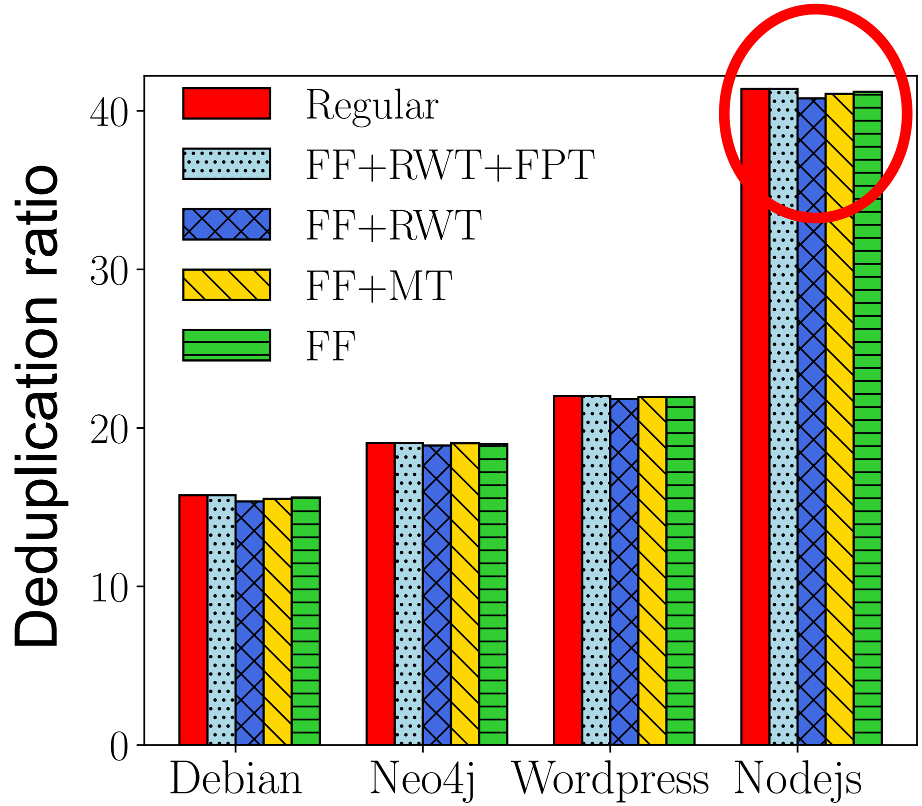
Synthetic Datasets: Insert/Delete



- Chunking speedup correlates to the deduplication ratio.
- Deduplication ratio is little affected (except for one very aggressive validation criterion).

Real-world Datasets: Chunking Speed





- Chunking speedup approaches deduplication ratio.
- Negligible deduplication ratio reductions (if any).

Conclusions

- RapidCDC represents a **disruptively new** approach to improve CDC chunking speed.
- It increases chunking speed by **up to 33X** without loss of deduplication ratio.
- Its adoption in an existing CDC deduplication system **does not** require any major change of its current operation flow.
- Its implementation in any existing CDC deduplication systems requires **minimal code changes** (100-200 lines of C code in our prototype)
- A prototype implementation is available at *https://github.com/moking/rapidcdc*