Knockoff: Cheap versions in the cloud

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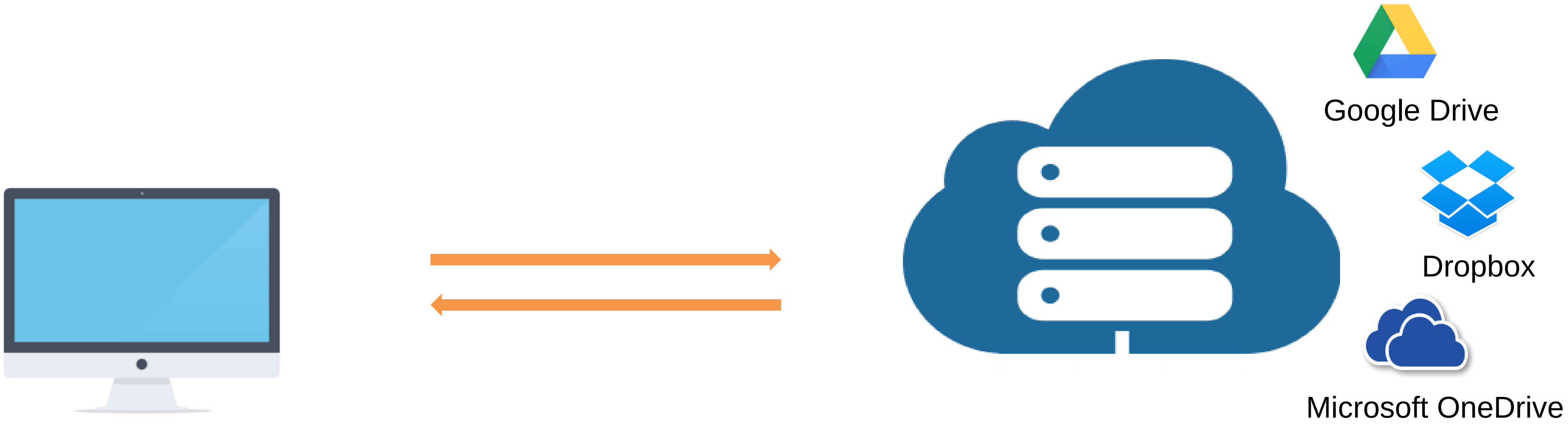
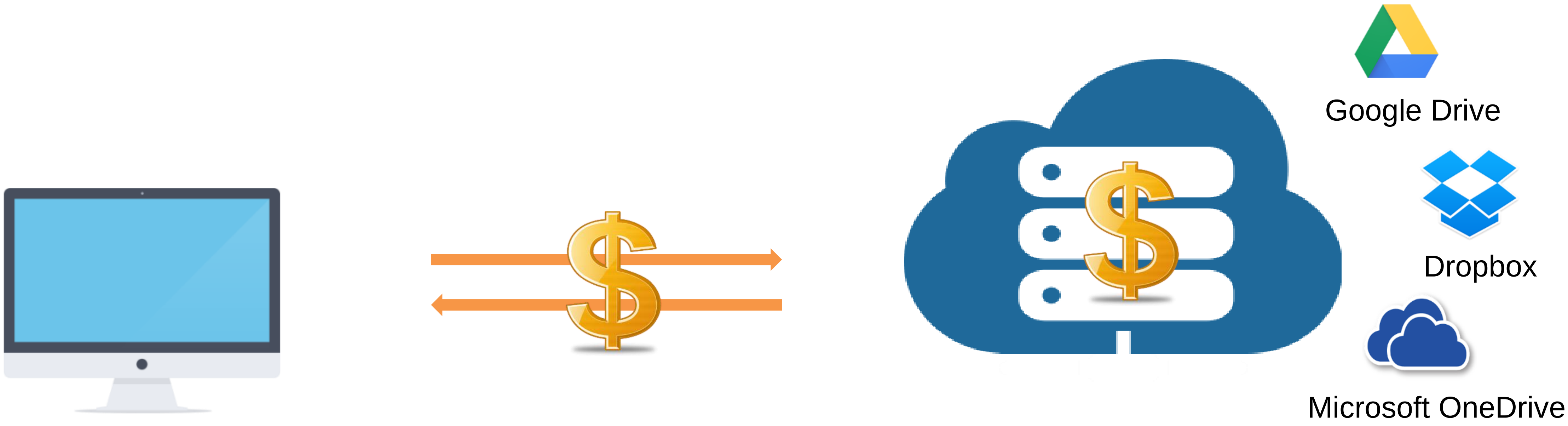
Cloud-based storage



Pros:

- Ease-of-management
- Reliability

Cloud-based storage



Challenges:

- Storage costs
- Communication costs

Versioning increases costs

Google Drive

Dropbox

Microsoft OneDrive

Pros:

- Recovery of lost data
- Auditing
- Troubleshooting

Versioning

Reducing costs: a new direction

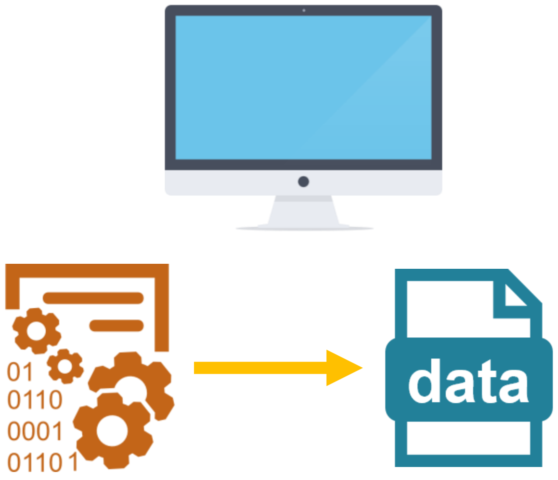
- Established methods exploit similarities in data
  - Chunk-based deduplication
  - Delta compression
  - Greater work for incremental gains

- Our goal: explore an orthogonal new dimension
  - Deterministically recompute data in lieu of communication, storage

File: data or computation?

Computation File data

File: data or computation?



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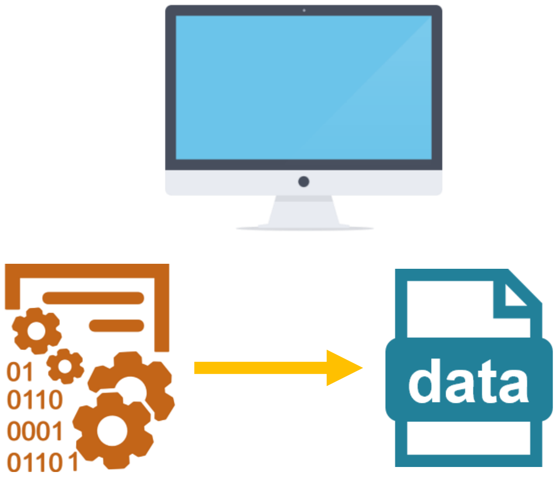

Computation

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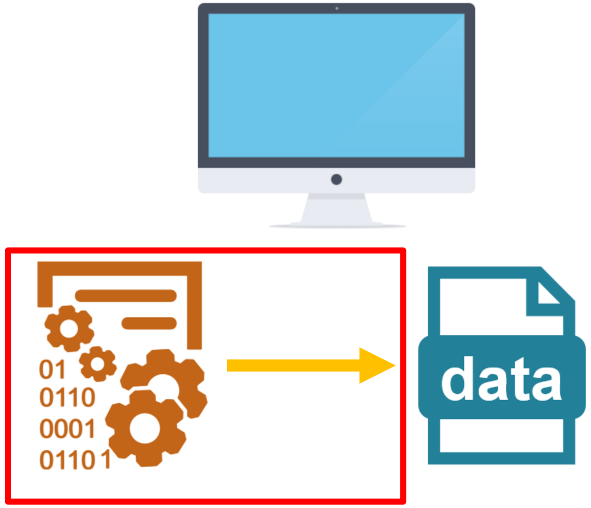

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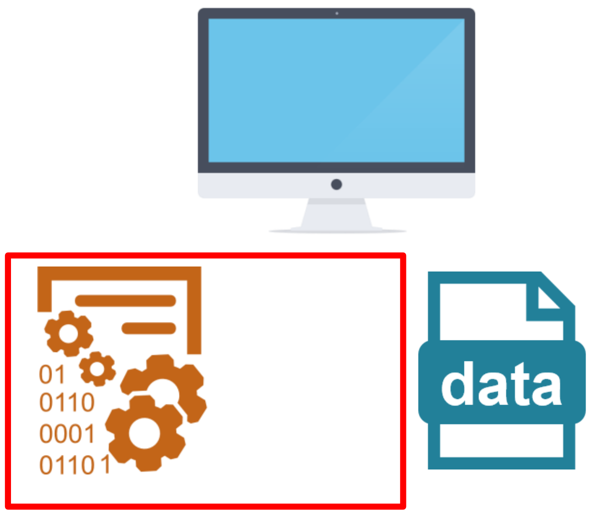

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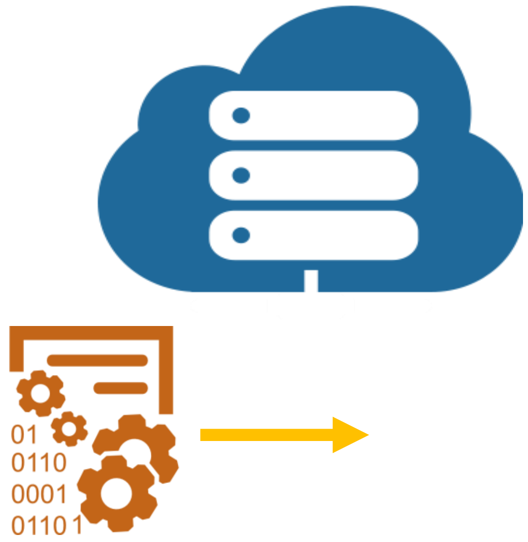

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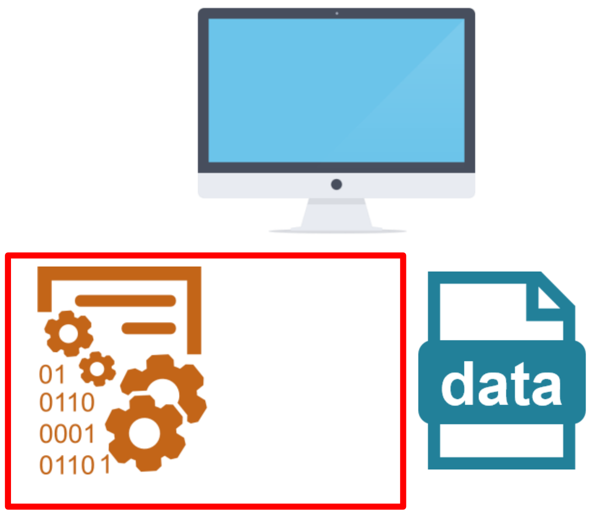

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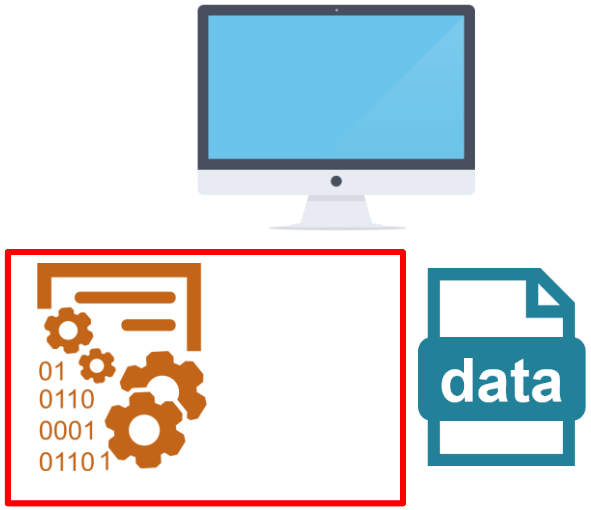


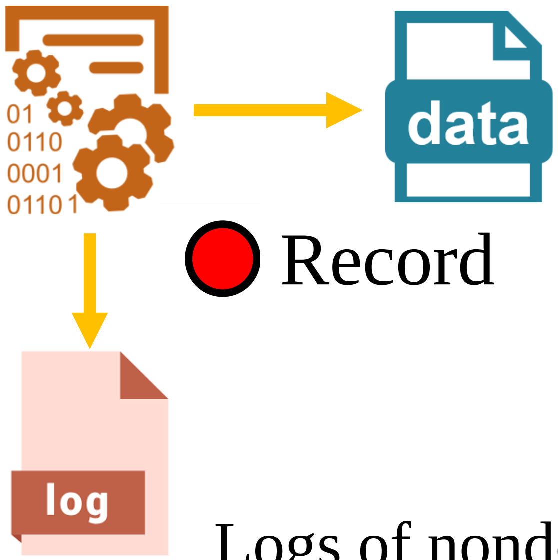
Computation File data

Different output data

How can we address non-determinism?

File: data or computation?

- Deterministic record and replay

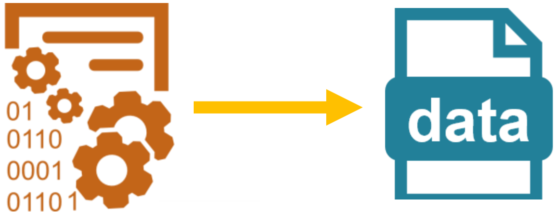


Record

Logs of nondeterminism

File: data or computation?

- Deterministic record and replay



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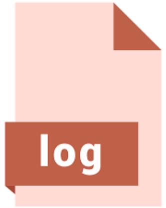

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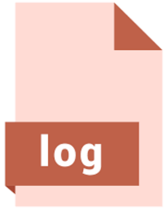

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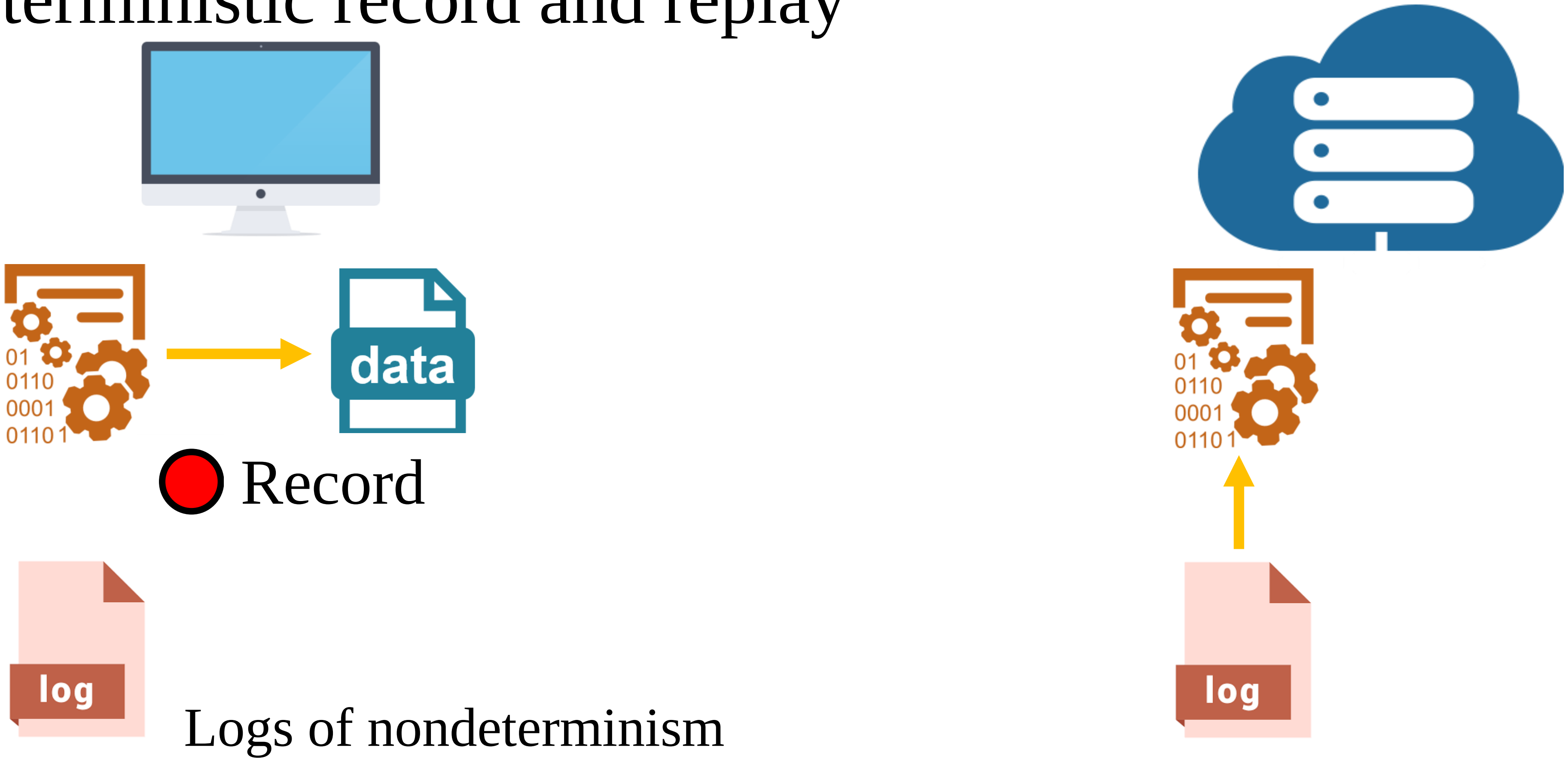

File: data or computation?

- Deterministic record and replay

Knockoff

- Selectively substitutes computation for data
- Benefits
  - Reduction compared to chunk-based deduplication
    - Communication costs: 21%
    - Storage costs: 19%
  - Benefits increases as we retain versions more frequently
  - A new fined-grained versioning policy

Outline

- Introduction
- Writing files
- Storing files
- Evaluation

Knockoff

- Knockoff selectively represents a file as:
  - ❑ Normal file data (by value)
  - ❑ Logs of the nondeterminism needed to recompute the file (by operation)

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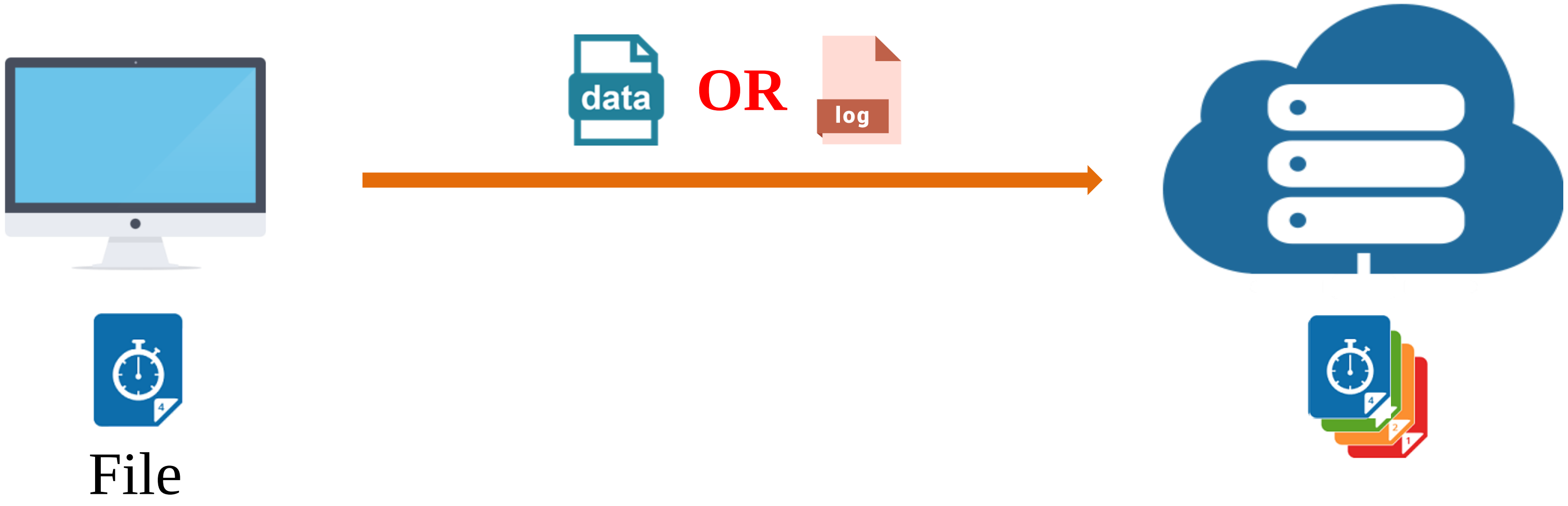

Knockoff

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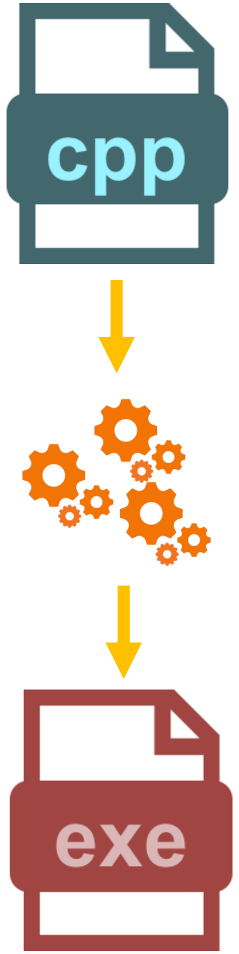
  - ❑ Logs of the nondeterminism needed to recompute the file (by operation)

An example log for compilation

	Log entry	Values
1	*open*	rc=3
2	*mmap*	rc=<addr>,file=<id,version>
3	*gettimeofday*	rc=0,time=<time>
4	*pthread_lock*	rc=0
5	*SIGCHILD*	
	…	…



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	…	…

Return values from syscalls

Ordering of thread synchronization

Signals

An example log for compilation

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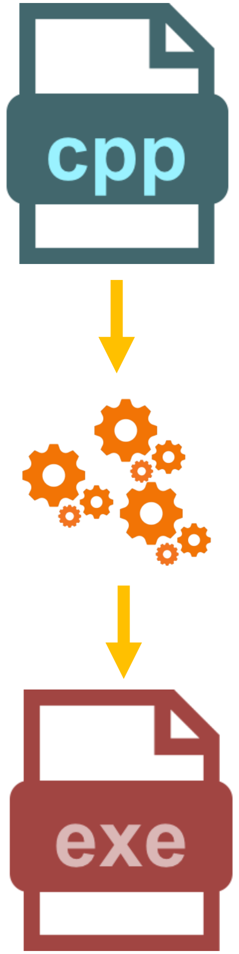

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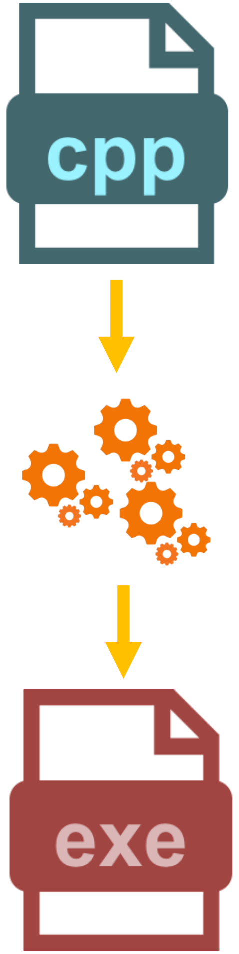
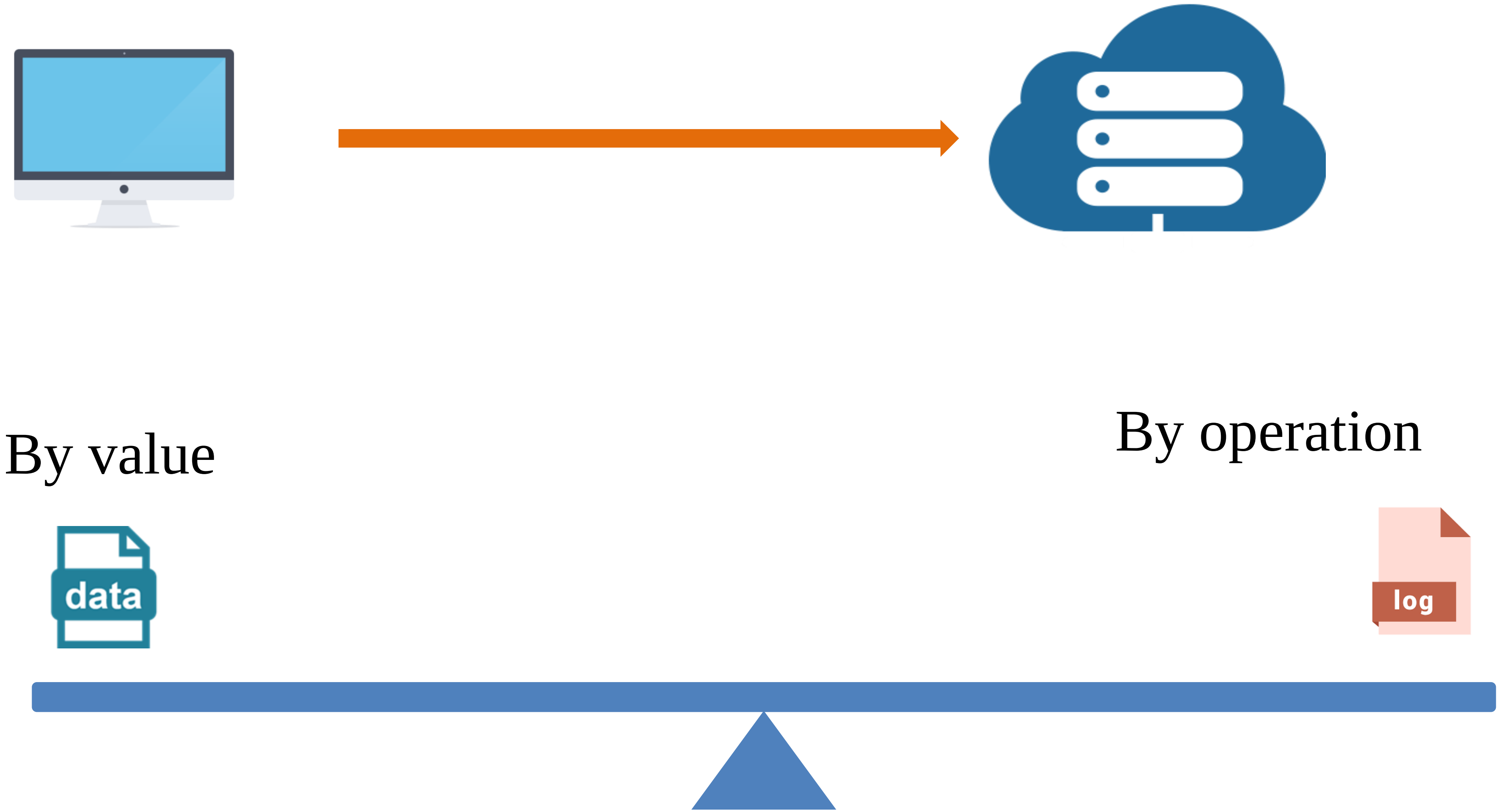


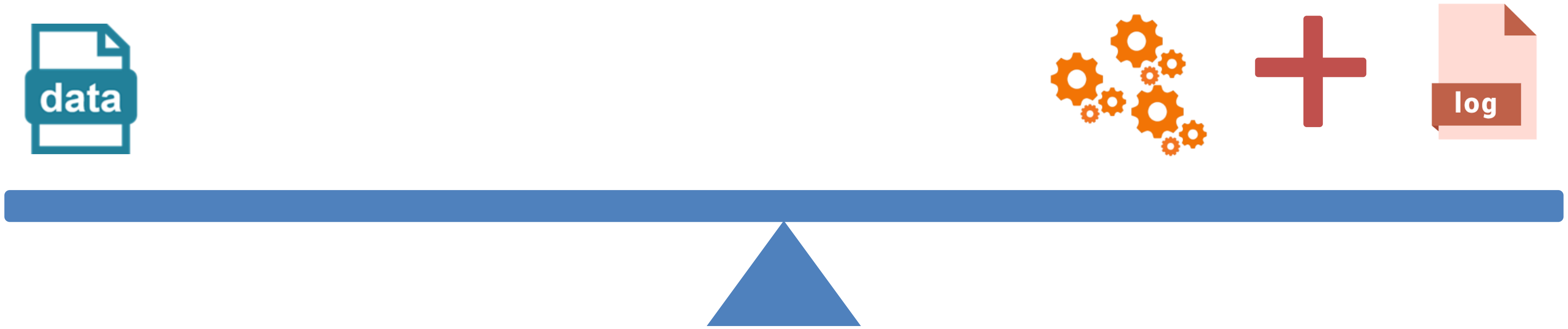
Writing files



Writing files

By value

By operation

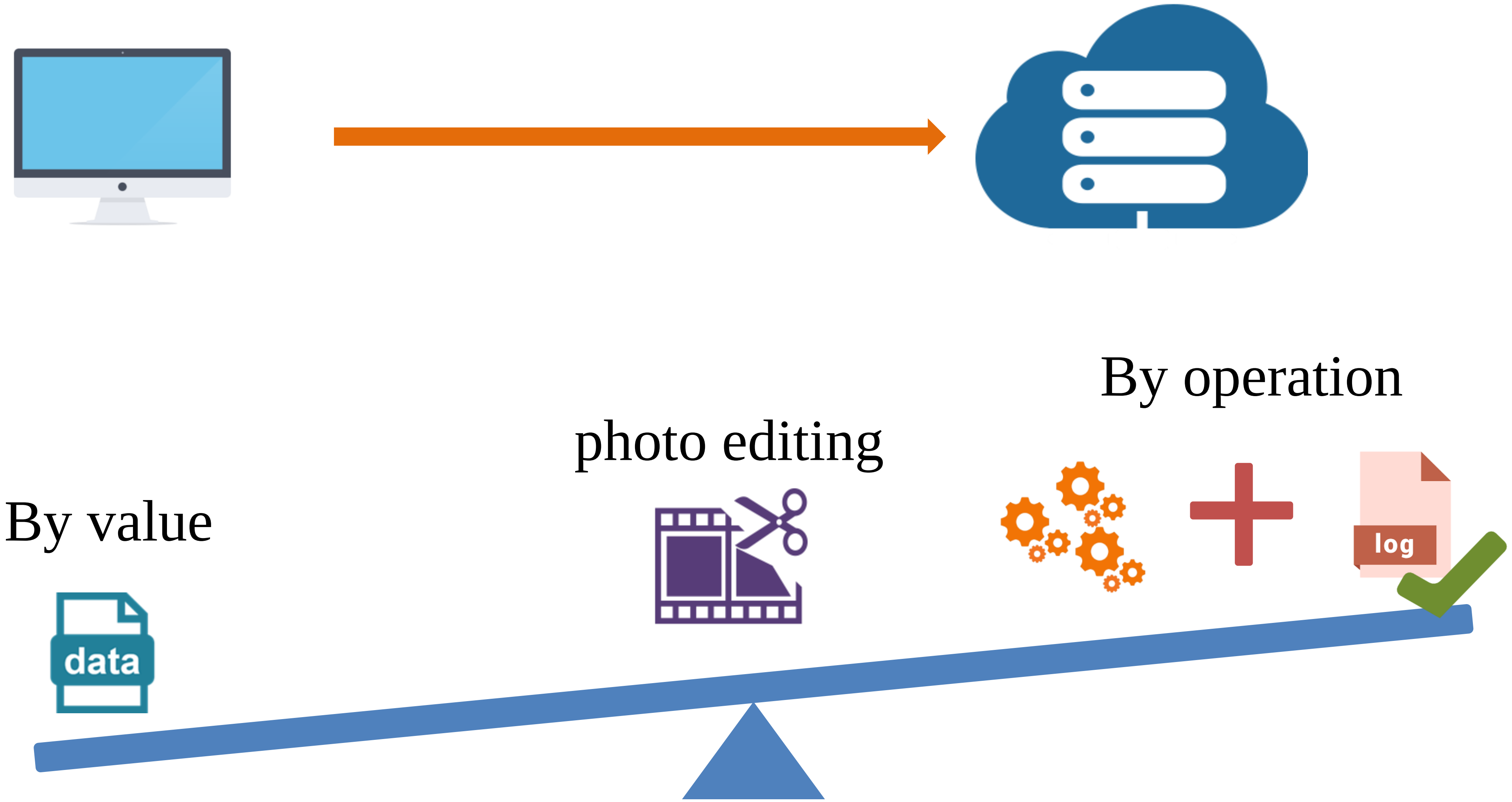


Writing files

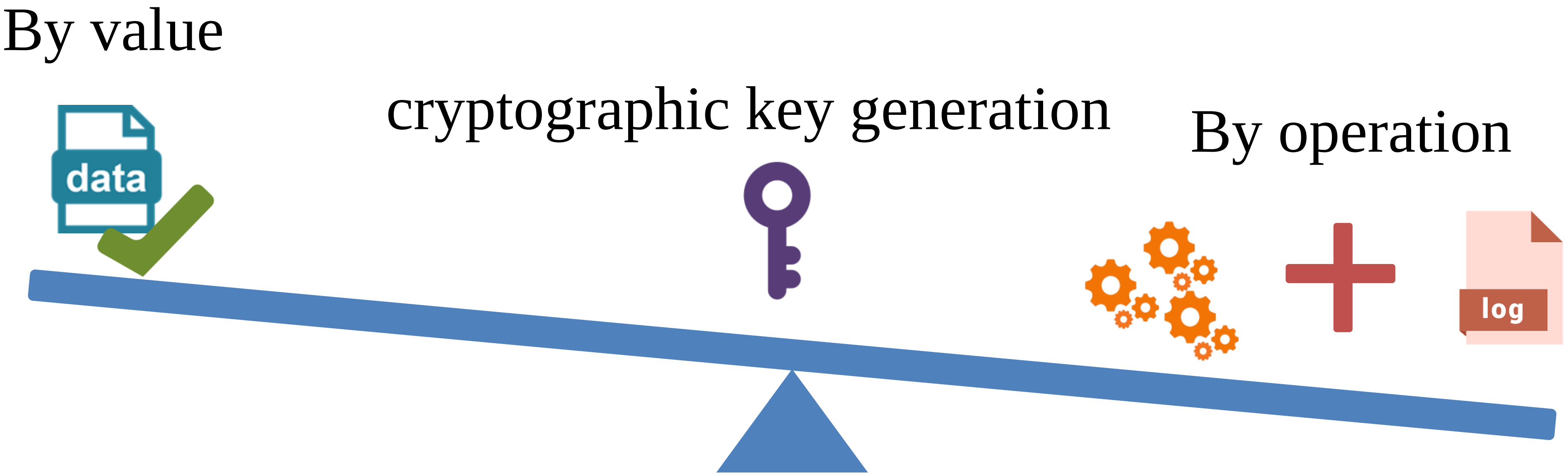
By value

By operation

Writing files



Writing files



Outline

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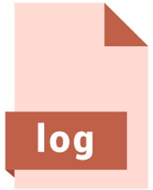
Storing files

- Store files by value or by operation?

- A tradeoff between latency and costs
  – Current versions: by value
  – Past versions: by value or by operation

Storing past versions

- Maximum materialization delay
  - Time bound for reconstructing any version



Regeneration time = **20s** < Materialization delay = **60s**

Storing past versions

- Maximum materialization delay
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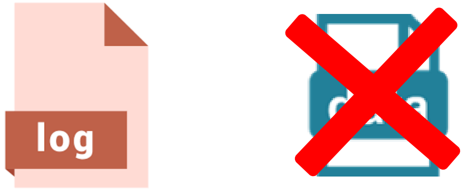

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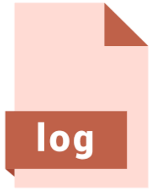

Regeneration time = **100s** > Materialization delay = **60s**

Storing past versions

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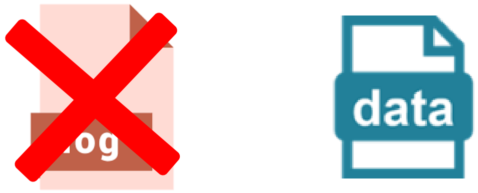


Regeneration time = **100s** > Materialization delay = **60s**

Storing past versions

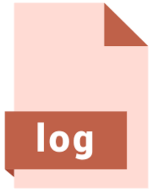
- Maximum materialization delay
  – Time bound for reconstructing any version
- Longest path > materialization delay

Total regeneration time = **20s**

<

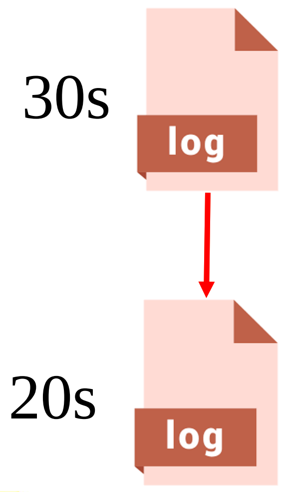
Materialization delay = **60s**

20s



Storing past versions

- Maximum materialization delay
  - Time bound for reconstructing any version
- Longest path > materialization delay

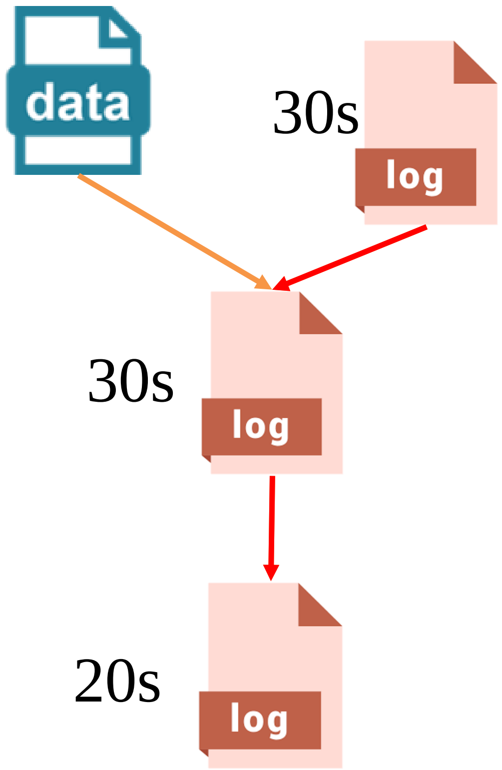


Total regeneration time = **50s**

$<$

Materialization delay = **60s**

Storing past versions



- Maximum materialization delay
  - Time bound for reconstructing any version
- Longest path > materialization delay

Total regeneration time = **80s**

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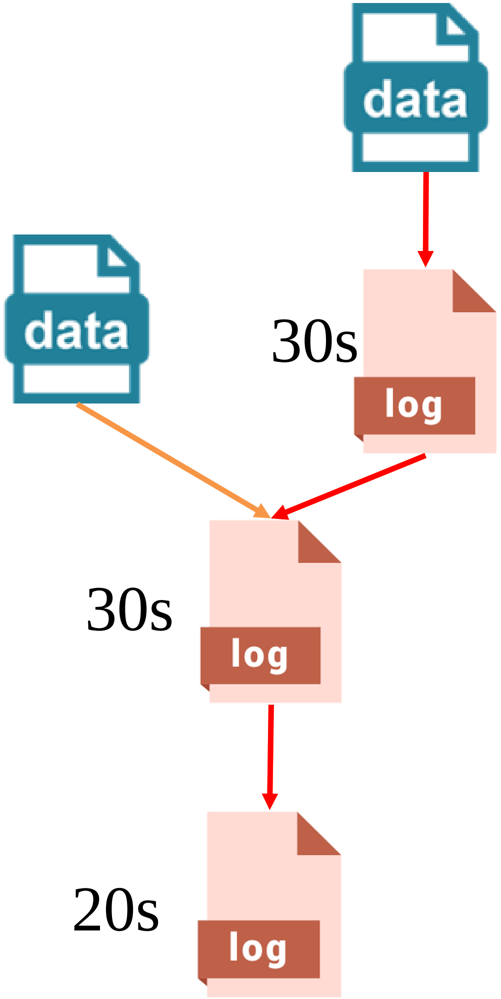
Materialization delay = **60**s

Storing past versions



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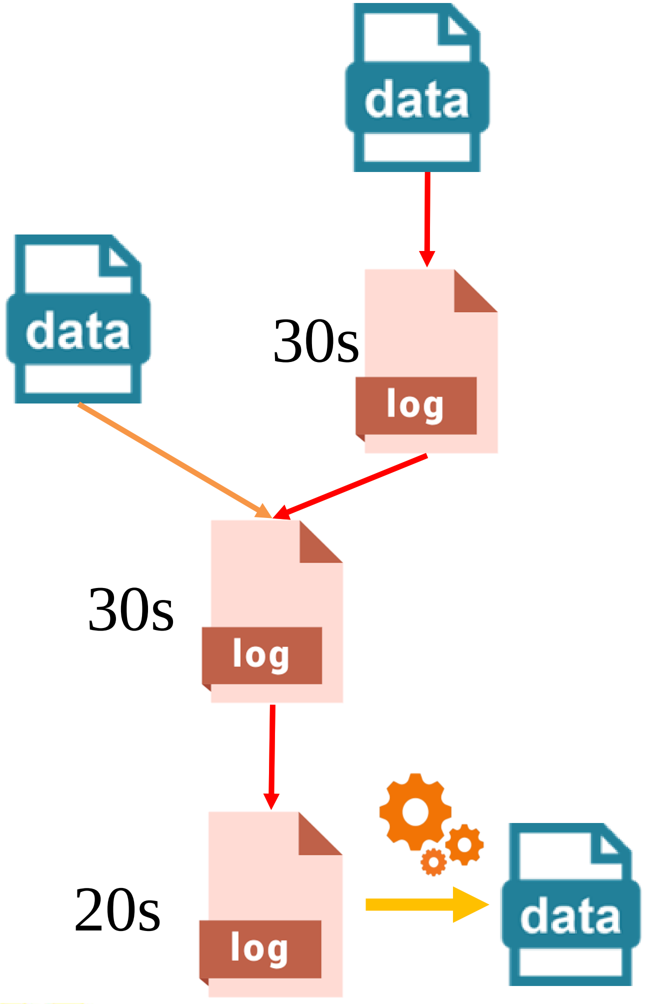
>

Materialization delay = **60**s

Storing past versions



- Maximum materialization delay
  - Time bound for reconstructing any version
- Longest path > materialization delay

Total regeneration time = **80s**

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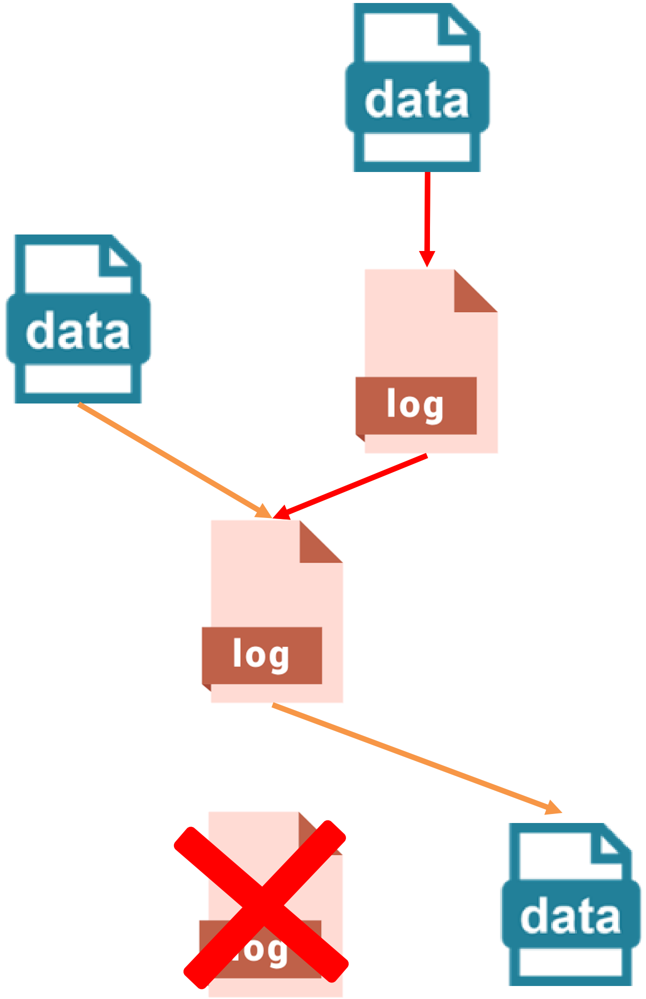
Materialization delay = **60**s

Storing past versions

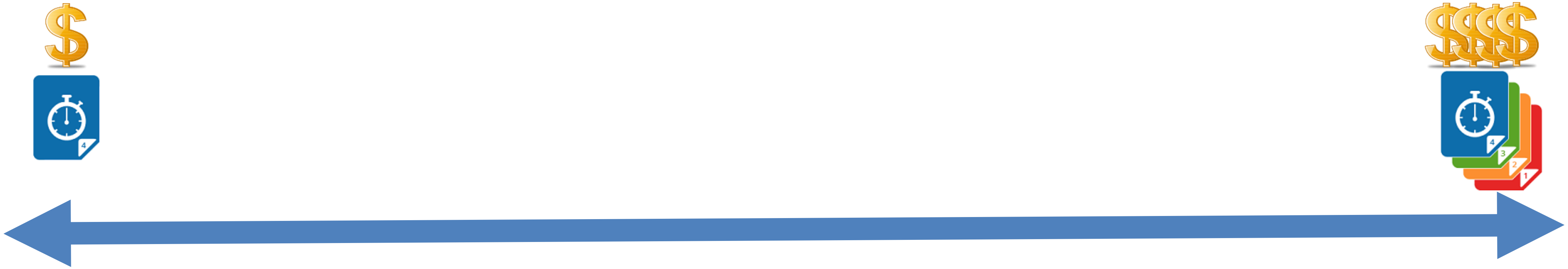


- Maximum materialization delay
  - Time bound for reconstructing any version
- Longest path > materialization delay
  - A greedy algorithm

Materialization delay = **60s**

Storing past versions: versioning policies

- Frequency of versioning



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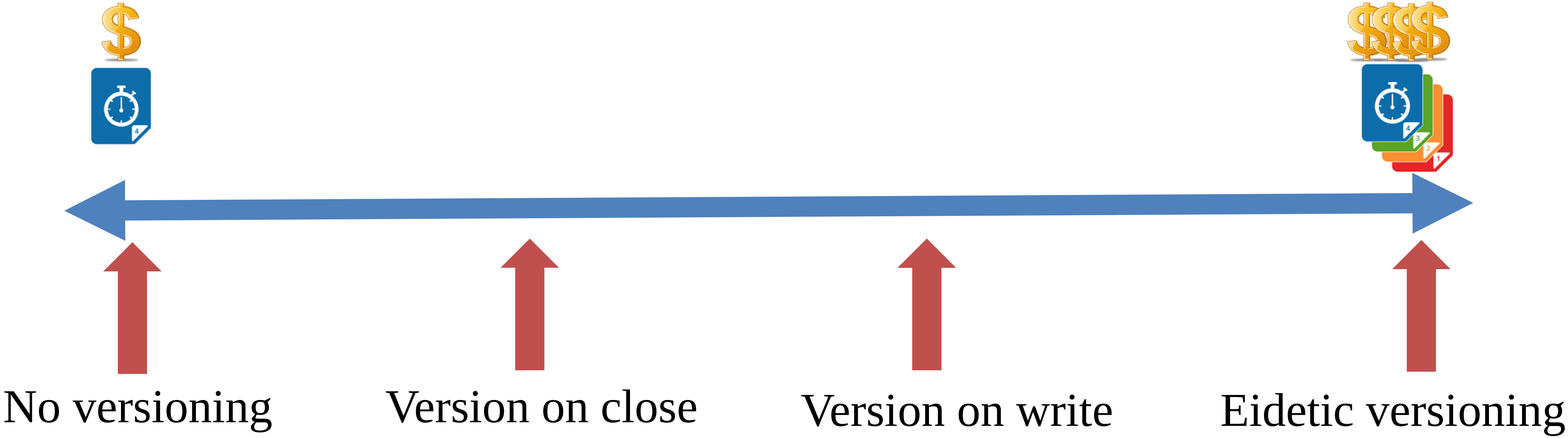

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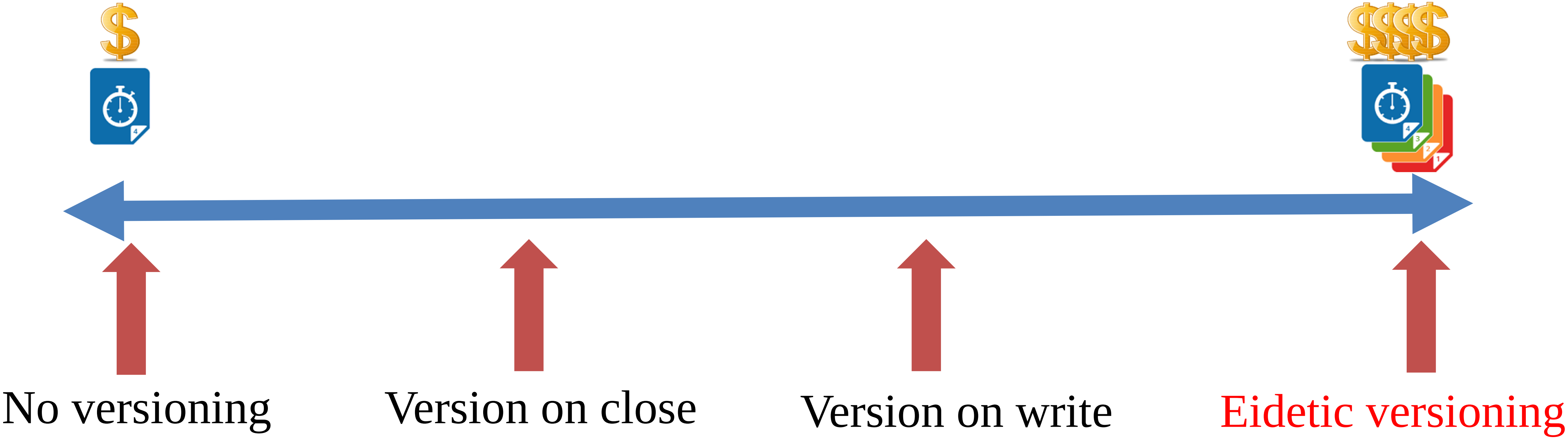

Memory-mapped files

Any past transient state in memory?

Optimization: log compression

- Chunk-based deduplication is effective for file data
  - Executions of the same application have similar patterns
  - Can it also be applied to computation (logs of nondeterminism)?

- Delta compression

Optimization: log compression

- Problem: a smattering of values differ in each log

	Log entry	Values
1	*open*	rc=3
2	*pthread_lock*	rc=0
3	*mmap*	rc=<addr>,file=<id,version>
4	*read*	rc=<size>,file=<id,version>
5	*gettimeofday*	rc=0,time=9.90
6	*write*	rc=<size>
7	*pthread_unlock*	rc=0
	…	…

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4	*read*	rc=<size>,file=<id,version>
5	*gettimeofday*	rc=0,time=1.10
6	*write*	rc=<size>
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	…	…

Optimization: log compression

- Problem: a smattering of values differ in each log

	Log entry	Values
1	*open*	rc=3
2	*pthread_lock*	rc=0
7	*pthread_unlock*	rc=0
	…	…

	Log entry	Values
1	*open*	rc=3
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	…	…

Delta compression: 42% reduction

Outline

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Evaluation

- How much does Knockoff reduce bandwidth usage?
- How much does Knockoff reduce storage costs?
- What is Knockoff’s performance overhead?

- For more experimental results, please refer to our paper

Experimental setup

- User study
  - 8 participants performed several simple tasks in one hour
- 20-day study
  - A single-user longitudinal study
- A variety of programs used
  - Various Linux utilities, text editors and programming languages

Bandwidth usage: user study

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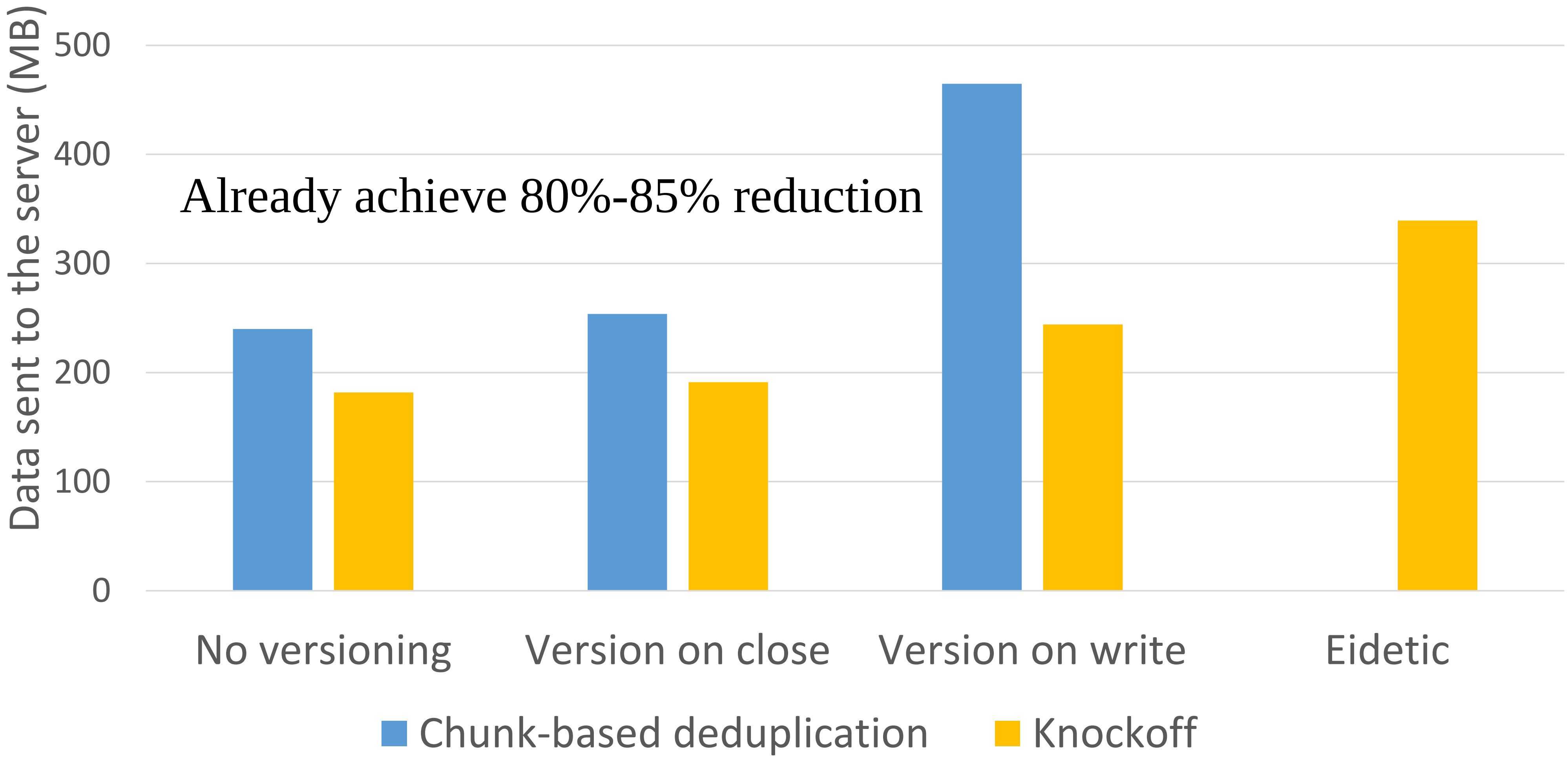

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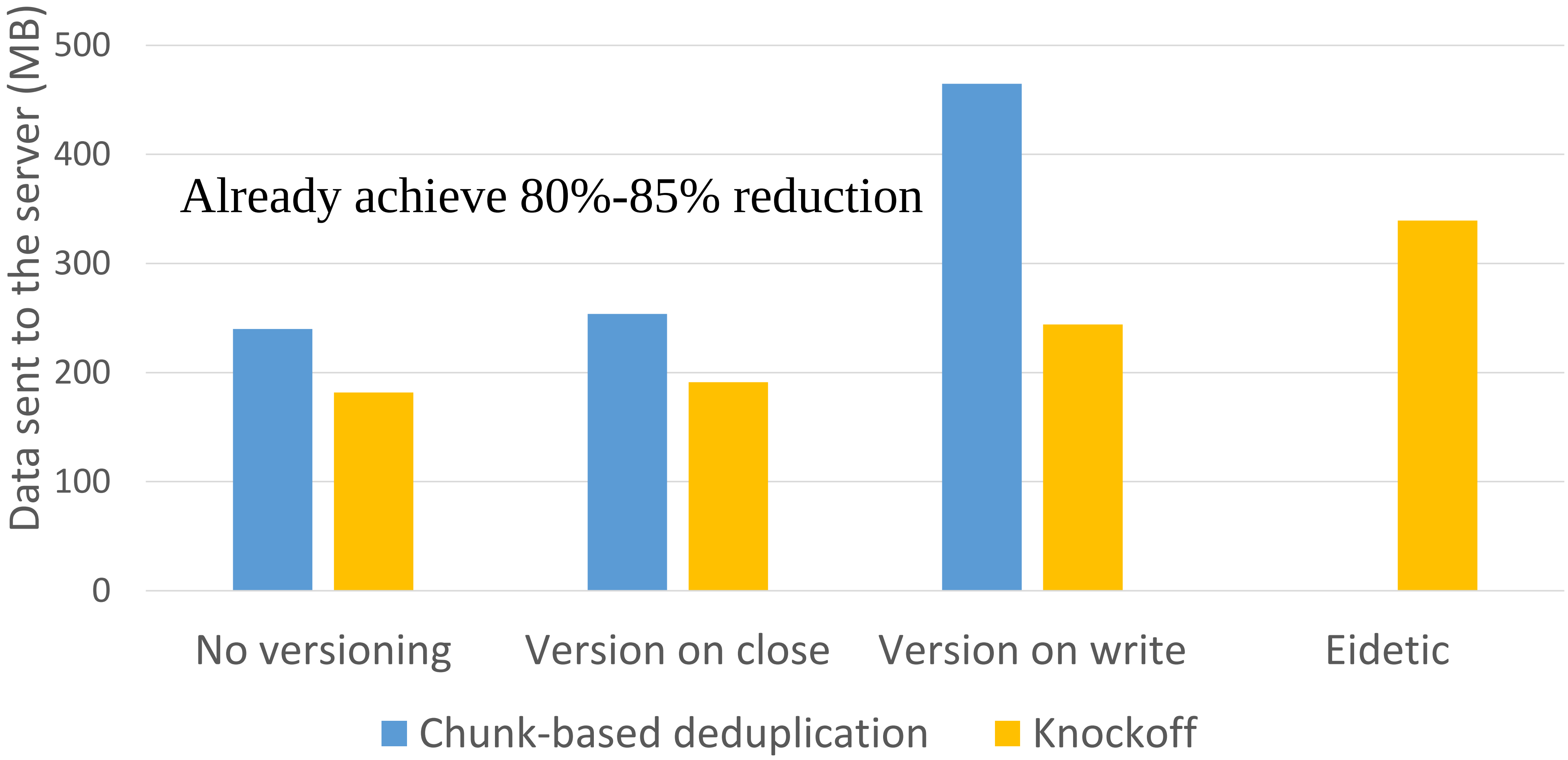

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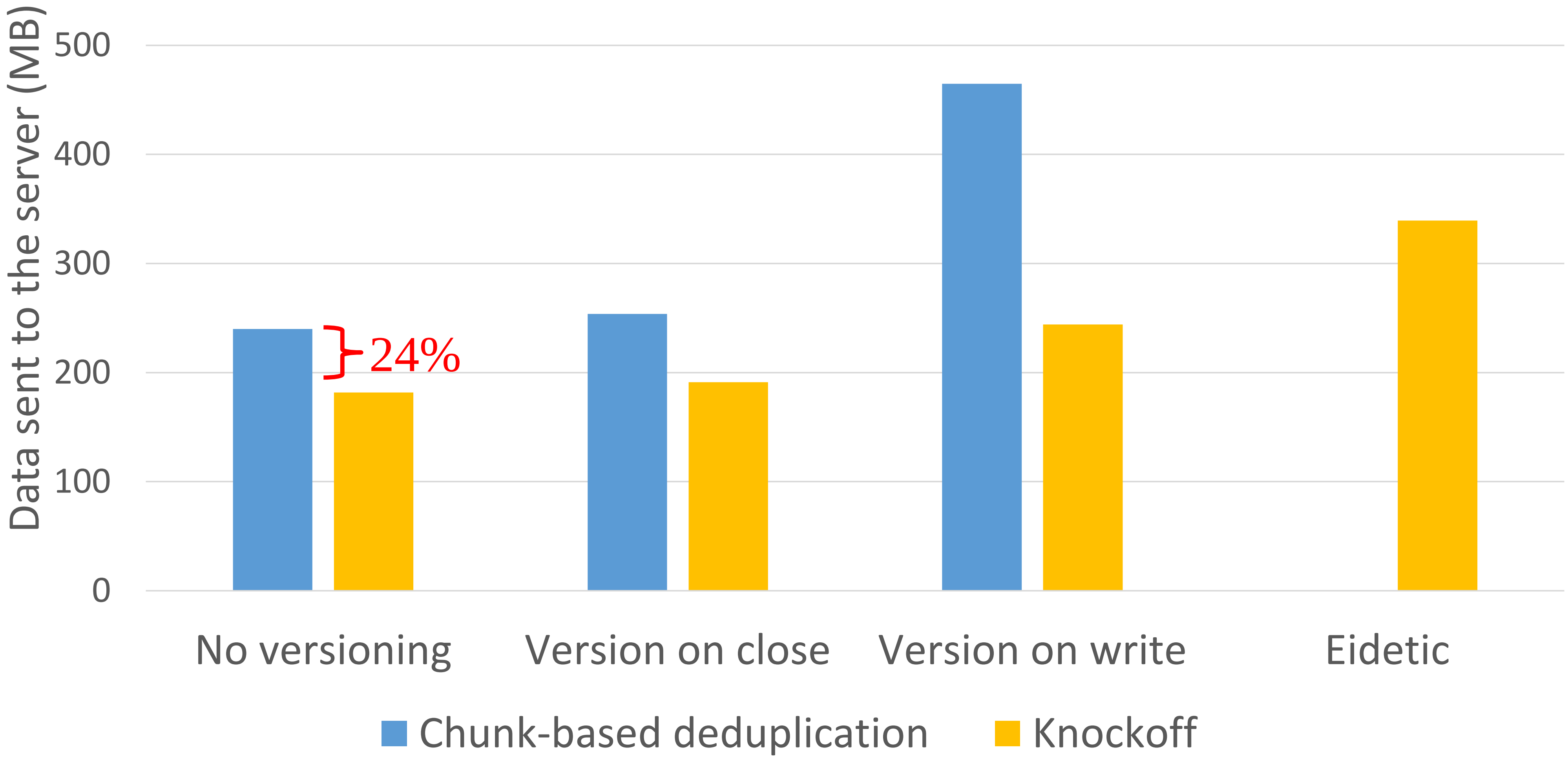

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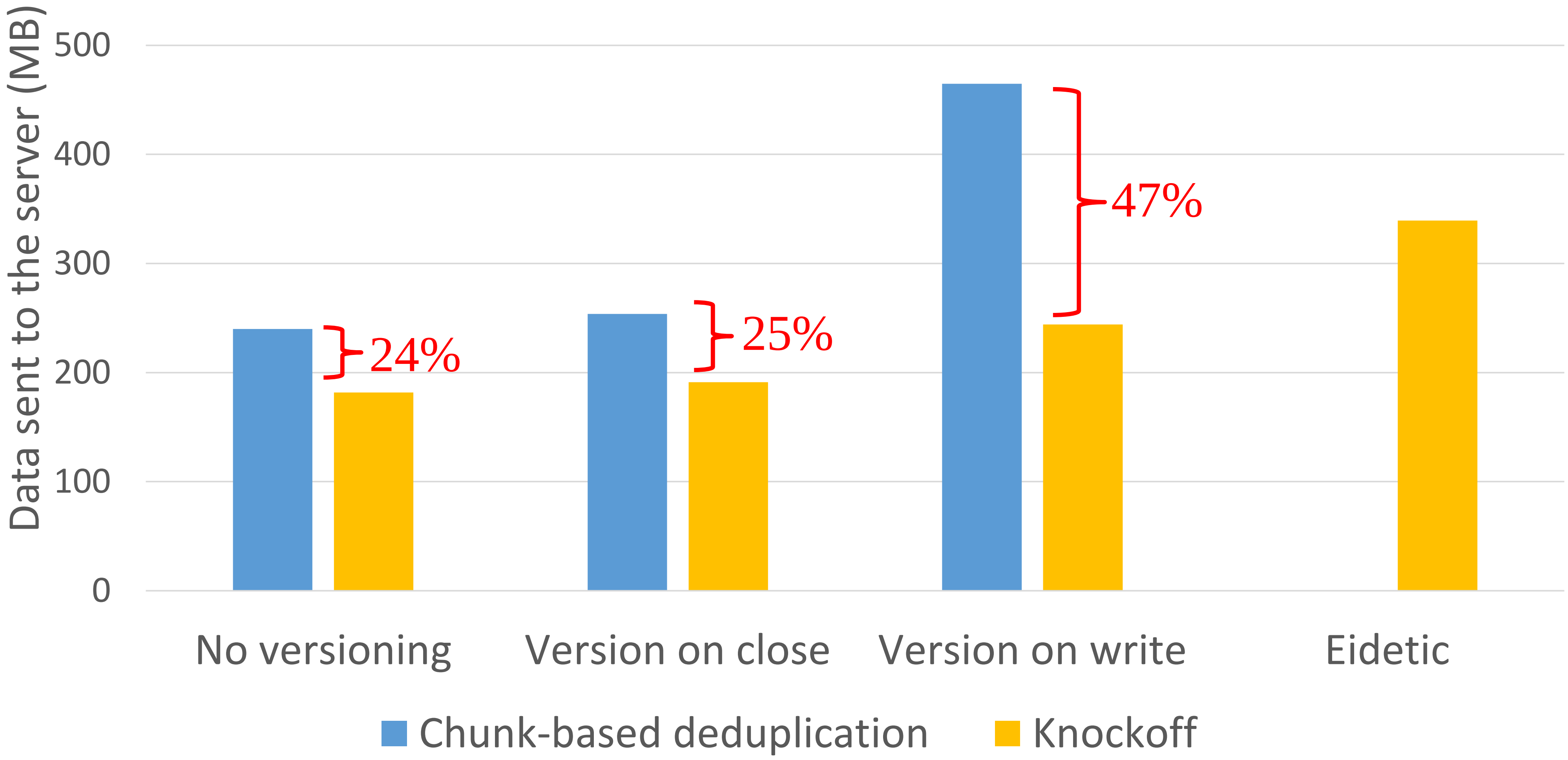

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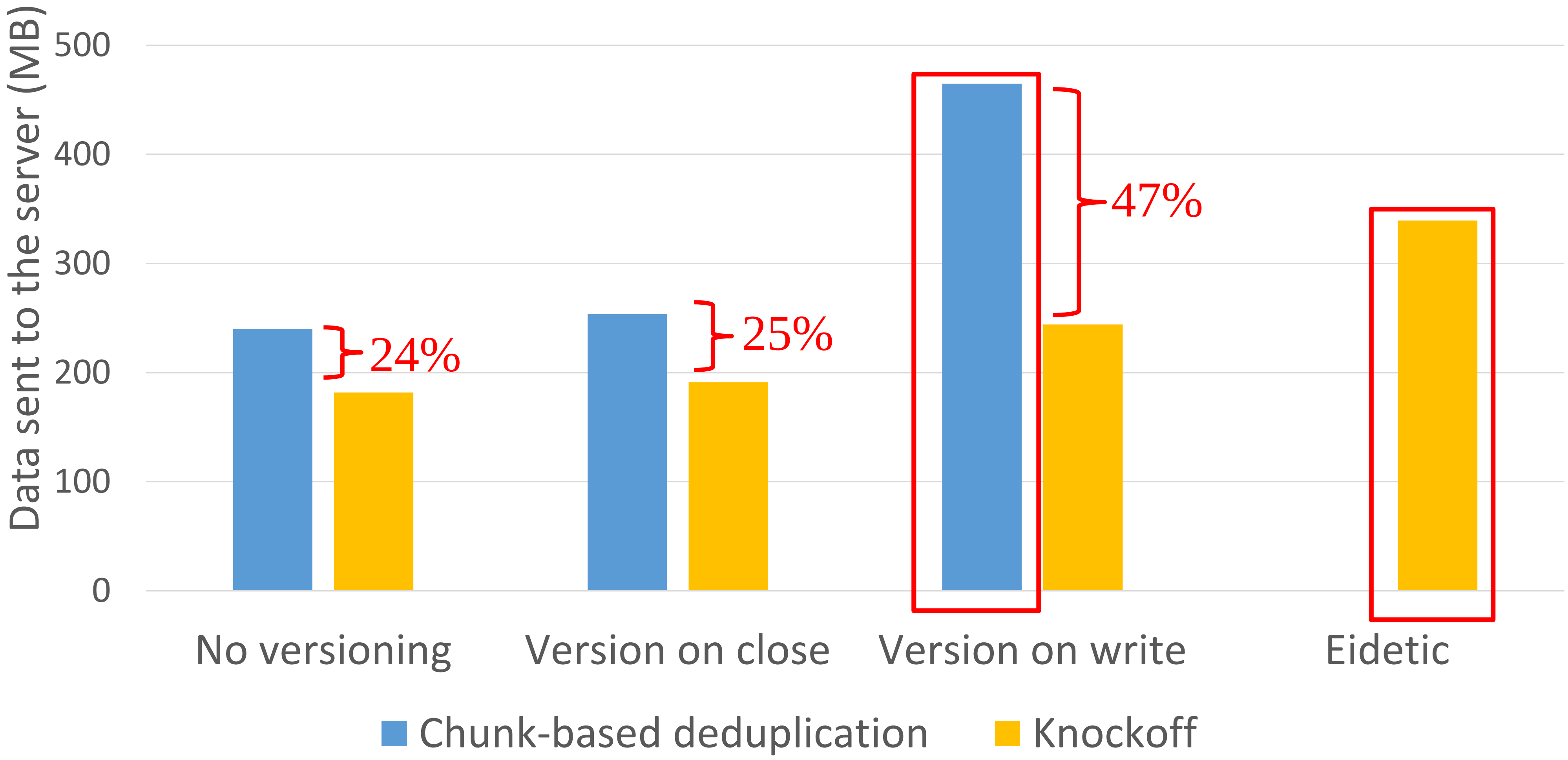
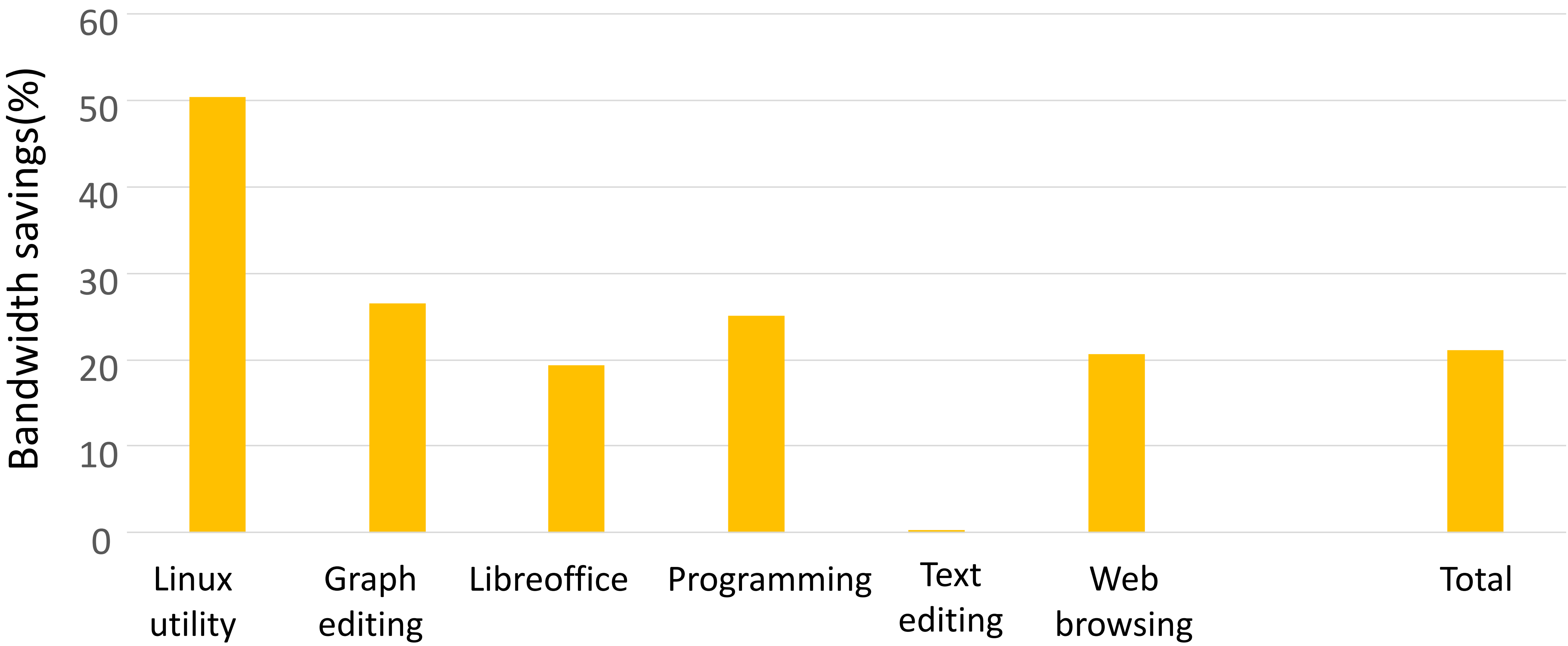
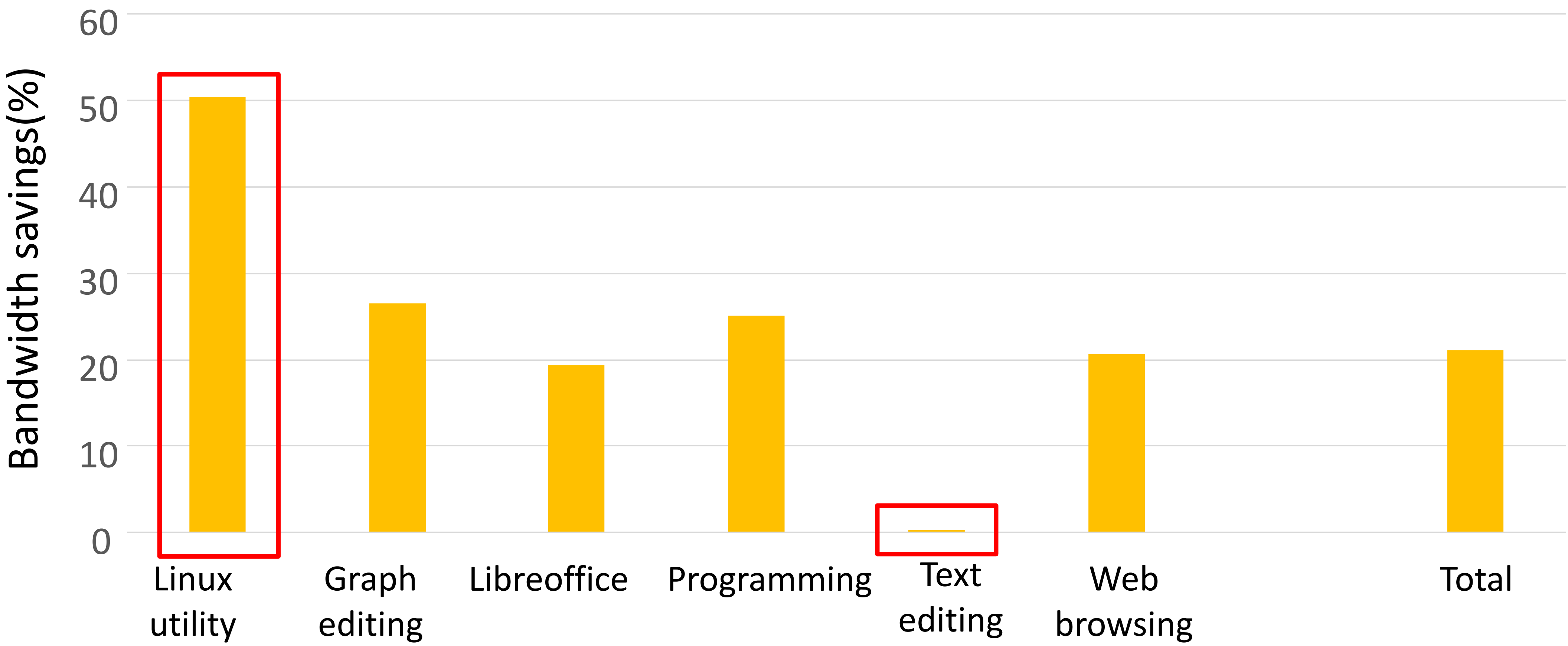


Variances across applications



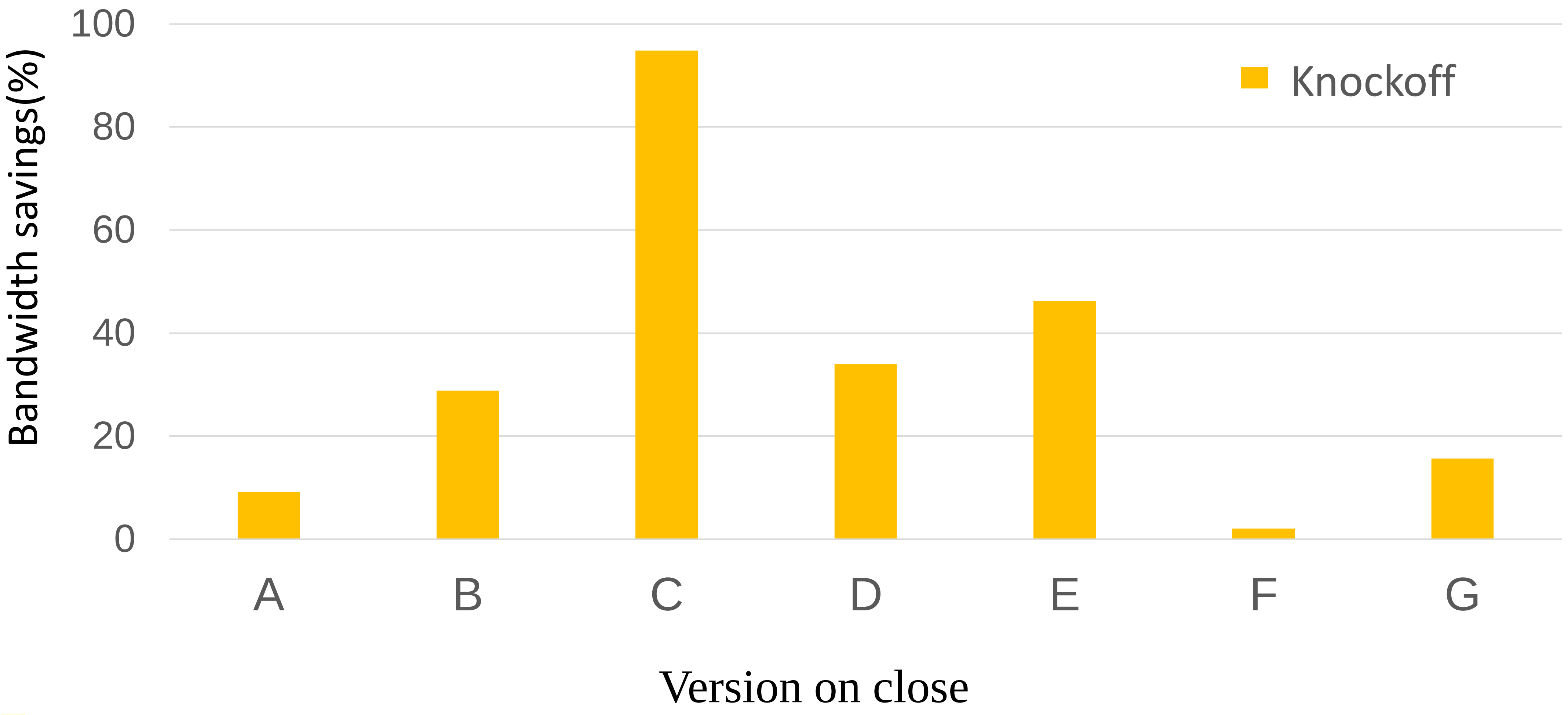
Version on close

Variances across applications



Version on close

Variances across users



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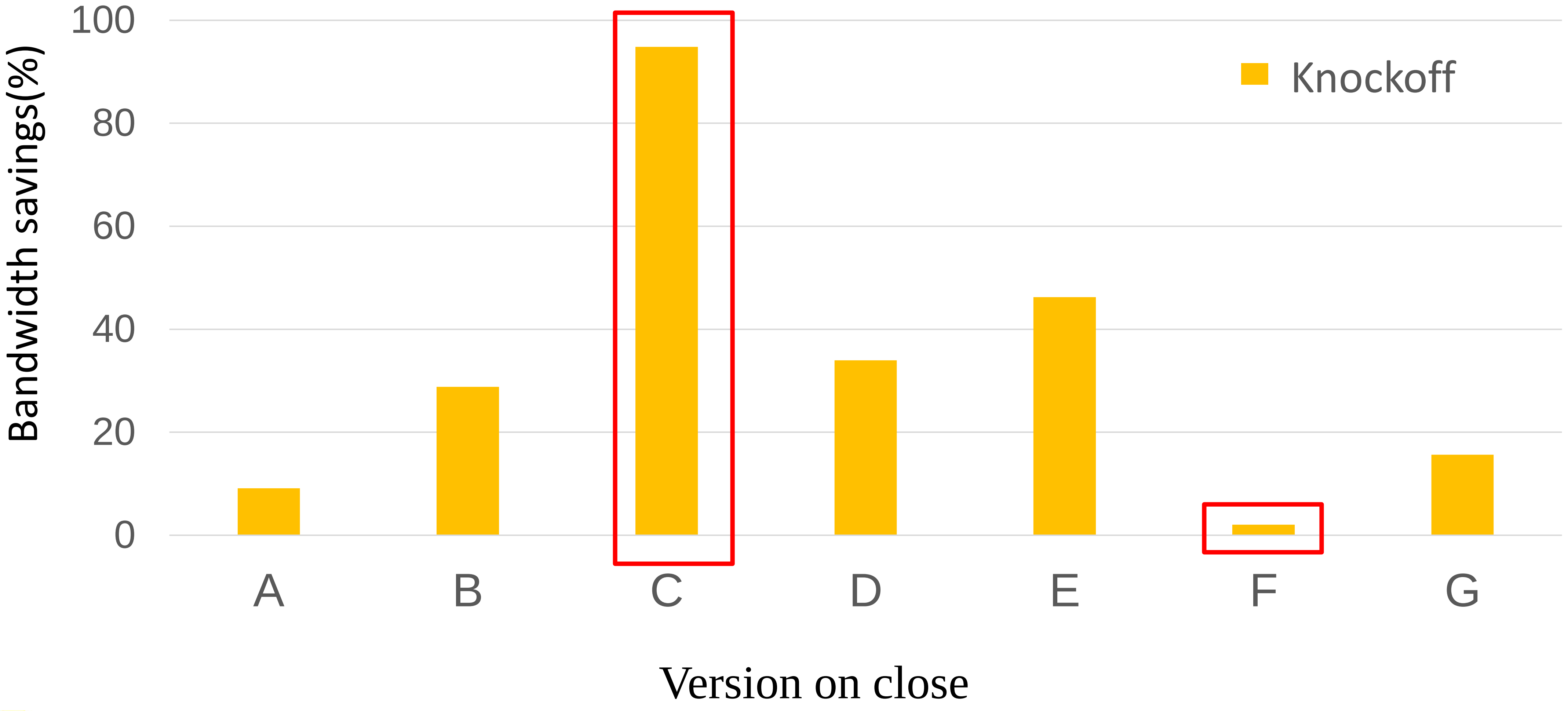
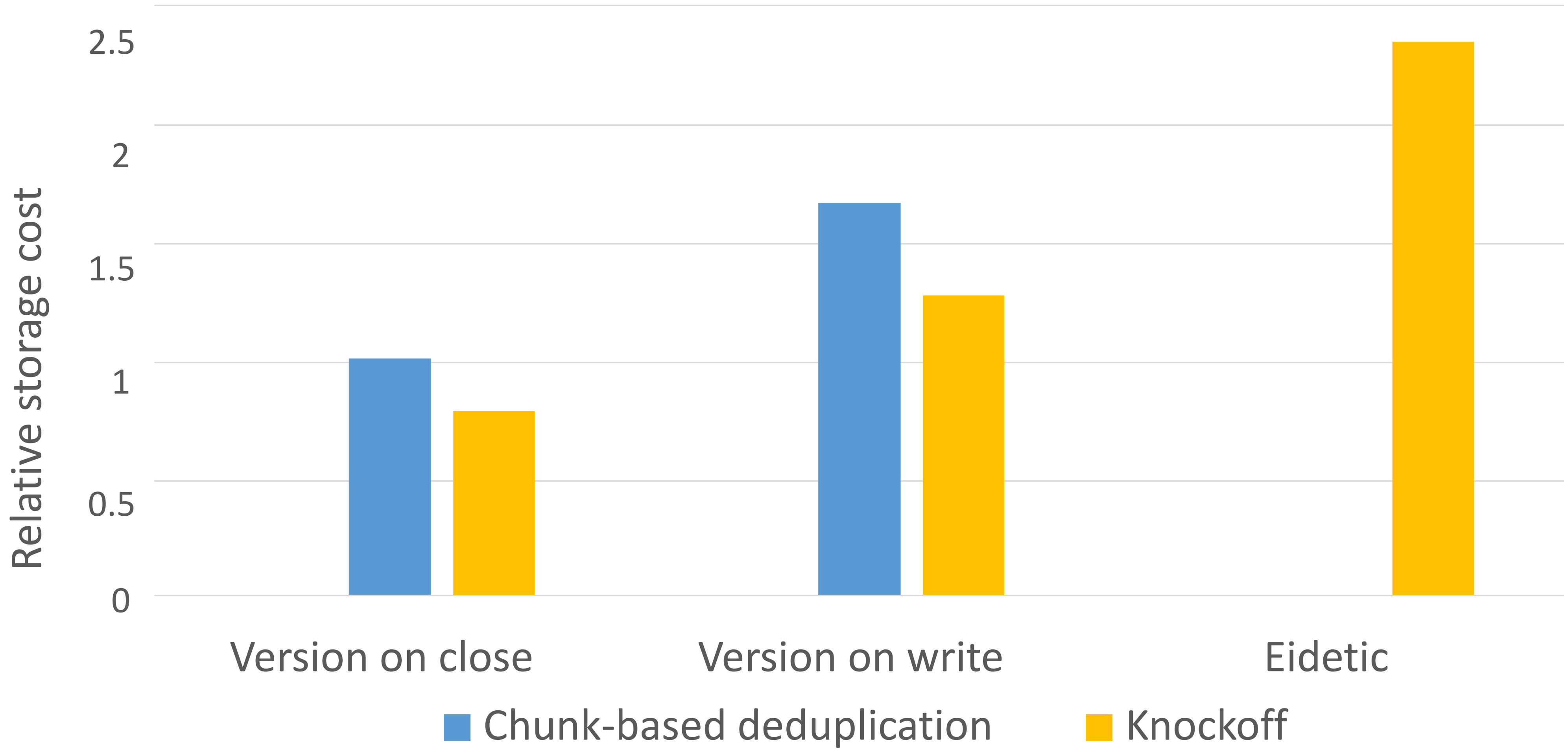


Relative storage costs for past versions



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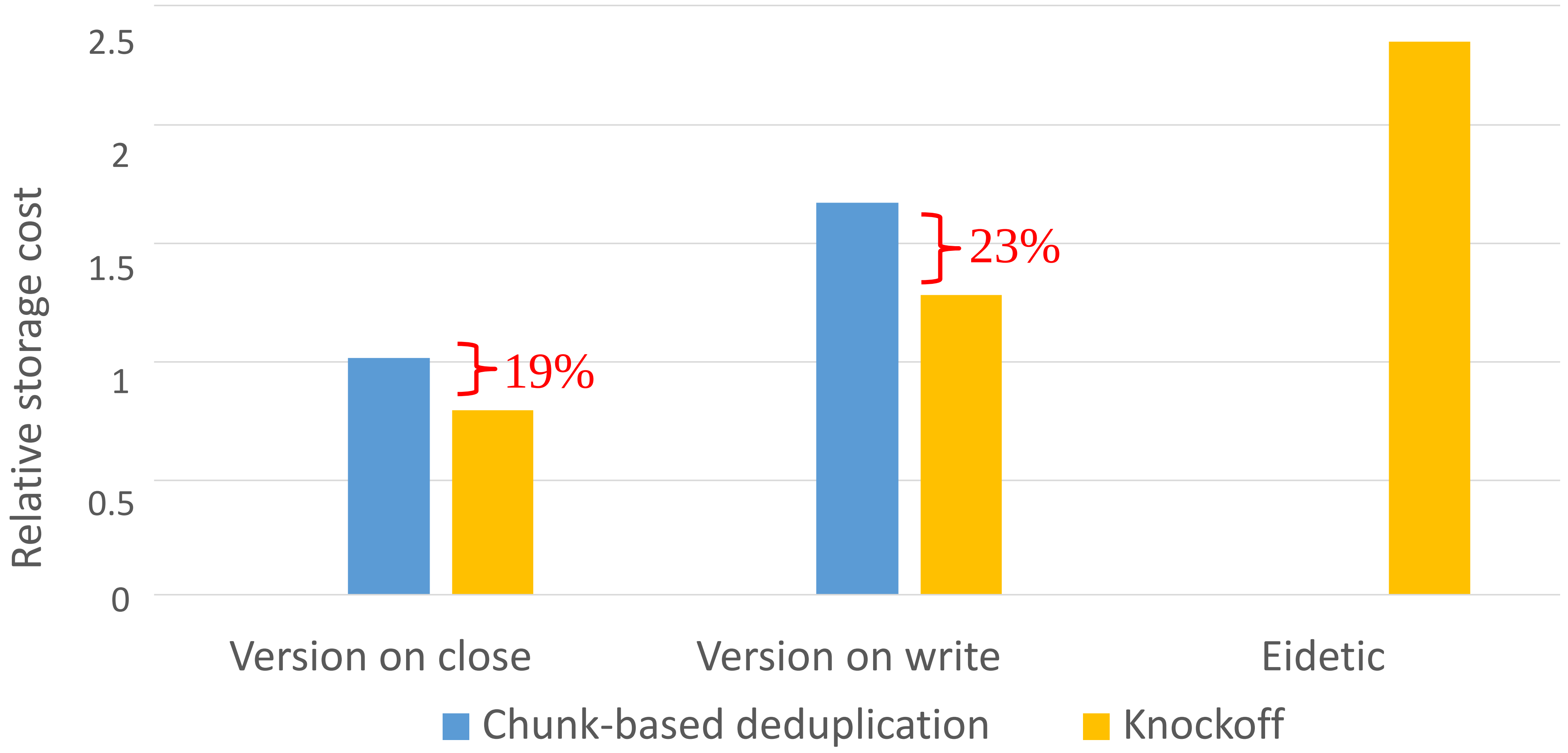

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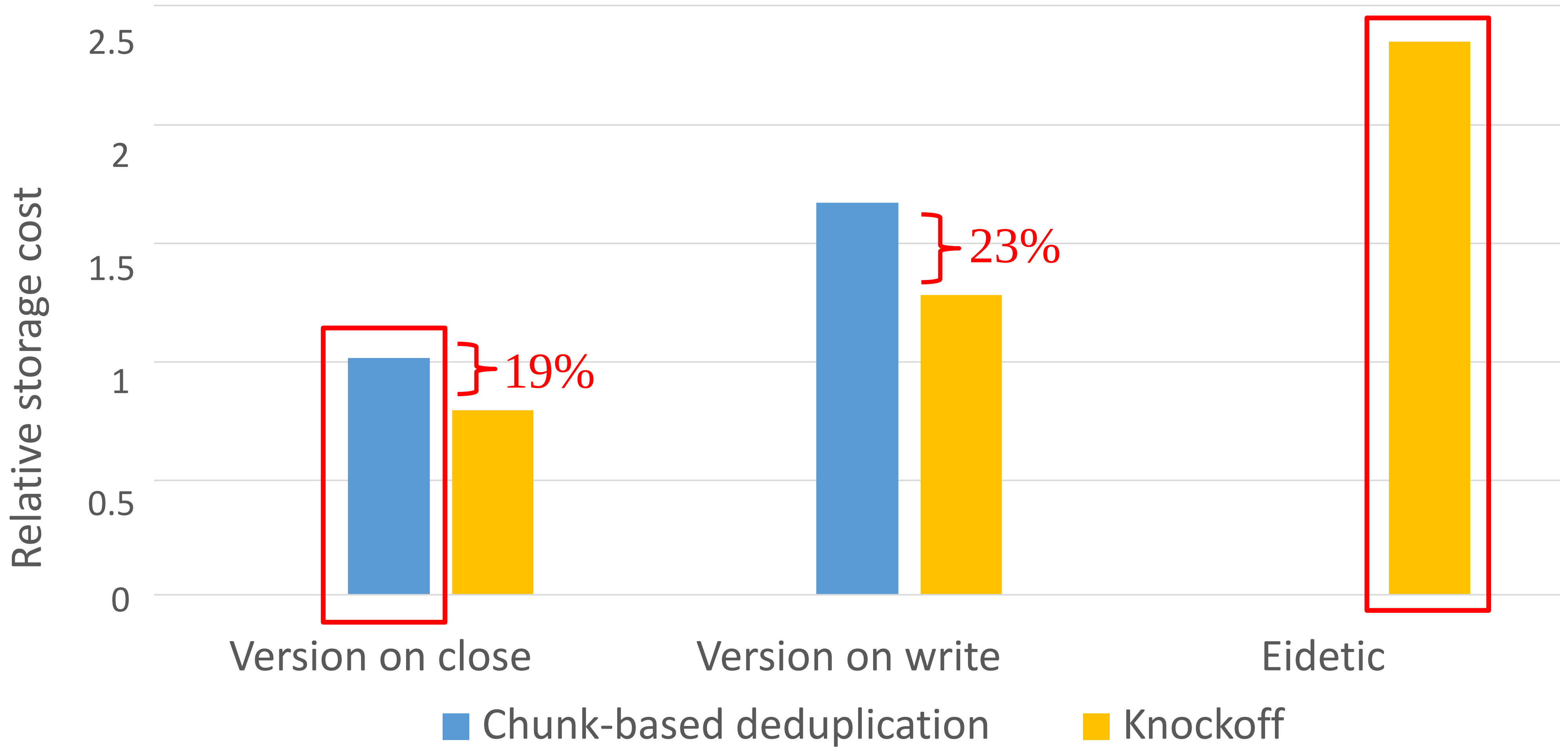
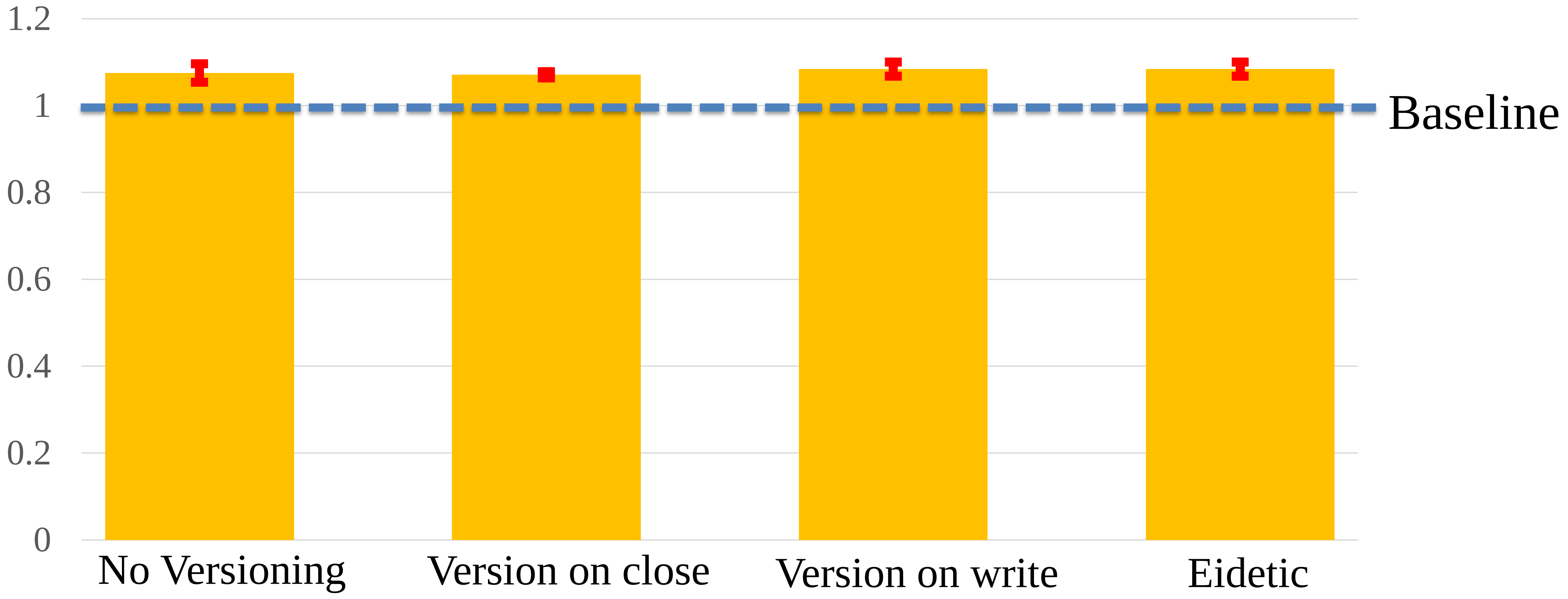


Performance overheads

- 7-8% performance overheads

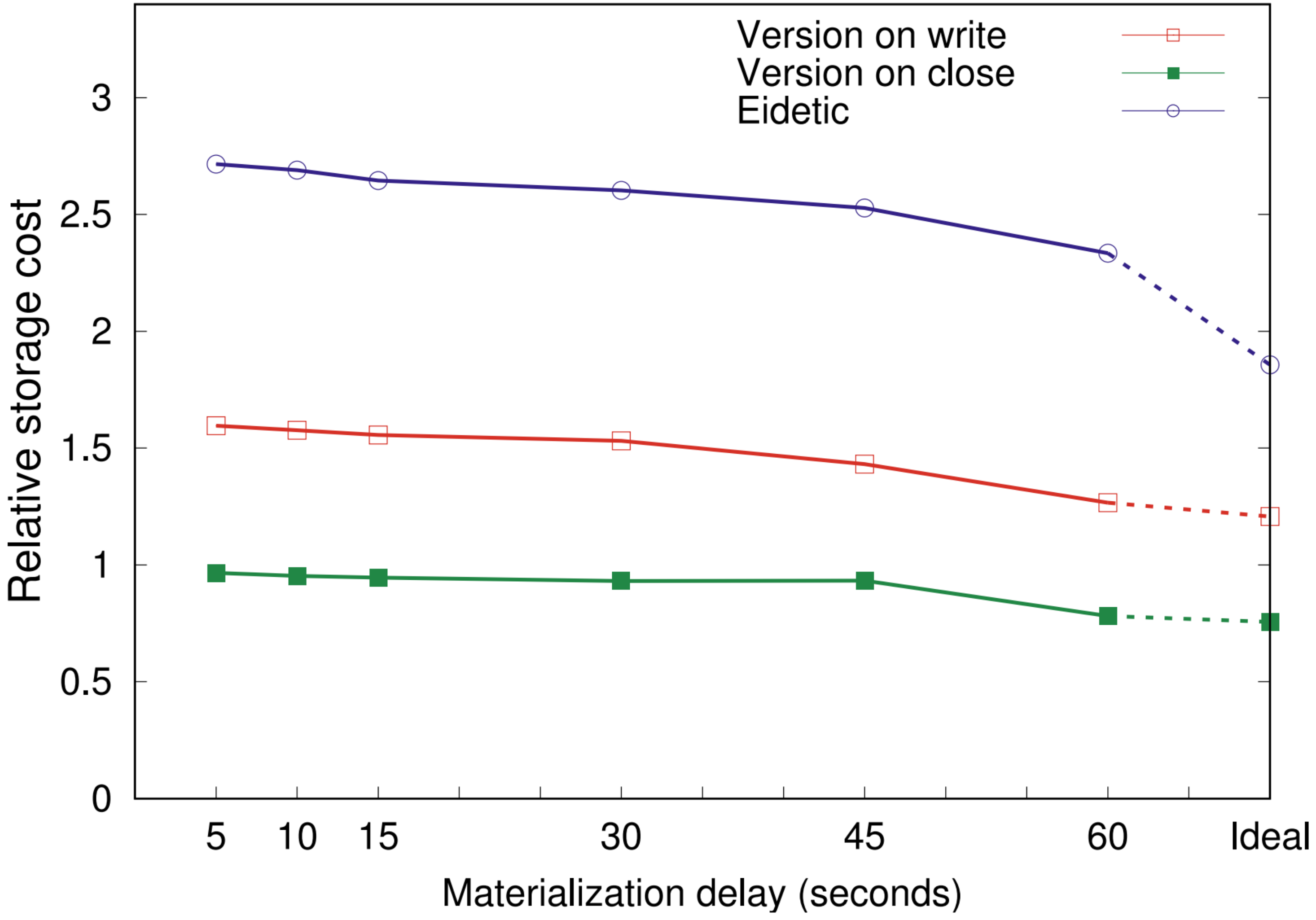


Conclusion

- A new dimension for reducing costs
- Selectively substitute computation for data
- A general-purpose system for deterministic recomputation
  - Reduces storage and communication costs for existing versioning policies
  - Enables eidetic versioning

Thank you!

Varying the materialization delay



Monetary costs

	Price($ per GB)	Knockoff savings					
		No version		Version on close		Version on write	
		20-day study	User study	20-day study	User study	20-day study	User study
4G network	4.50	21.0%	21.8%	21.2%	21.7%	22.9%	46.3%
Expensive ISP	0.20	20.3%	18.4%	20.5%	18.5%	22.0%	43.3%
Cheap ISP	0.05	18.1%	13.8%	18.2%	14.5%	19.2%	34.9%
Hypothetical ISP	0.005	8.2%	4.9%	8.4%	5.8%	8.2%	11.5%

Table 2: Relative cost savings from using Knockoff for different versioning policies. We show costs for a typical 4G cellular network, an expensive current ISP, a cheap current ISP, and a hypothetical ISP that is an order of magnitude cheaper than the cheap current ISP.

Workload characteristics

	20-day study	User study
Disk read (MB)	5473	2583
Disk write (MB)	6706	4339
File open count	261523	418594
Number of executions	3803	1146
Number of programs	75	63

Table 1: Workload characteristics