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How to Build Exascale Storage with QLC

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@purestorage

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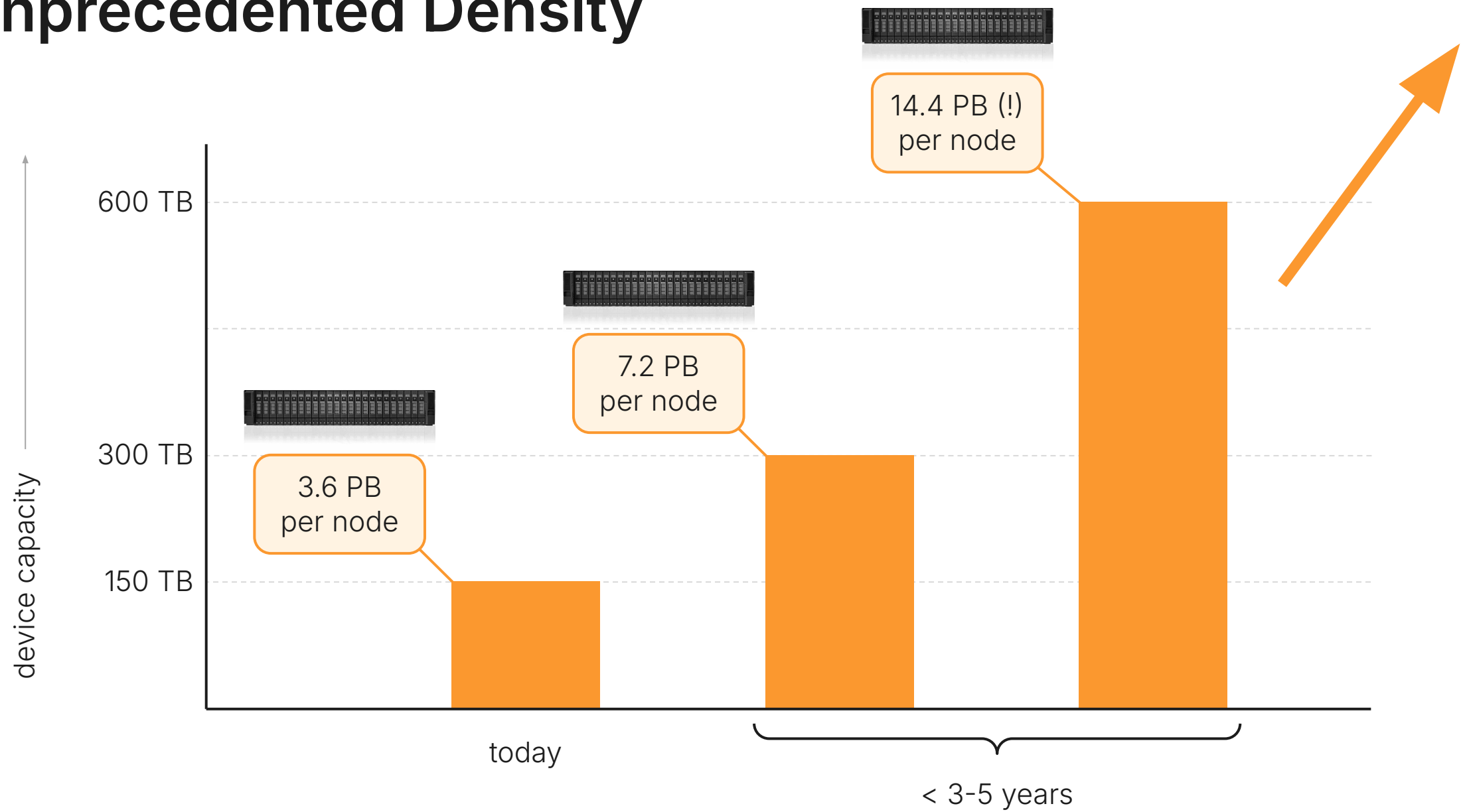
Agenda

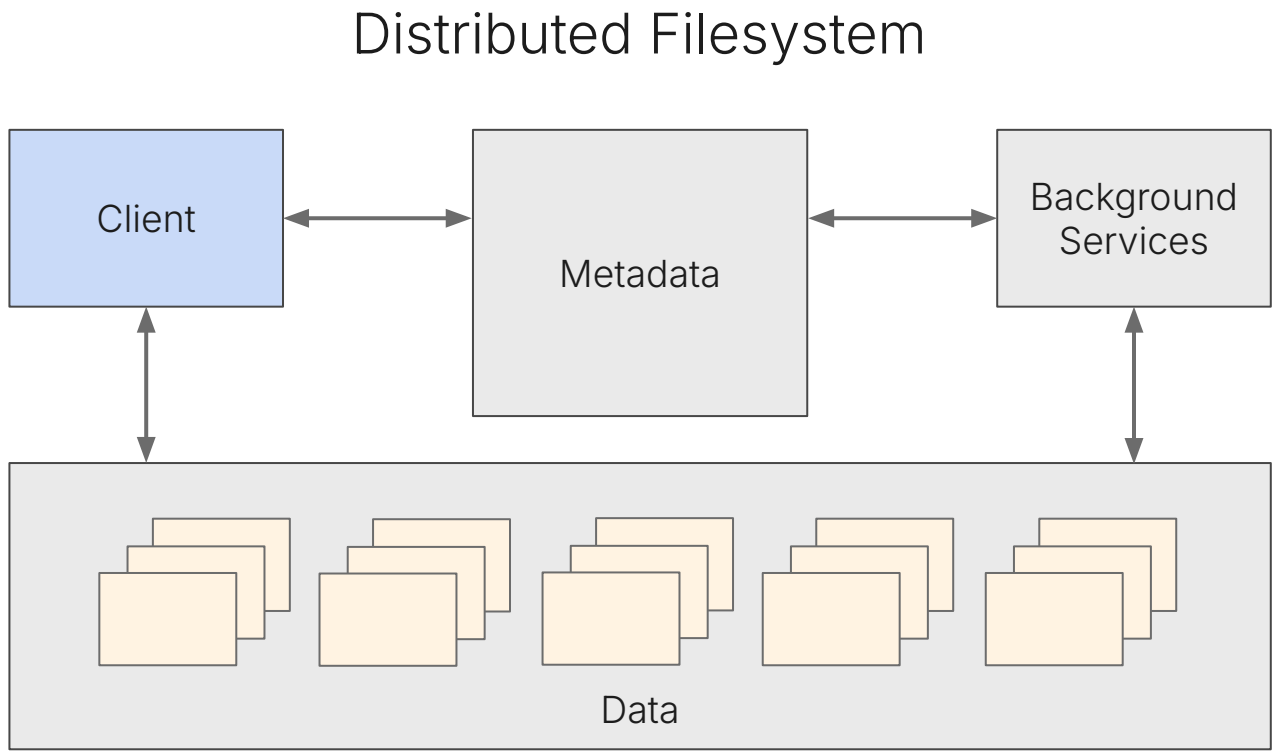
Context	Exascale Storage
Problem	QLC Challenges
Solution	Architectural Perspective

Unprecedented Density

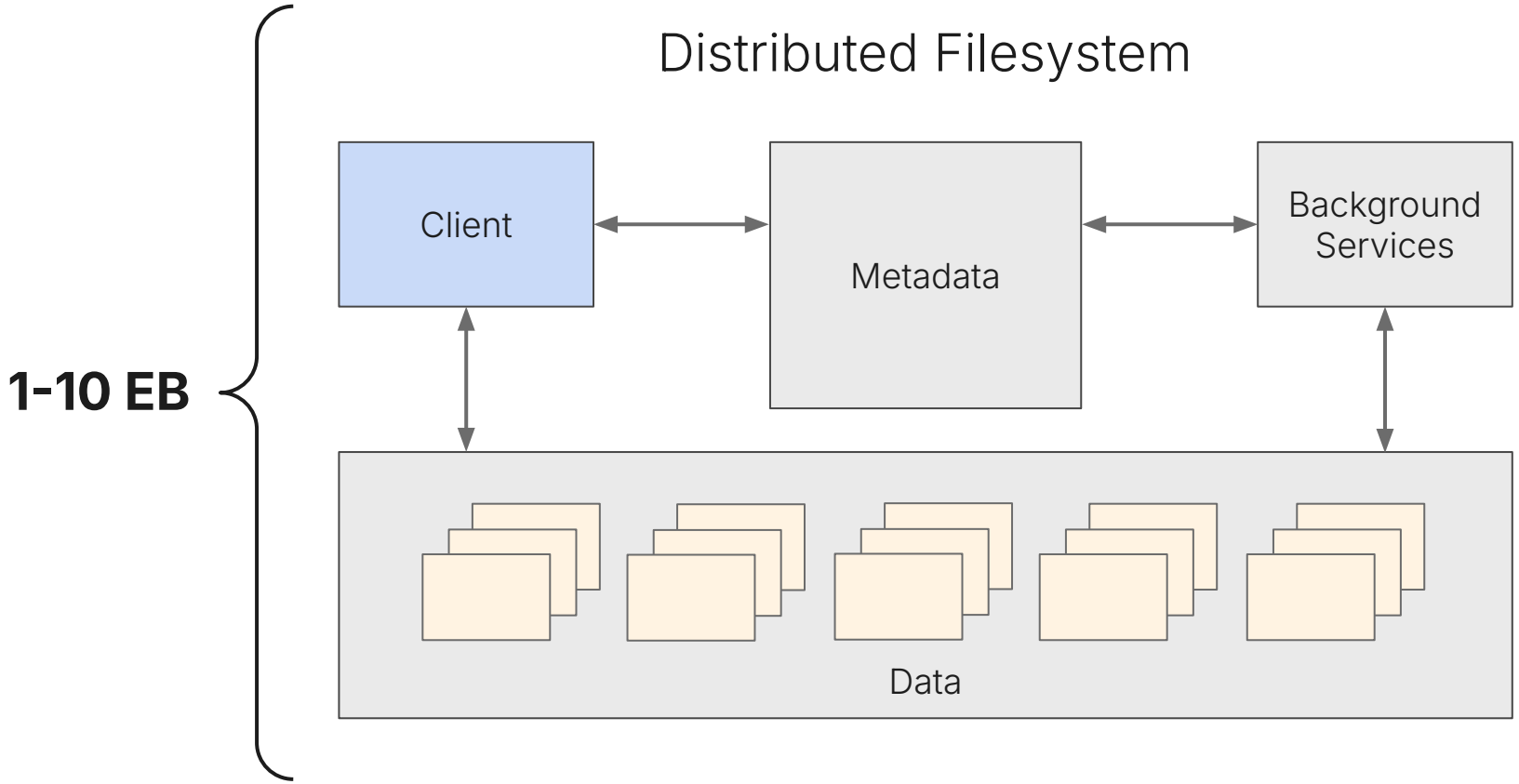


Exascale Storage

Use Cases
- GenAI
- Warm/Cold Object
- Archive
- Database



Exascale Storage



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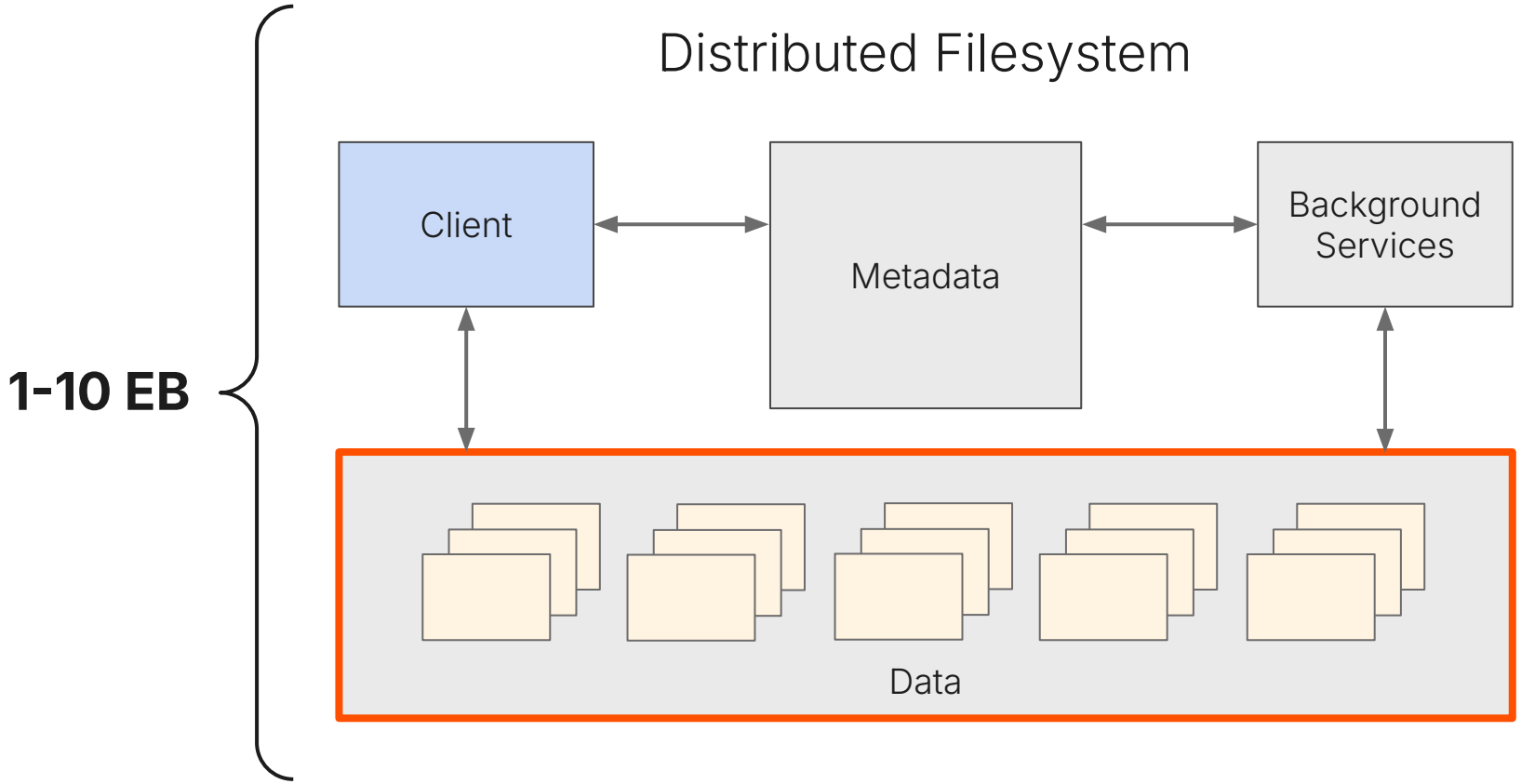
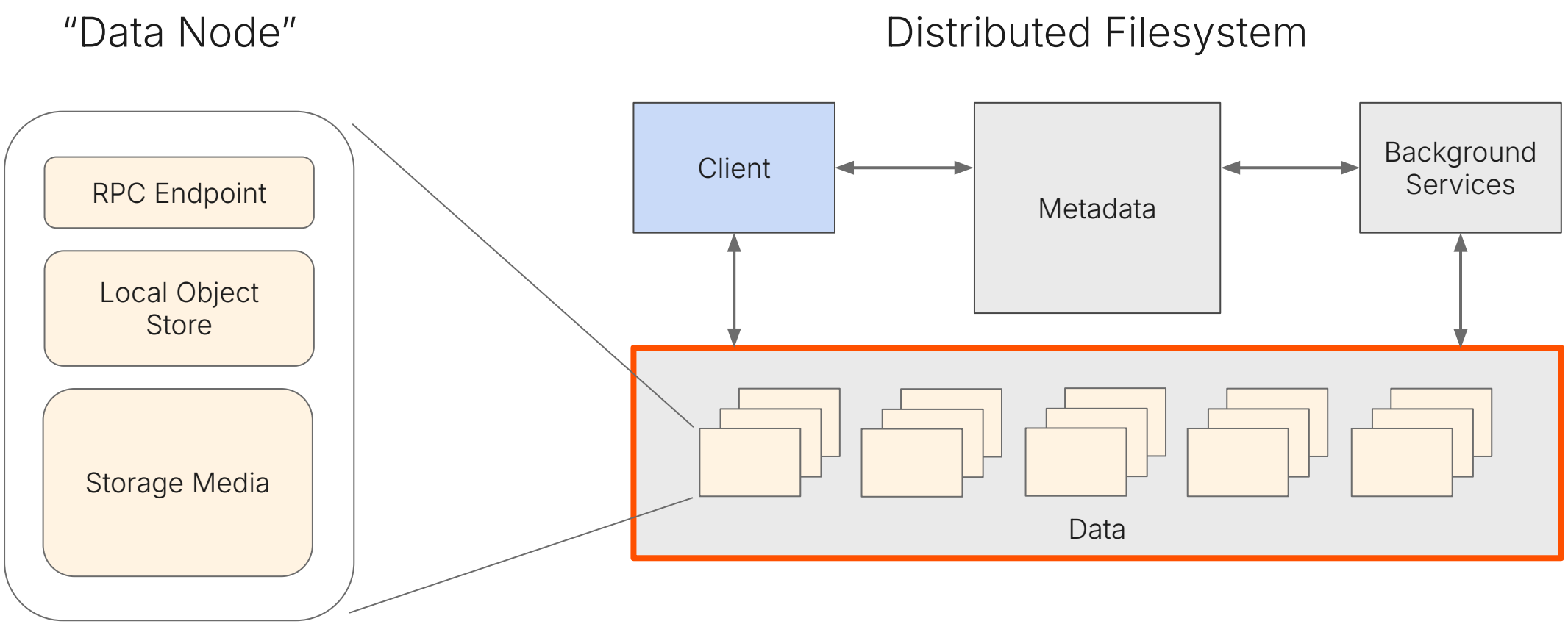
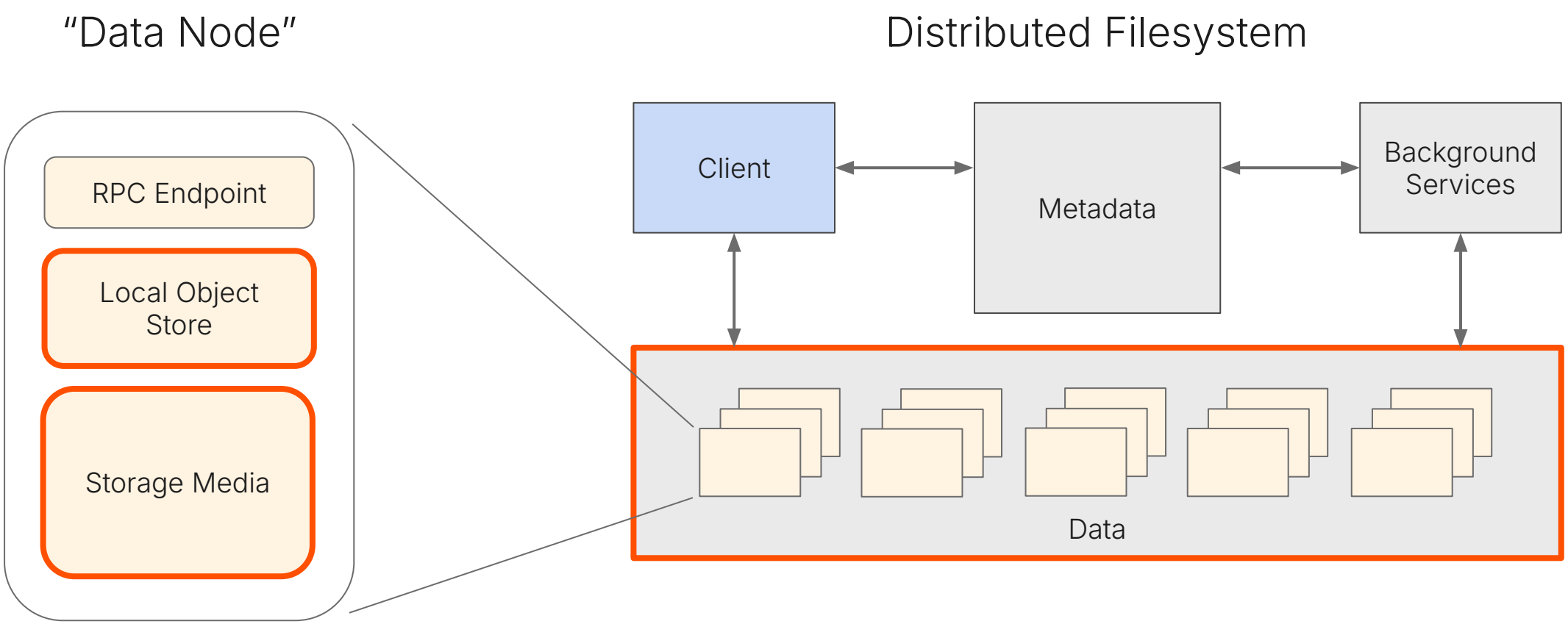


Exascale Storage



Exascale Storage



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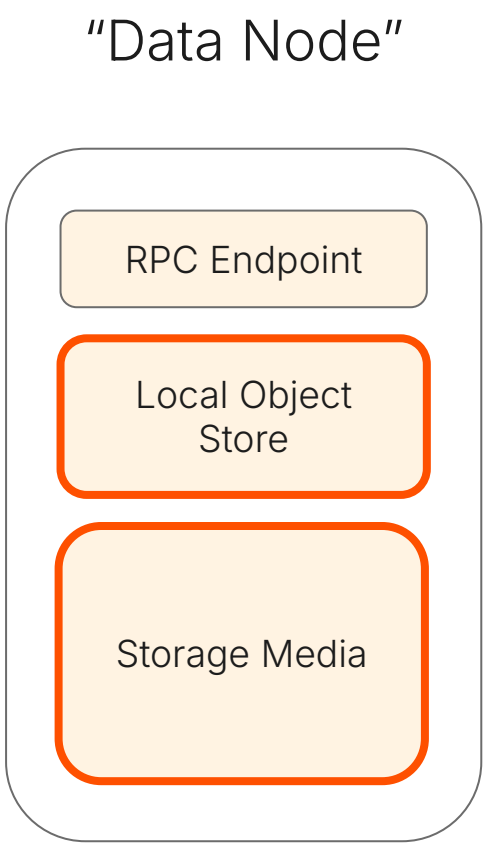
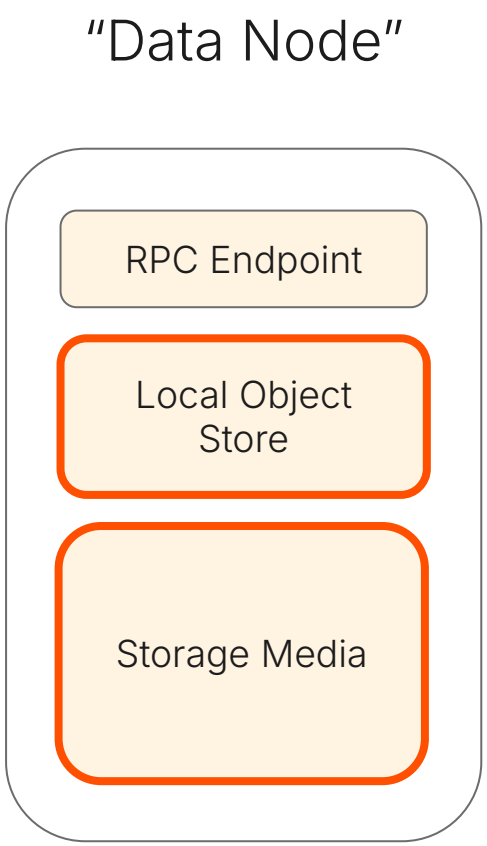


“Local Object Store”
- flat namespace
- append-only objects
- protected by cluster-level ECC
- no standard, many proprietary implementations

Not: **general purpose storage**
- filesystems (xfs, ext4, ntfs)
- fully-featured, hierarchical, overwrite-in-place
- standardized (POSIX)

Not: **cloud “object storage”**
- HA
- external, standardized API
- served by a large distributed cluster

Exascale Storage



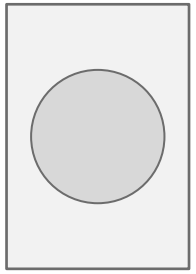
At exascale, efficiency is paramount!

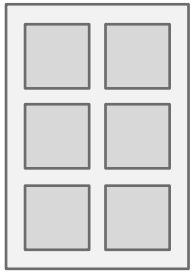
- power/TB
- performance/TB
- cost (media, CPU, memory, racks…)
- end-to-end perspective

Opportunities for efficiency:

1. leverage QLC media
2. customize for the “data node” workload

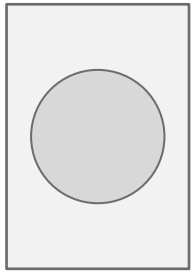
QLC

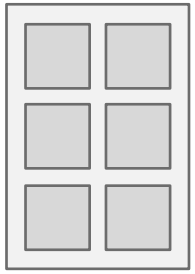


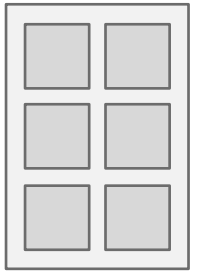


		HAMR HDD 30 TB	TLC 30 TB
per TB	$	1x	6x
	power	1x	2.8x
	read throughput	1x	280x
	write throughput	1x	90x
	IOPS	1x	30,000x

QLC







	HAMR HDD 30 TB	QLC 150 TB	TLC 30 TB
per TB $	1x	3x	6x
per TB power	1x	0.5x	2.8x
per TB read throughput	1x	60x	280x
per TB write throughput	1x	7x	90x
per TB IOPS	1x	2,000x	30,000x

Agenda

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Problem QLC Challenges

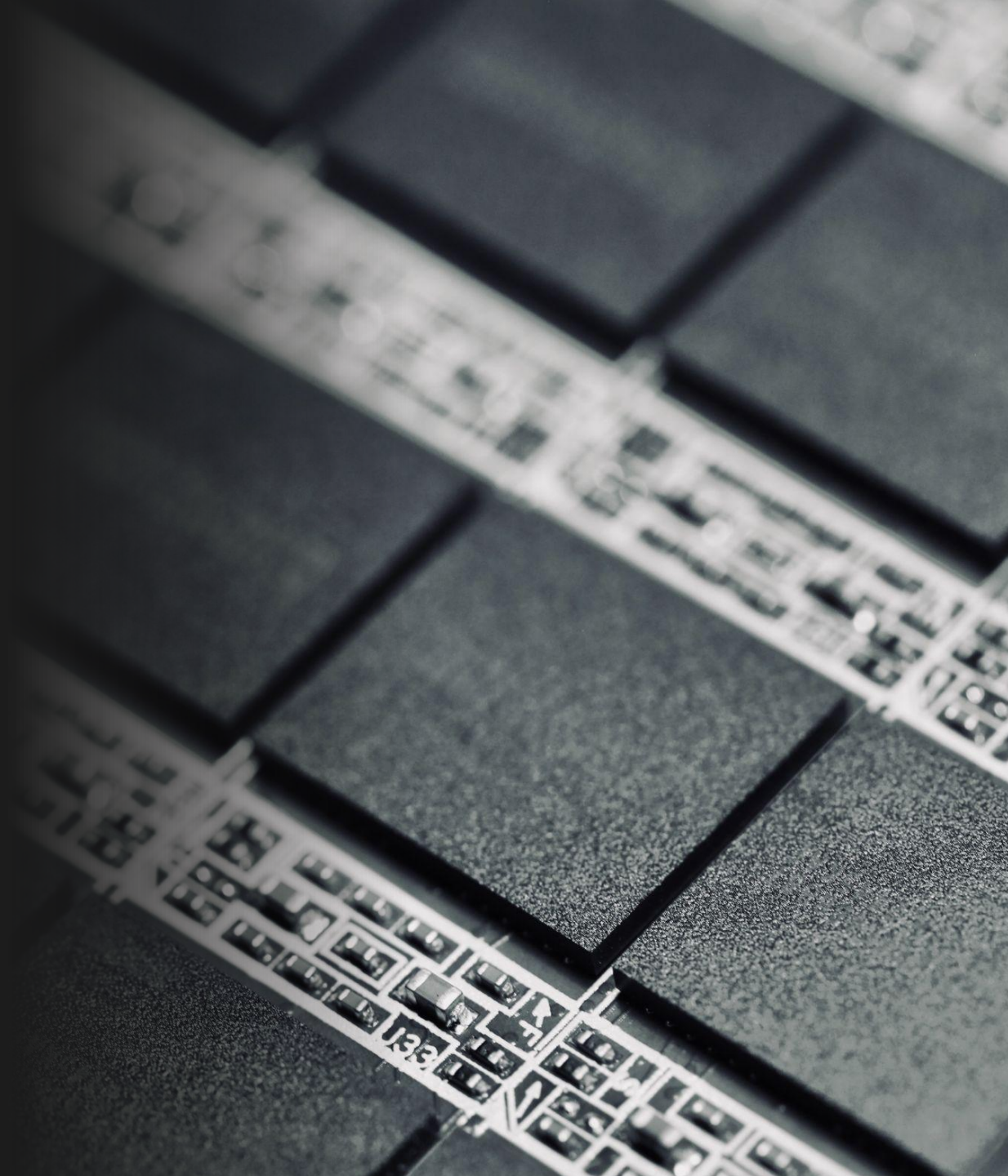
Solution Architectural Perspective

QLC Challenges

Scale

Endurance

Reliability



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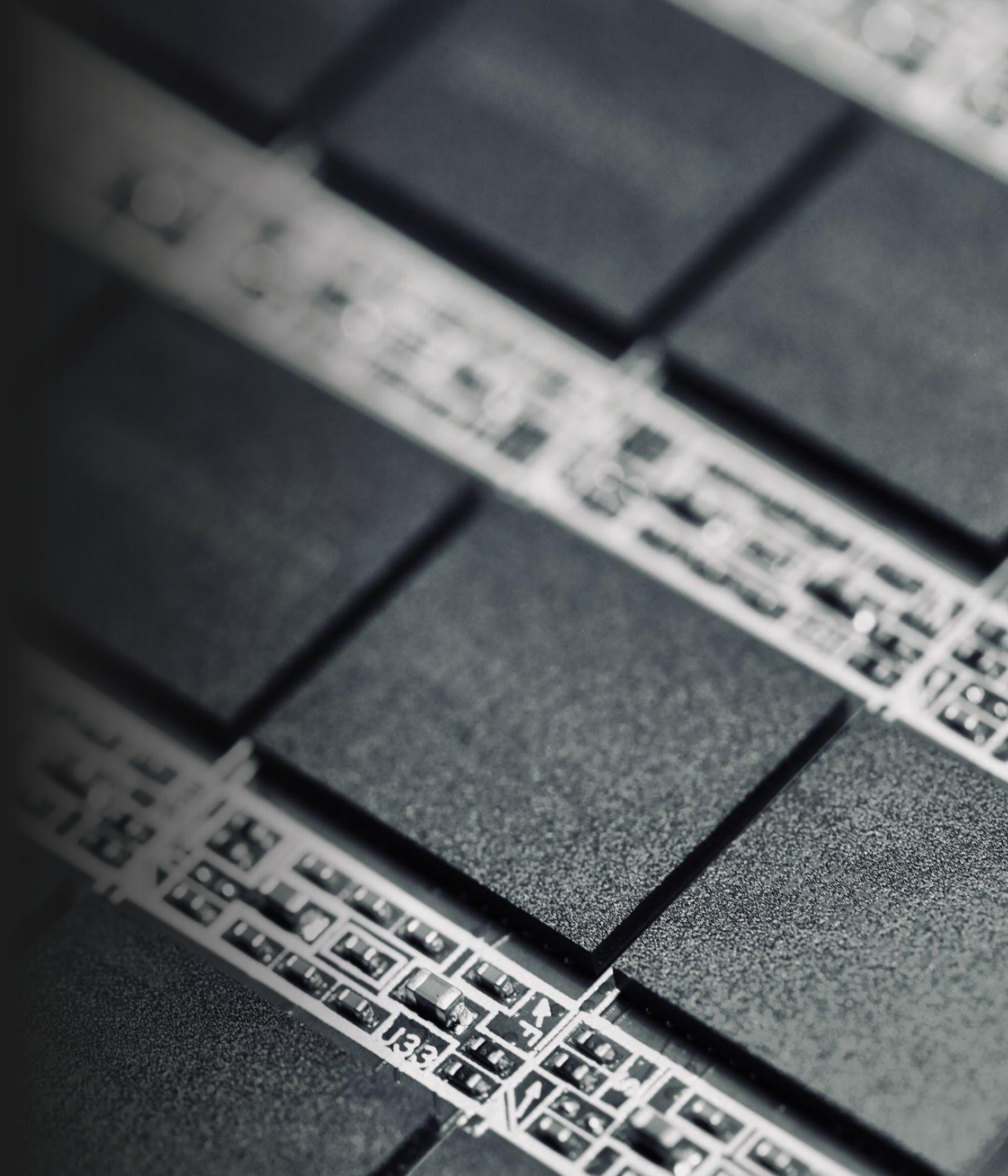
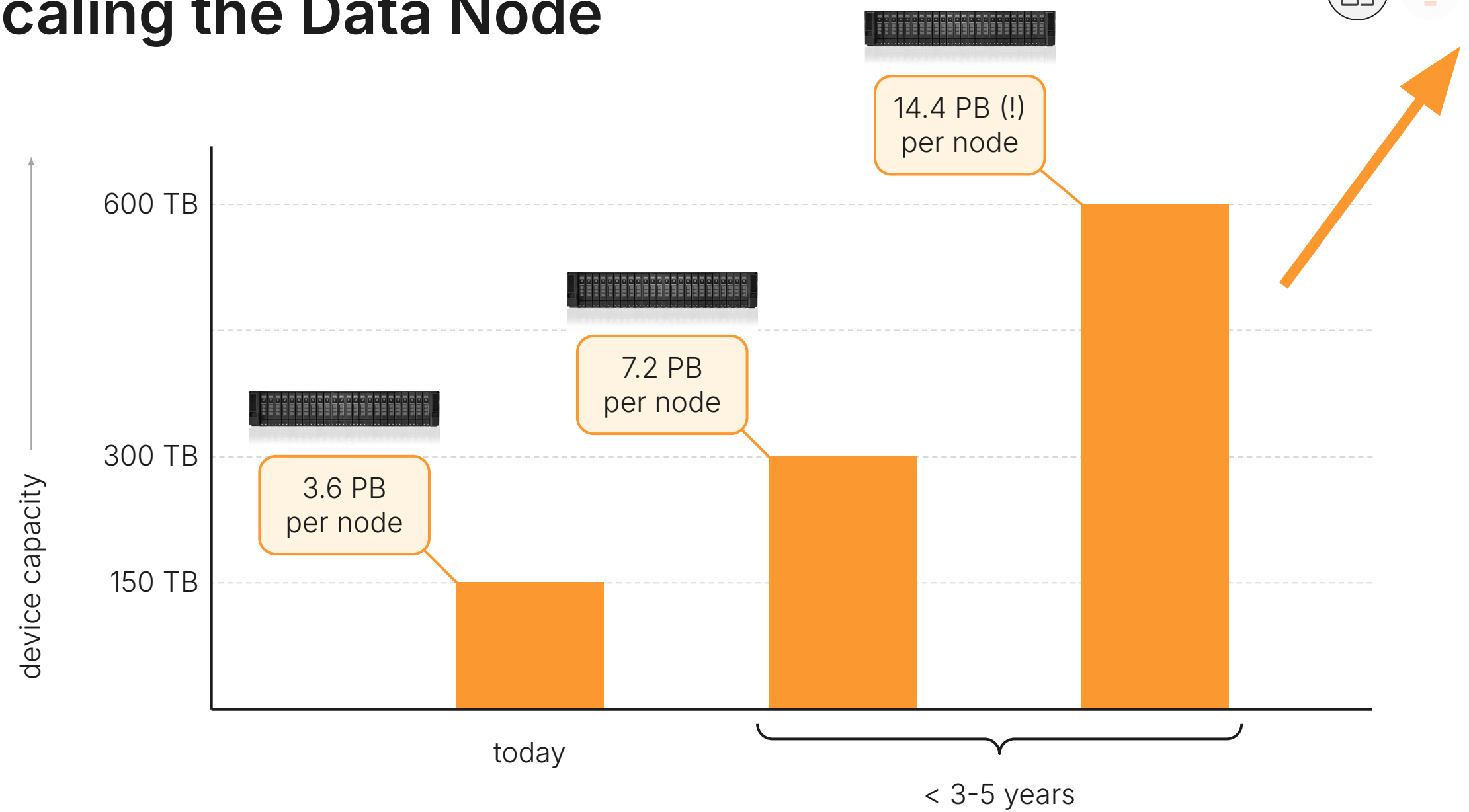


Scaling the Data Node

Scale



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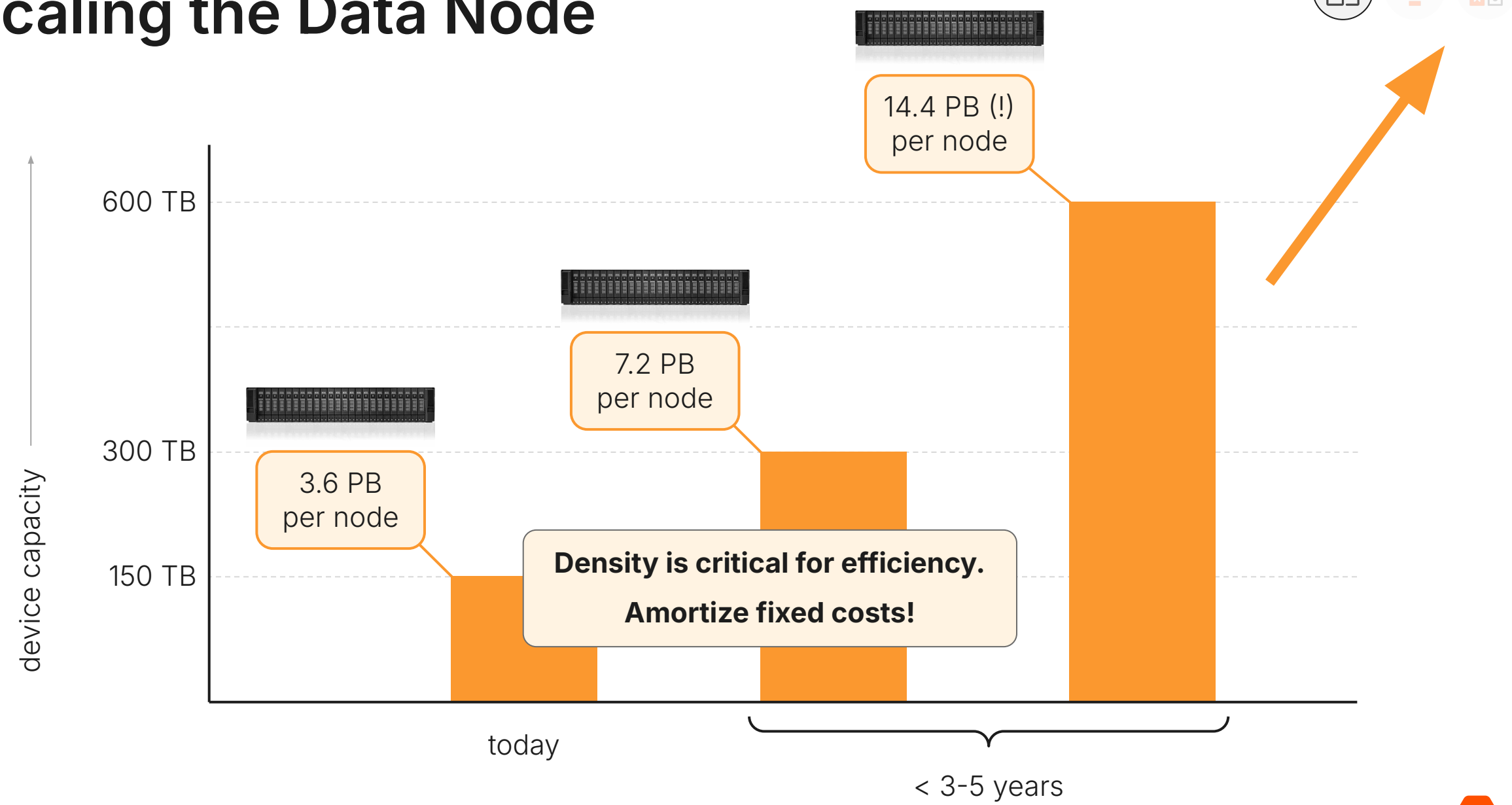
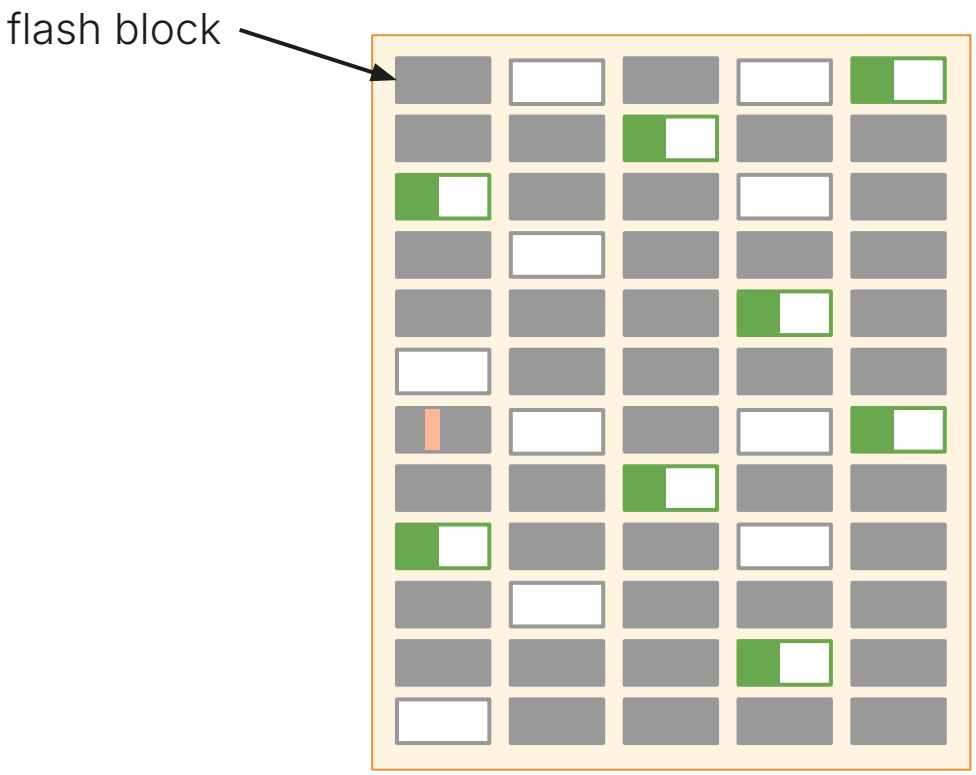


Review: FTL



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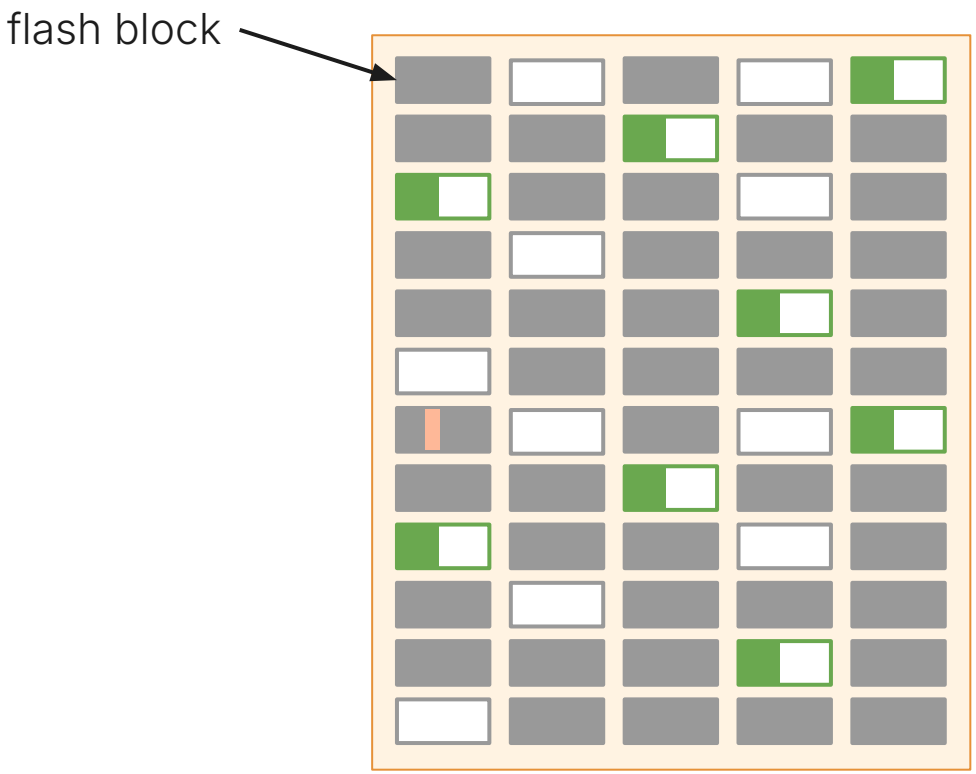
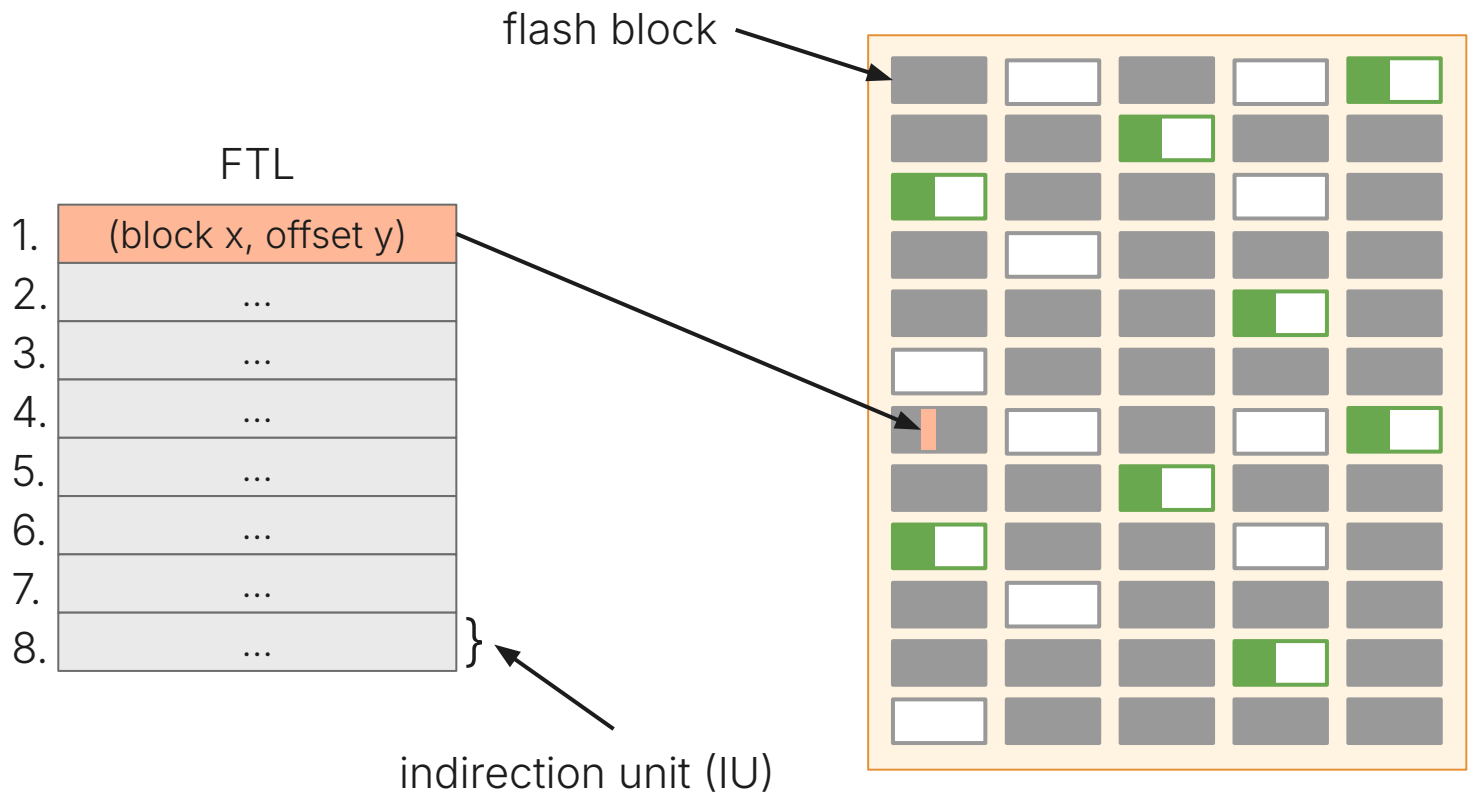


Open: accepting new writes via append

Full: no new writes, reads are ok

Erased: empty, ready to write

Review: FTL



Open: accepting new writes via append

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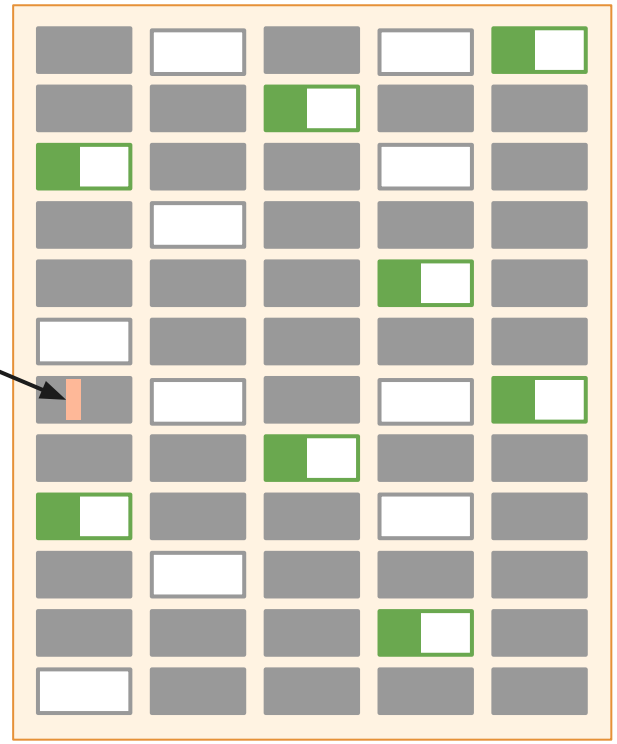
Review: FTL


```
write: {
  lba: 5,
  data: 0xfa...
}
```



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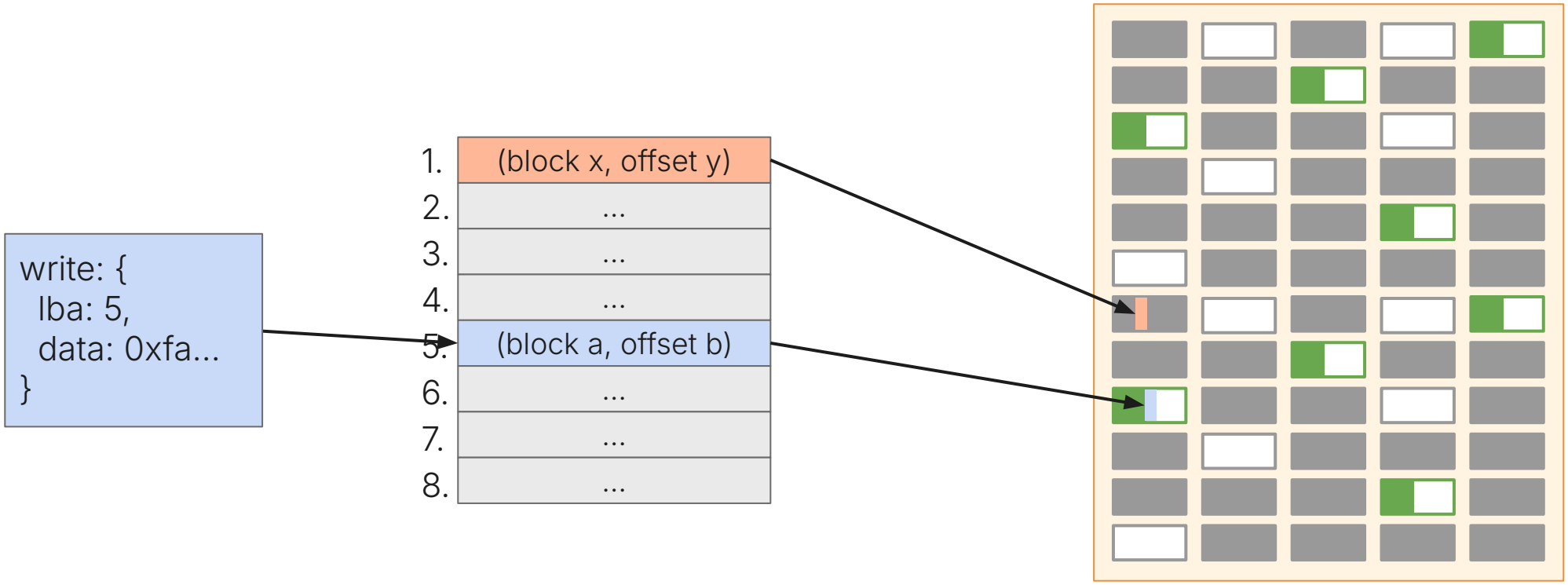

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Scaling the FTL

4B per IU mapping: addresses 2^{32} IUs, aligns nicely in memory

IU size	**flash:memory ratio**	**total memory** *per 14 PB node*	**addressable capacity** *per FTL partition*	**# FTL partitions**
4 KiB	1024:1	~14 TB	16 TiB	~800

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Expensive!
- Reduce mapping bits? More partitions!
- Page FTL into flash? Tail latency!

Inflexible!
- Increase mapping bits? More memory!

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Increase IU size!

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new high-cap SSDs	16 KiB	4096:1	~3.4 TB	64 TiB	~200
	64 KiB	16384:1	~850 GB	256 TiB	~50

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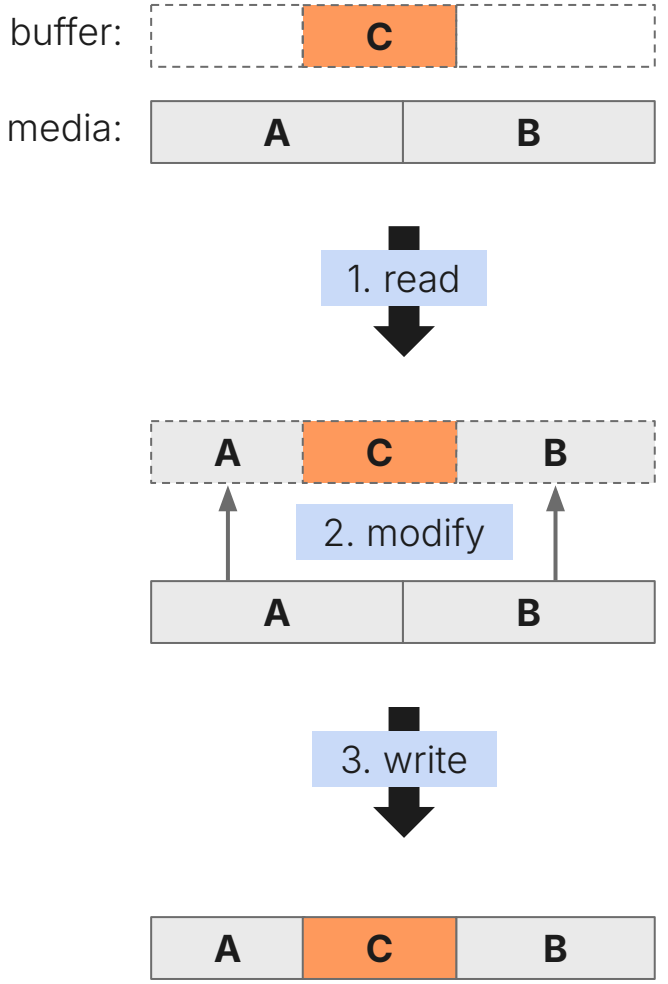
	64 KiB	16384:1	~850 GB	256 TiB	~50
the future of ultra-dense QLC	512 KiB	131072:1	~100 GB	2 PiB	~6
	...				

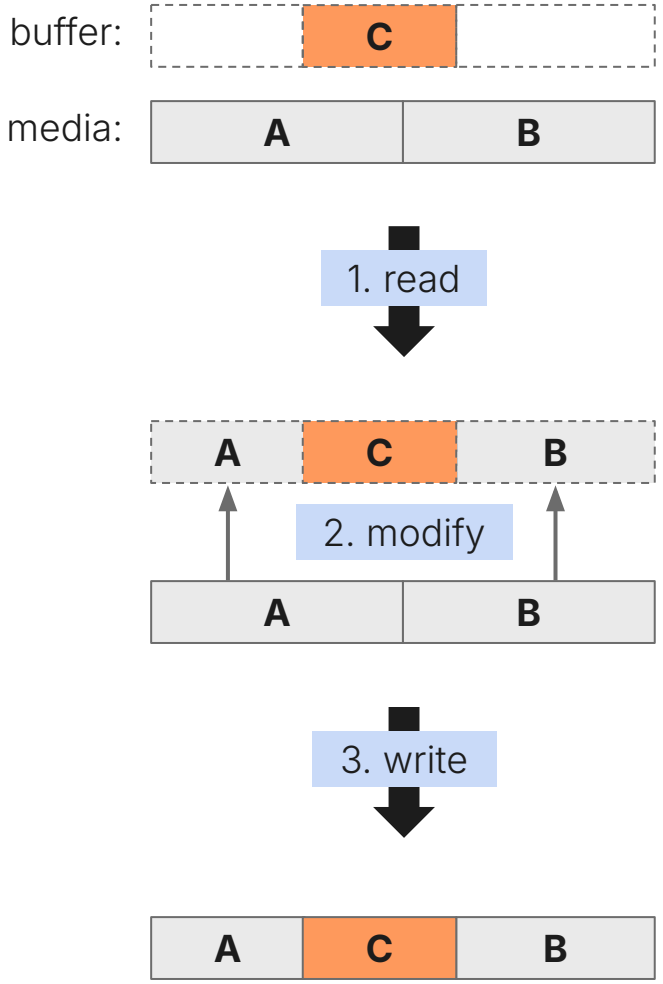
Pitfall: Read-Modify-Write



Pitfall: Read-Modify-Write

Scale

- extra read and write load → **reduced perf, endurance**
- extra media round-trip → **increased latency**
- write size **and alignment** are important
- overhead **scales with IU size**
- this is a real problem for **general-purpose** systems



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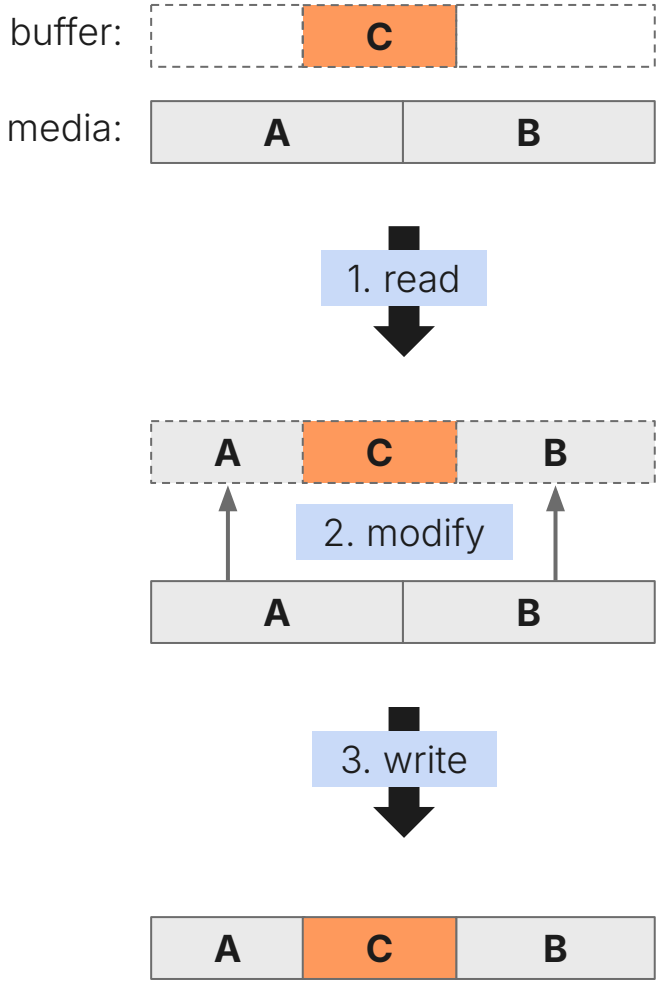
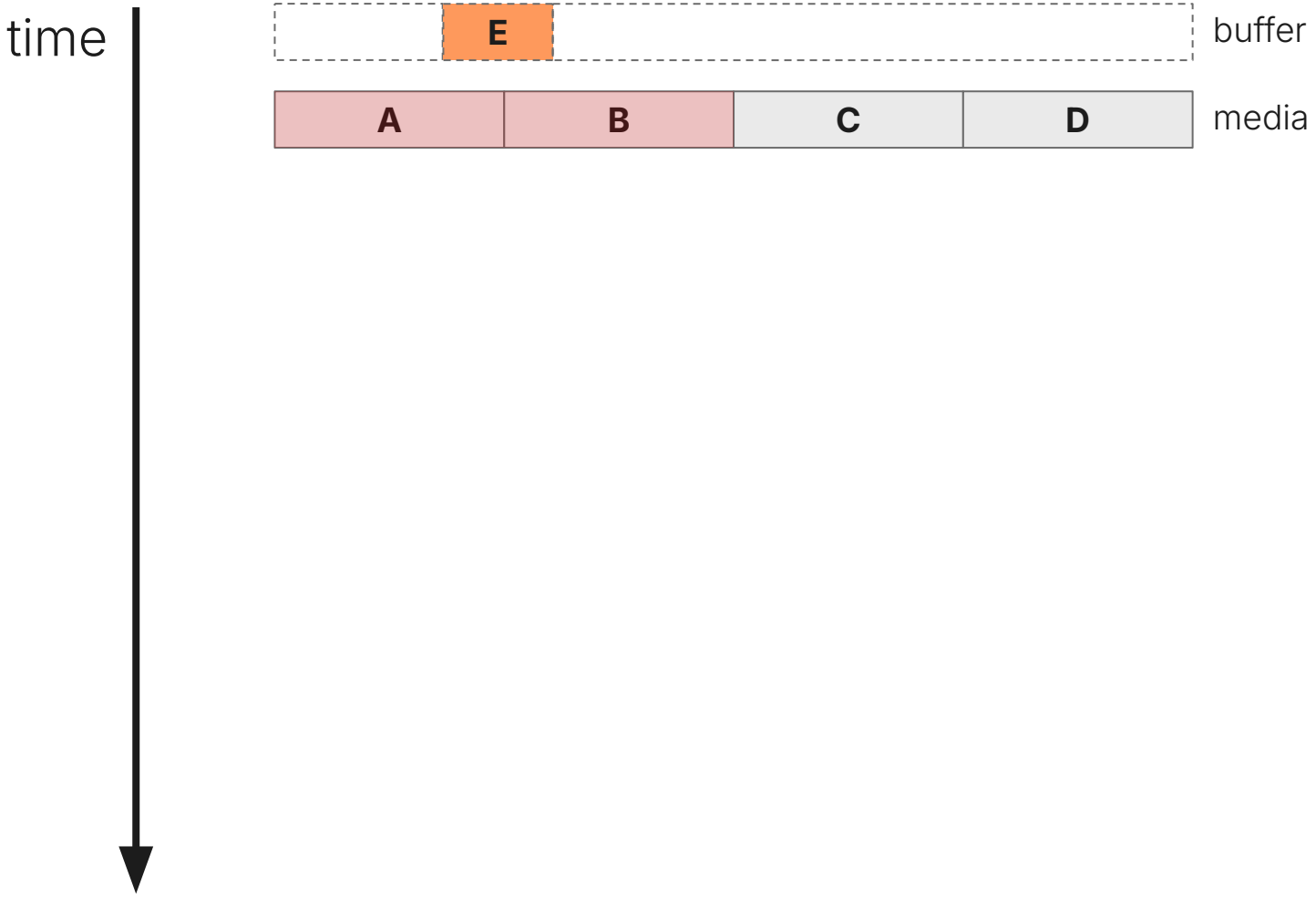


Key Insight: Take advantage of exascale workload patterns to deliver a large IU with minimal RMW.

Write Coalescing

Scale



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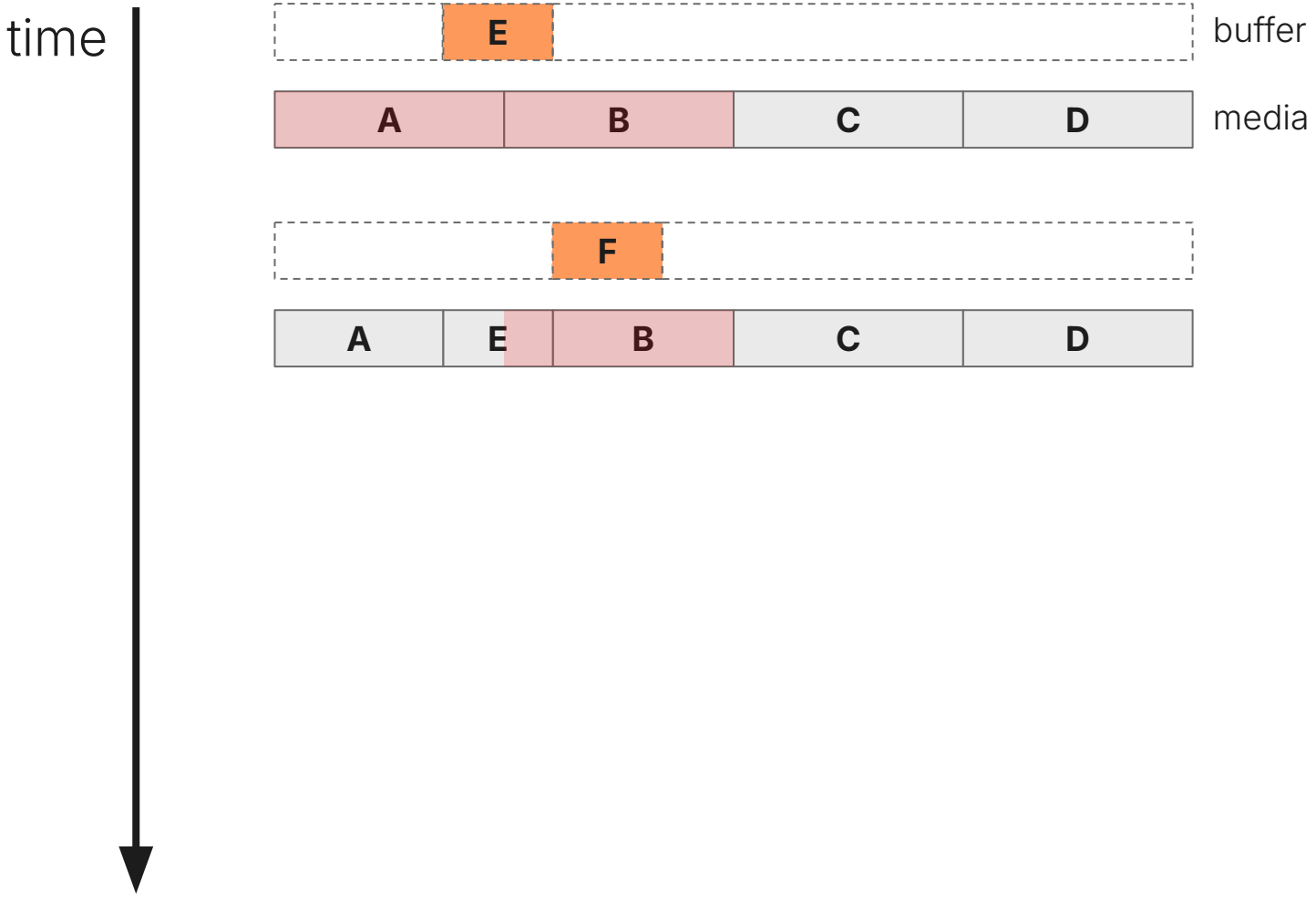

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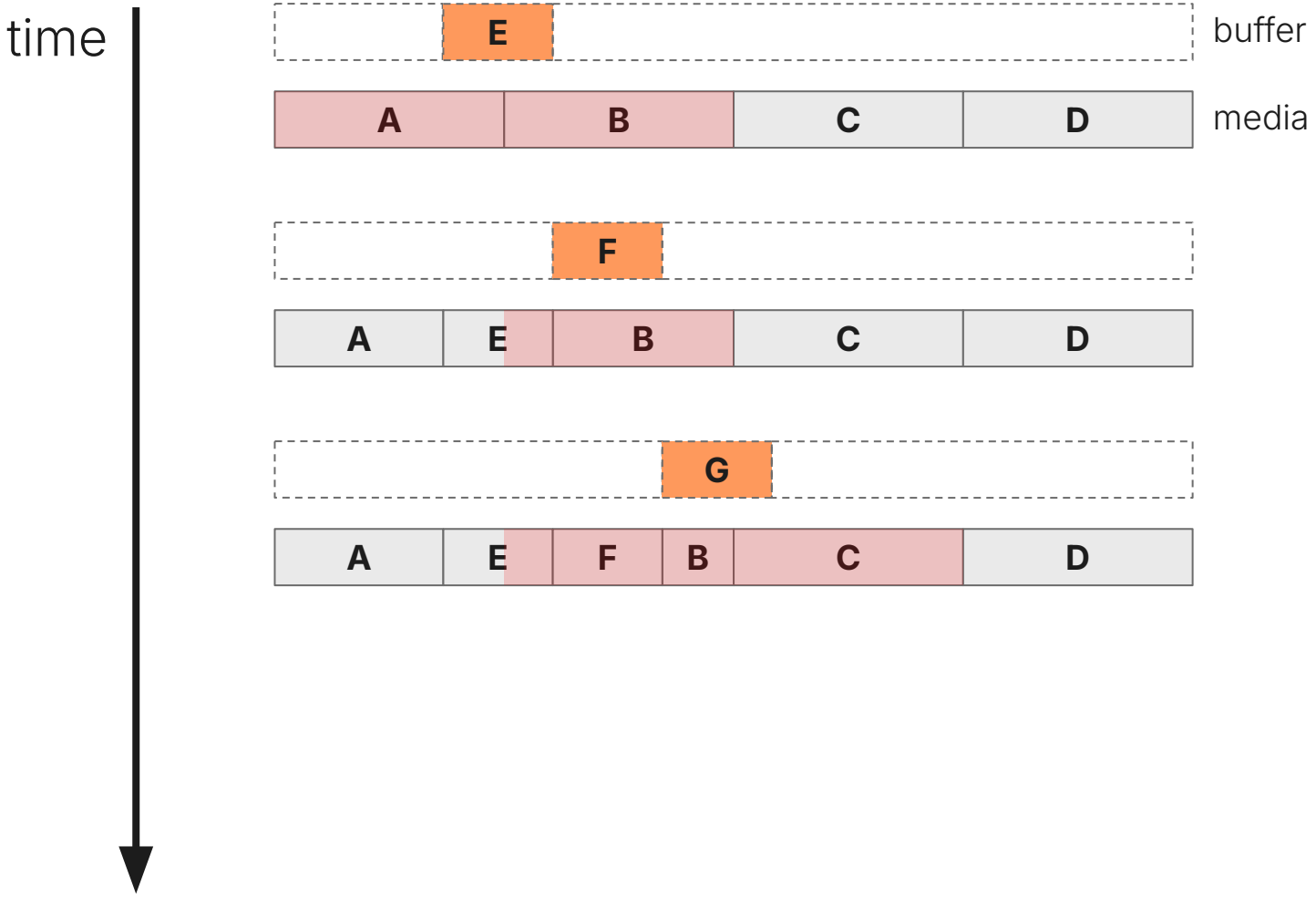

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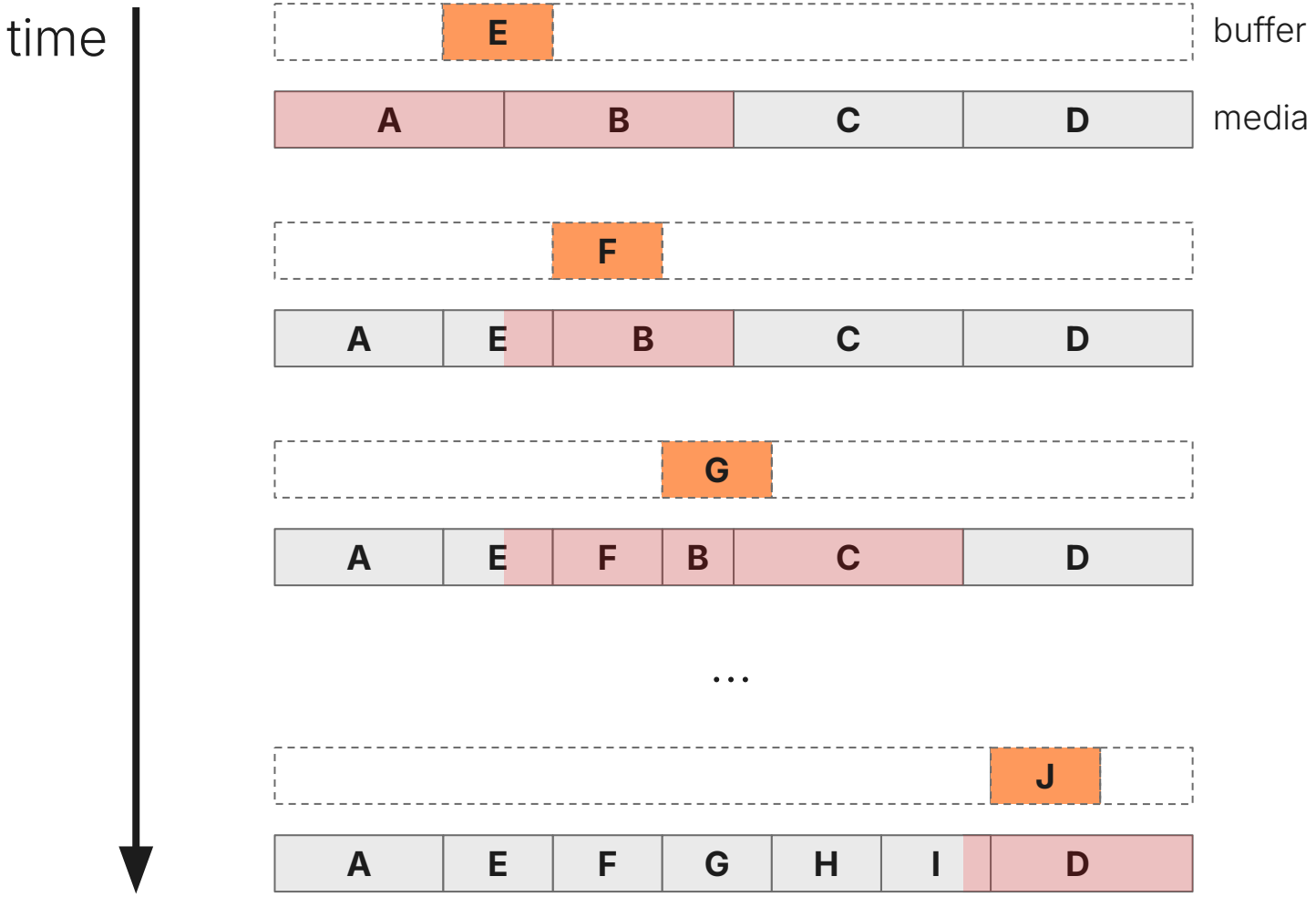

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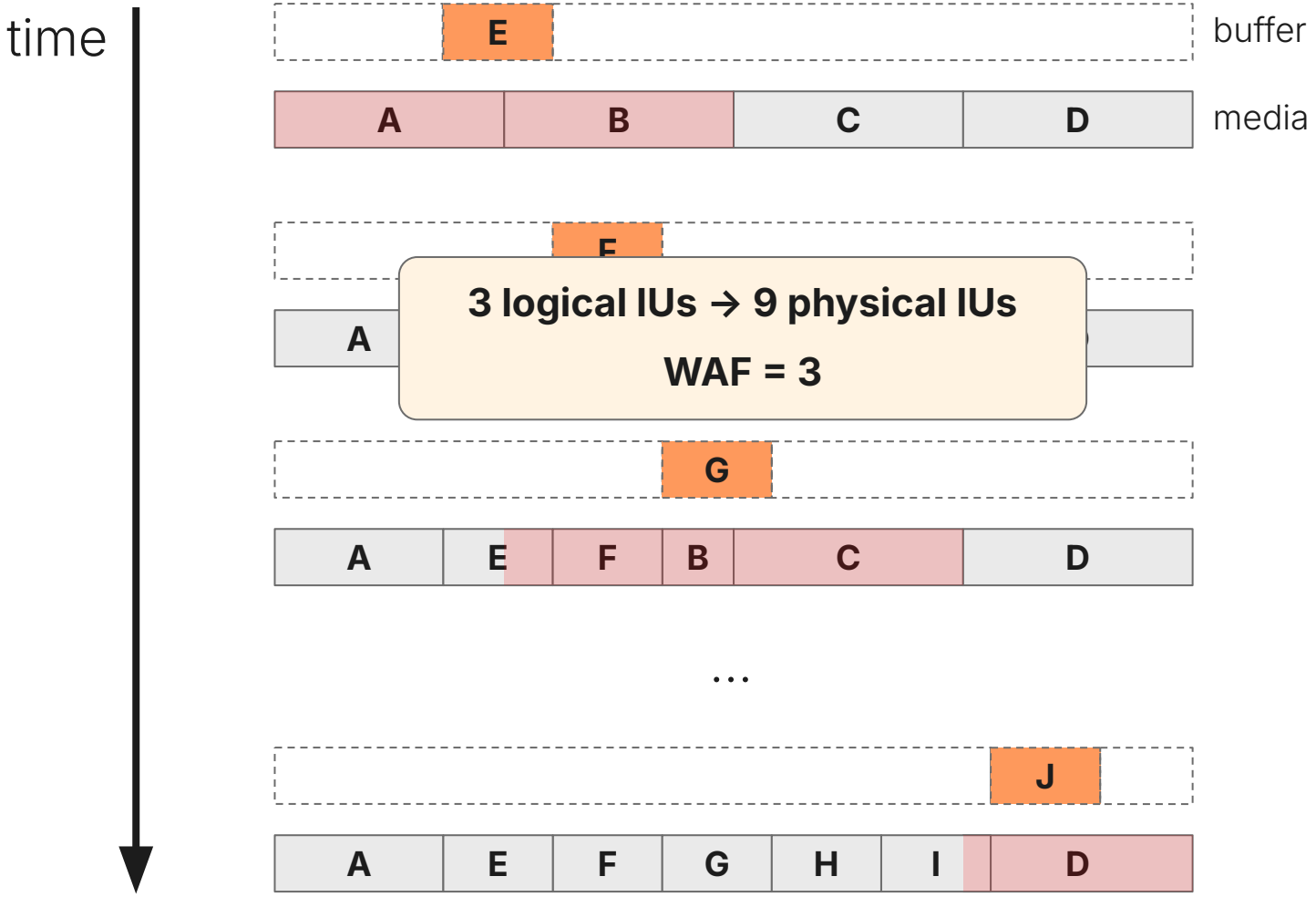

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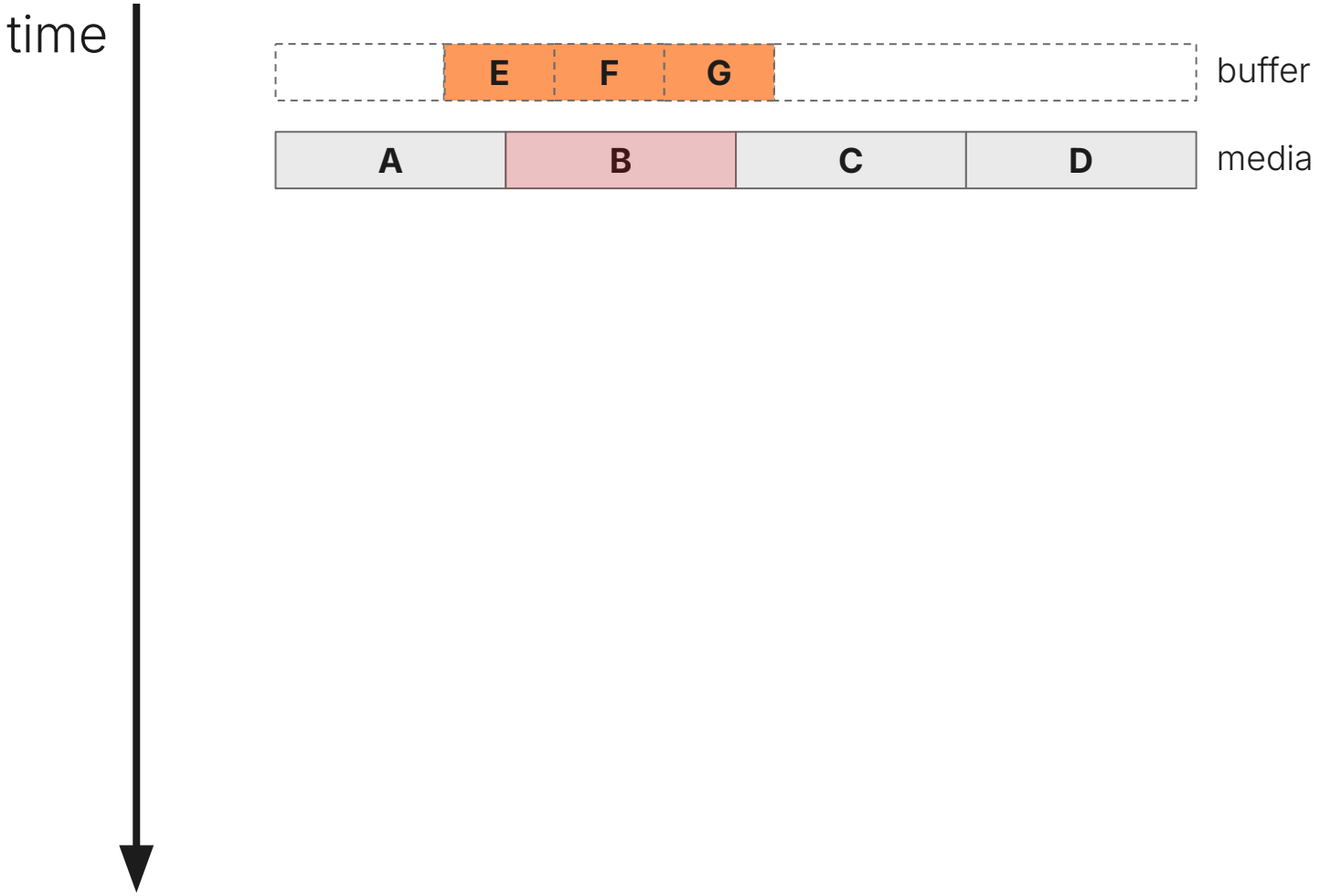

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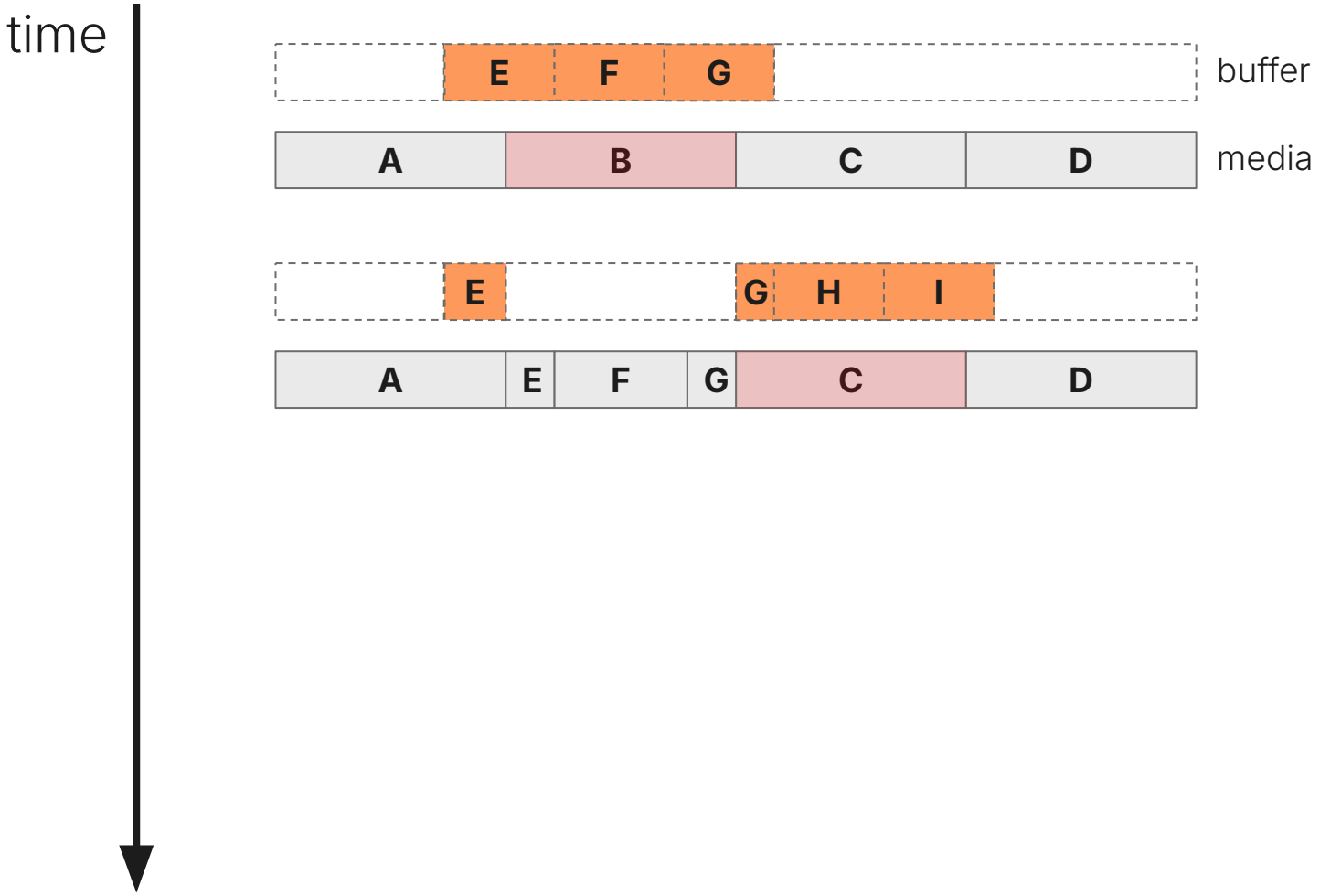

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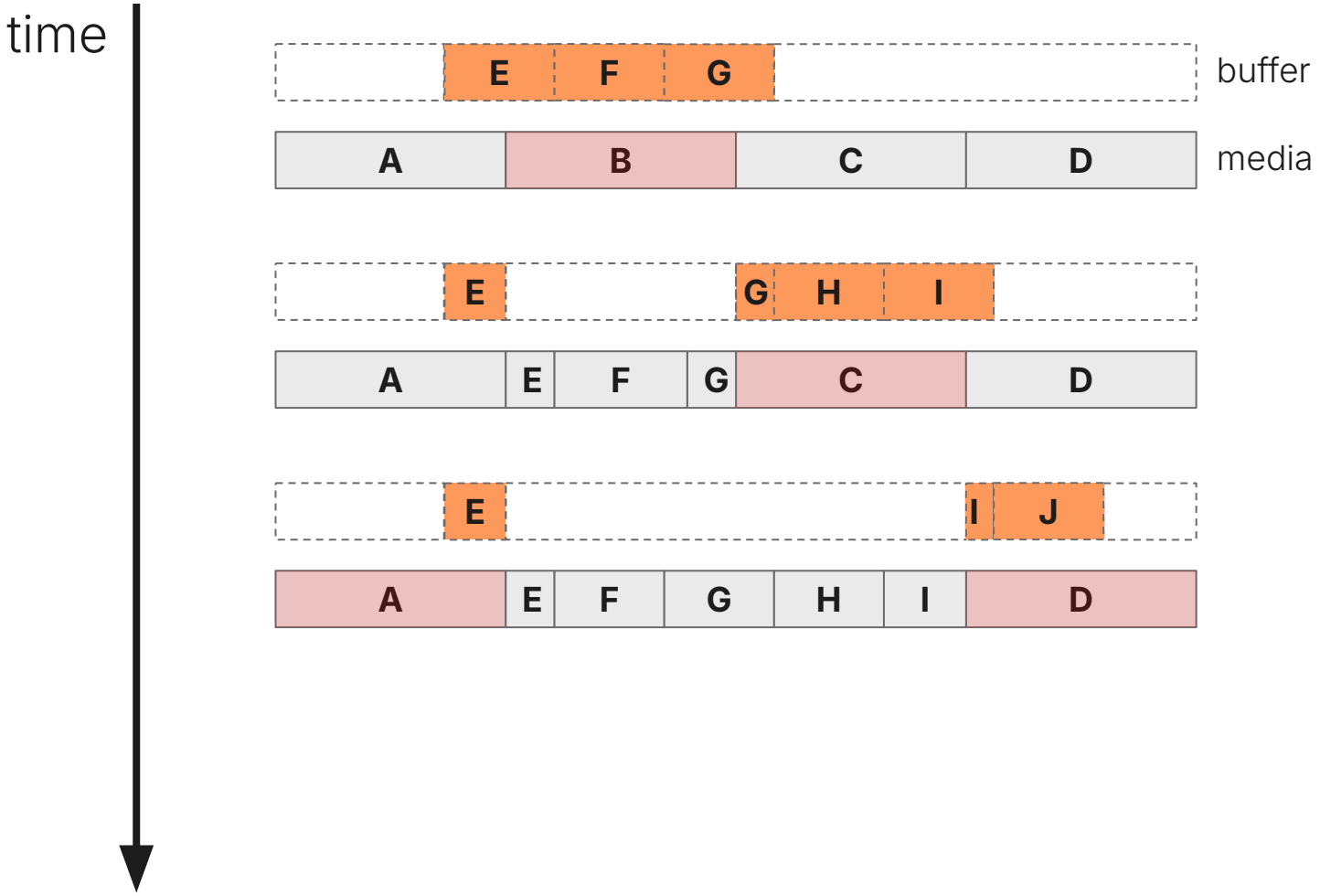

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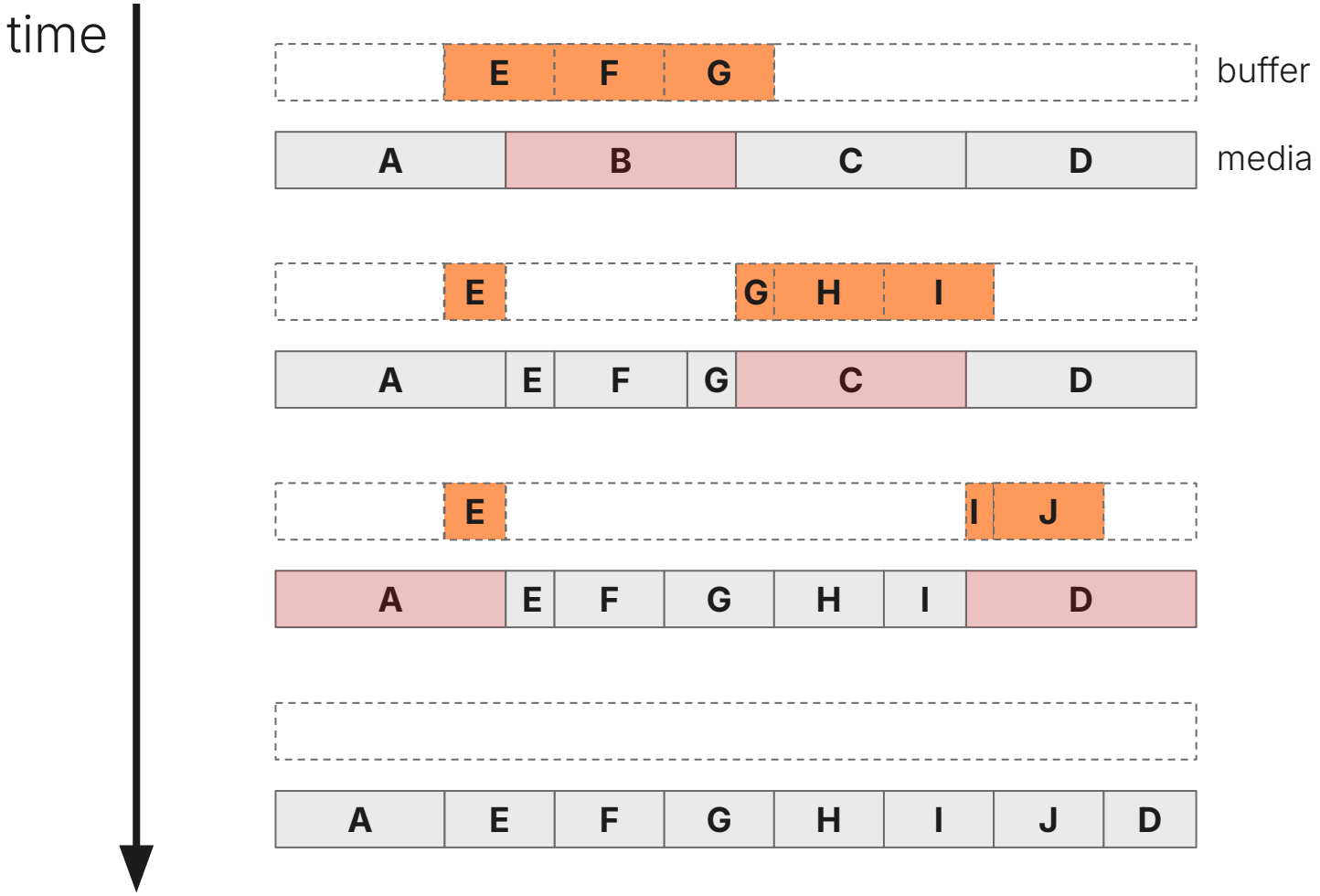

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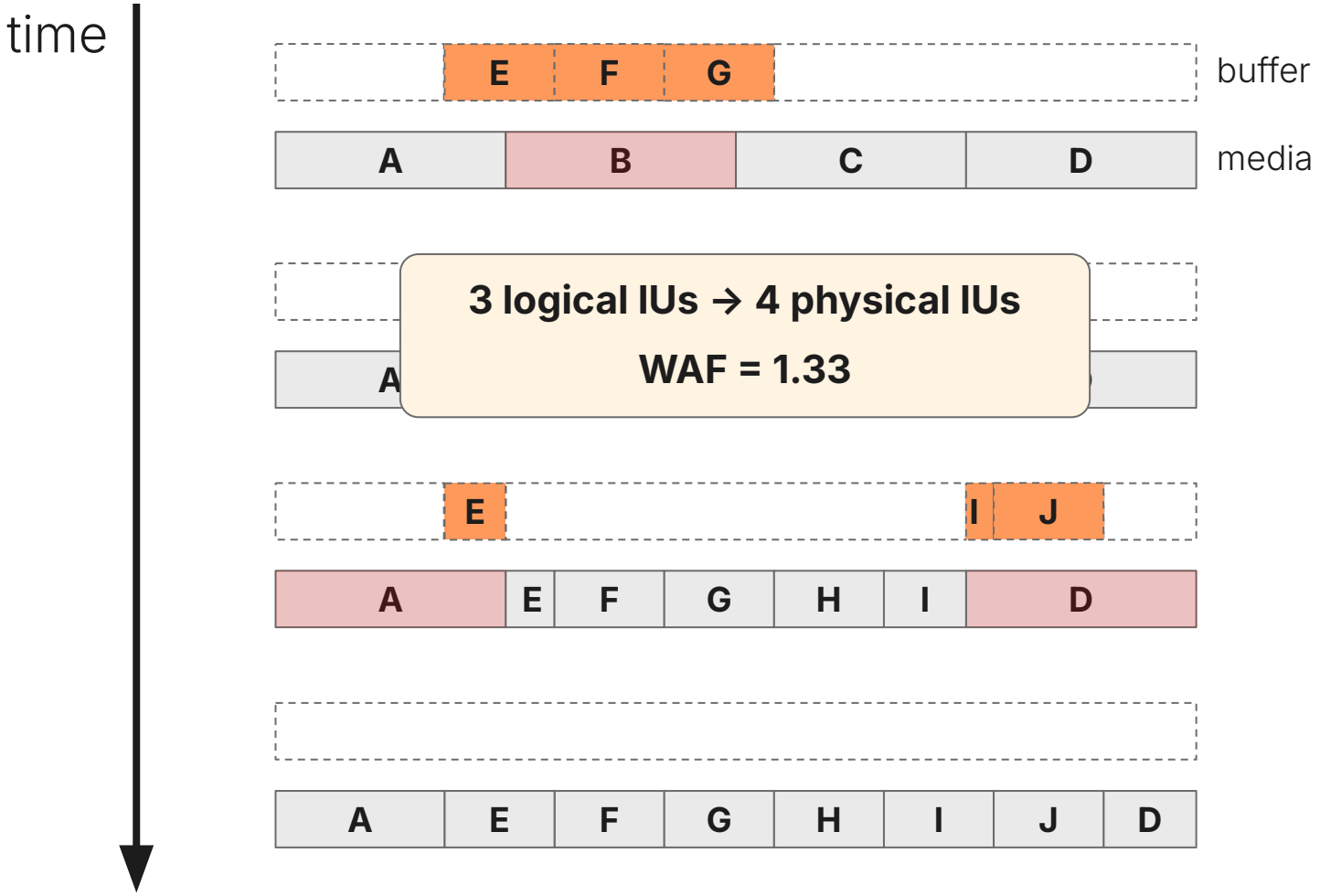
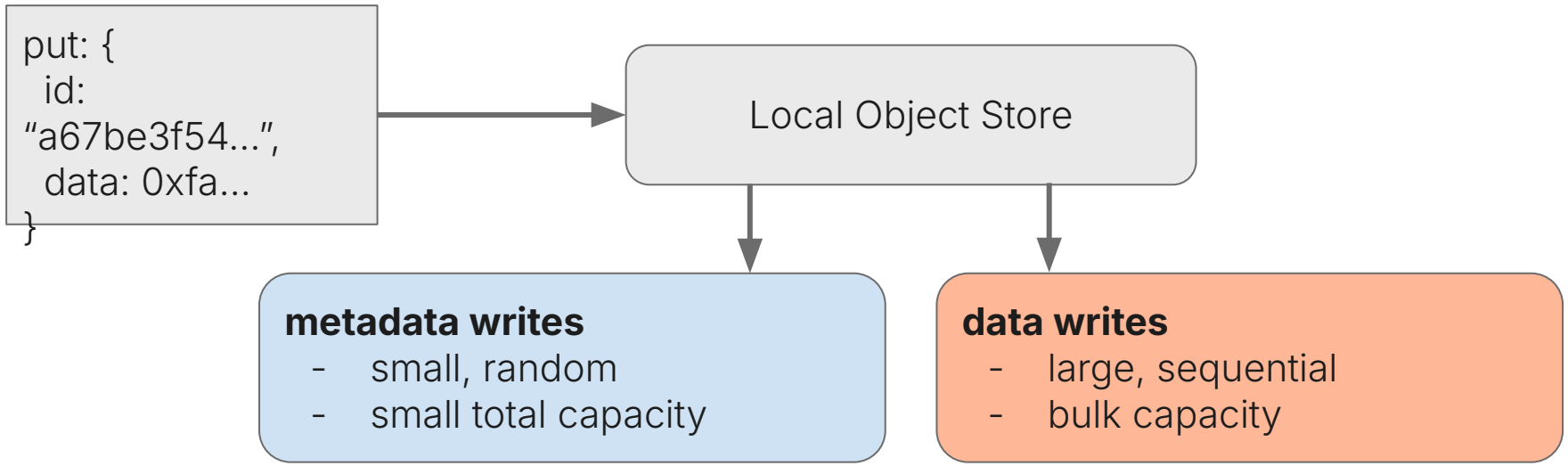


Configurable IUs

Scale



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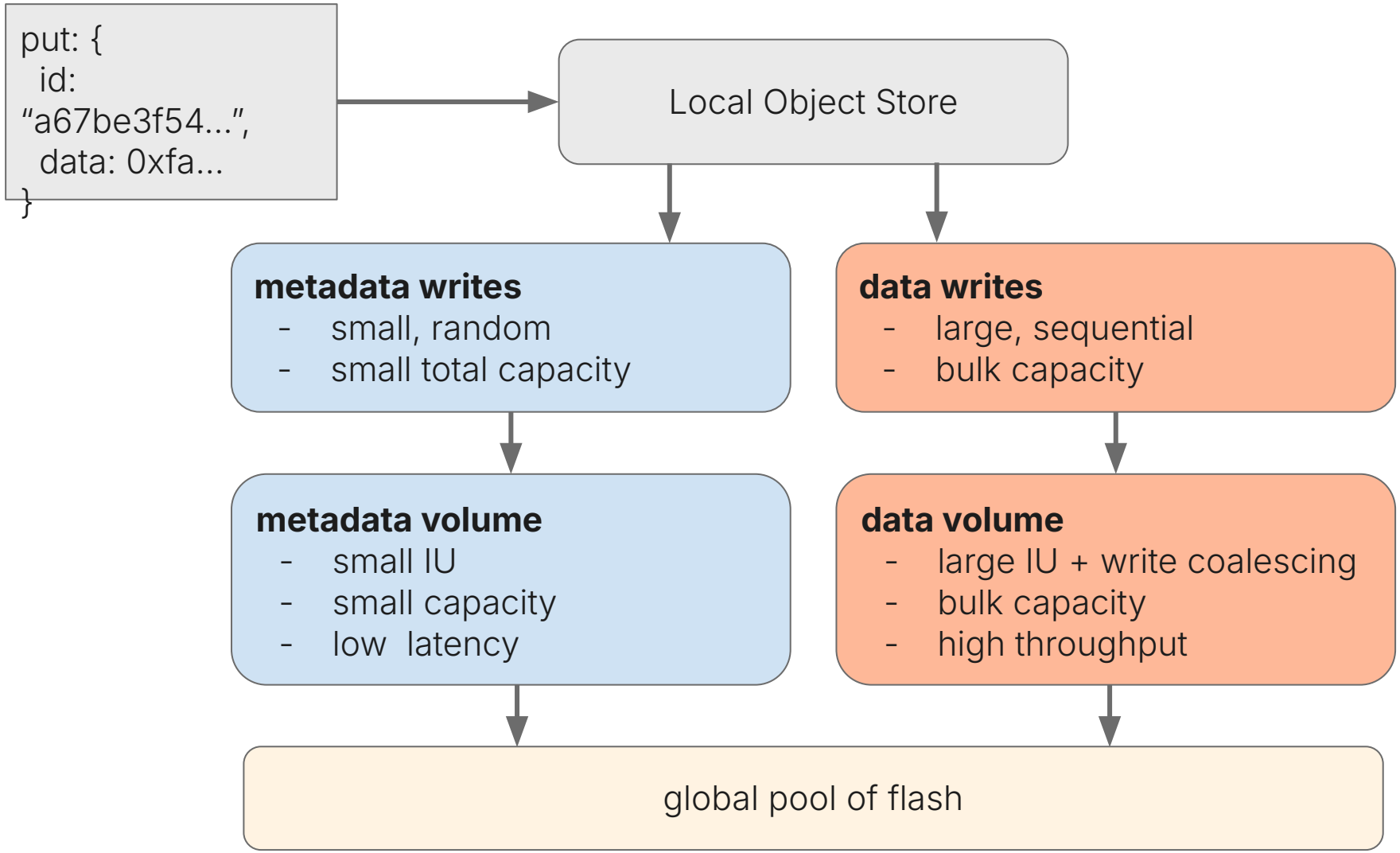

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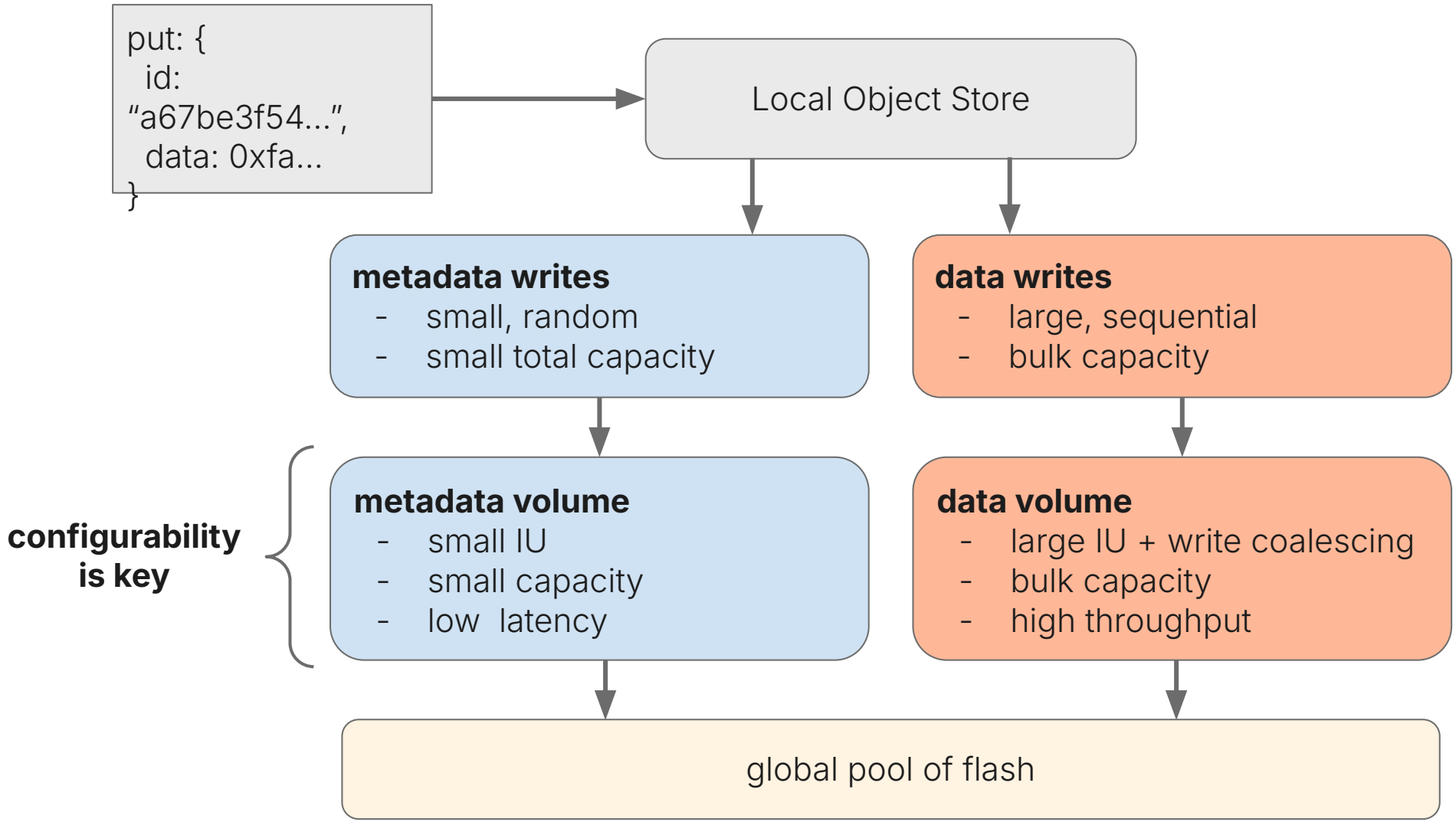
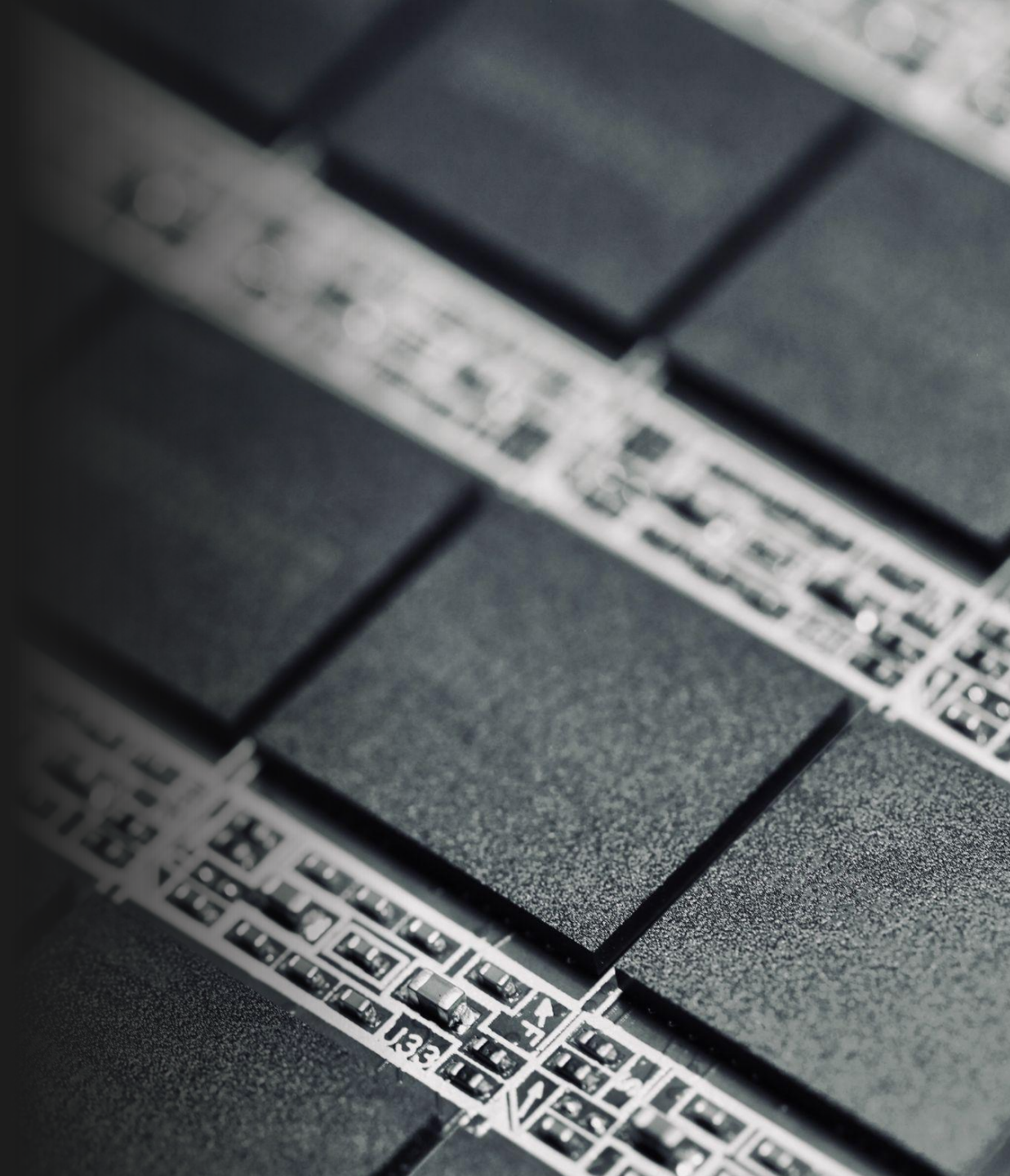


QLC Challenges

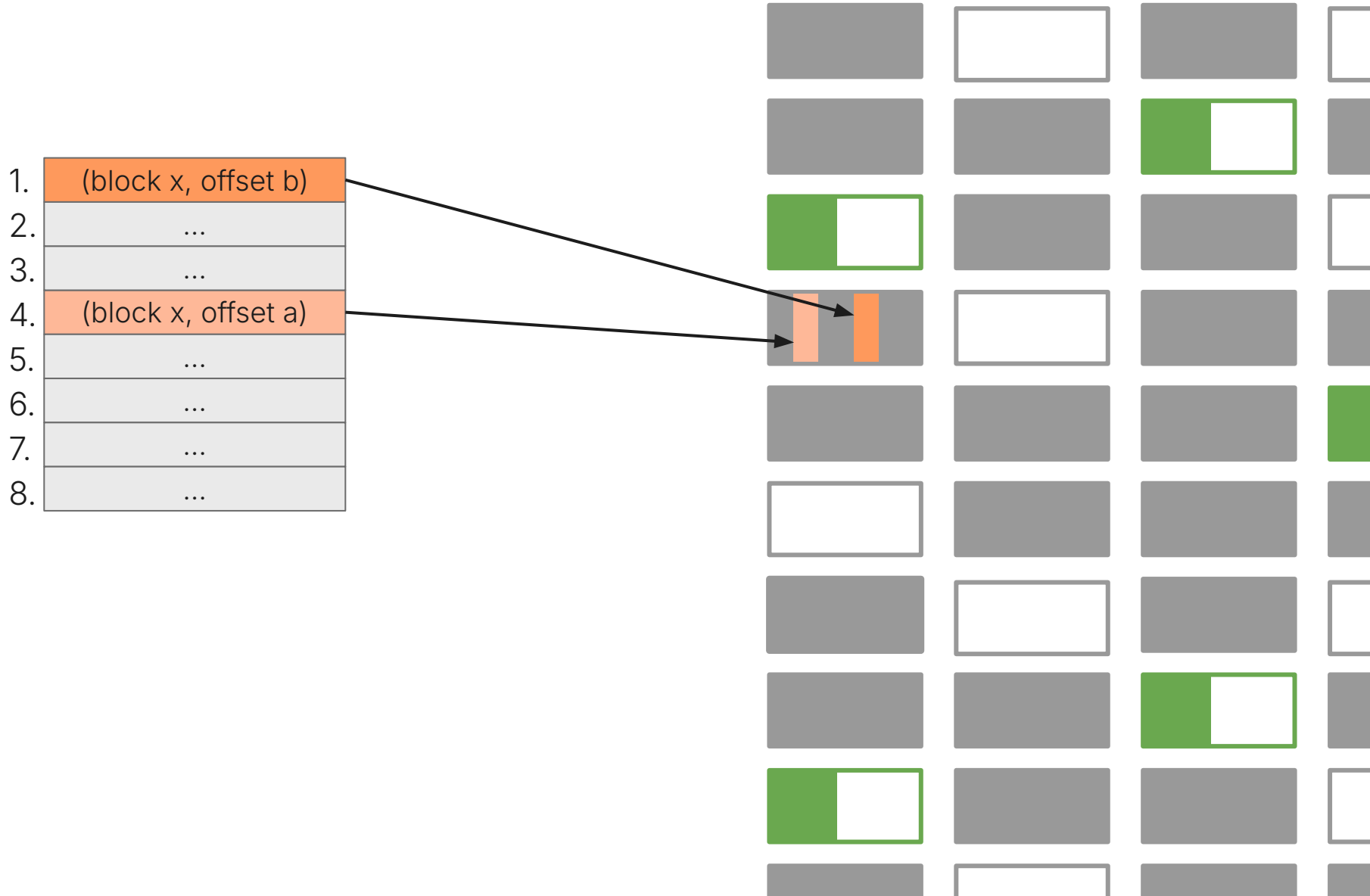
Scale

Endurance

Reliability



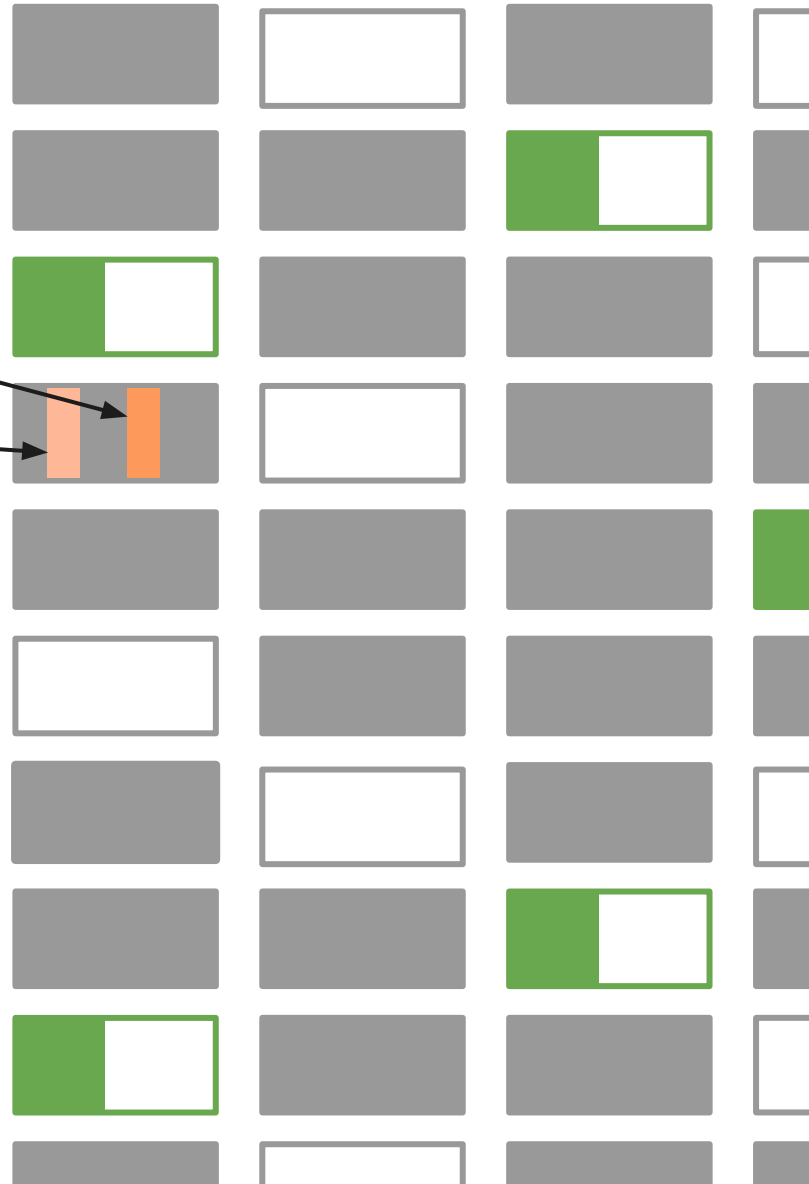
Review: Garbage Collection



Review: Garbage Collection


```
write: {
  lba: 1,
  data: 0xfa...
}
```

1.	(block x, offset b)
2.	...
3.	...
4.	(block x, offset a)
5.	...
6.	...
7.	...
8.	...



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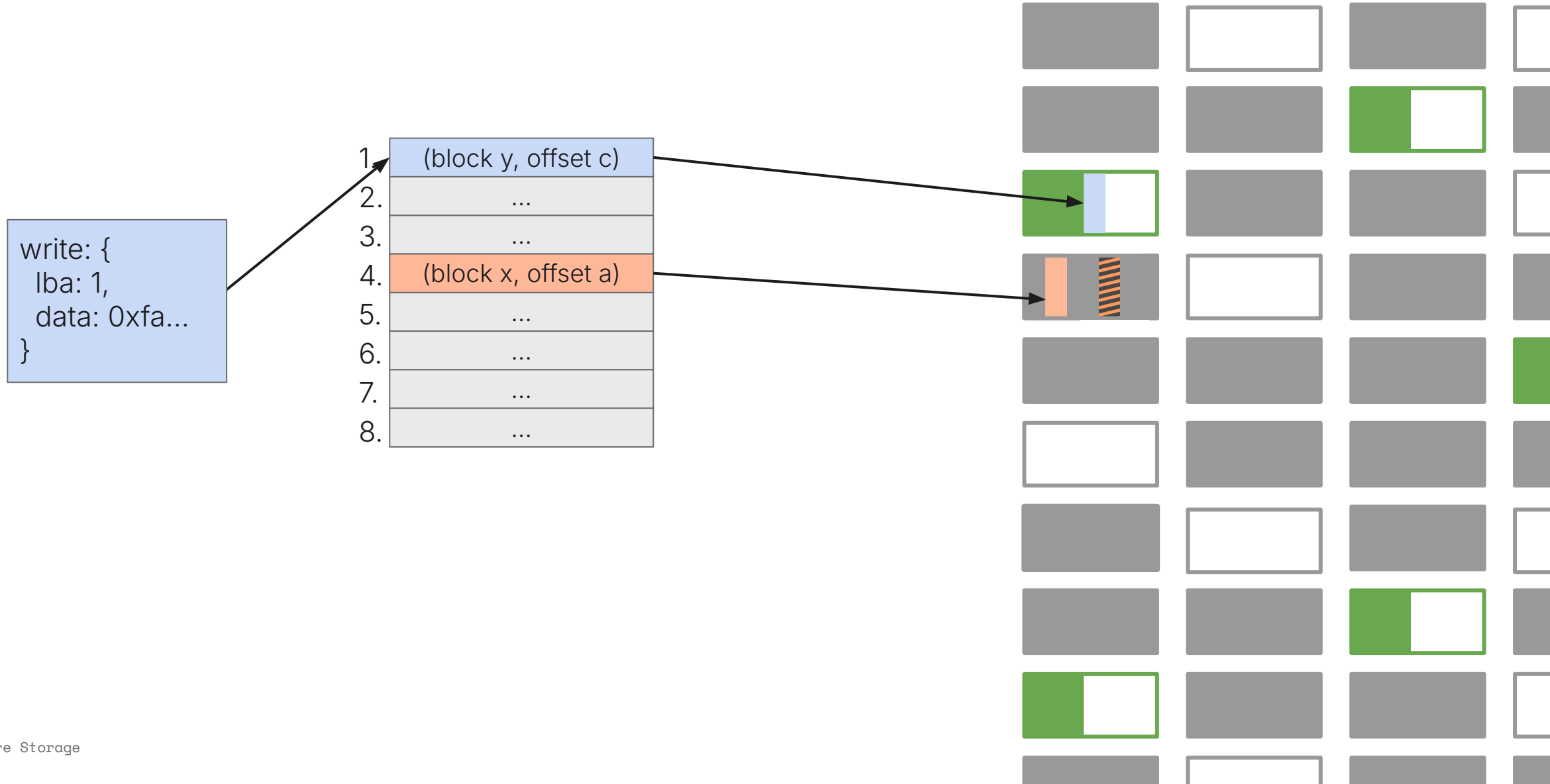

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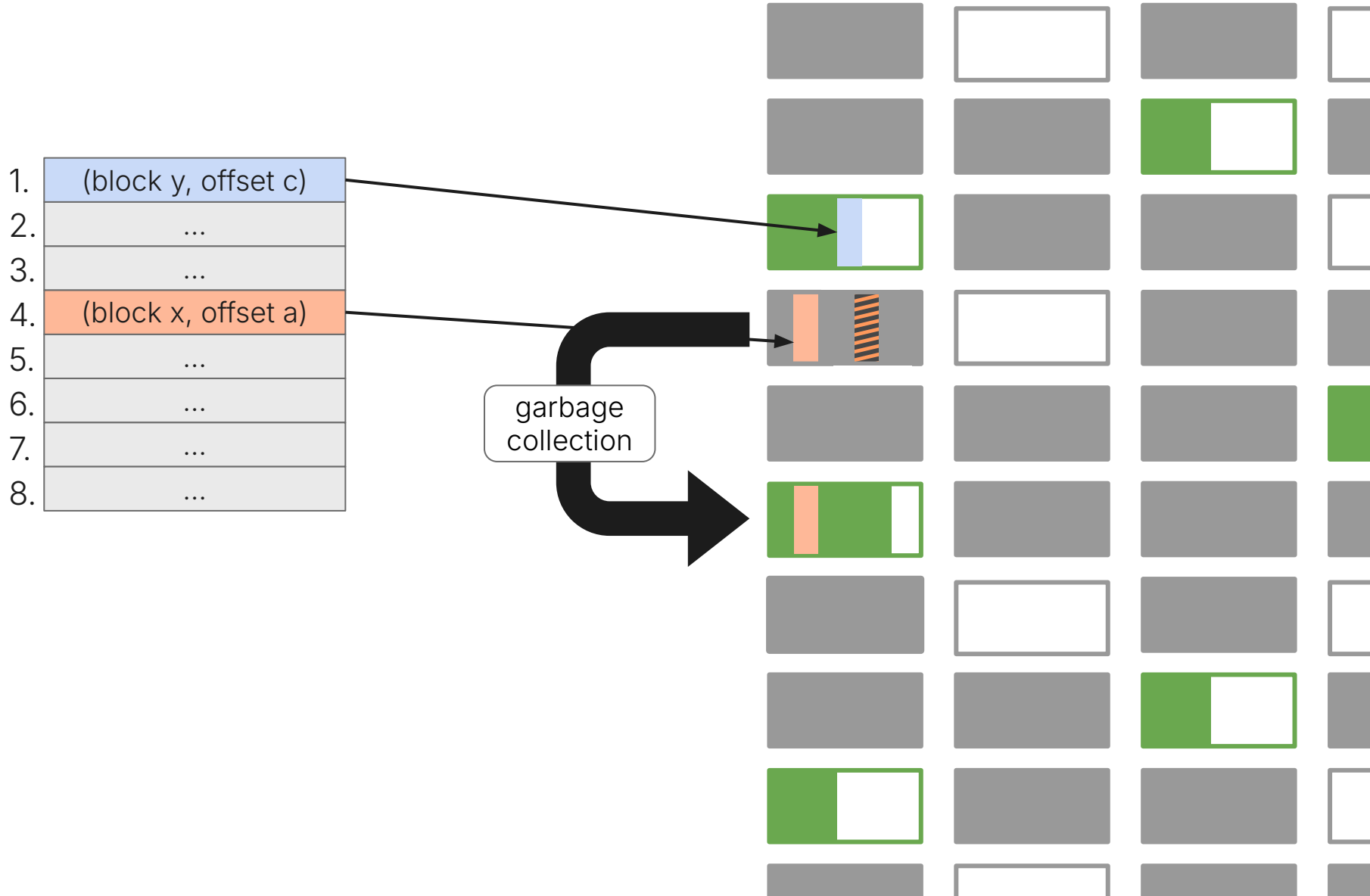

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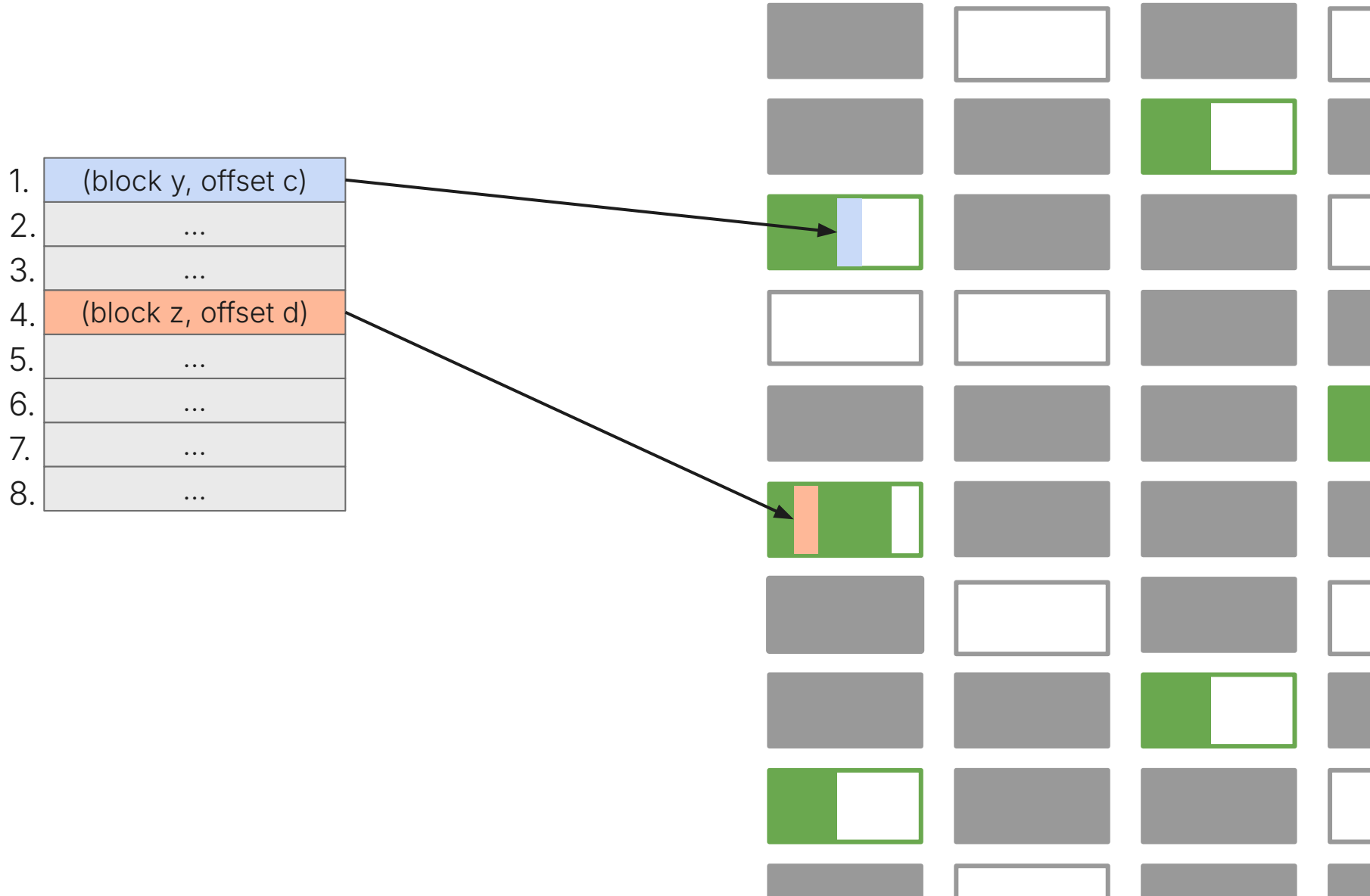

Write Amplification

$$\text{WAF} = \frac{\text{physical written}}{\text{logical written}}$$

- QLC has relatively **low endurance**: O(thousands)
- WAF reduces media lifetime (and performance!) linearly
  e.g. WAF=2 → ½ total lifetime bytes written by user
- GC is the **dominant contributor** to WAF (others: RMW, retention)
- Option: increase over-provisioning? → direct impact to cost!
- Option: use smarter GC algorithms? → no help to random-write benchmarks!

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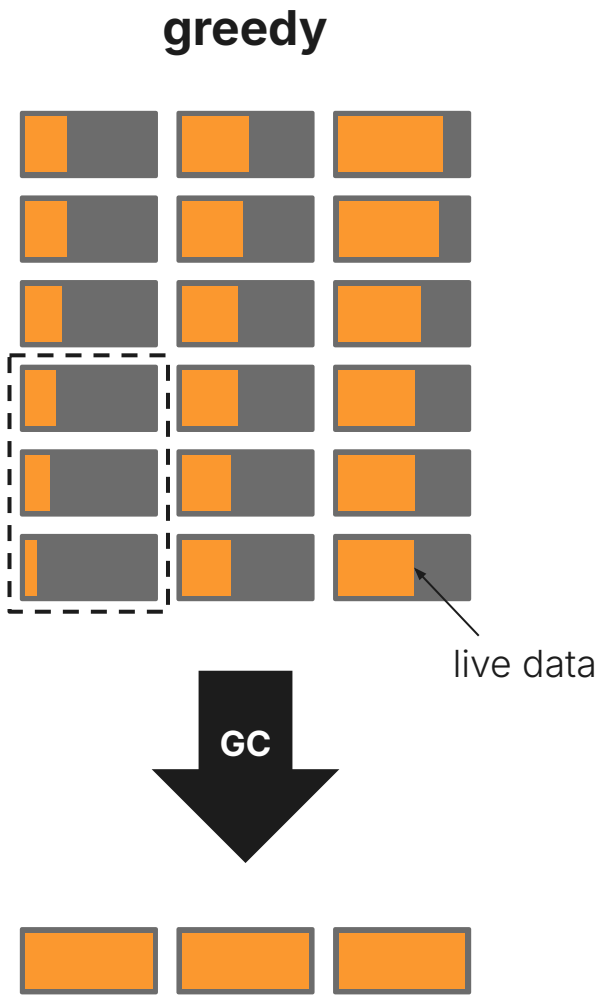
Key Insight: Target real-world workloads with smarter algorithms to minimize WAF.

Smarter Algorithms



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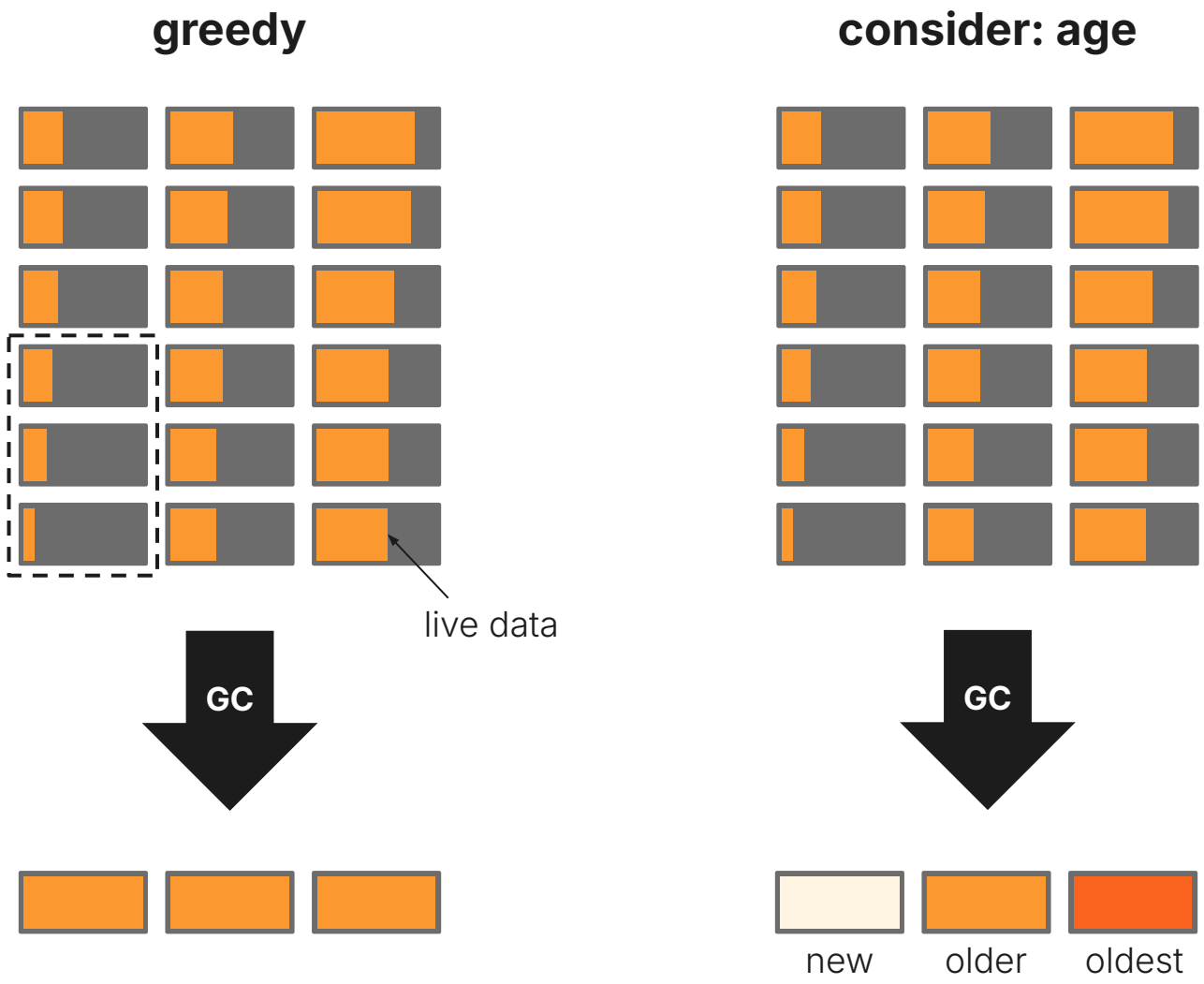
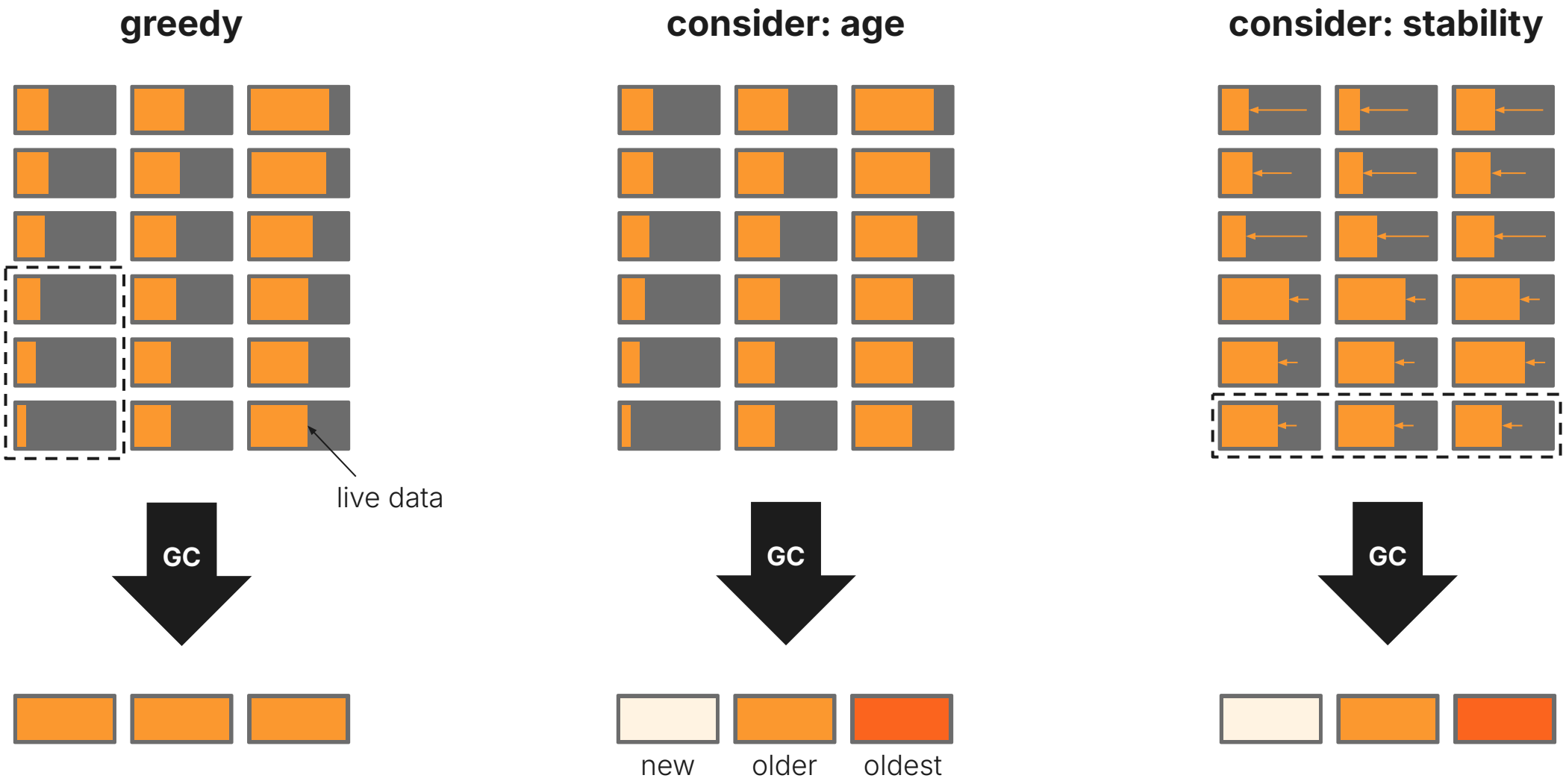


Smarter Algorithms



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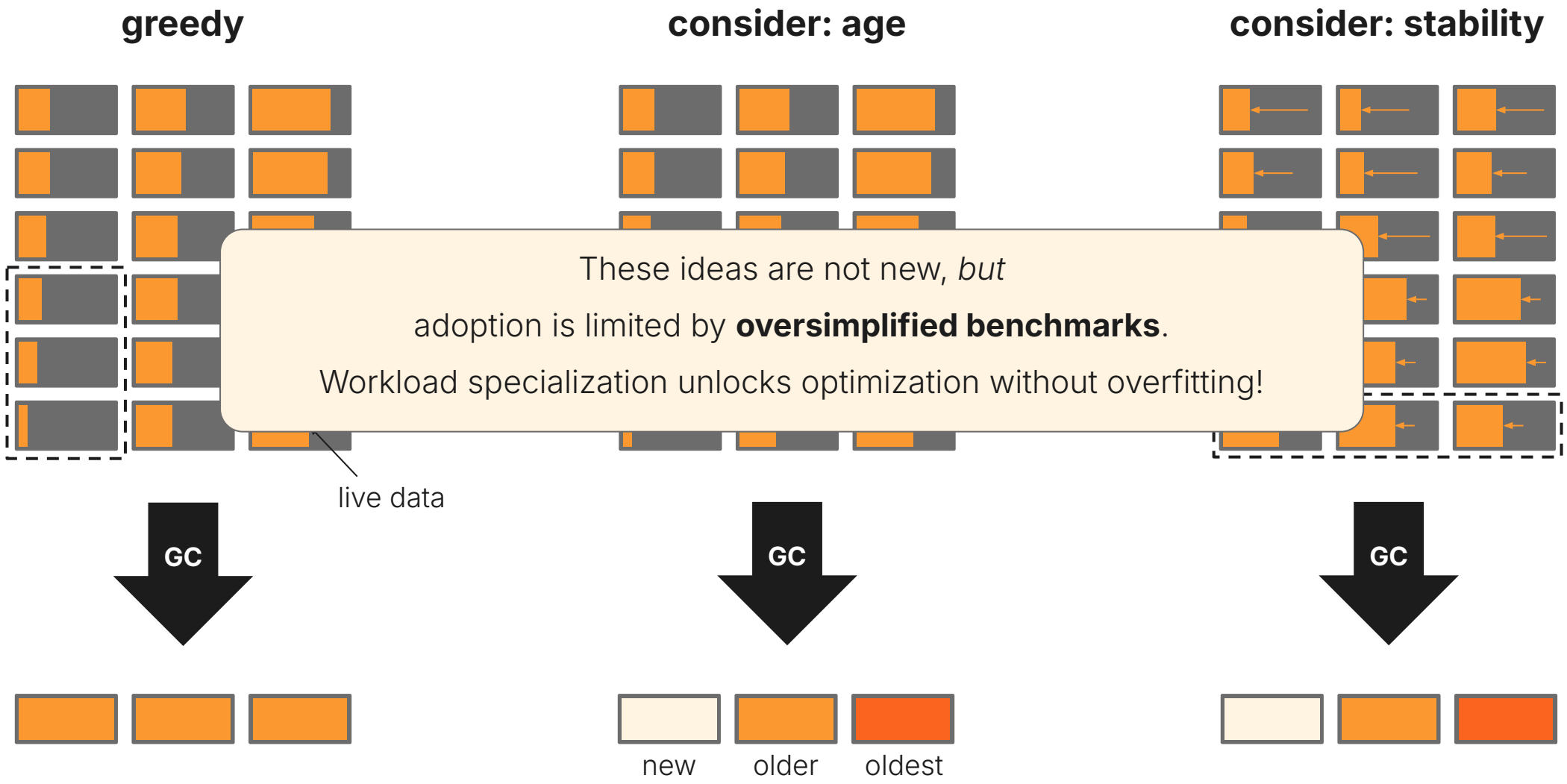
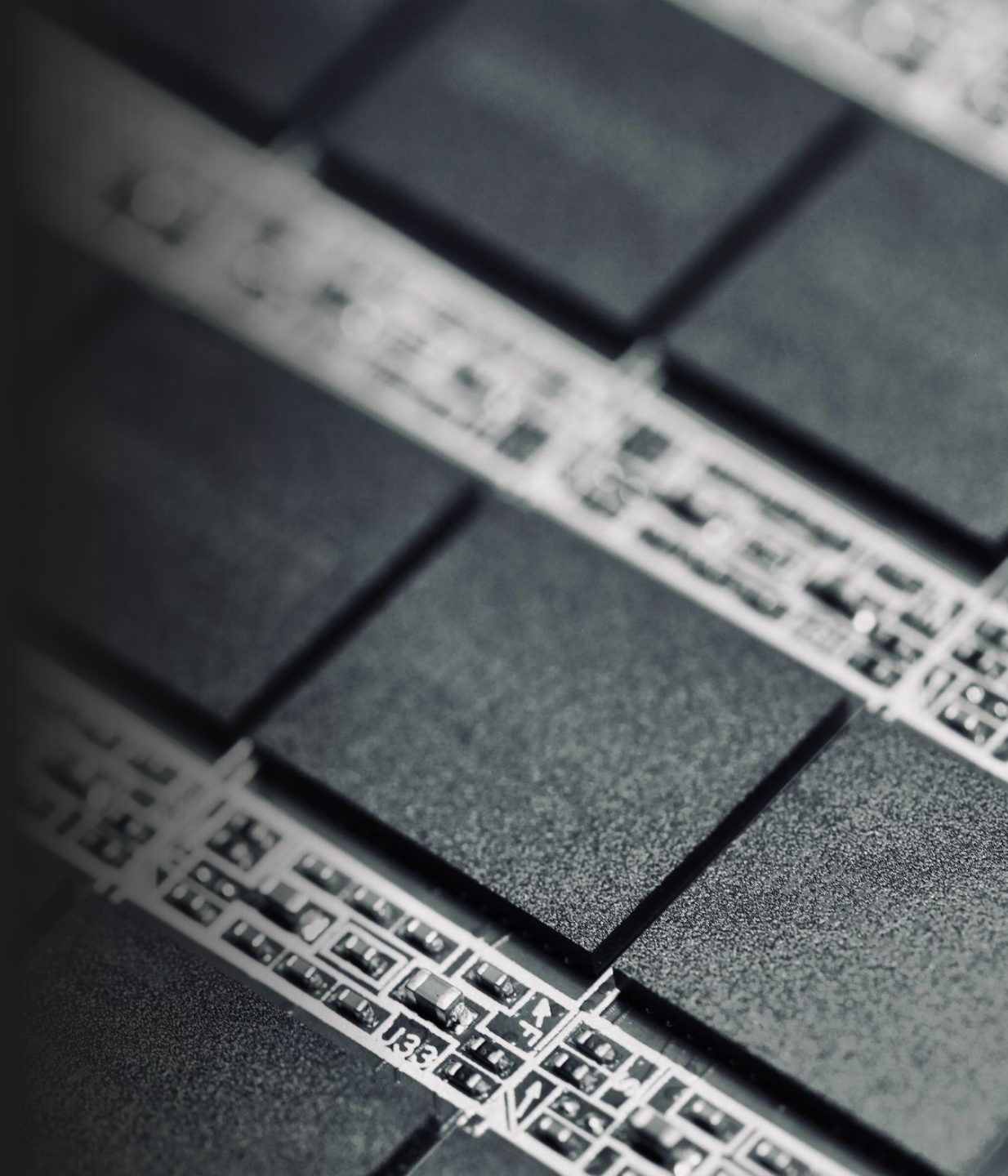


QLC Challenges

Scale

Endurance

Reliability



Blast Radius

- failure modes:
  - sector ~KB
  - flash block ~100s MB
  - flash die ~100s GB
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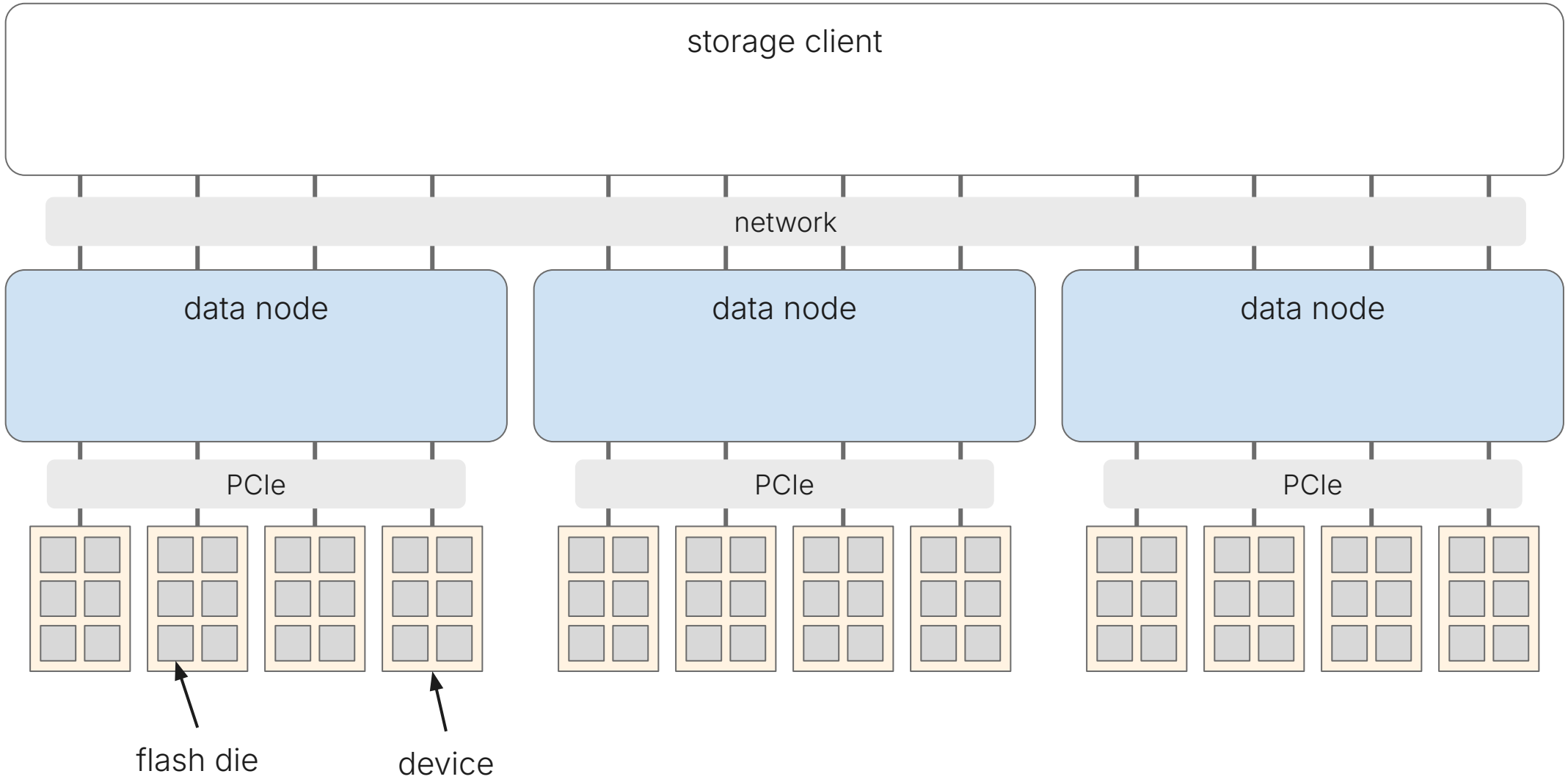
  - data node ~PB

- QLC density → large devices/nodes → increased impact of failures

Rebuilding Failures



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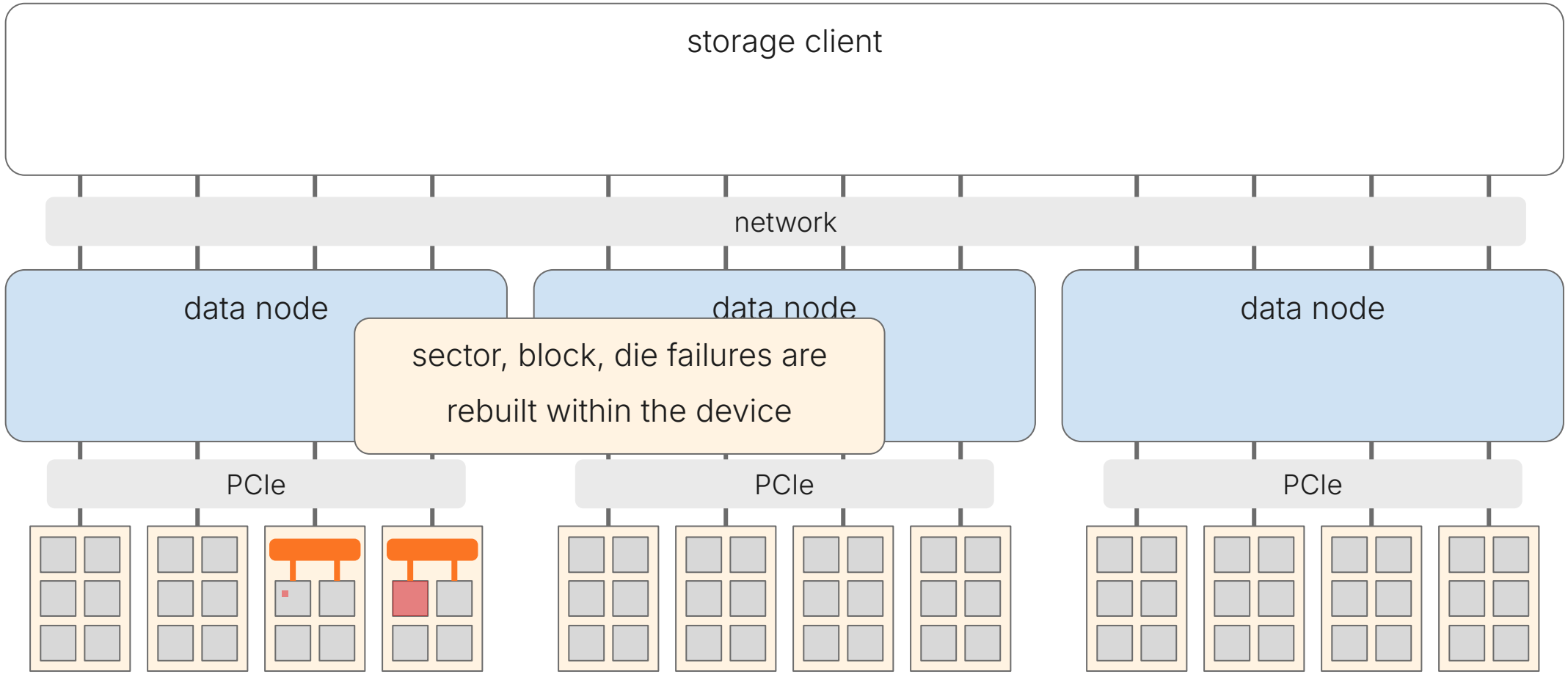

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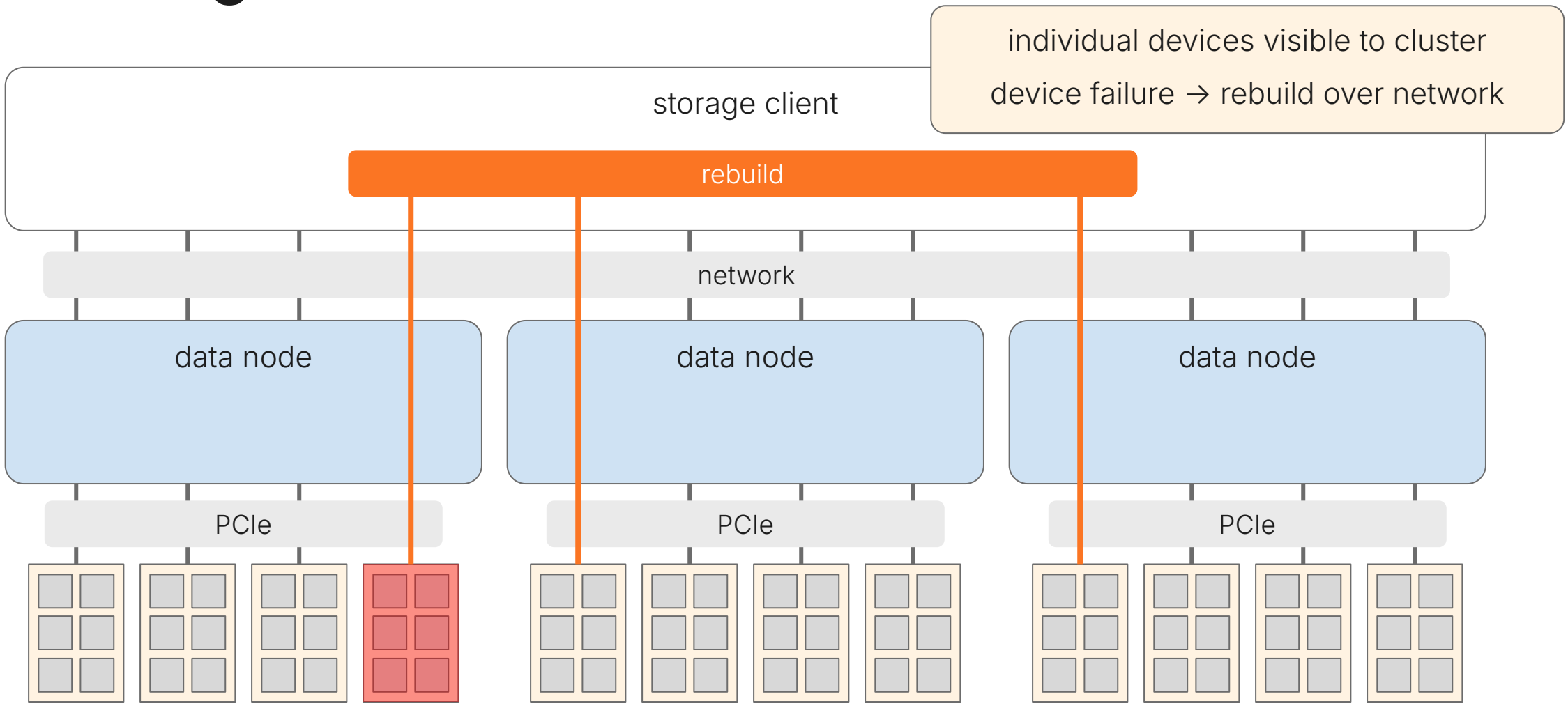

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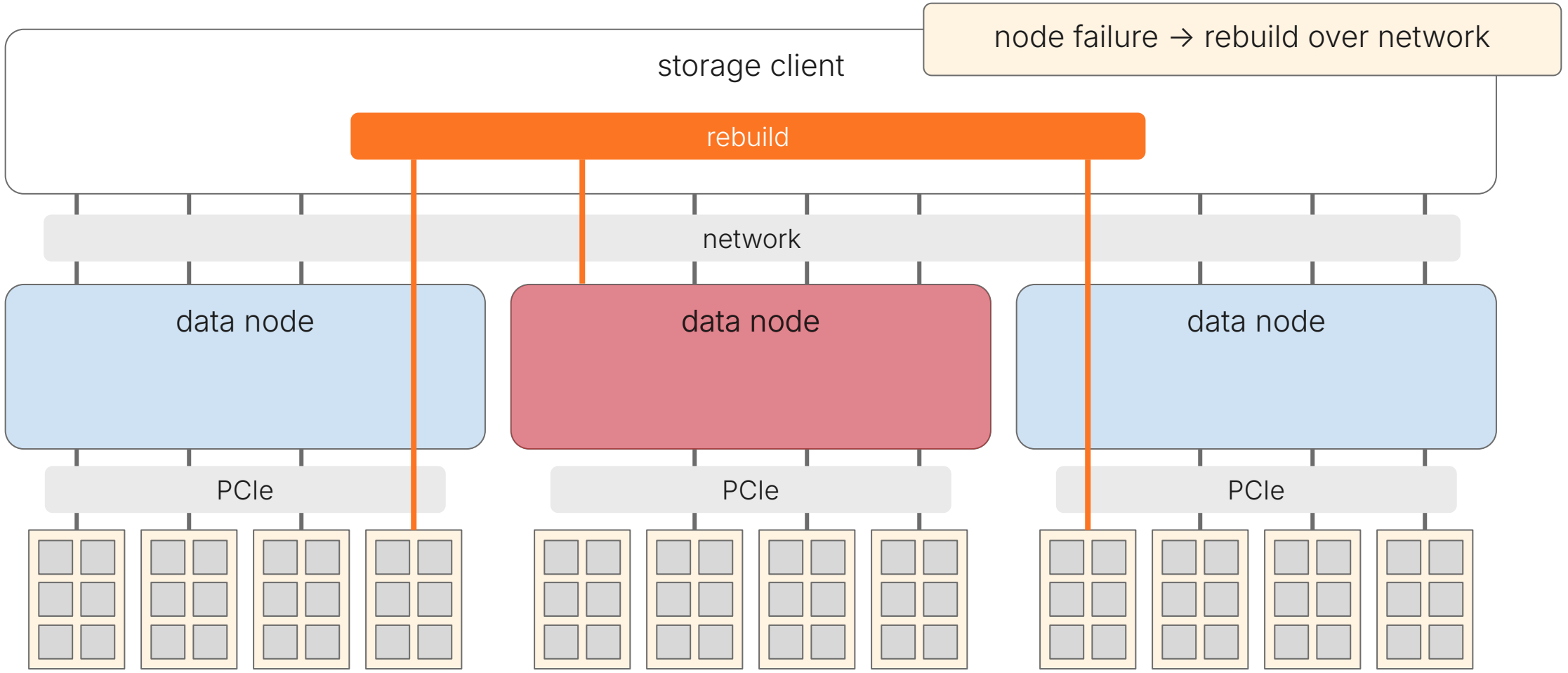

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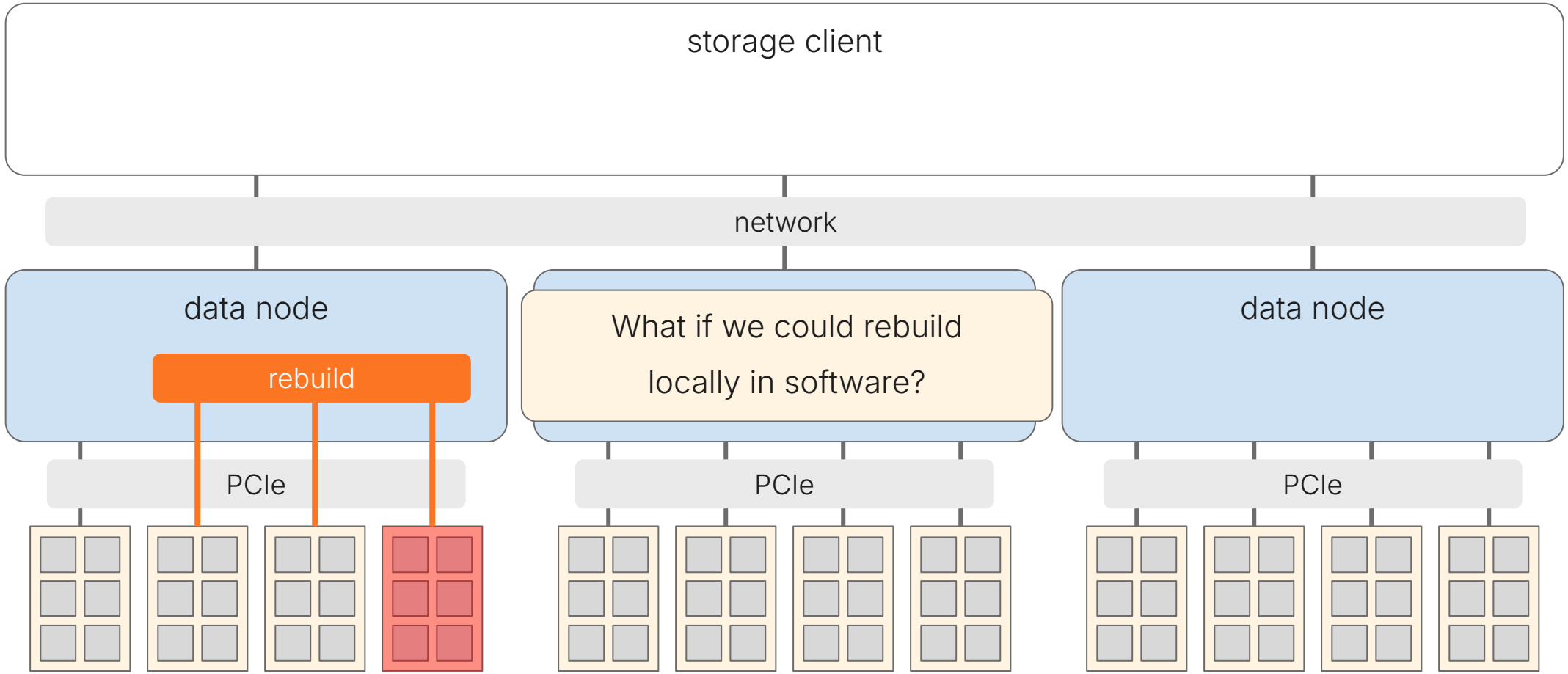
Key Insight: Protect efficiently against dominant failure modes.

Node-Local Parity?



Recap: QLC Challenges

Scale

- large IUs
- write coalescing
- data/metadata

Endurance

- real workloads
- smarter algos
- minimize WAF

Reliability

- failure modes
- blast radius
- local parity

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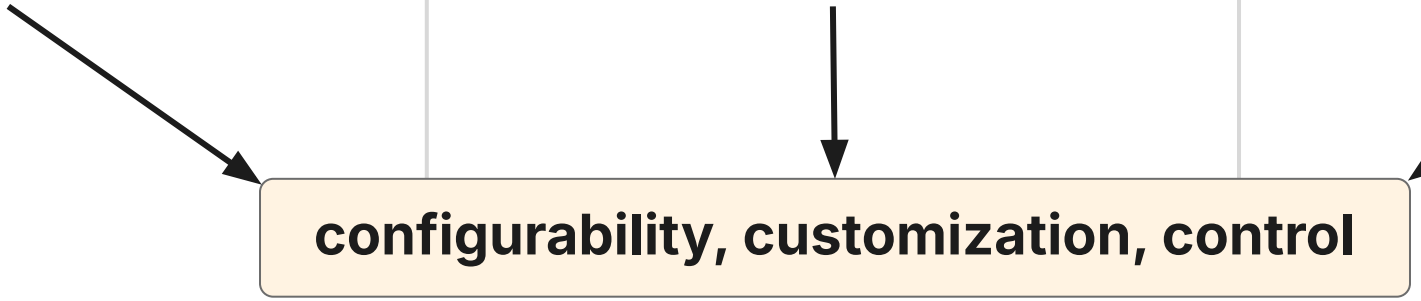
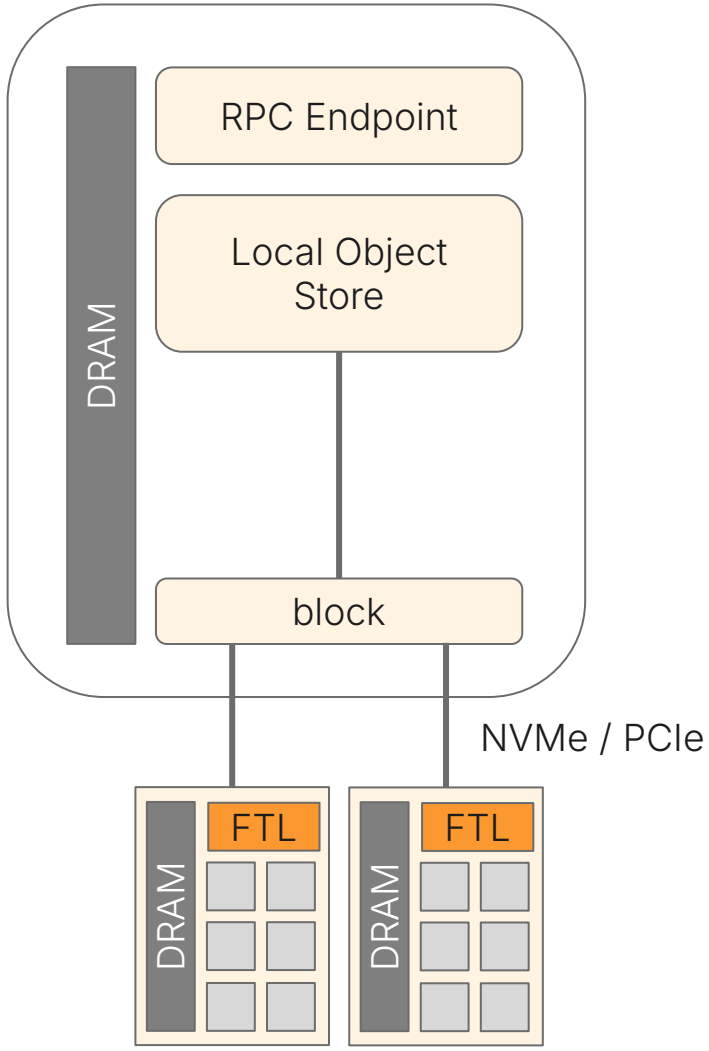


Agenda

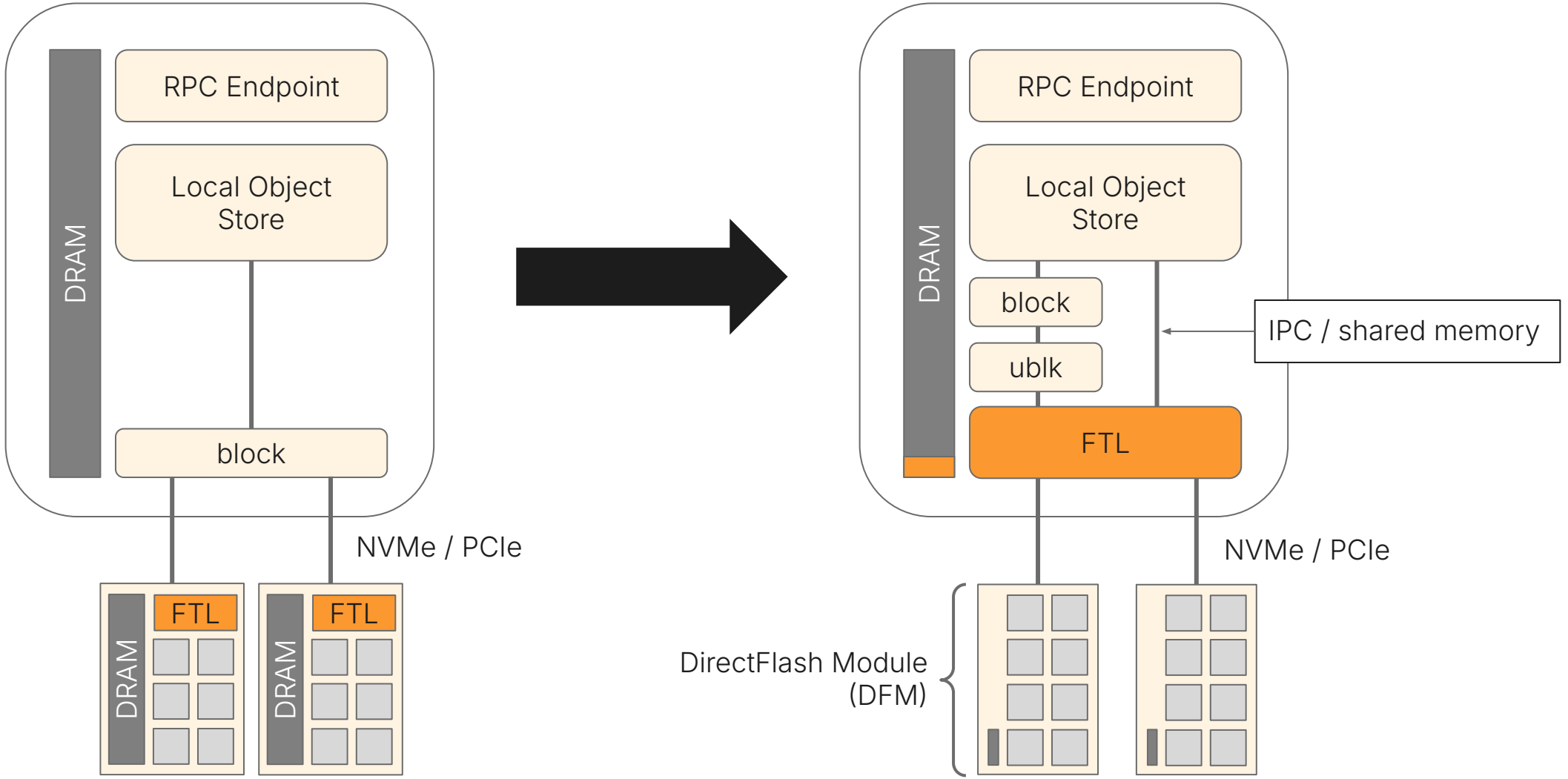
Context	Exascale Storage
Problem	QLC Challenges
Solution	Architectural Perspective

Host-Based FTL



NVMe / PCIe

Host-Based FTL



Late-Binding Configuration

Scale

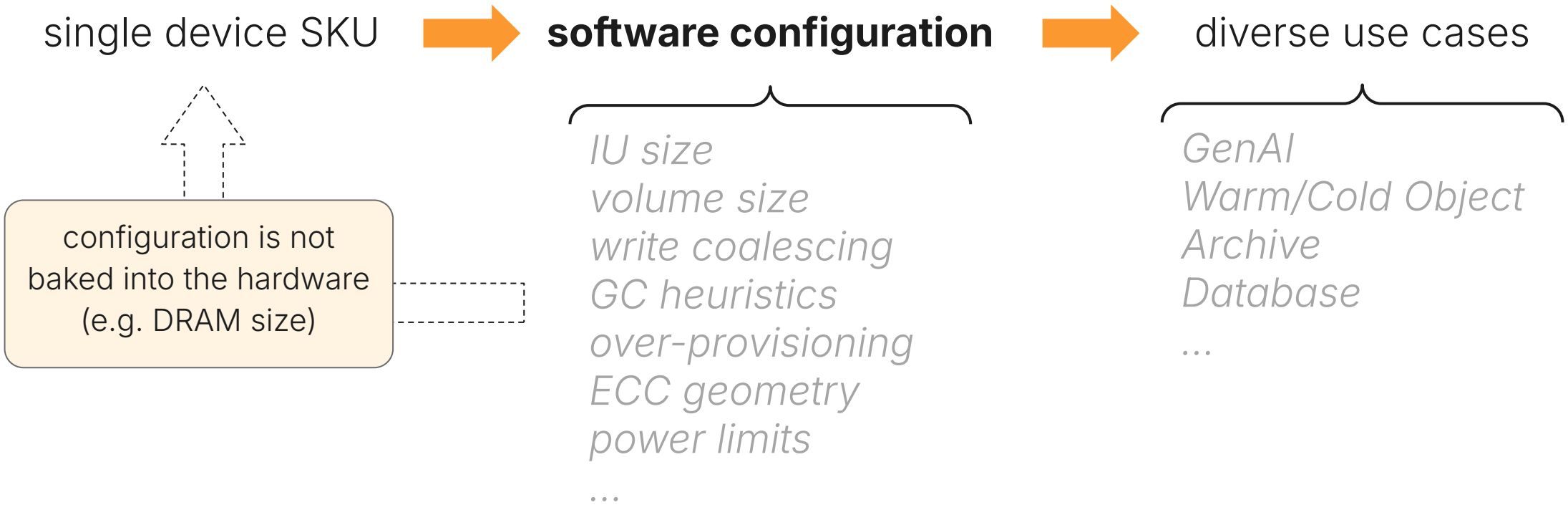
single device SKU → **software configuration** → diverse use cases

IU size
volume size
write coalescing
GC heuristics
over-provisioning
ECC geometry
power limits
...

GenAI
Warm/Cold Object
Archive
Database
...

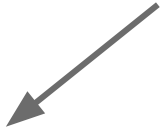
Late-Binding Configuration

Scale



What Next?

driving efficiency in exascale storage



configurability

Scale drives the balance from abstraction to full-stack optimization.

Configure storage media to match the natural patterns of the local object store.

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driving efficiency in exascale storage

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Scale drives the balance from abstraction to full-stack optimization.

Configure storage media to match the natural patterns of the local object store.

media lifetime

low WAF → media lasts **10 years**

How can we fully leverage this, technically and operationally?

PURESTORAGE®