Out of sight, but no longer out of mind: Tackling stored data's emissions footprint

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MICRO 2026 - Sustainability computing architecture



Storage in datacenters account for:

33% of operational emissions [Wang ISCA ’24]



Storage in datacenters account for:

33% of operational emissions [Wang ISCA ’24]

61% of embodied emissions

So let’s talk about storage

Vast amount of storage devices in datacenter

In 1 rack: 8-16 CPUs, 704 HDDs, 21 PB

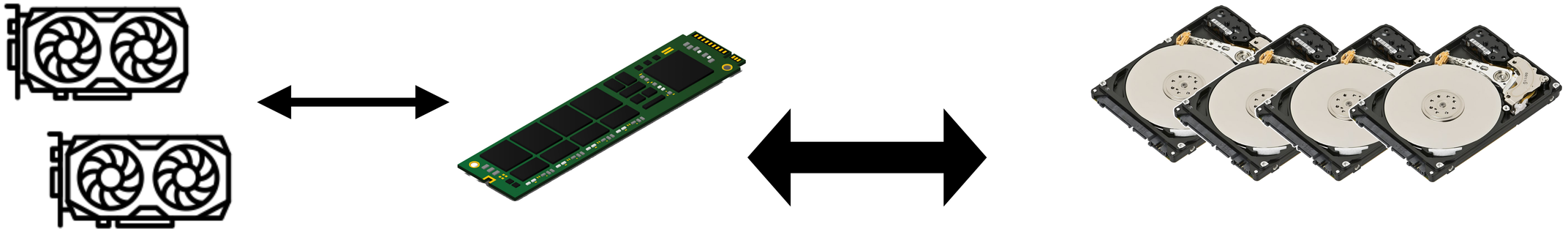


In 1 rack: 36 CPUs, 216 SSDs, 9 PB

Across cluster: 1,000,000s of disks and growing

Storage is different: Need for storage-specific solutions

Performance and **capacity** are both important



SSD as memory replacement

Store rarely accessed videos for years

Performance-oriented

Capacity-oriented

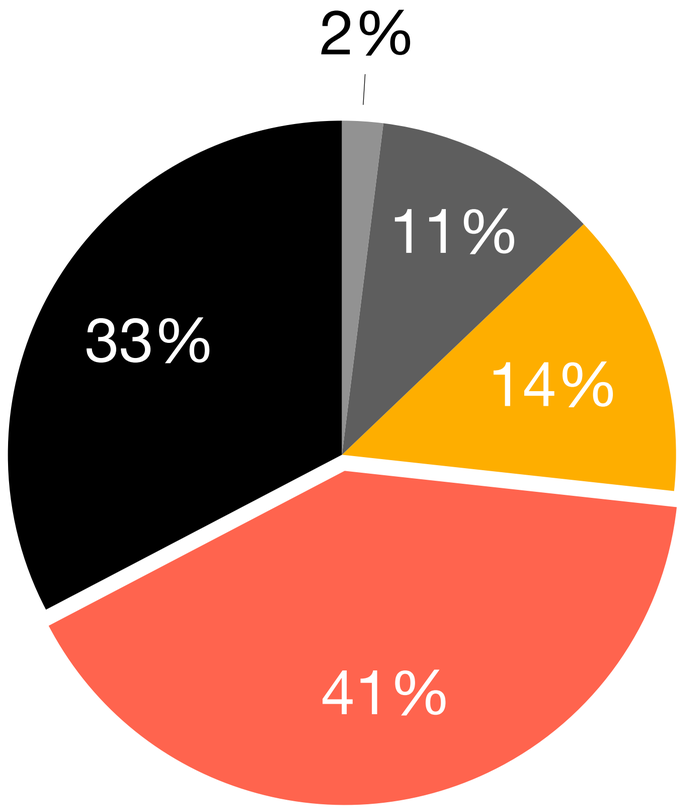
Where are storage emissions coming from?

HDD racks:



Capacity tier:
Less expensive per bit, large capacity





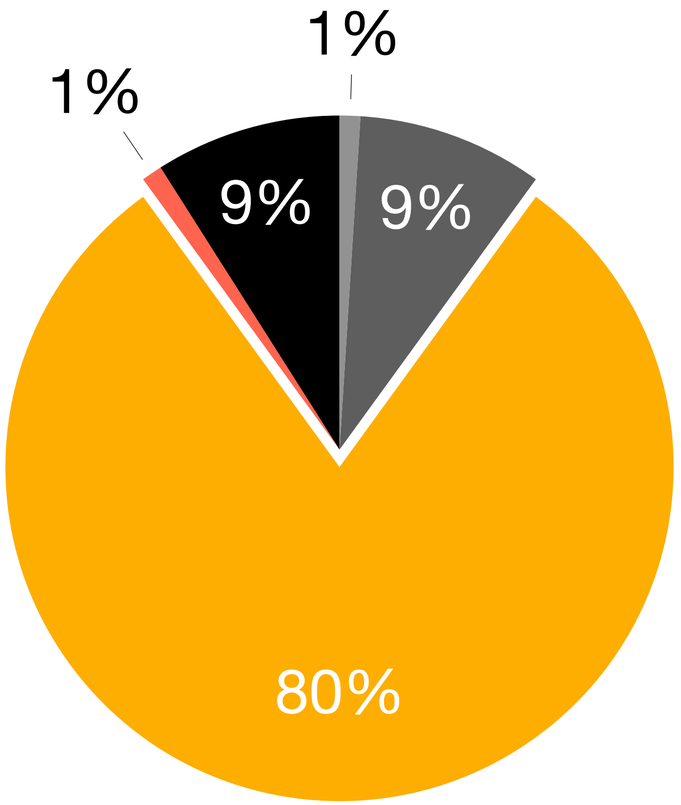
Where are storage emissions coming from?

SSD racks:



Performance tier:
More expensive per bit, lower capacity





4x operational emissions per TB, 10x embodied emissions per TB

Reducing storage emissions

Annual Emissions = Operational Emissions + Embodied Emissions

$$= \sum_{\text{Devices}} \left(\frac{\text{Watt Hours}}{\text{Device}} \times \frac{\text{Carbon}}{\text{Watt Hour}} + \frac{\text{Carbon}}{\text{Device}} \times \frac{1}{\text{Lifetime}} \right)$$

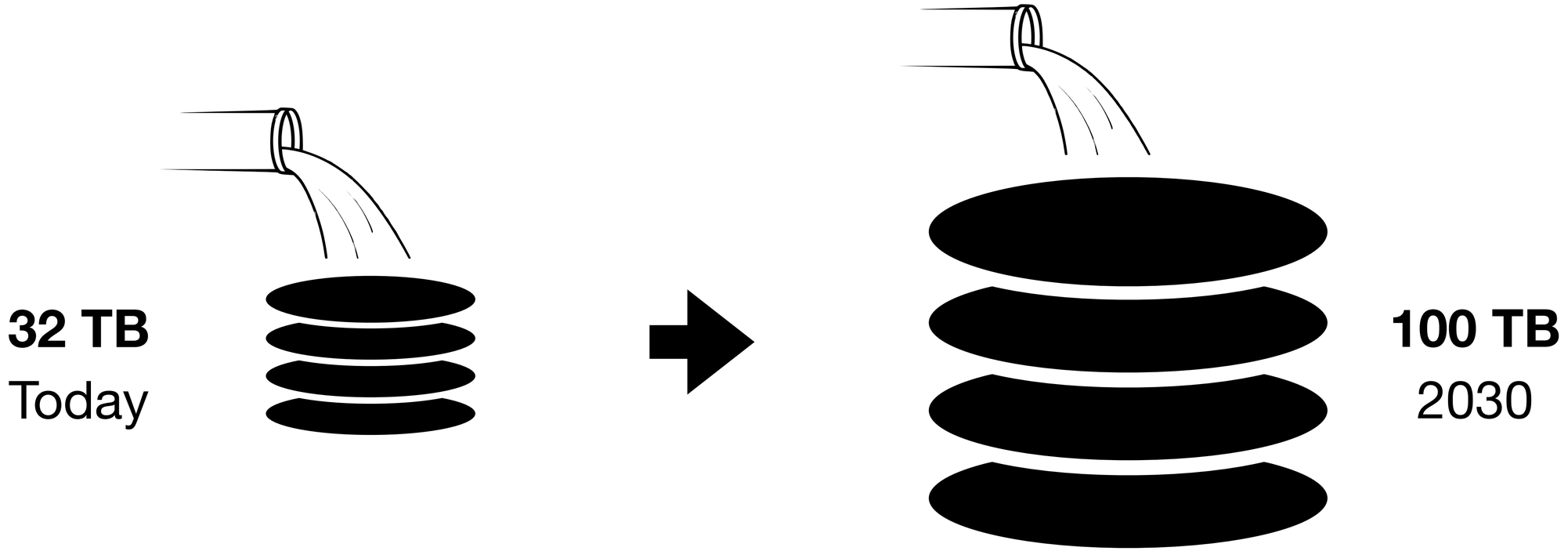
1) Lowering & shifting power demand

2) Fewer, denser Devices

3) Longer lifetimes

Storage is different: Denser drives → IO problems

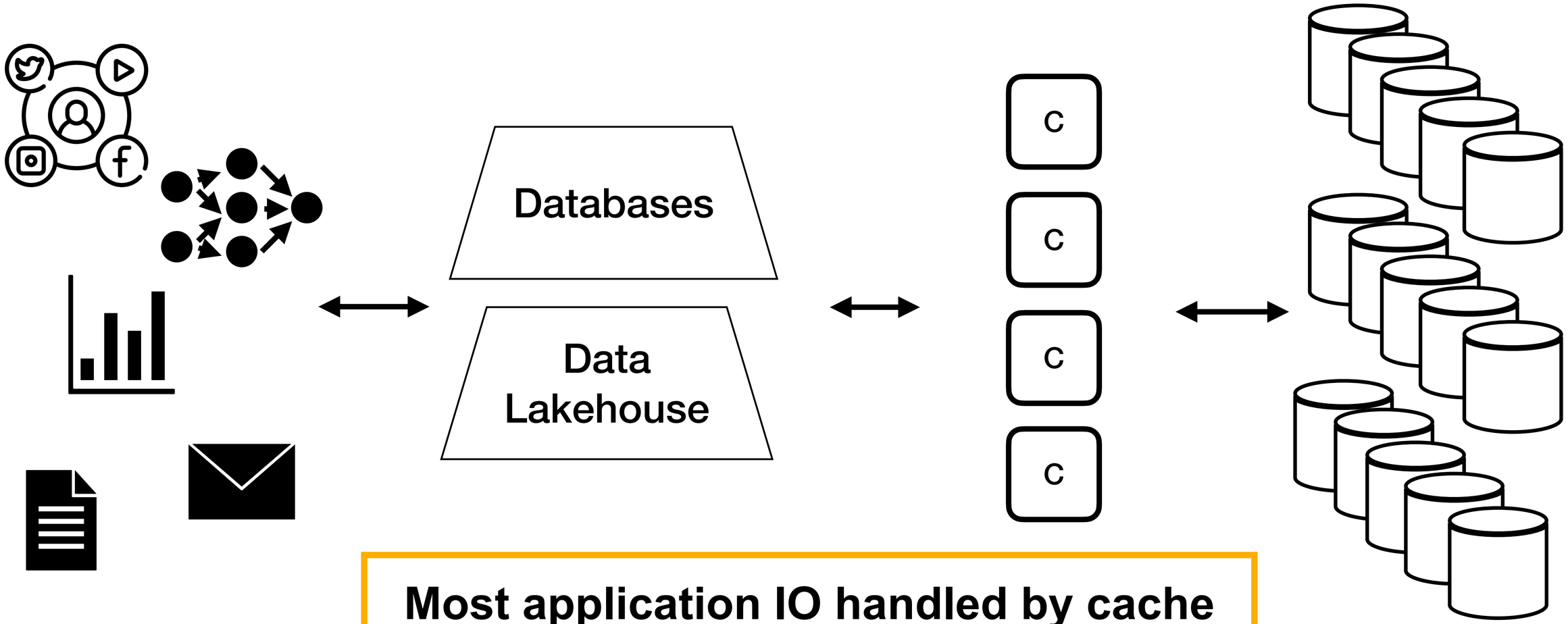
Both HDDs and SSDs are getting denser w/ similar manufacturer processes



IO per second (IOPS) will not significantly increase

Cross-datacenter design essential to reduce IO enough for new drives

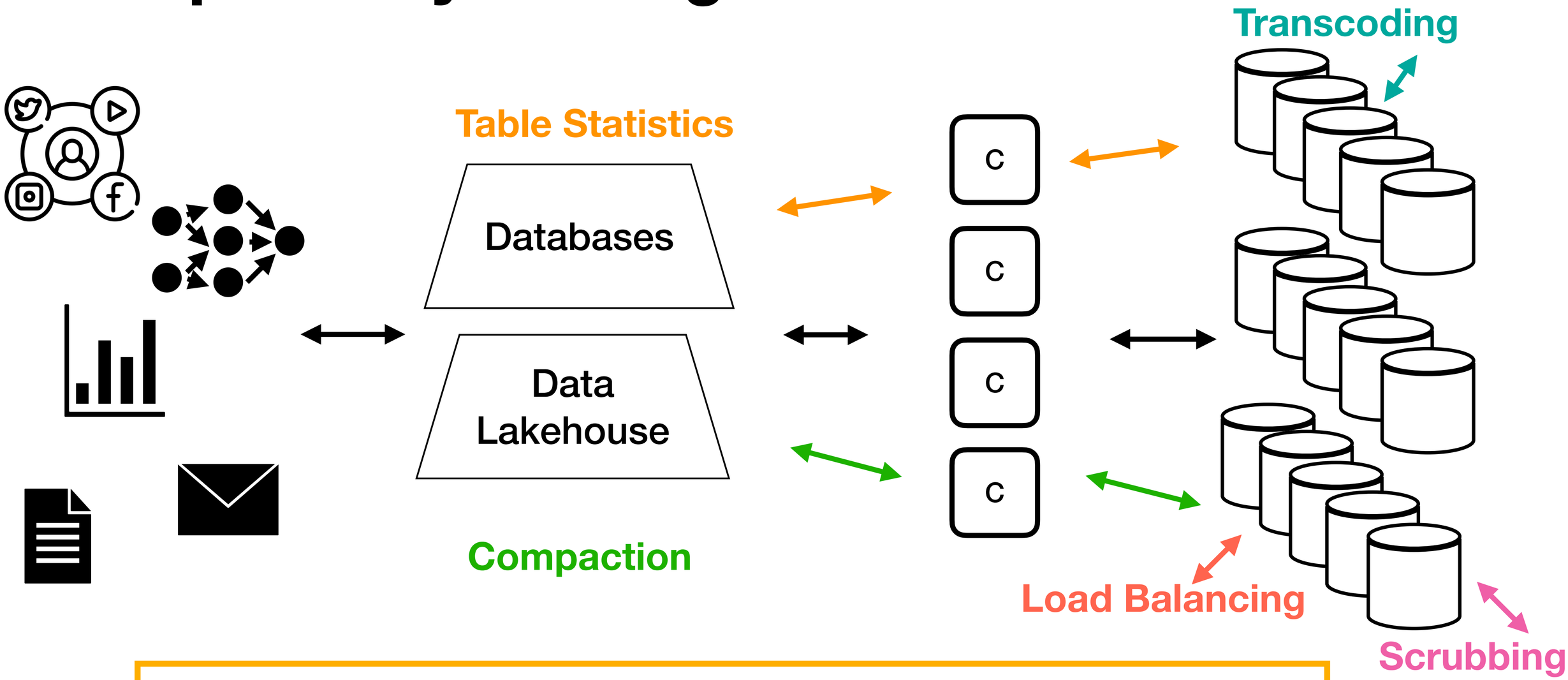
Where is IO coming from?



Most application IO handled by cache

Application **Data Management** **Caches** **Bulk Storage**

IO is primarily coming from data maintenance



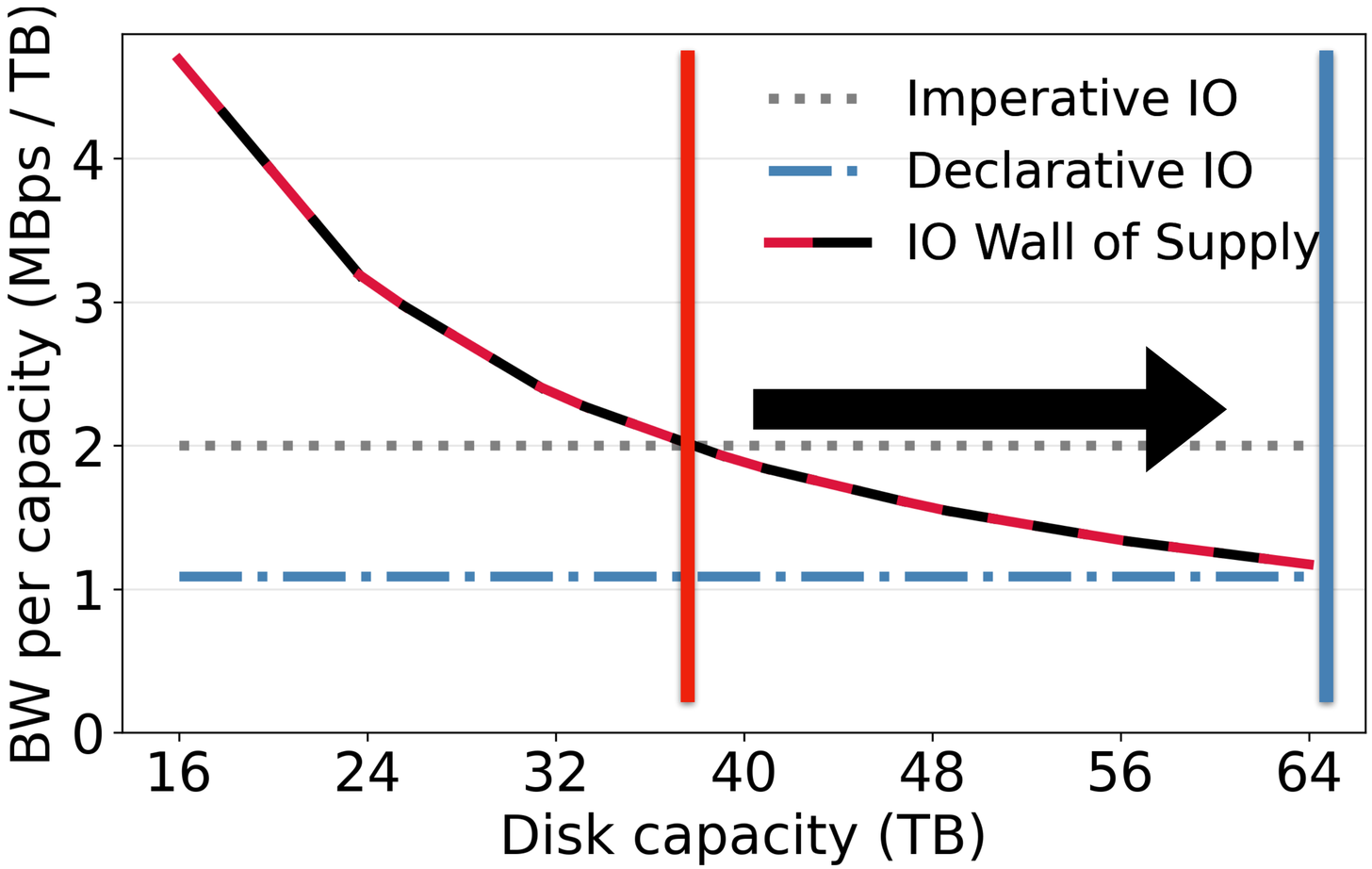
Appli

45-70% of IO is maintenance across 6 hyperscalers

Storage

Athlur et al. OSDI '26

Scaling the IO Wall with Declarative IO



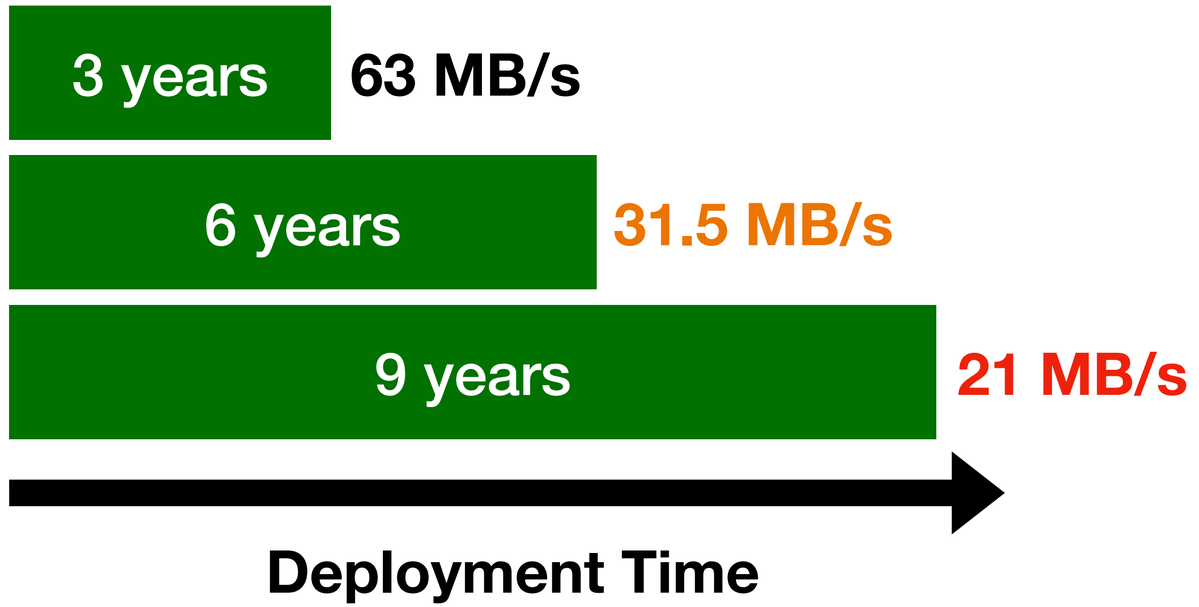
Declarative IO uncovers IO flexibility, enabling DINGO to combine IO

DINGO has 26-51% IO savings → allowing **1.7x larger HDDs**

Athlur et al. OSDI '26

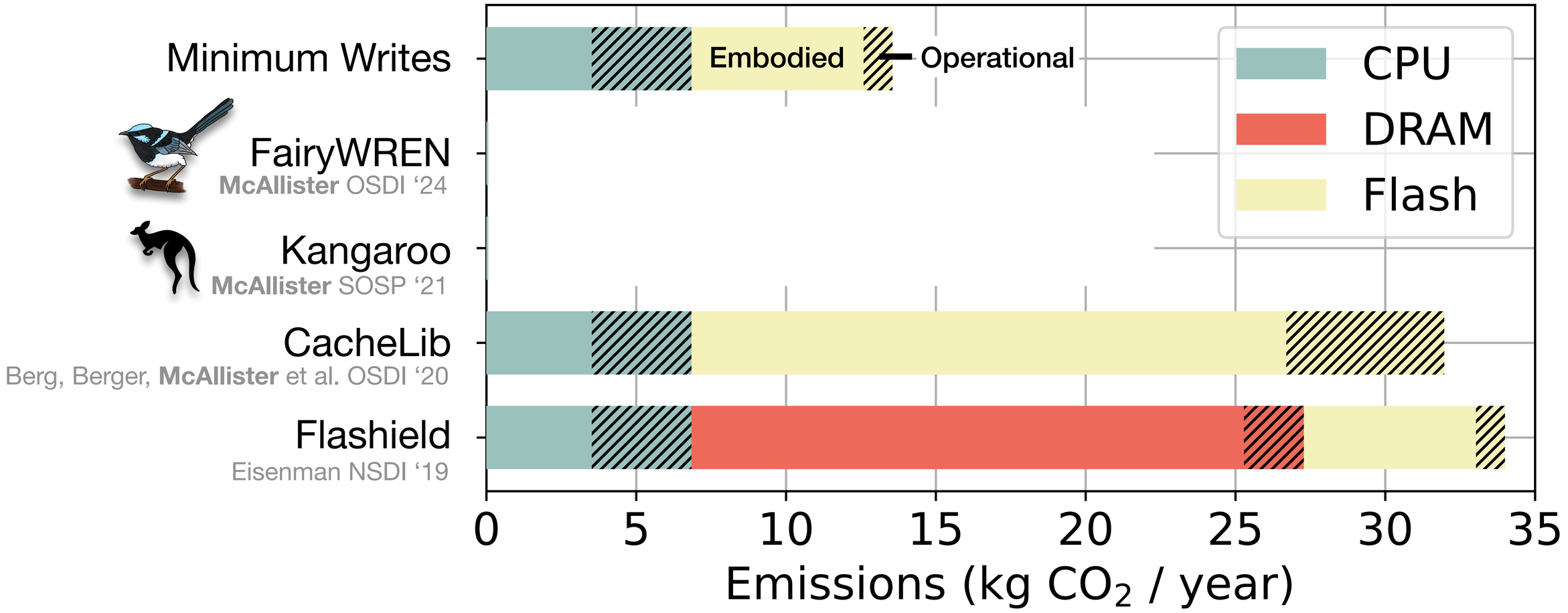
Storage is different: Storage wears out

Longer lifetime ➡ stressing limited flash write endurance



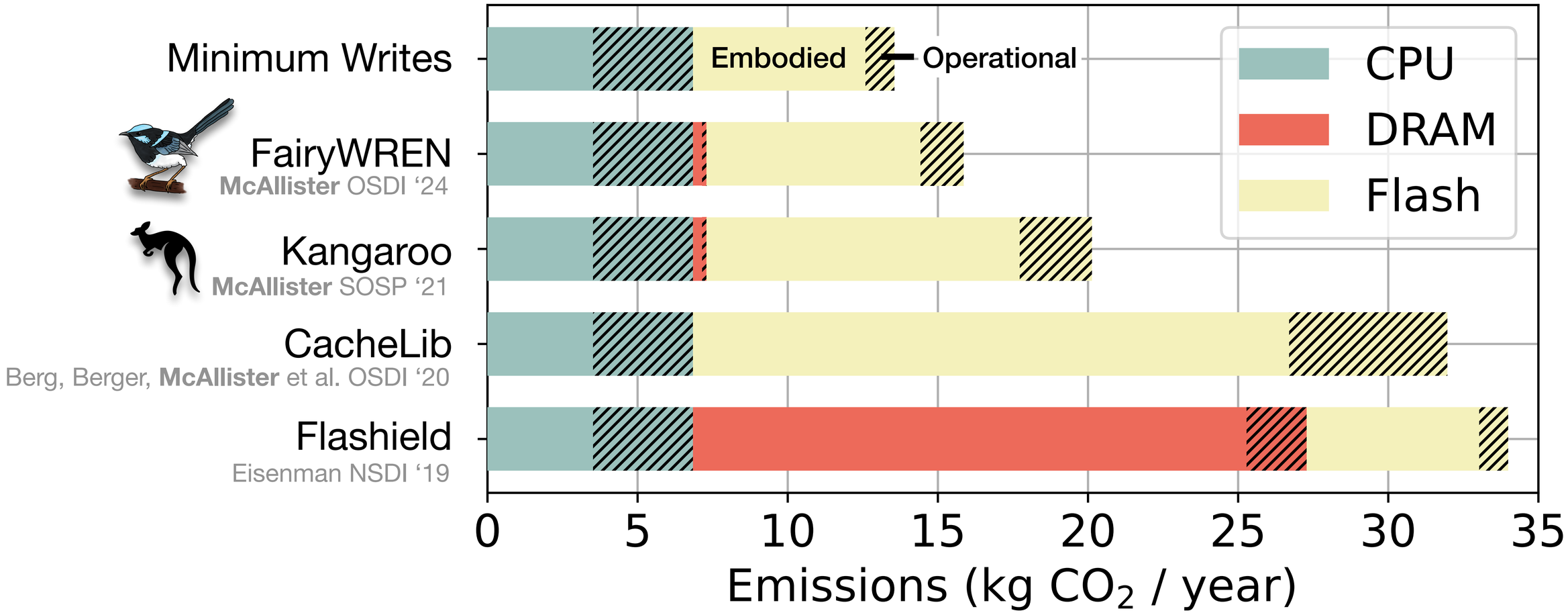
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Caching server emissions for 6 year lifetime, 30% miss ratio target on a Twitter trace



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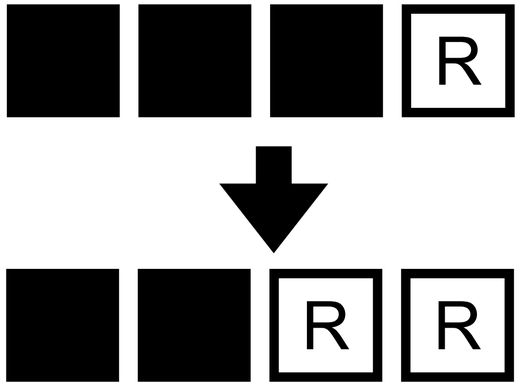


Kangaroo + FairyWREN reduce emissions >50%

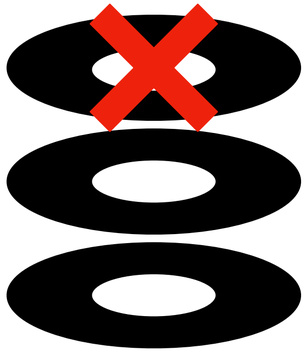
We need storage-specific solutions

From hardware to systems to applications

Extending useful lifetime



Adaptive Redundancy

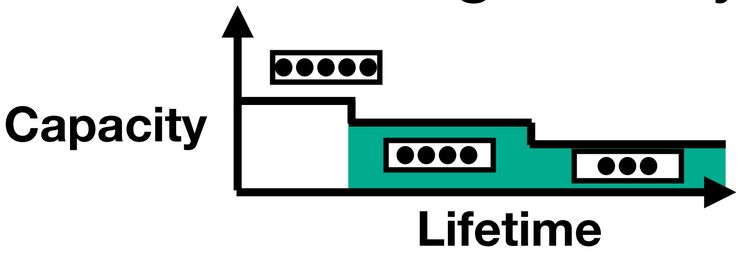


Partial failure

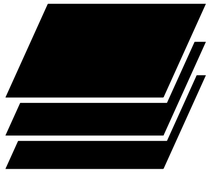
Caching

Second life in failure-tolerant applications

Enabling density with necessary performance



Dynamic density



Write-optimized co-design



Storage is different

We need solutions to reduce emissions in storage

Even more pressing as datacenters build out