Rethinking File Mapping in Persistent Memory

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EFES

Good News! PM has arrived!

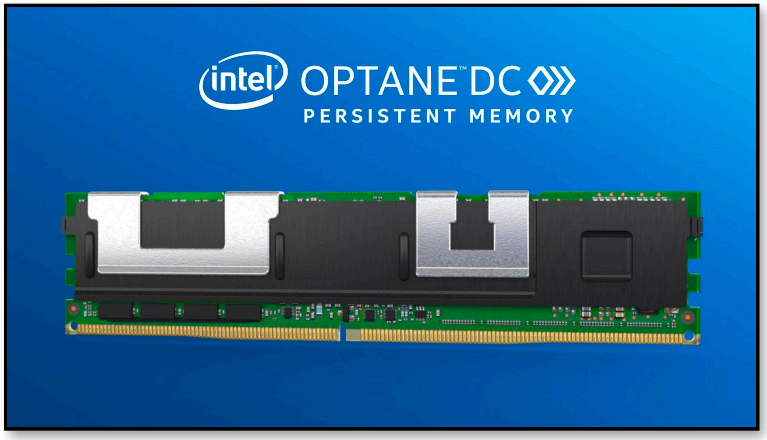

Image Source: https://www.intel.com/content/www/us/en/architecture-and-technology/optane-dc-persistent-memory.html

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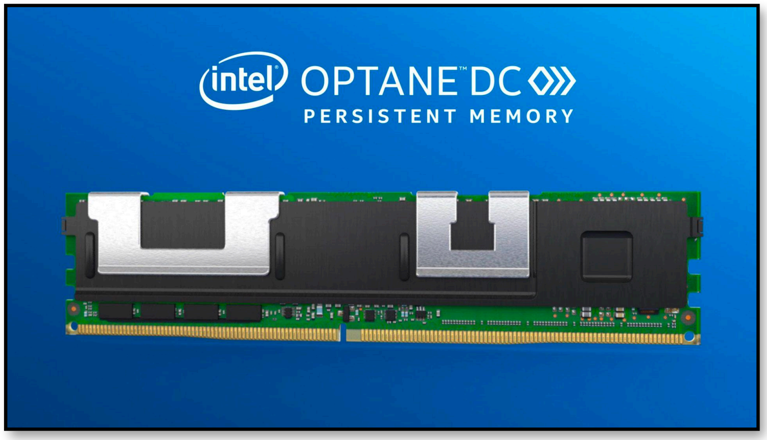
  - AKA non-volatile memory (NVM)



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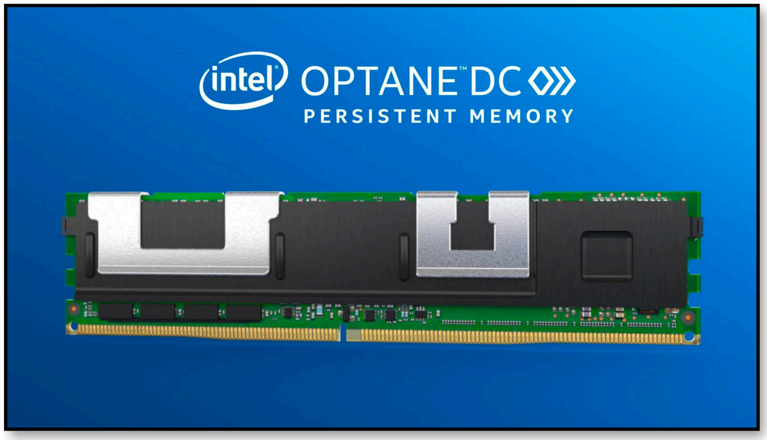

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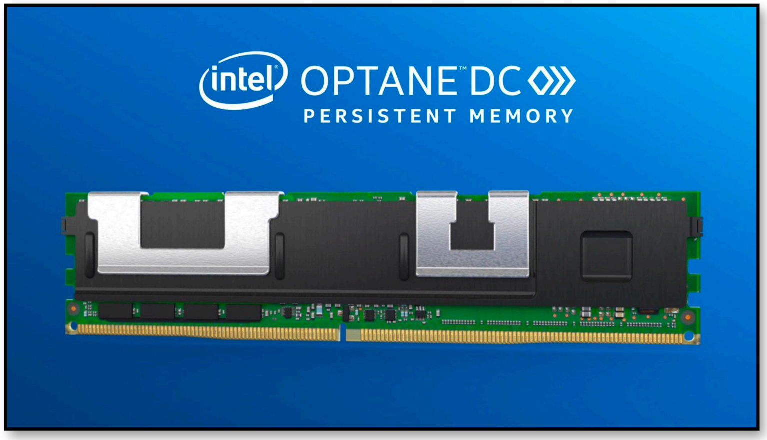

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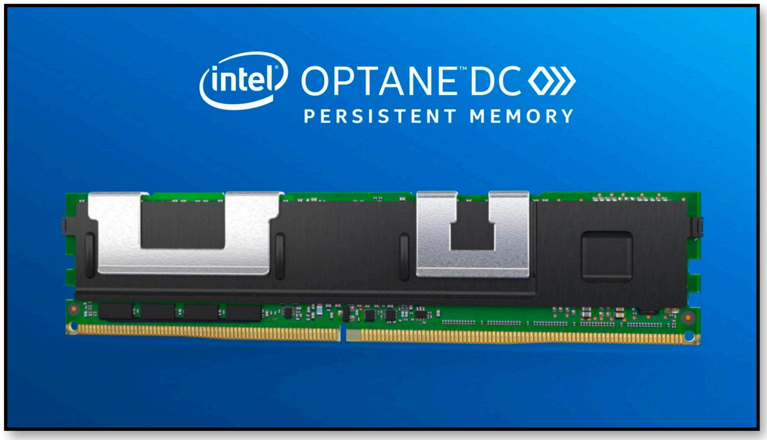
- ***No rigorous analysis of IO path performance!***



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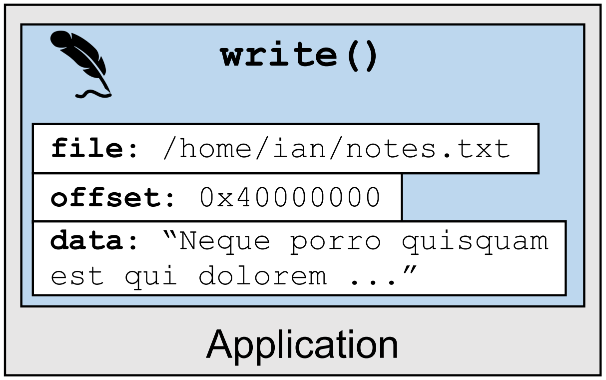

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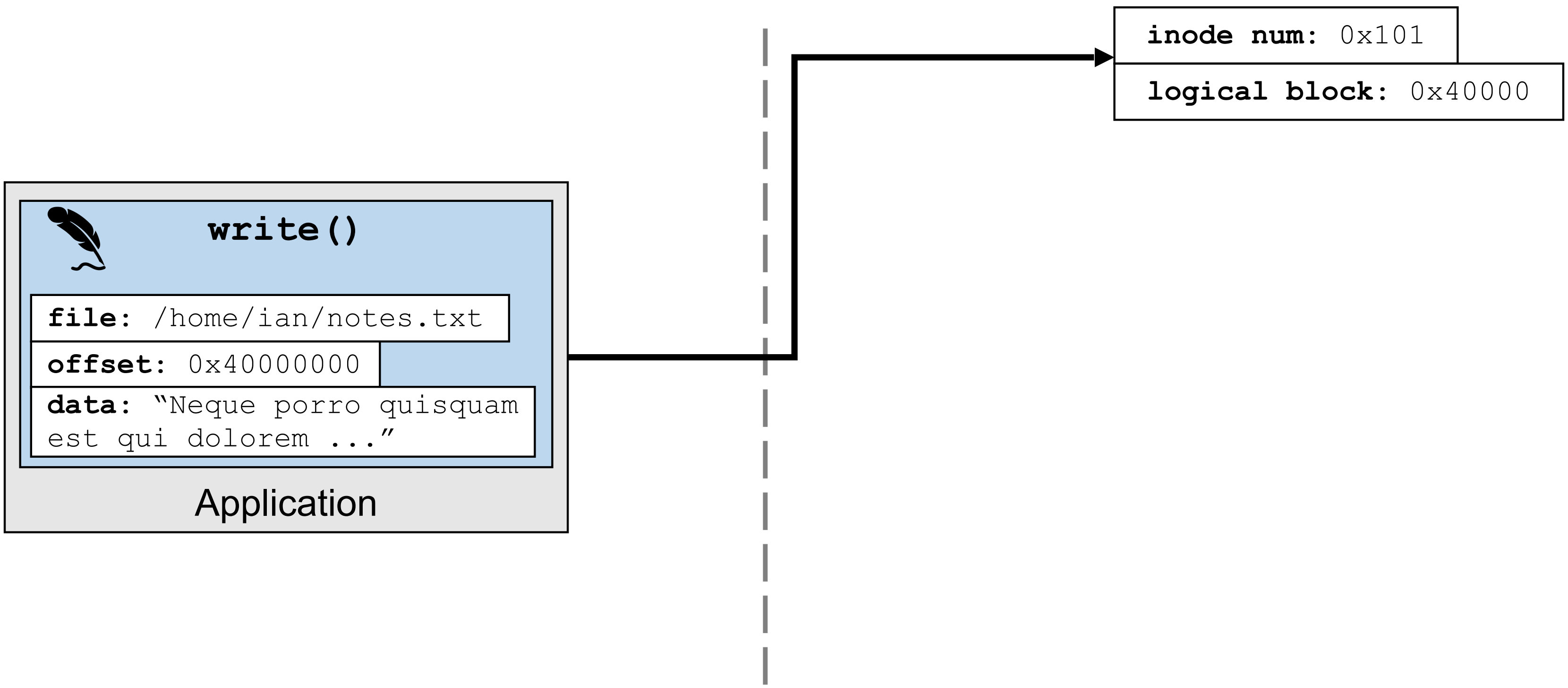
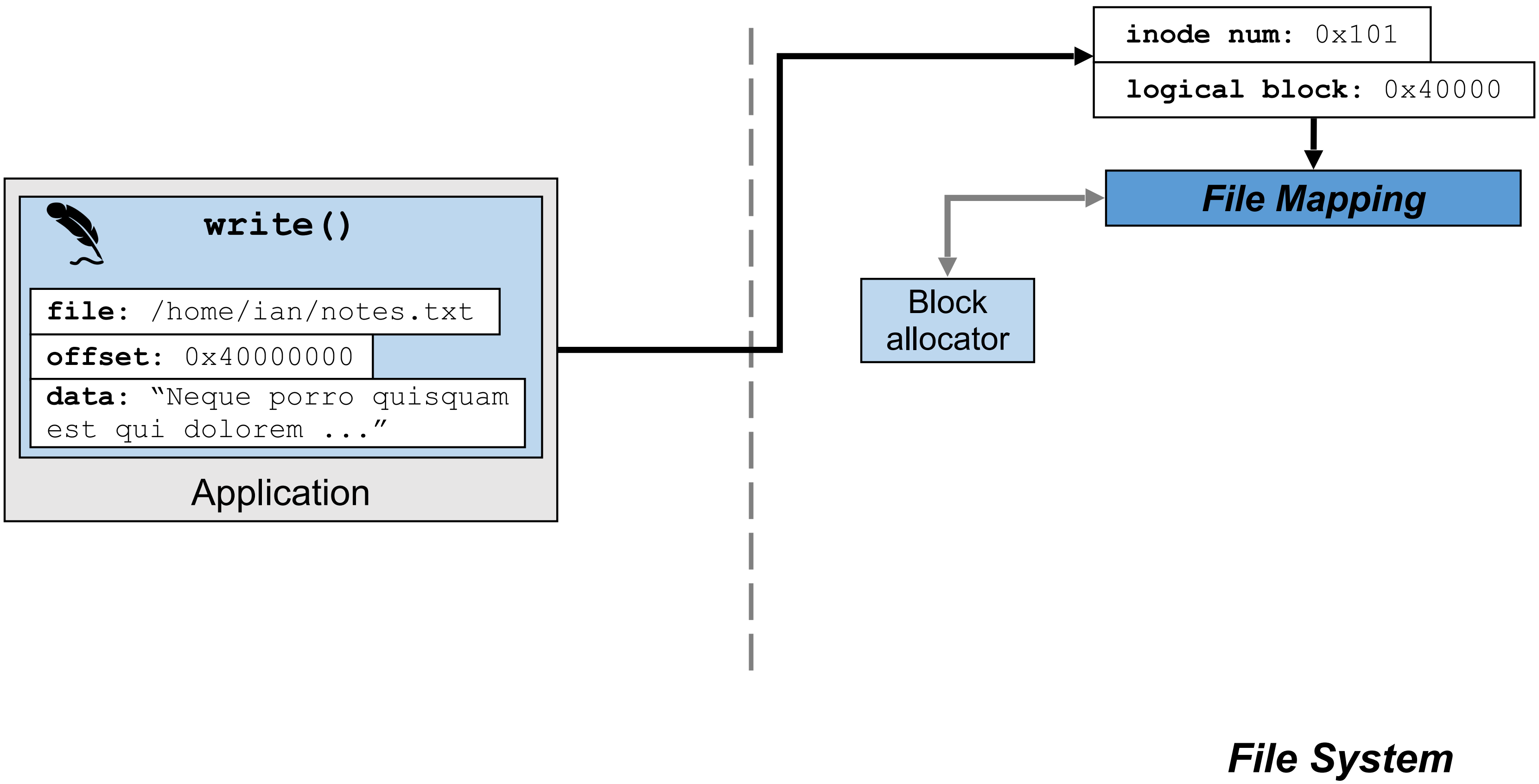


File System

File IO Before PM



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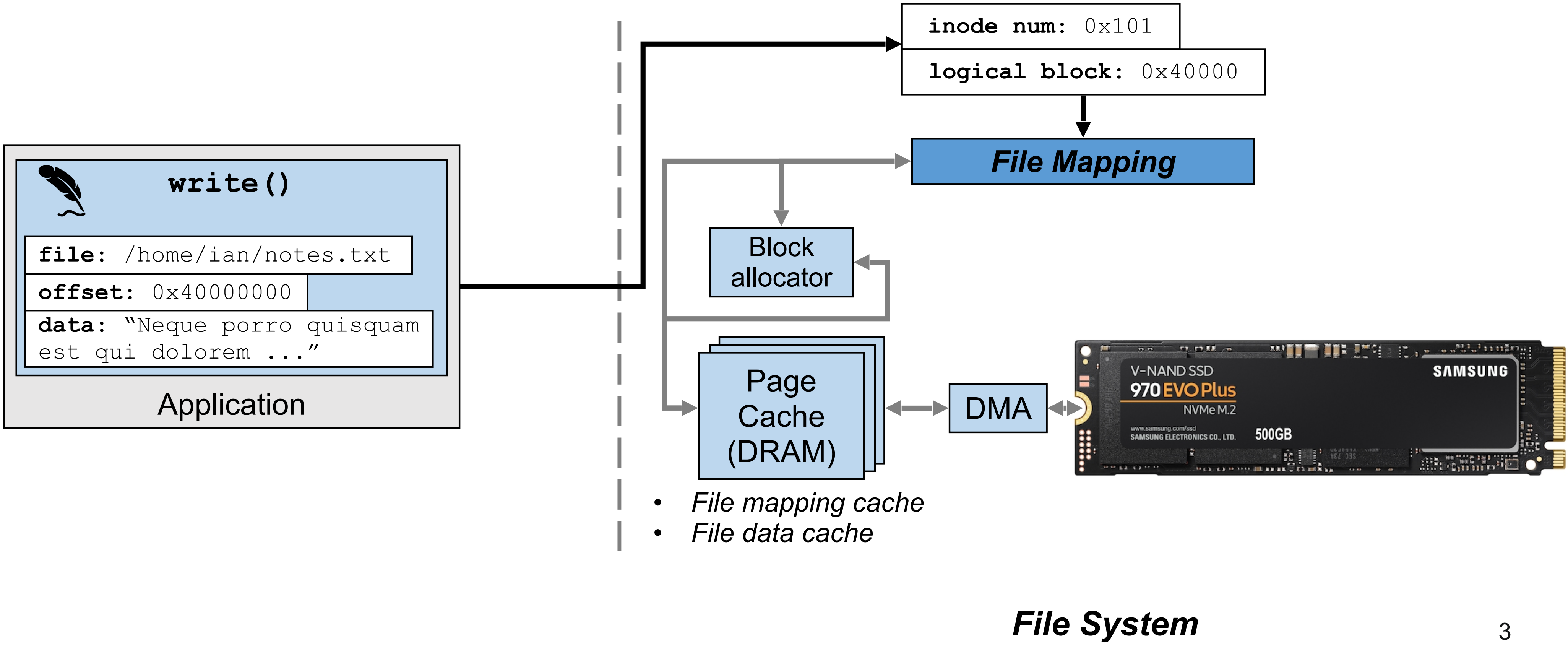

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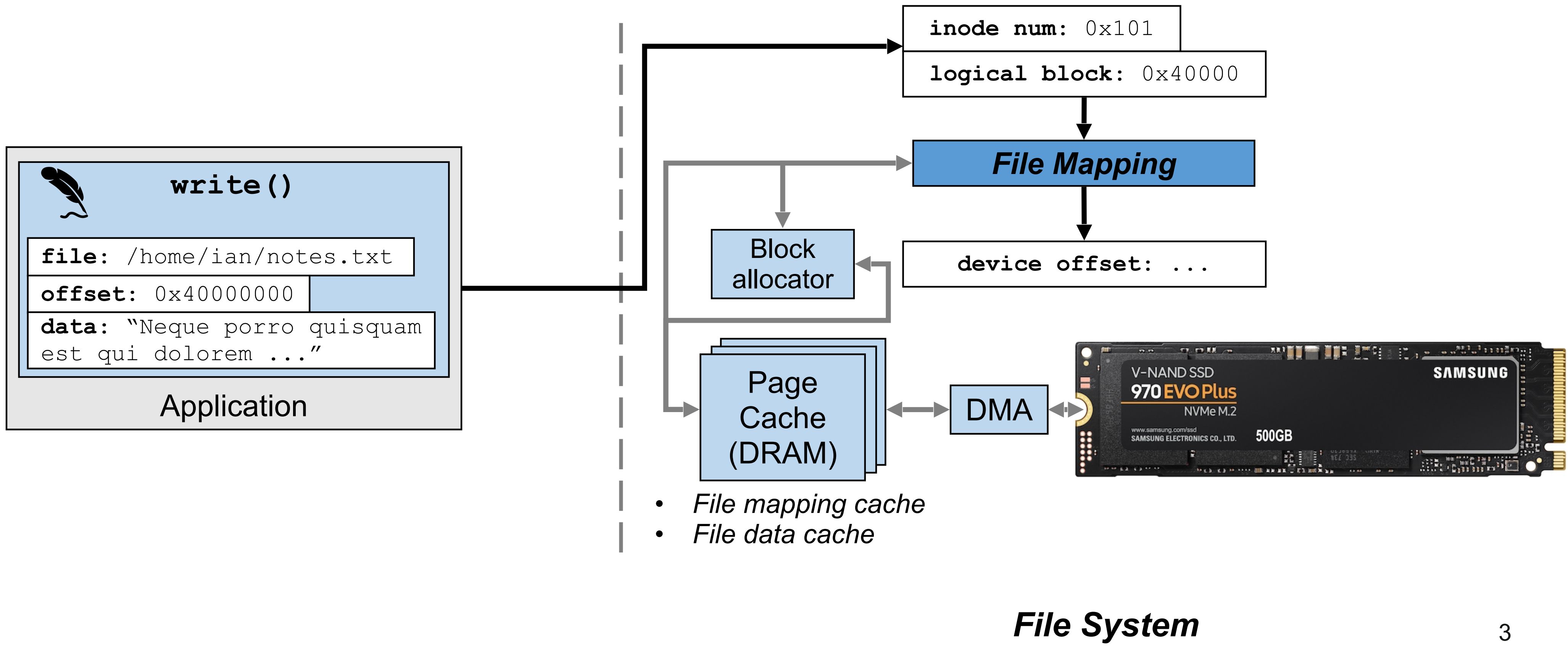

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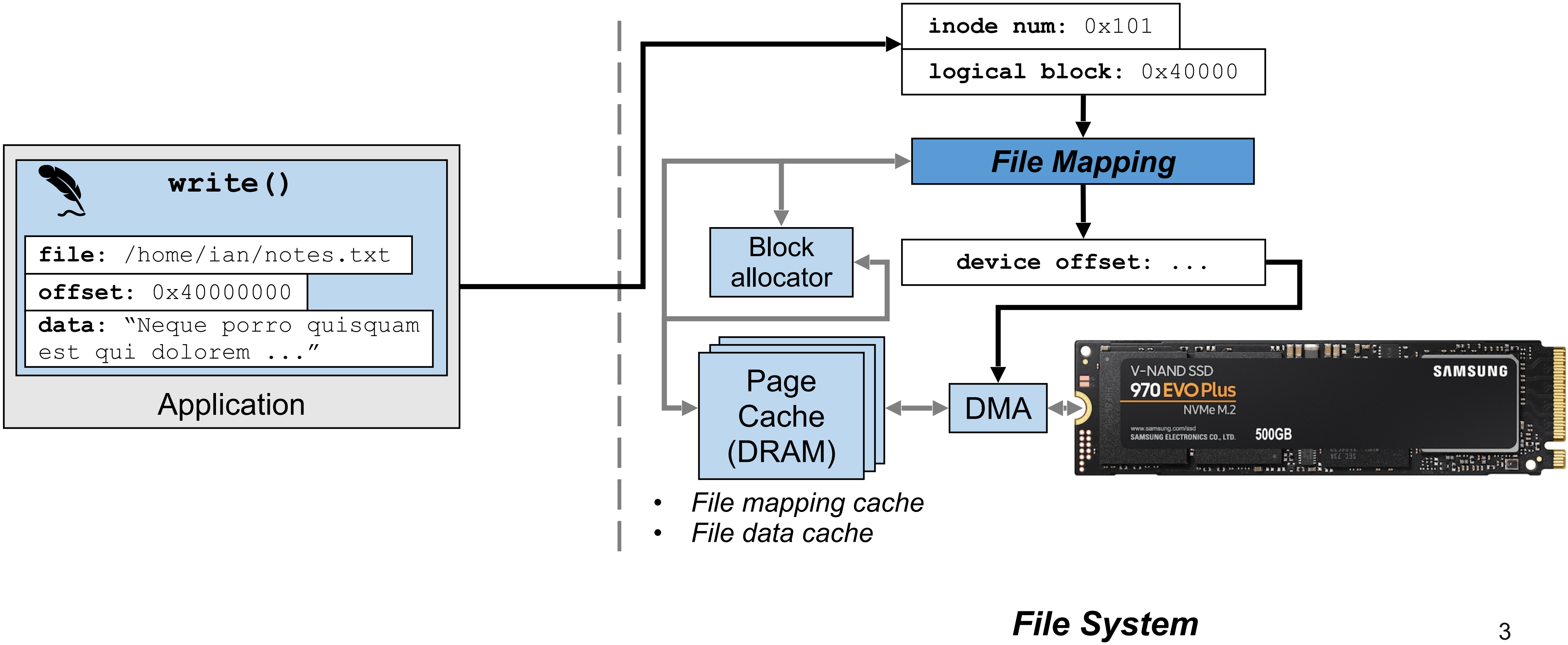
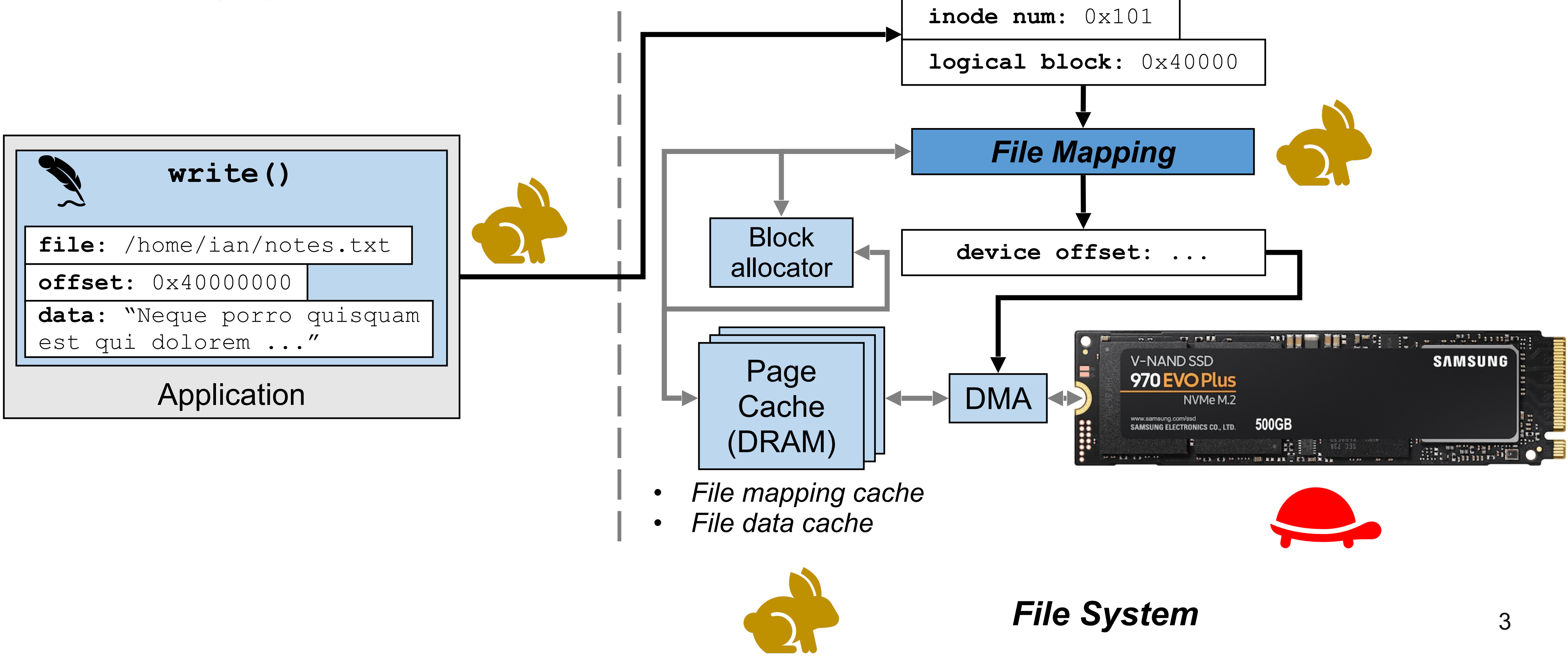


File IO Before PM

- When devices were slow, FS software overheads were negligible



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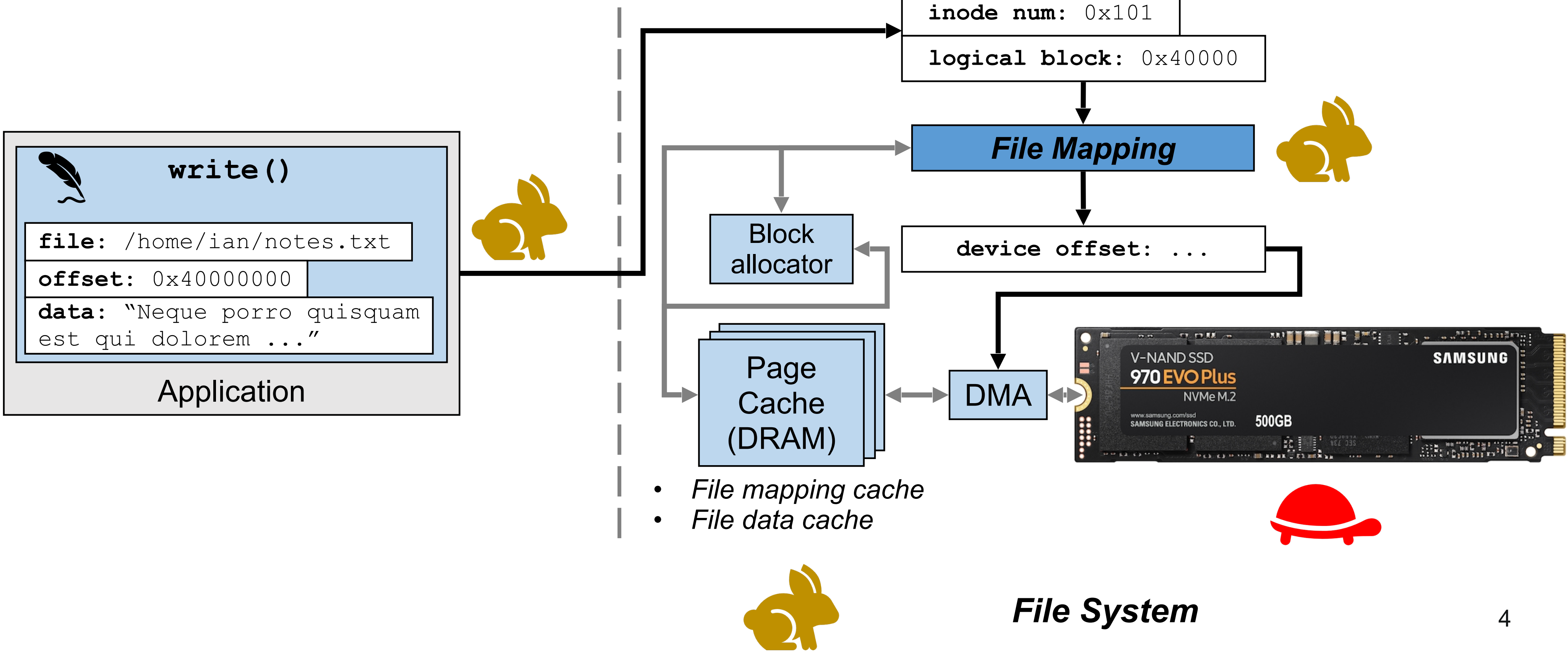

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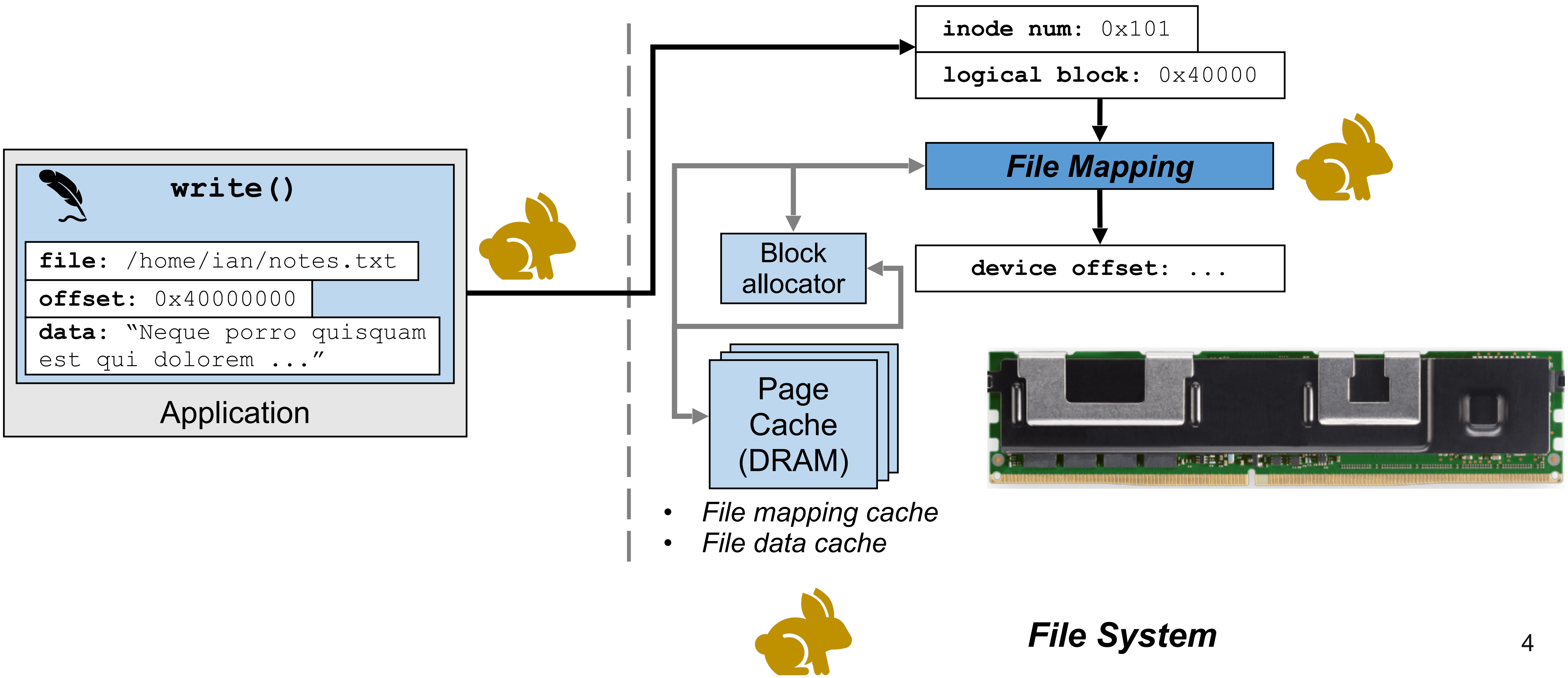

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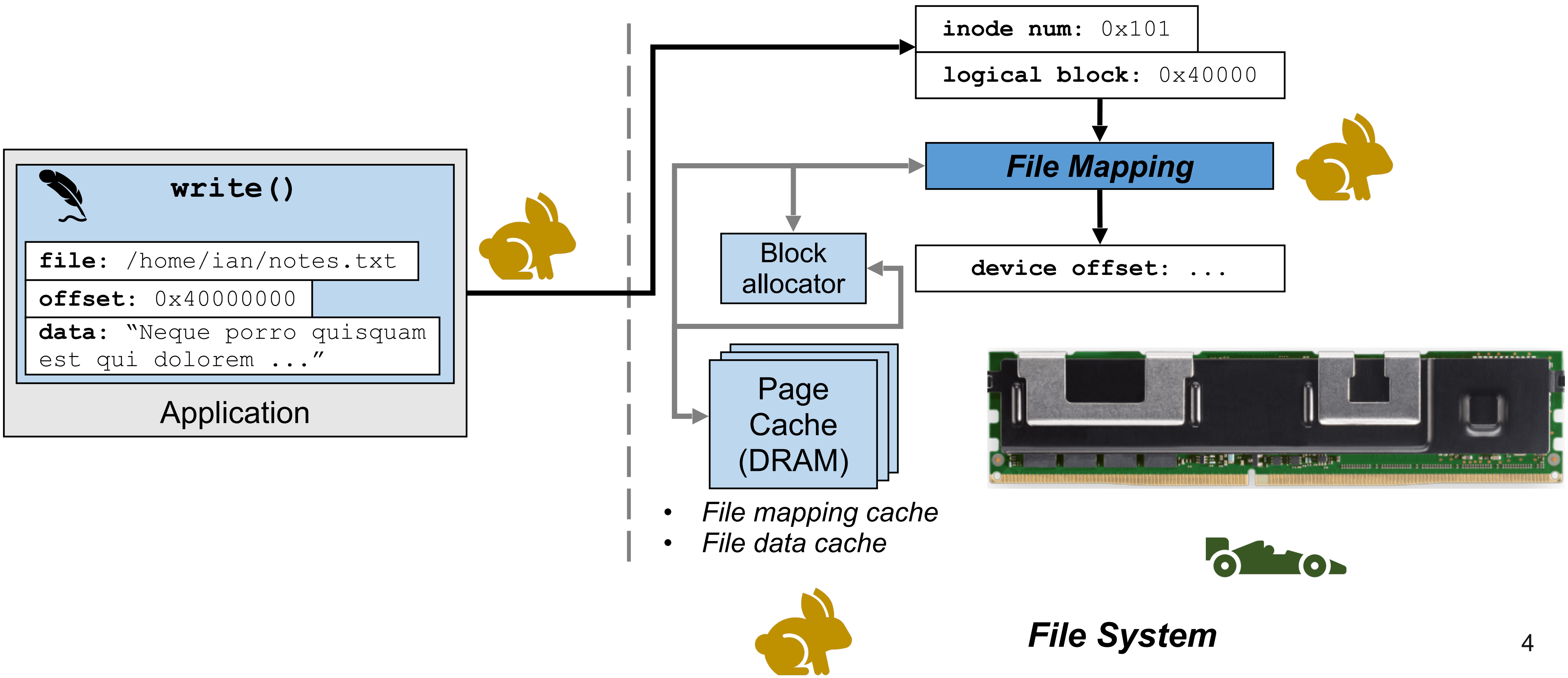

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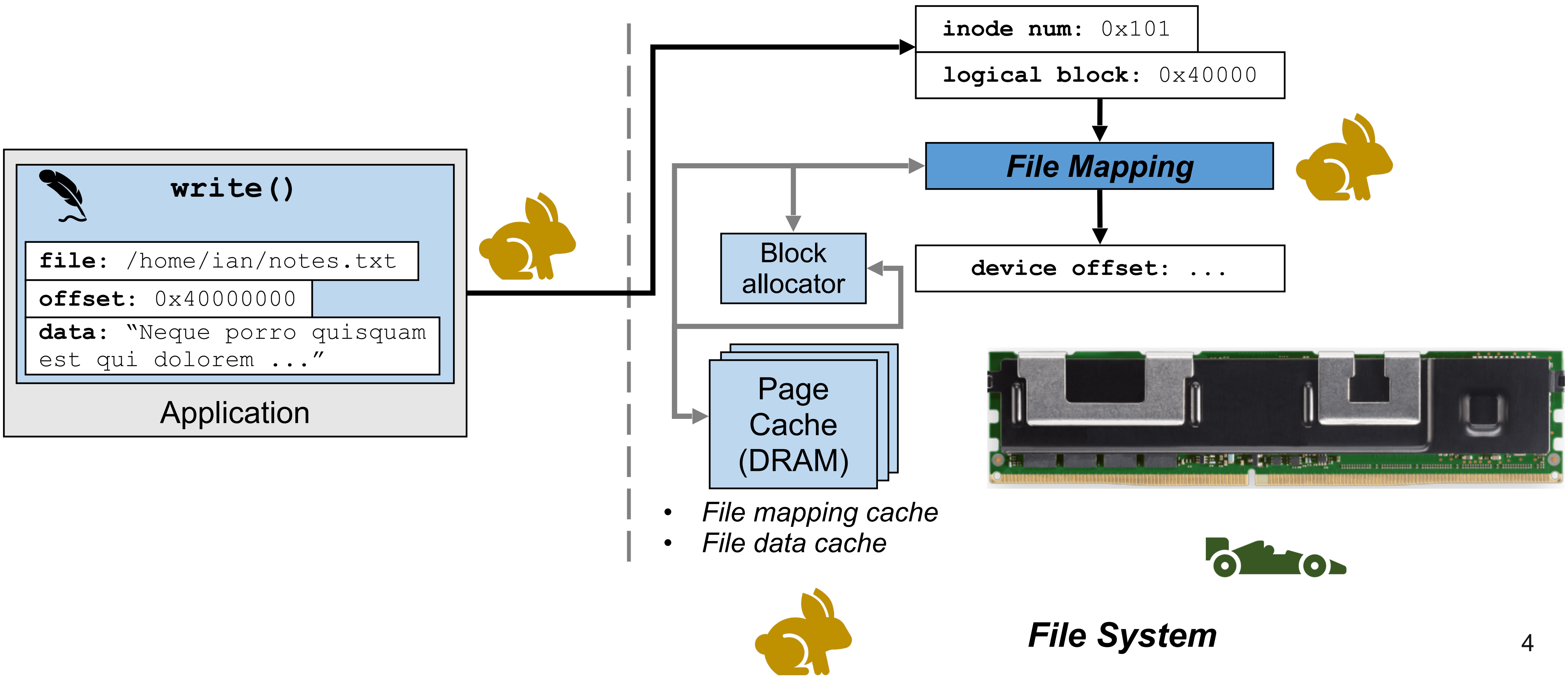

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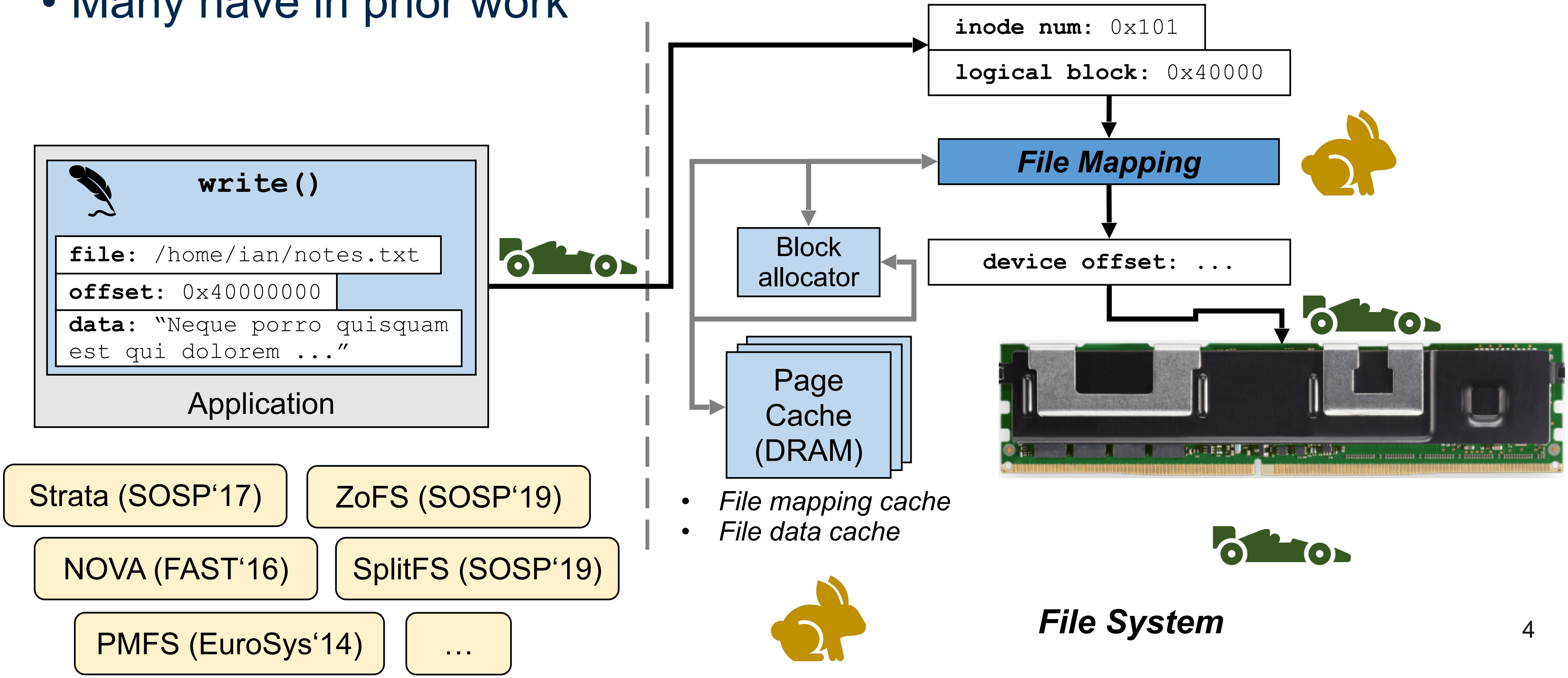

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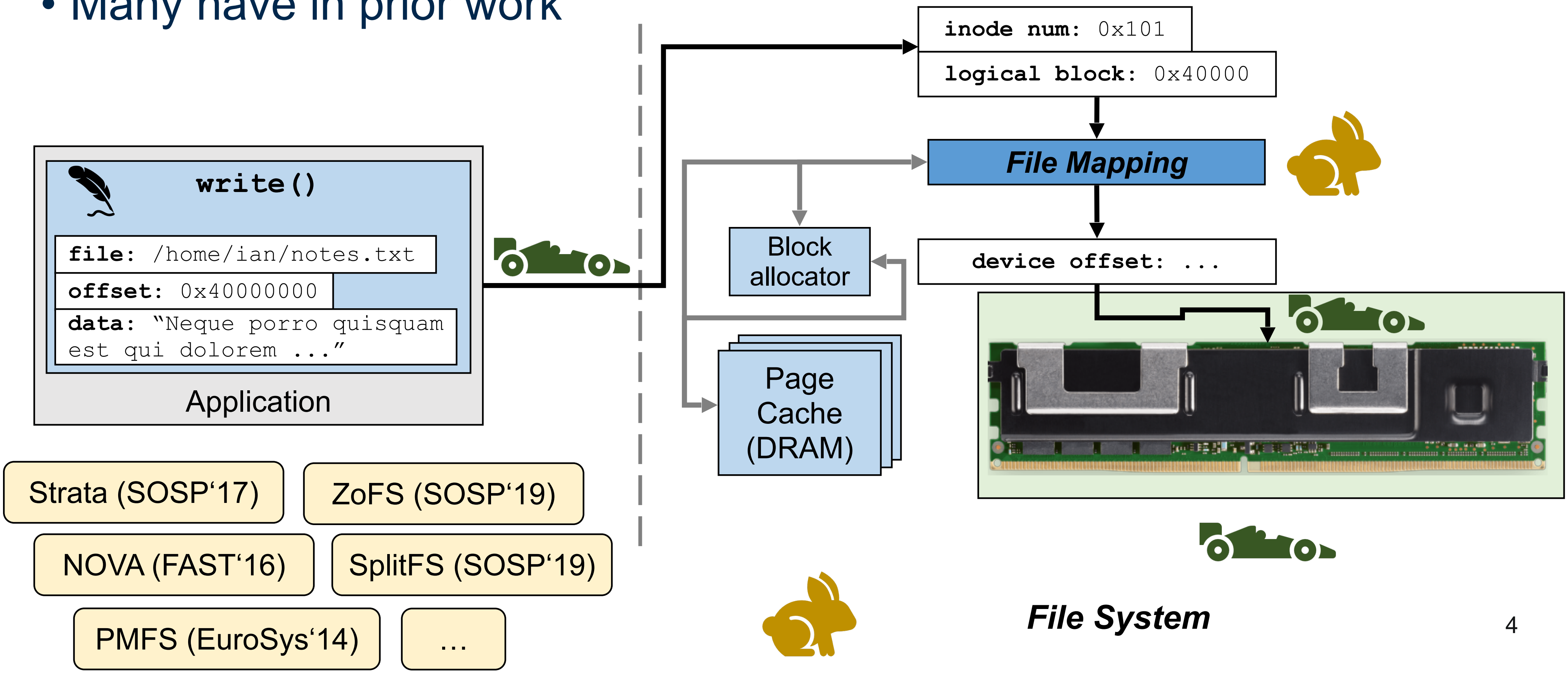

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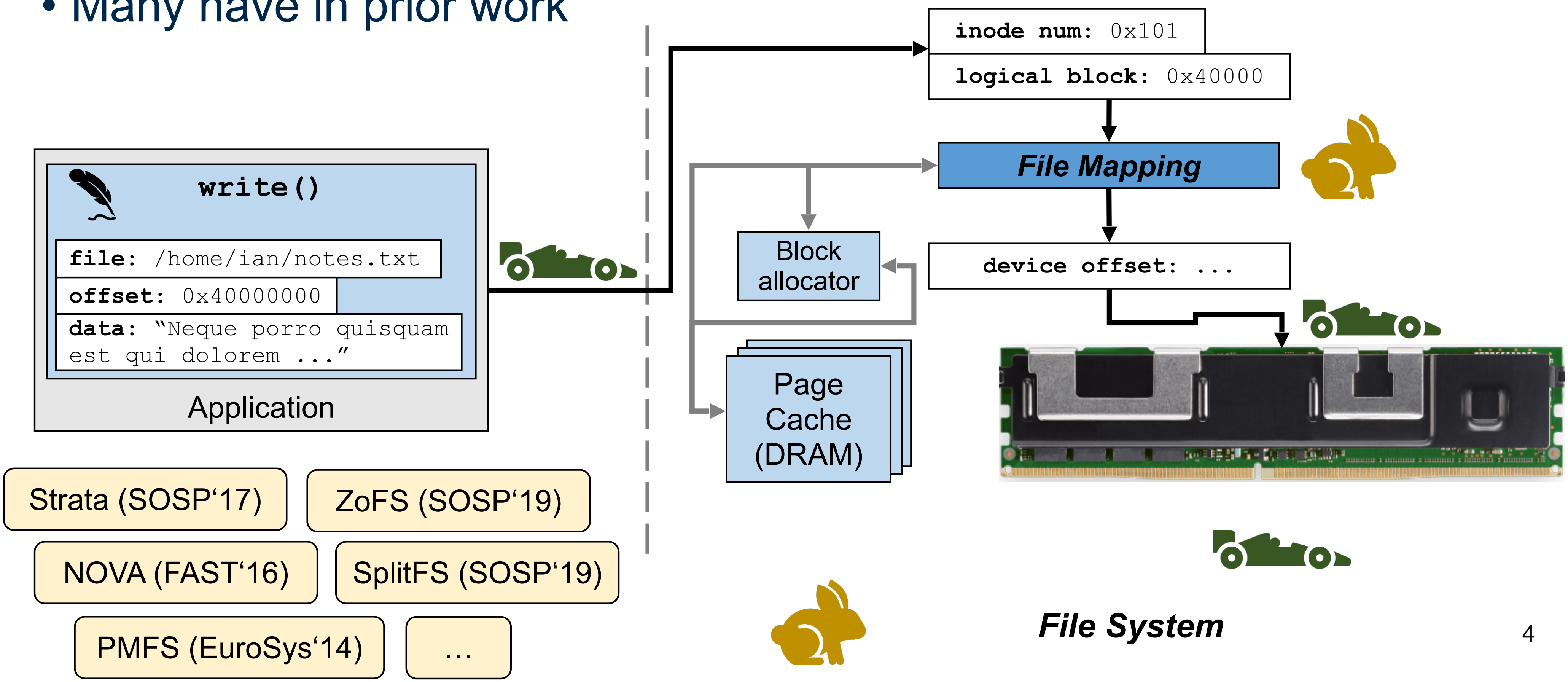

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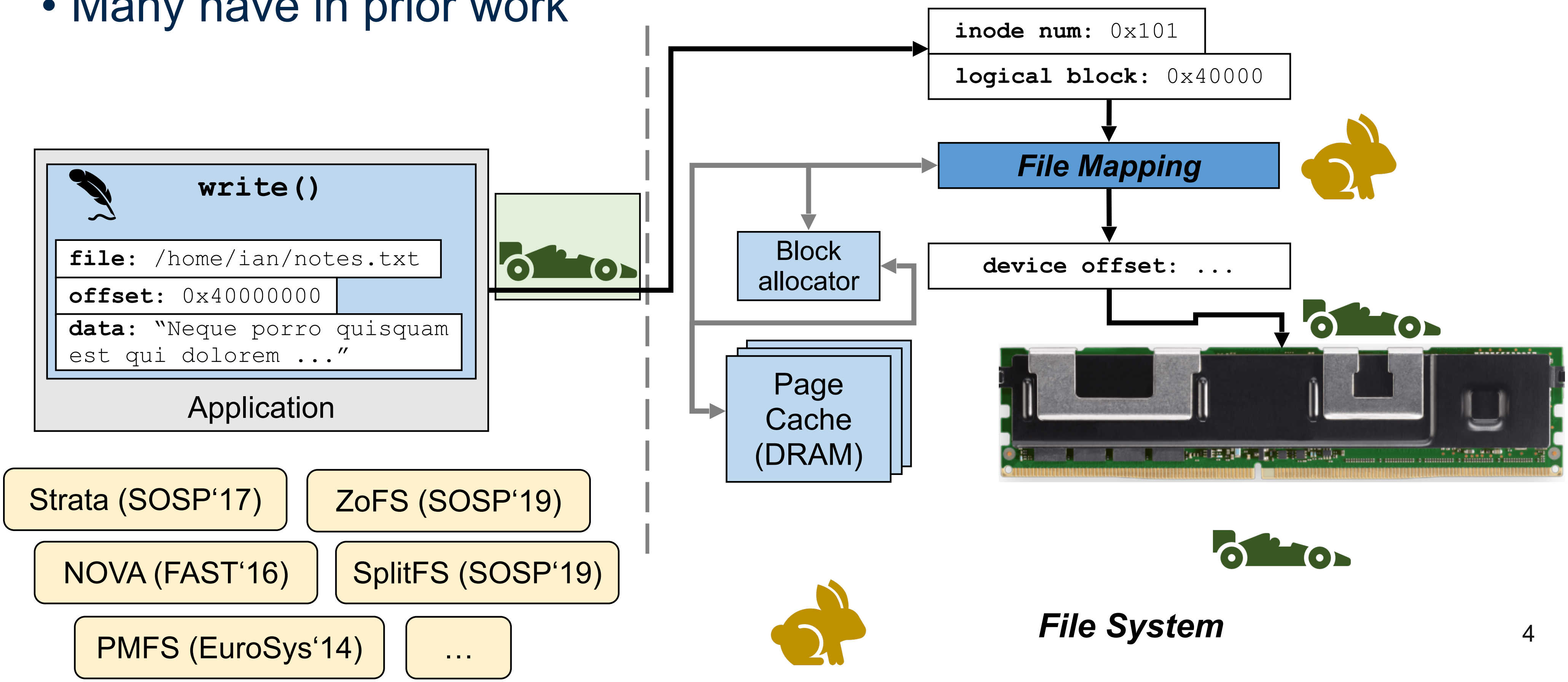

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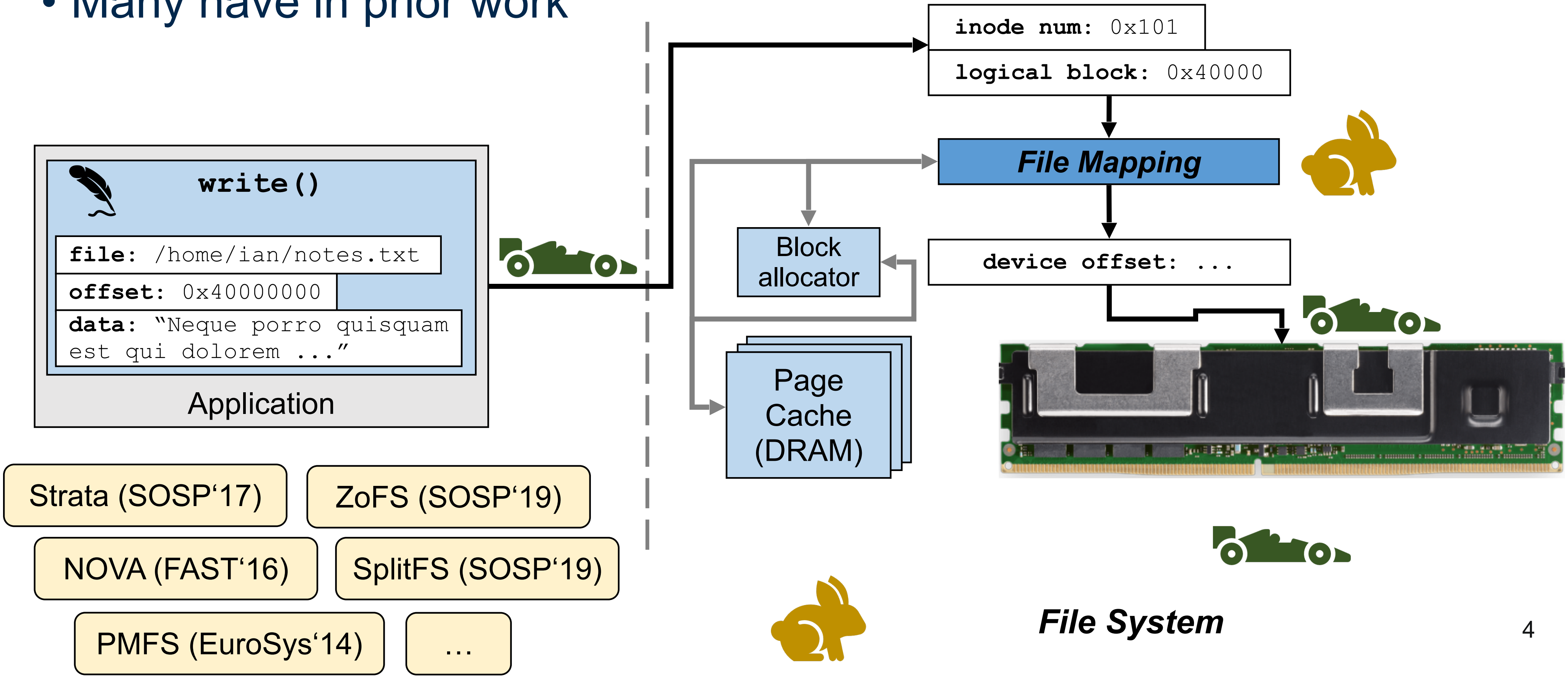

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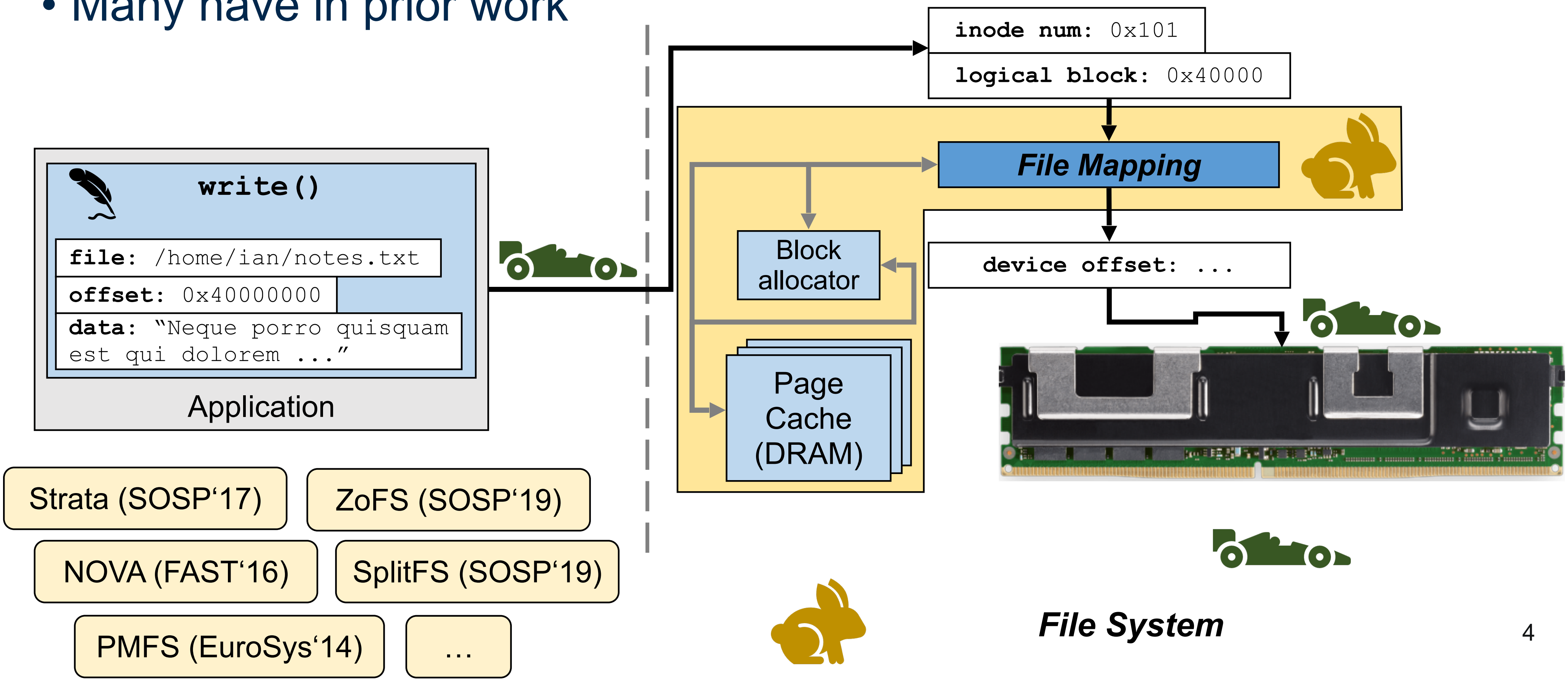

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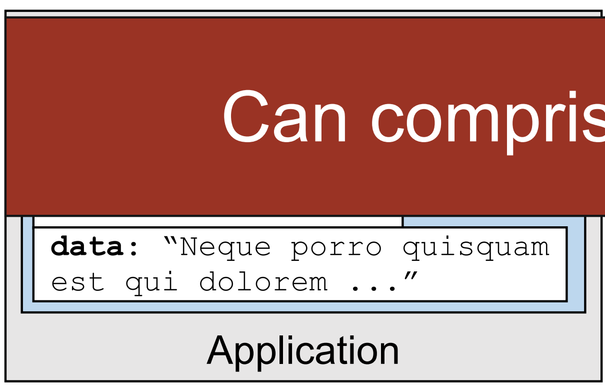

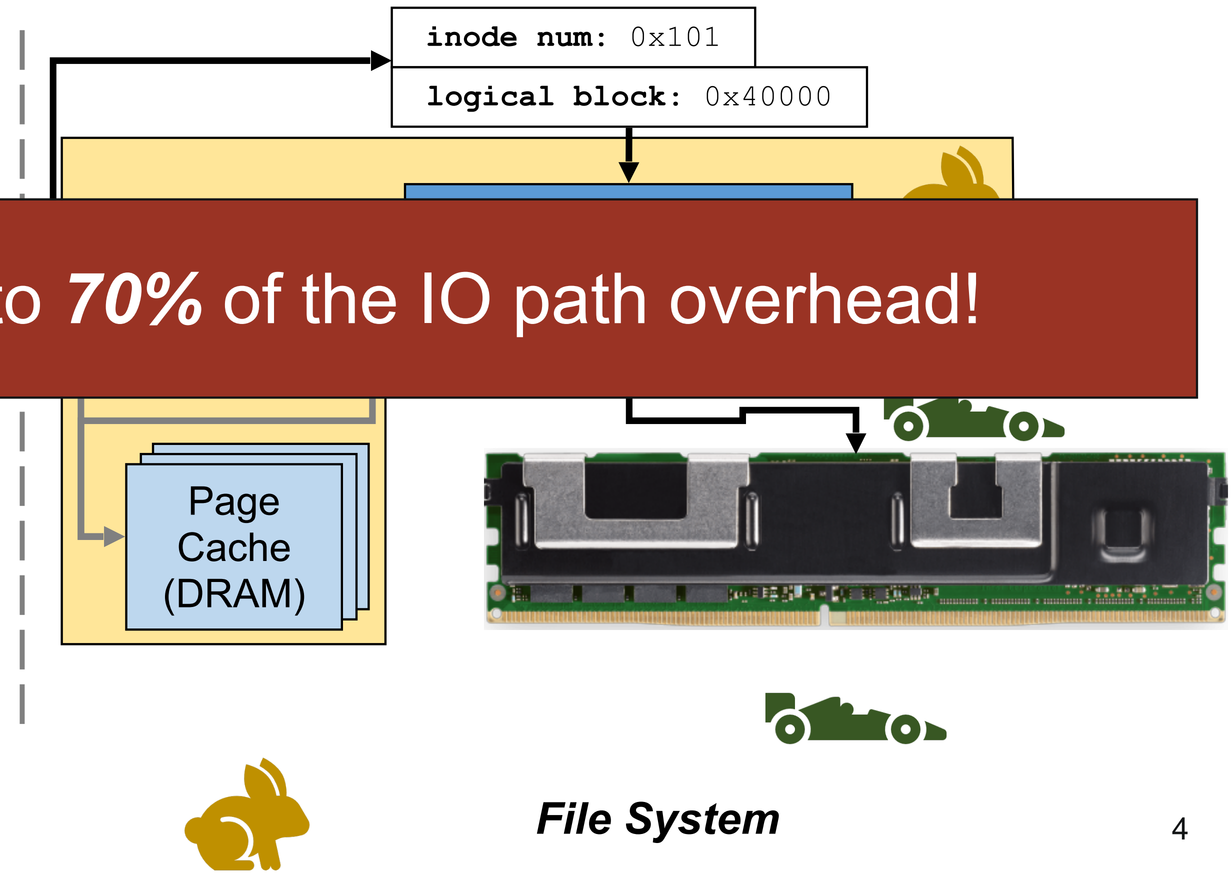

Can comprise up to *70%* of the IO path overhead!

Strata (SOSP'17) | ZoFS (SOSP'19) | NOVA (FAST'16) | SplitFS (SOSP'19) | PMFS (EuroSys'14) | …

Our Contributions

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File size?	Specialize for different file sizes?
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Storage structures?	Can we reuse PM storage structures?
Real workloads?	Are mapping optimizations impactful?

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- Evaluate on Filebench
  - fileserver (1:2 read/write ratio)
  - webproxy (5:1 read/write ratio)

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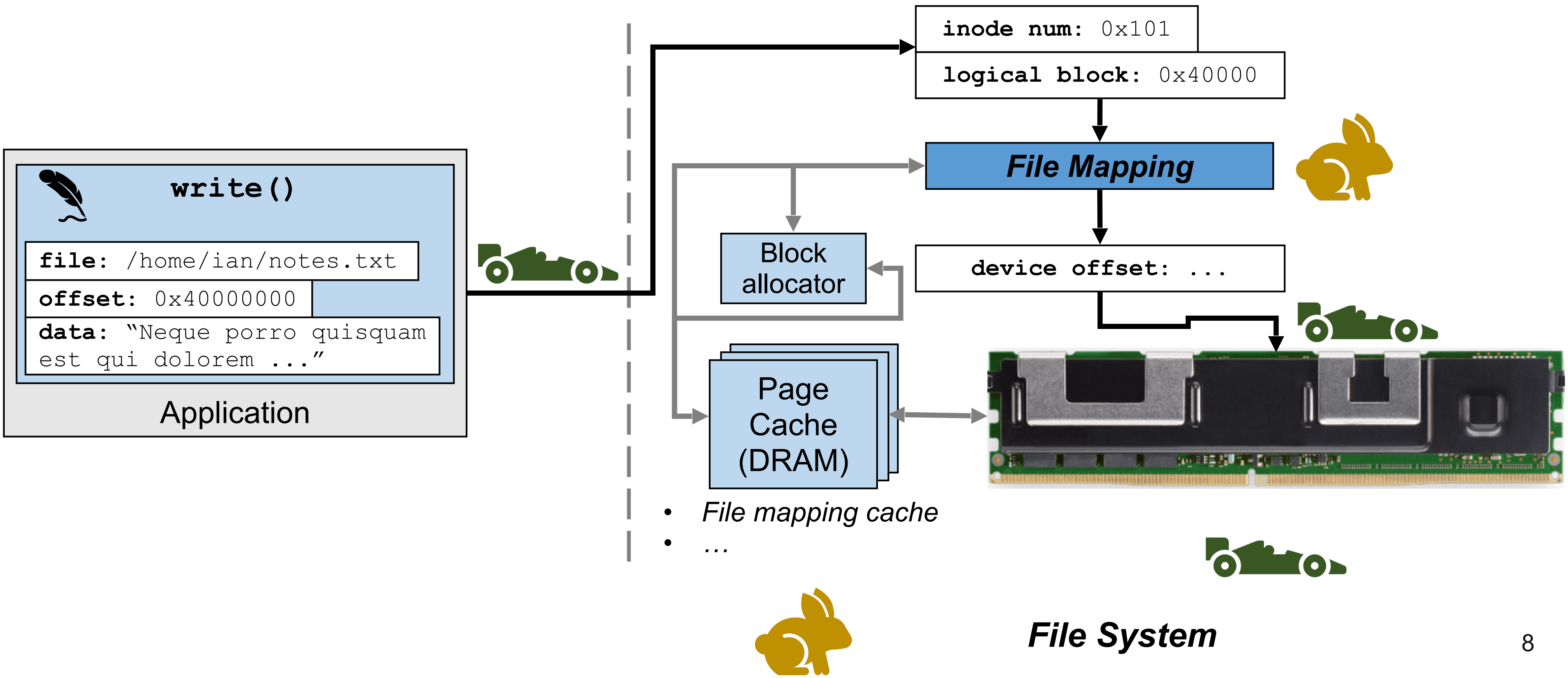

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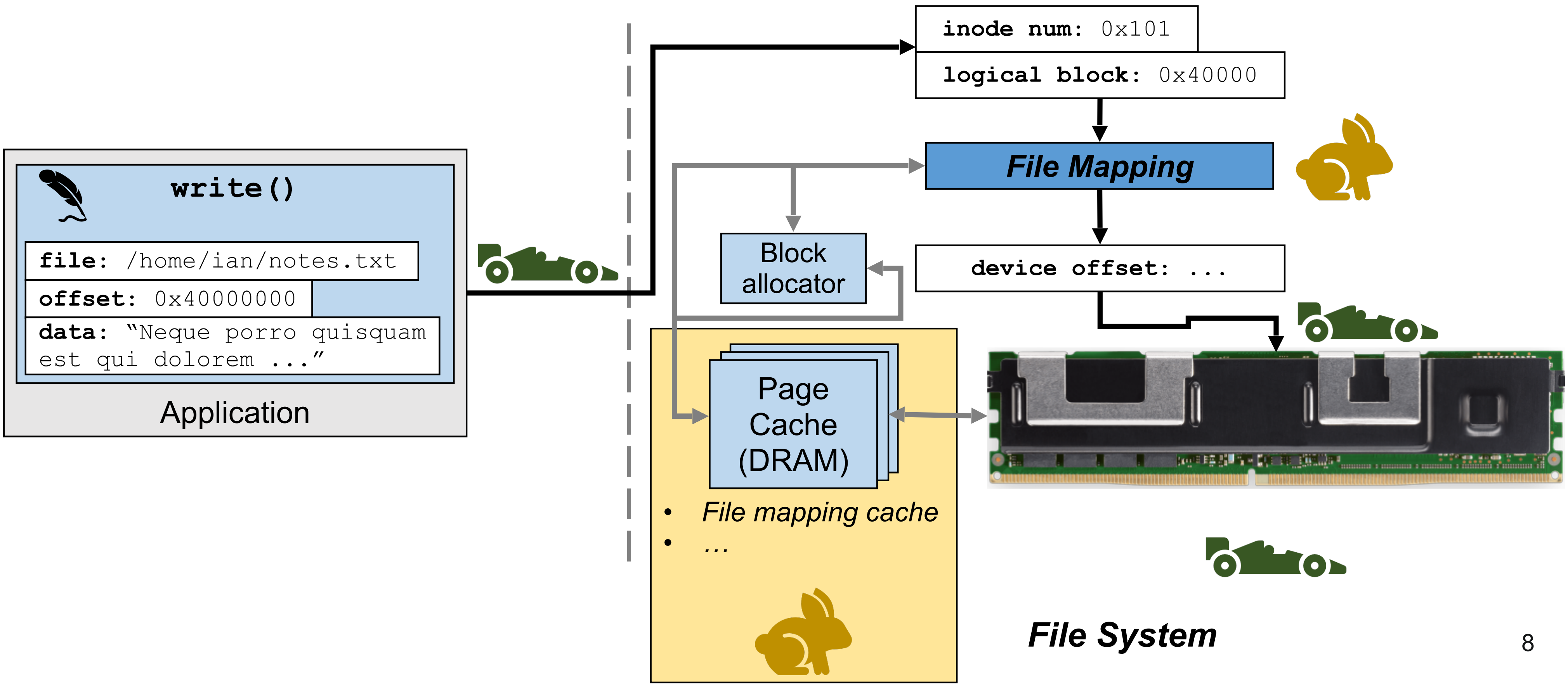

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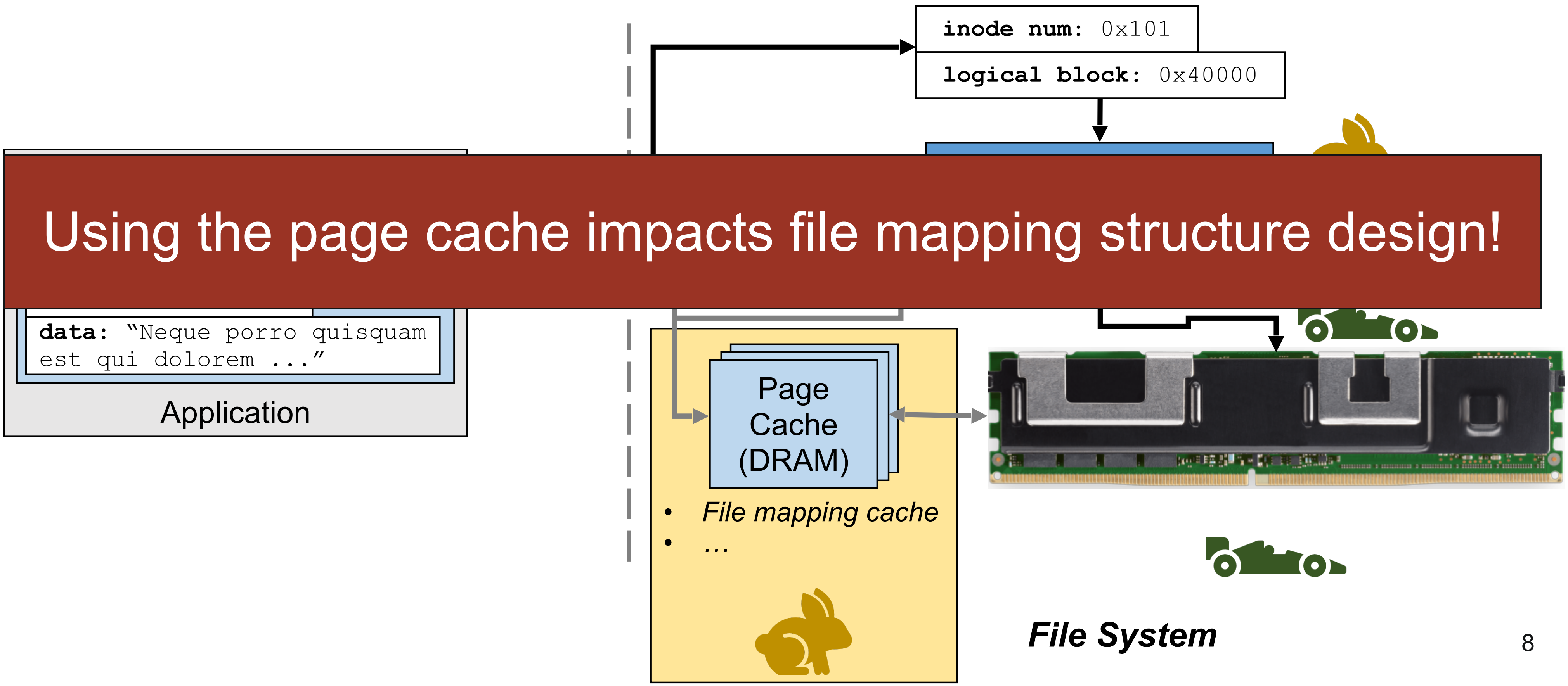

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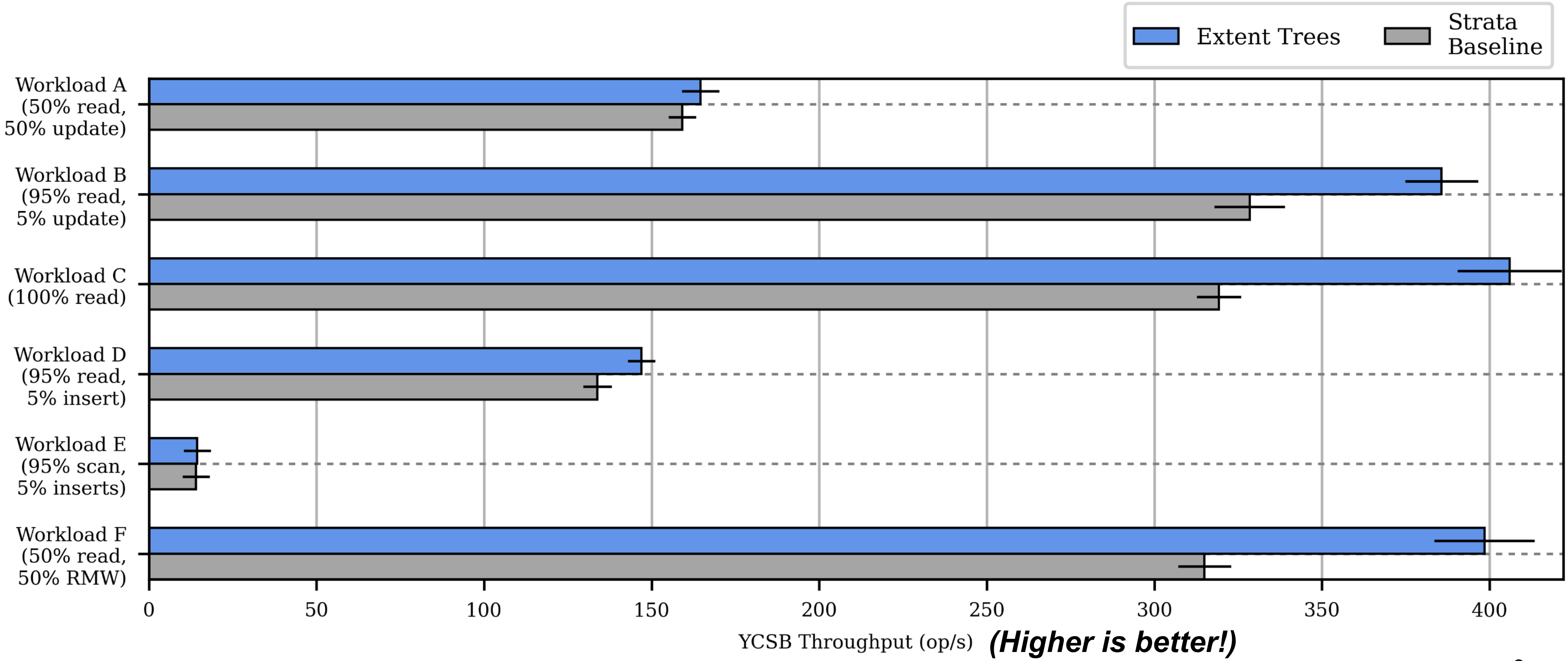

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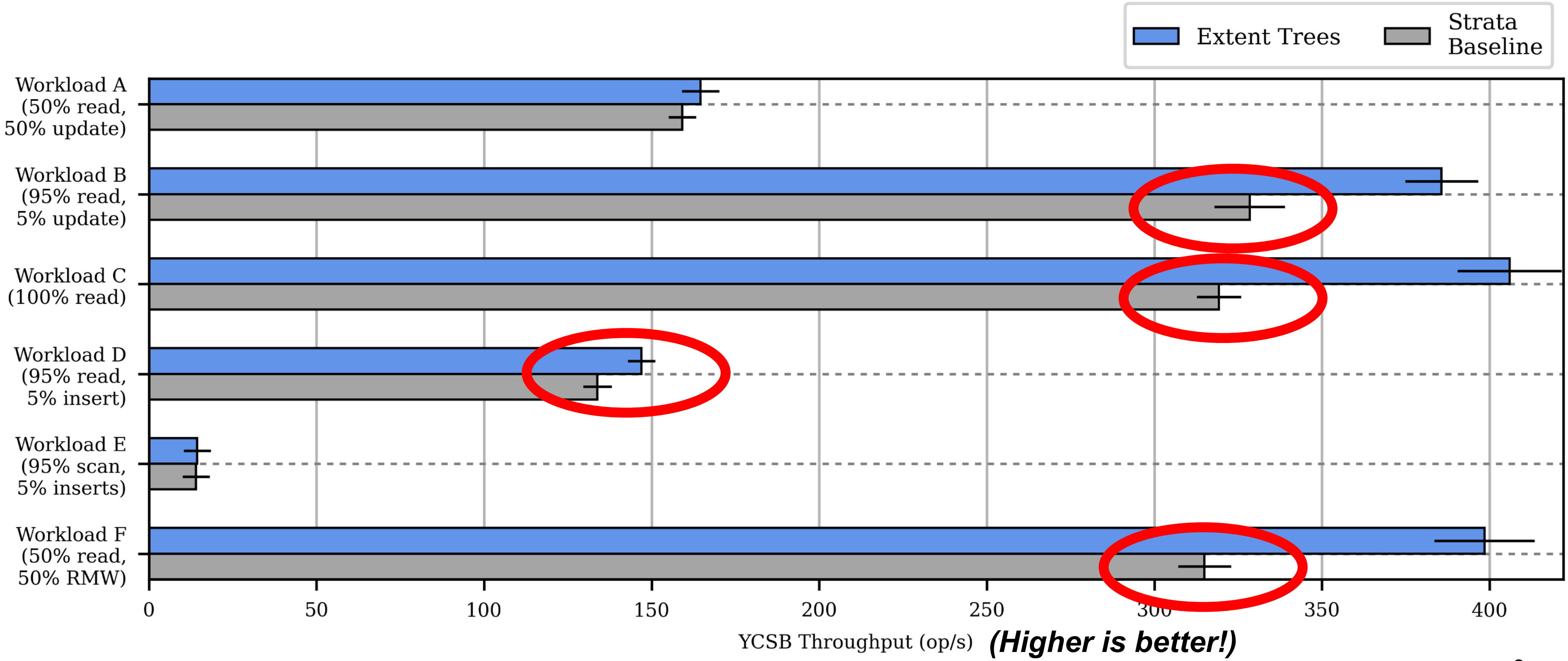

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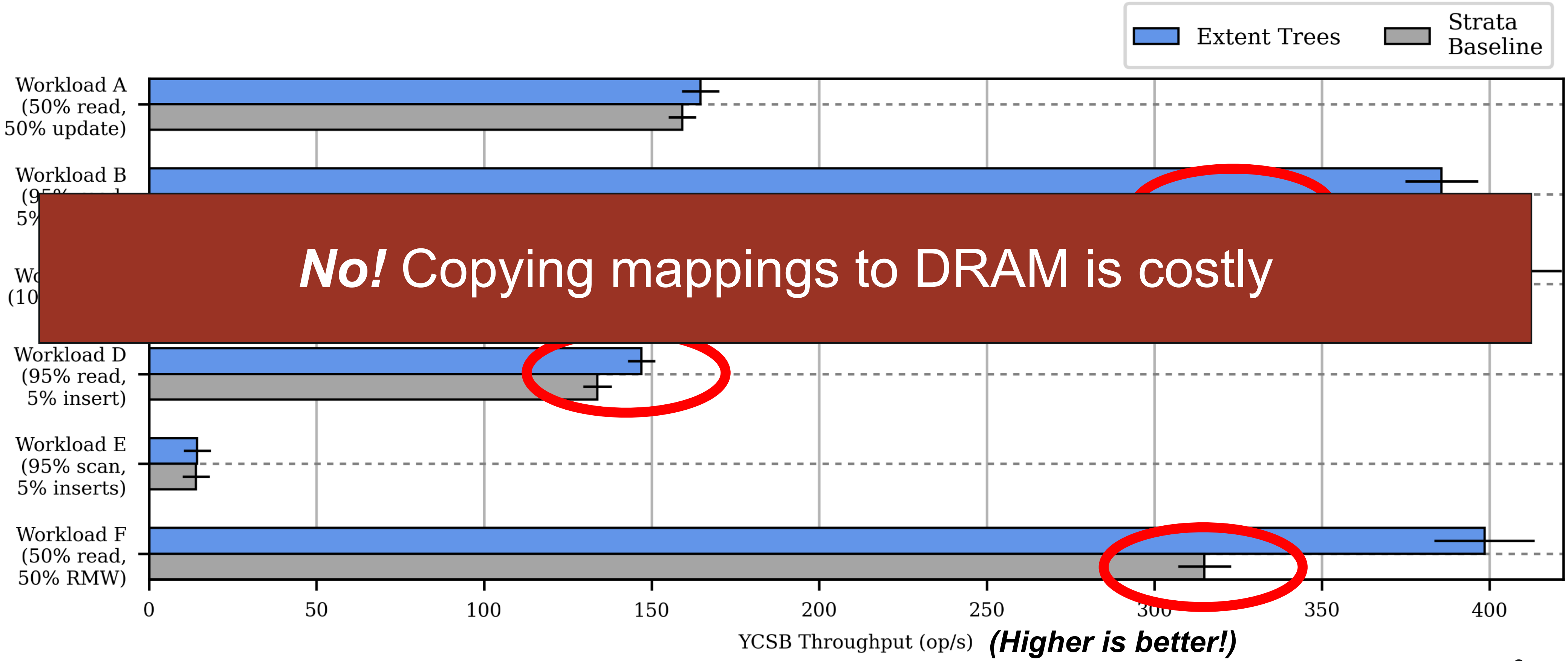

No! Copying mappings to DRAM is costly

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  - Cuckoo hashing
  - HashFS

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  - Possible due to no page cache + PM byte addressability
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File Number: 1
Logical Block: 21

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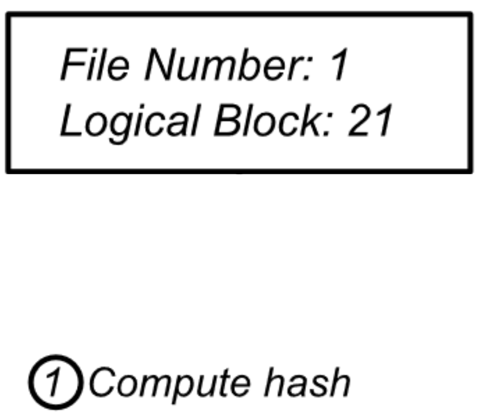

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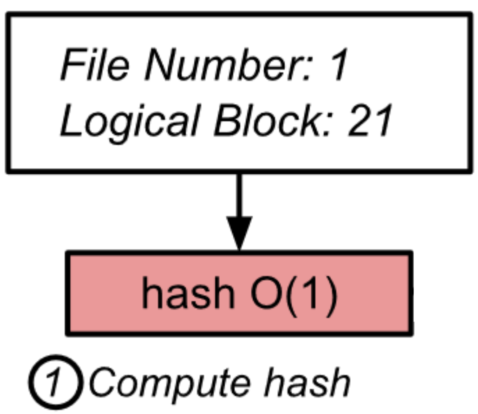

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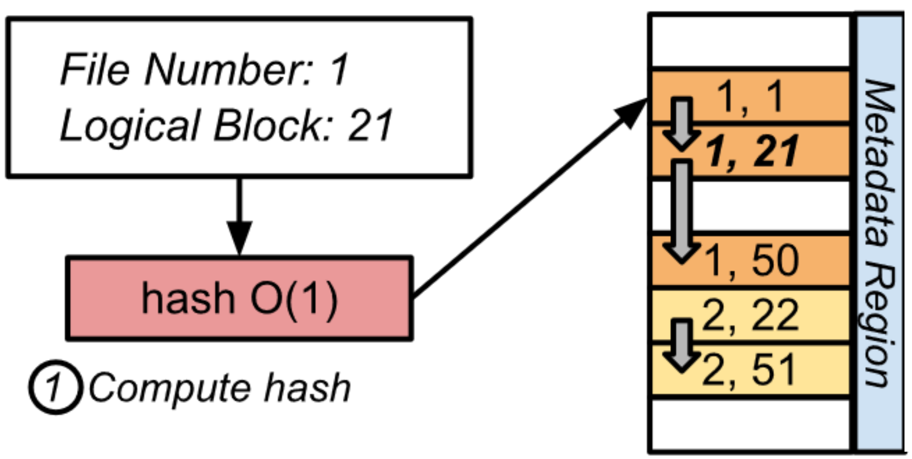

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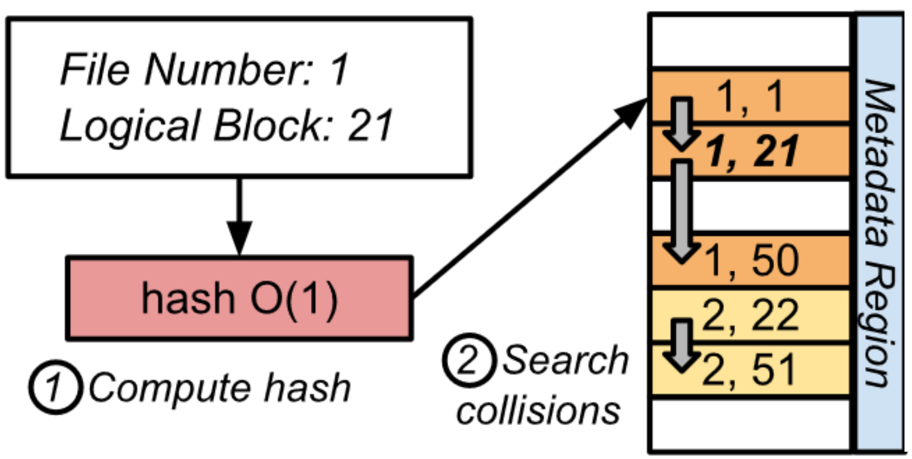

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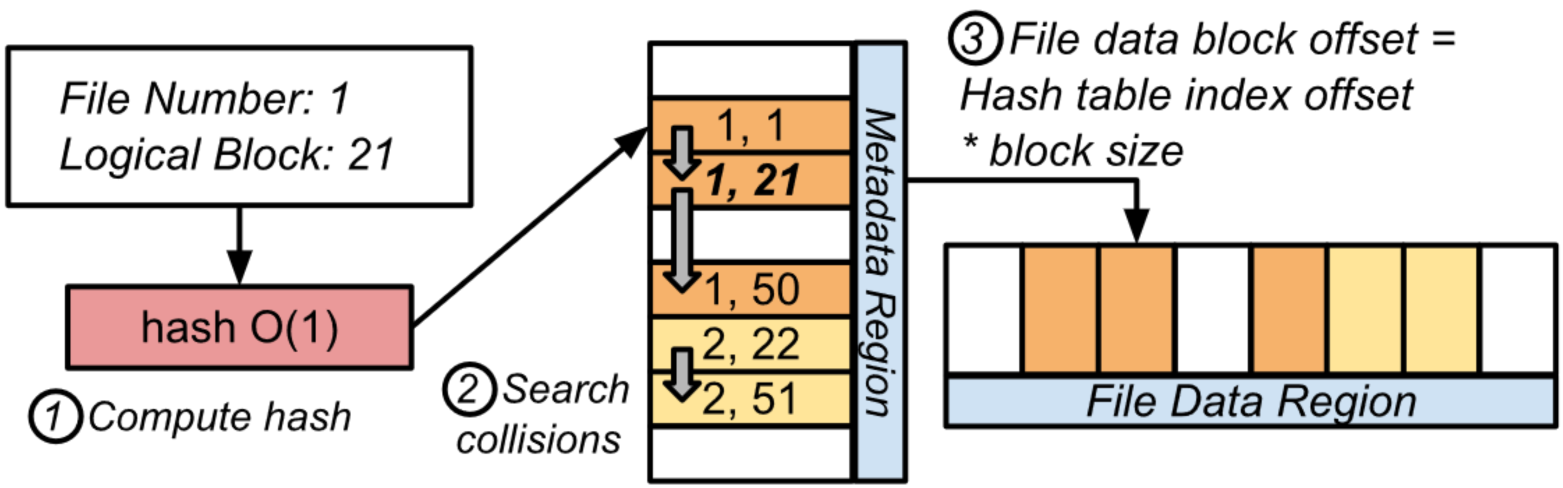

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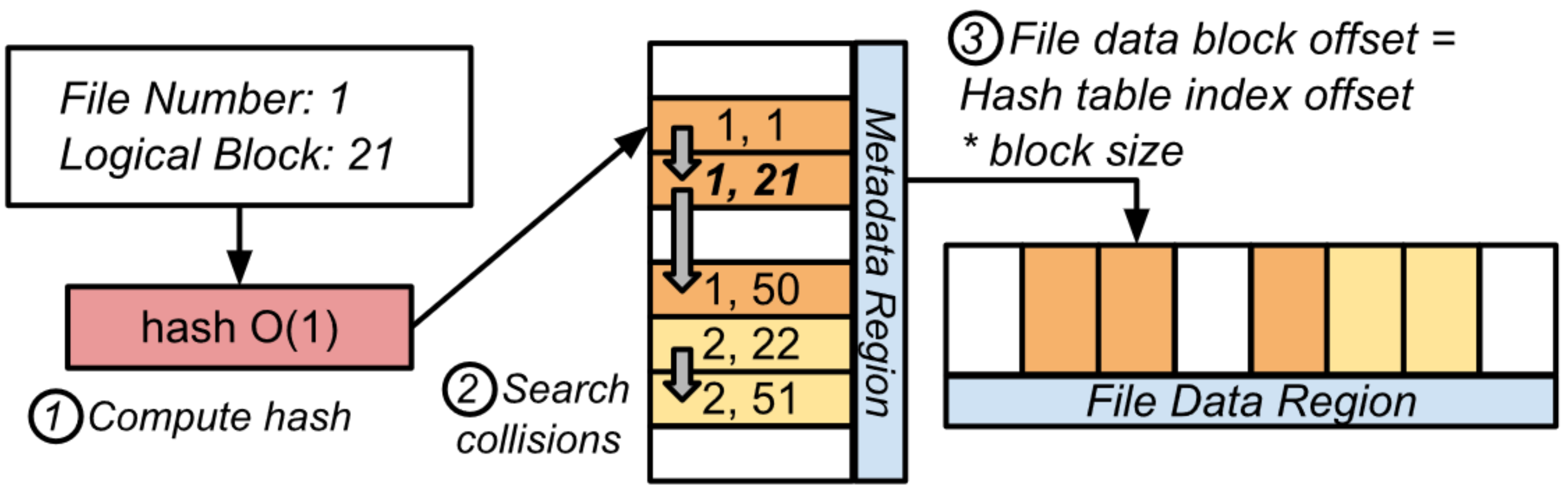
- Combined block-allocation and file-mapping scheme
  - Insert into hash table implicitly allocates block at corresponding offset
  - **Bypasses expensive block allocator management** (cf. our paper)



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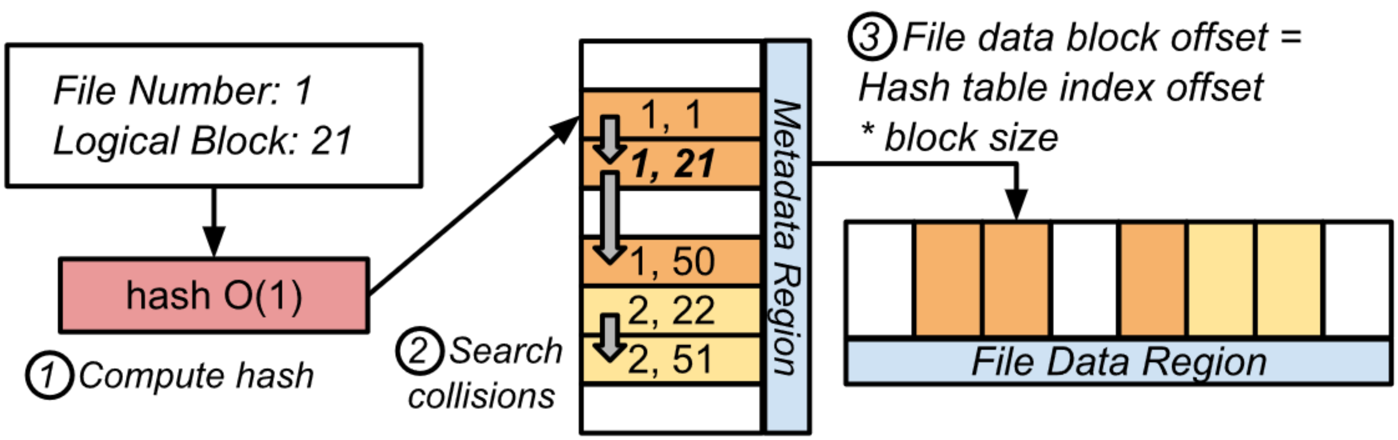

File Number: 1
Logical Block: 21
hash O(1)
1 Compute hash
2 Search collisions
1, 1
1, 21
1, 50
2, 22
2, 51
Metadata Region
3 File data block offset = Hash table index offset * block size
File Data Region

HashFS (cont.)

- Need to avoid all resizing (incurs high update latency)
  - Must also be a global structure (one structure for all files)
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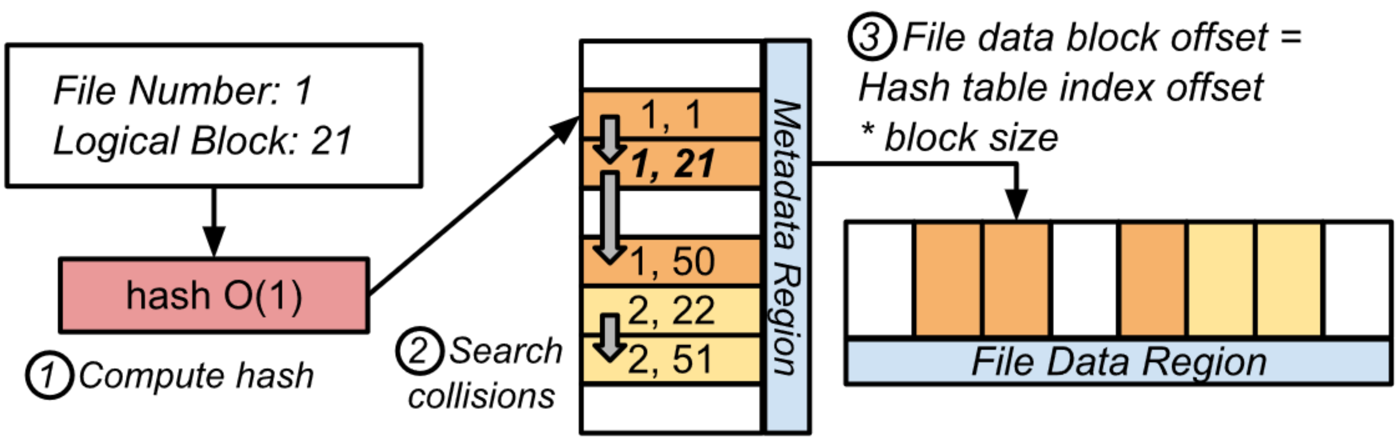

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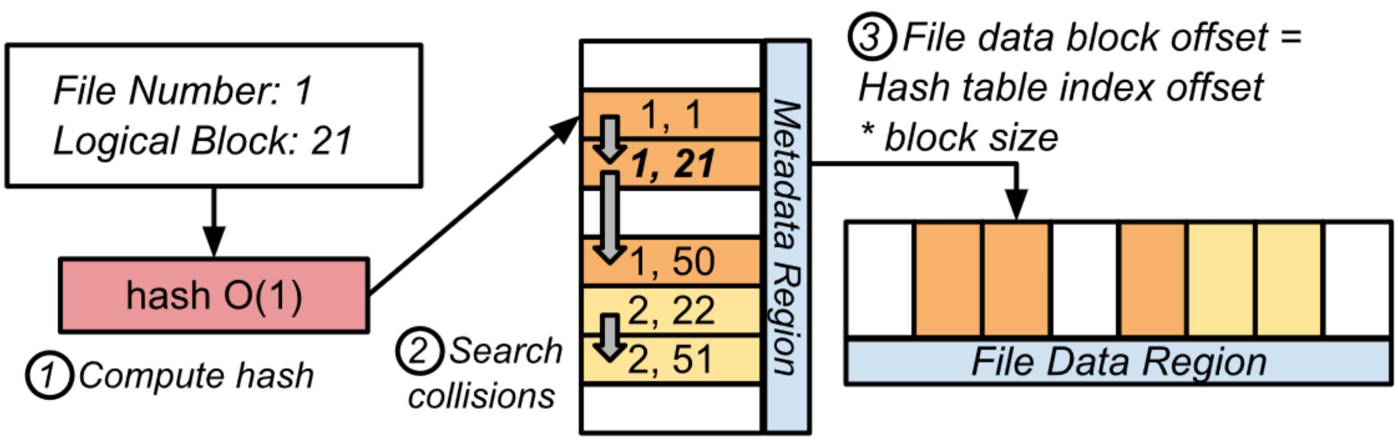
- FS optimization: use SIMD for large IO operations
  - Many file system workloads perform large IO operations
  - For efficiency, mapping structures must return ranges of mappings
  - **Perform hash table operations in parallel**



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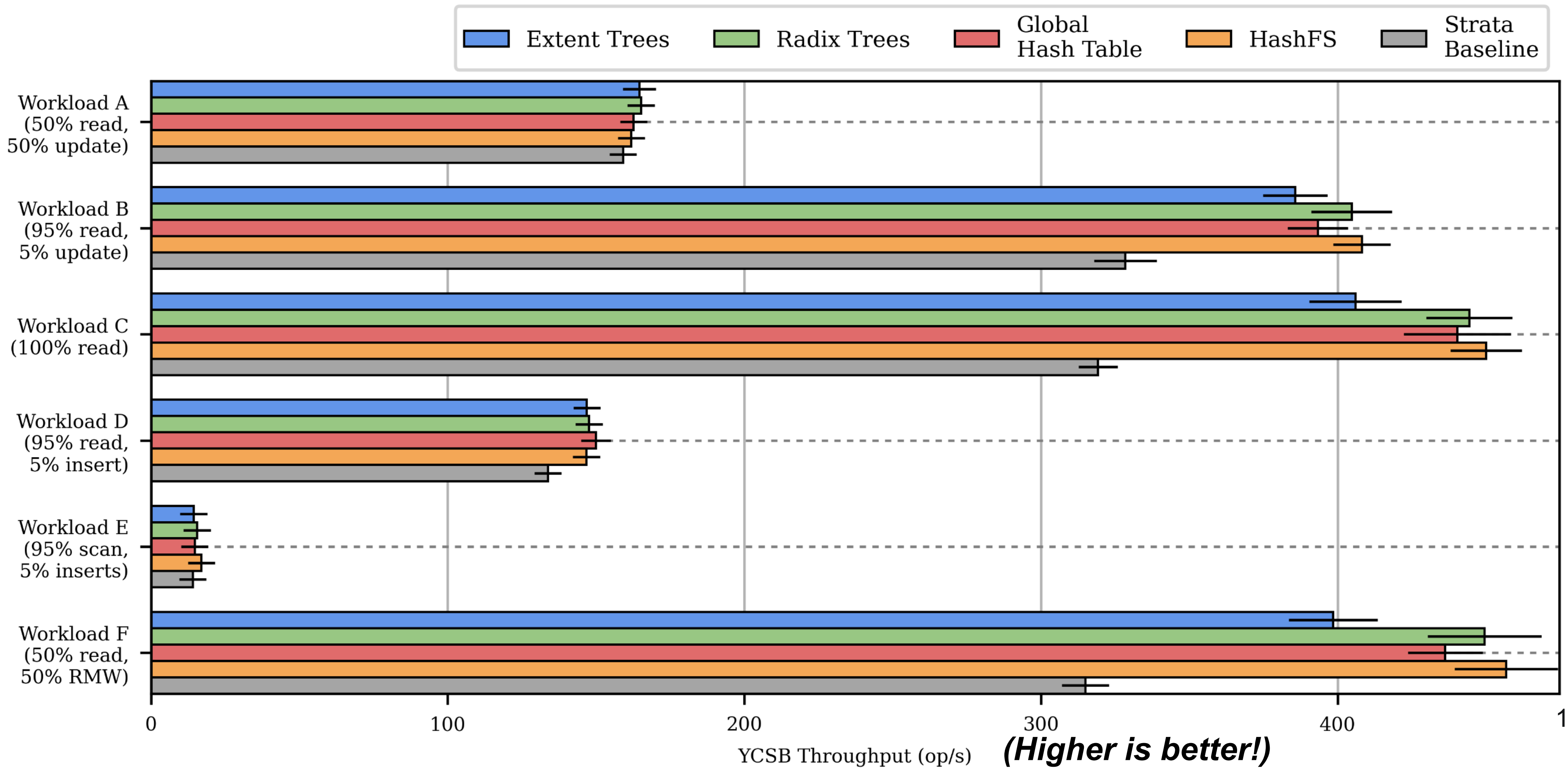

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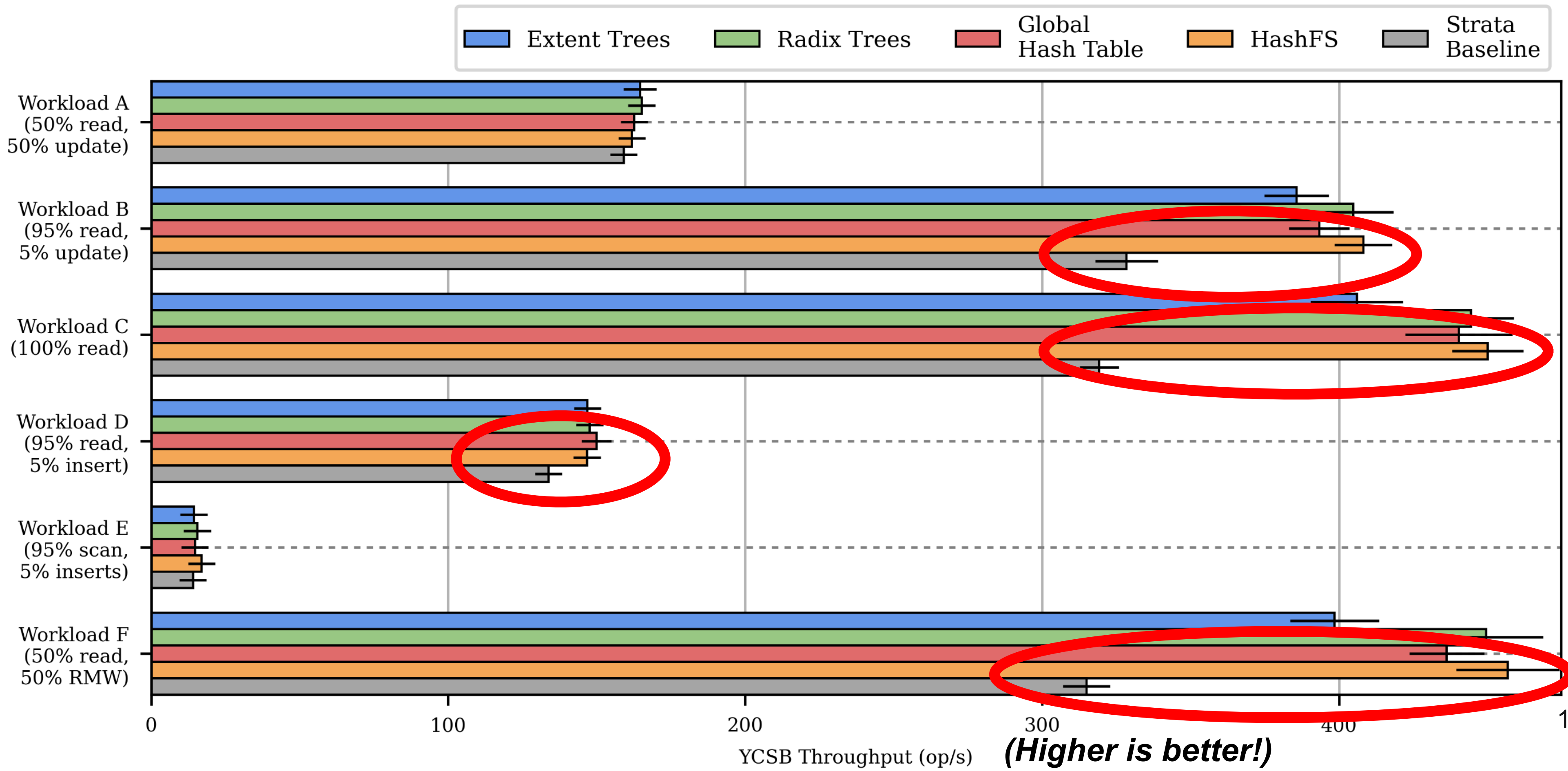

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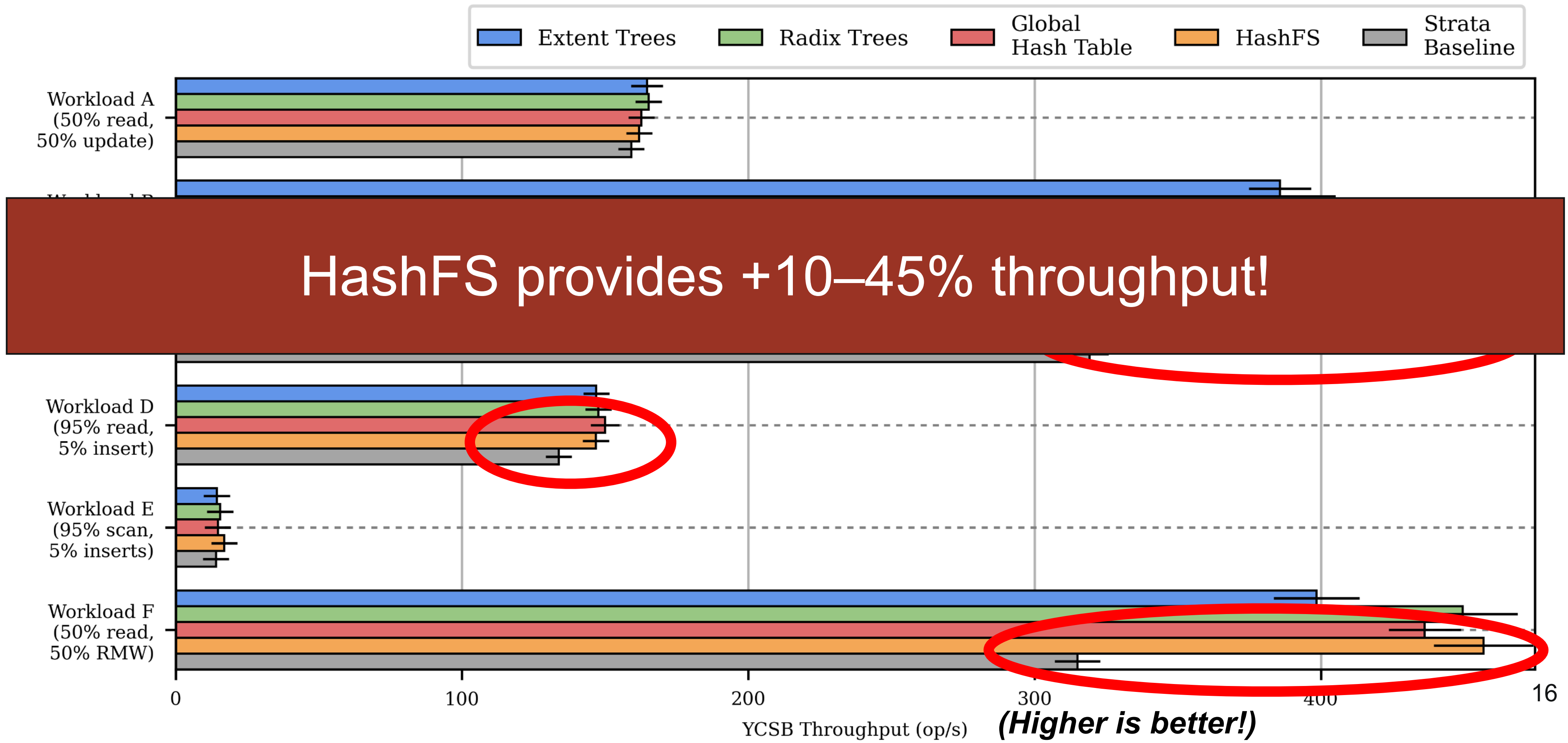

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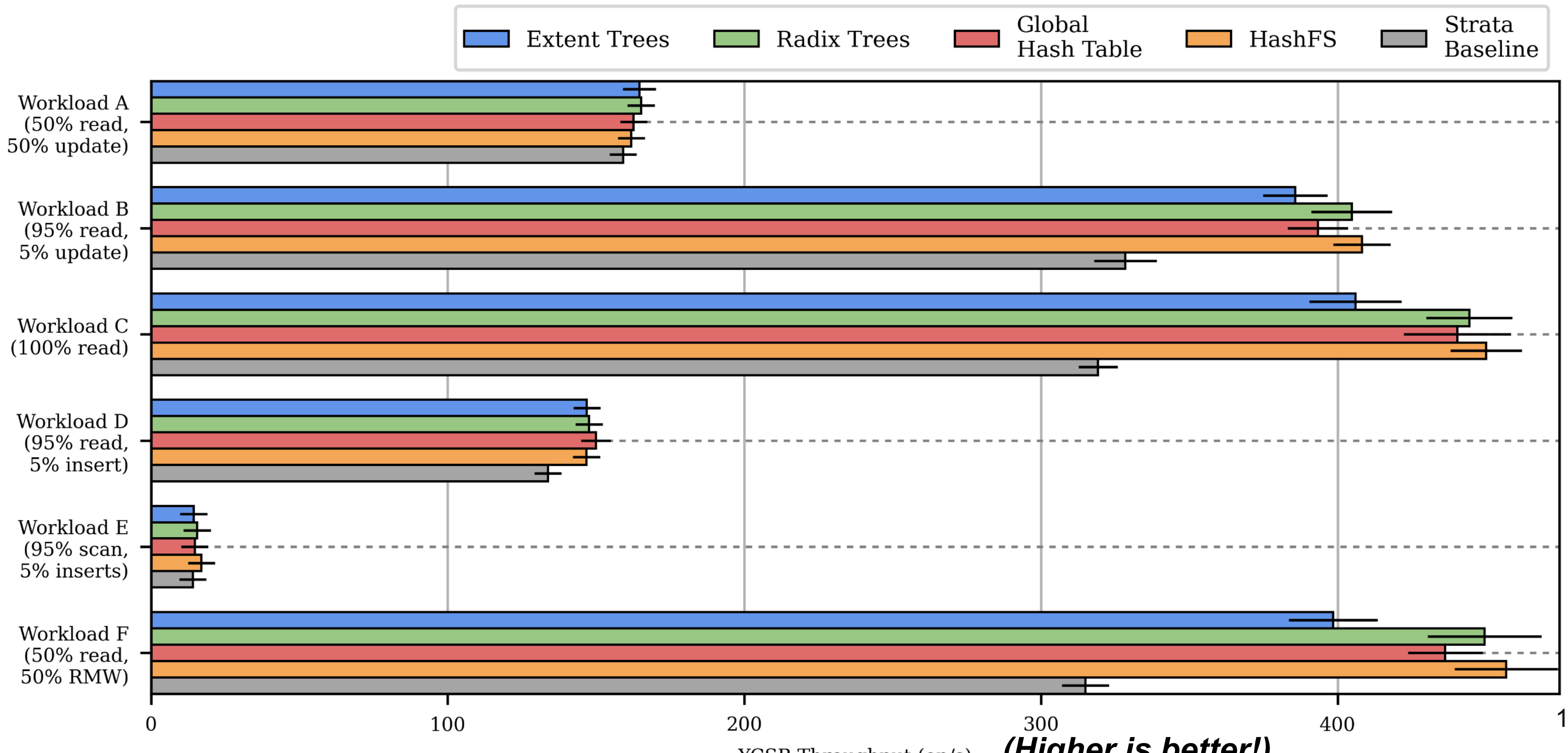

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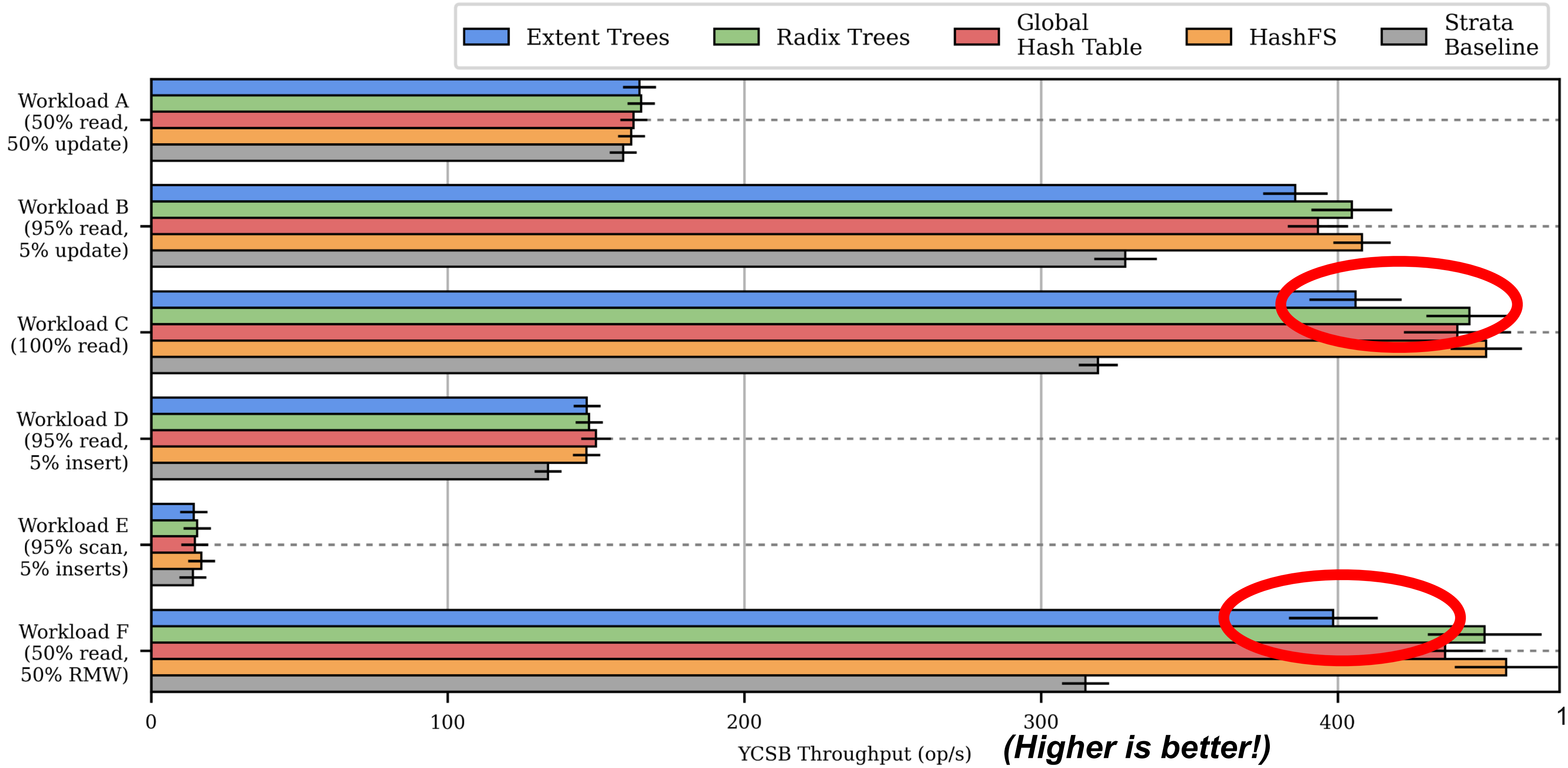

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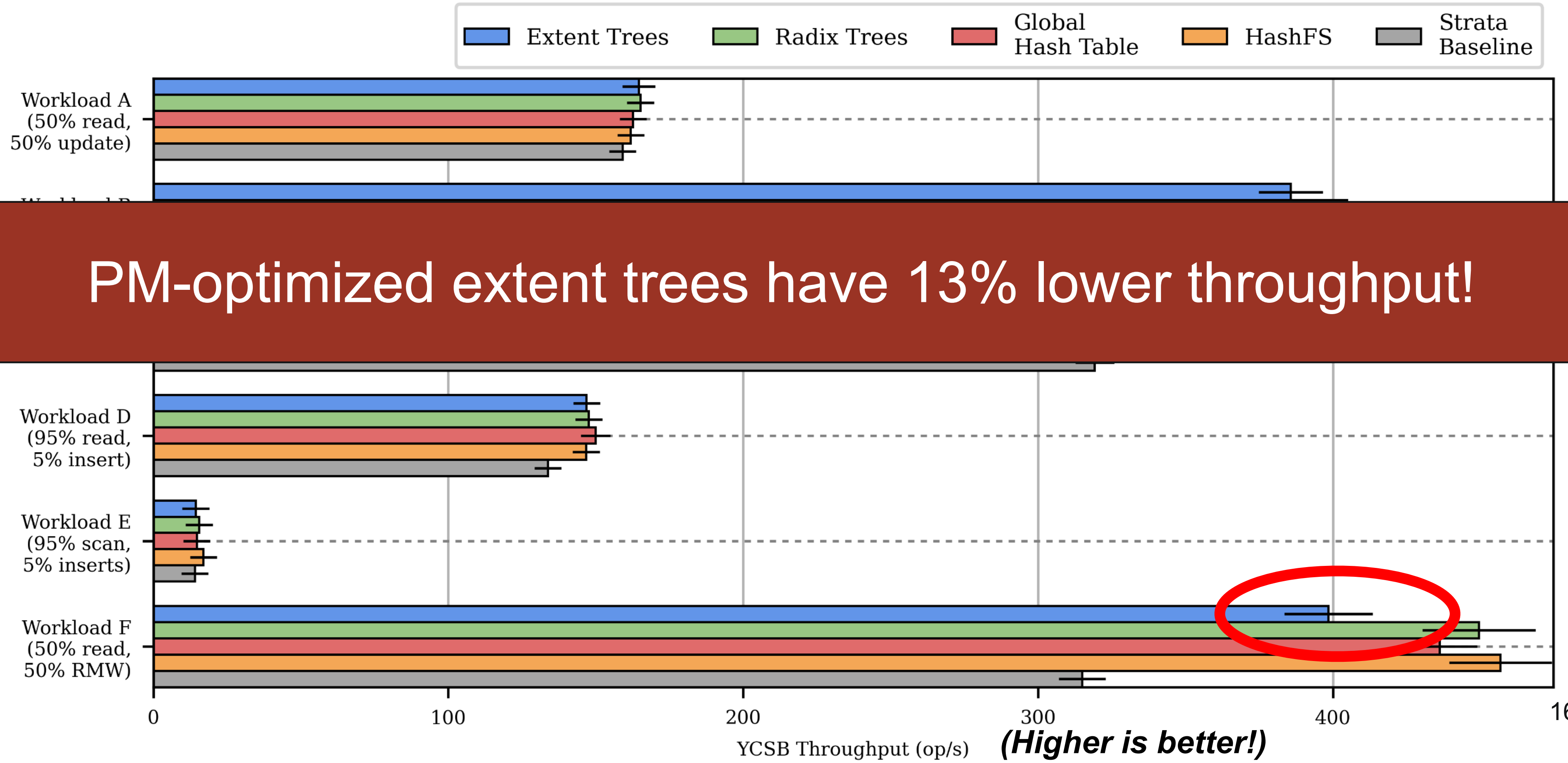

PM-optimized extent trees have 13% lower throughput!

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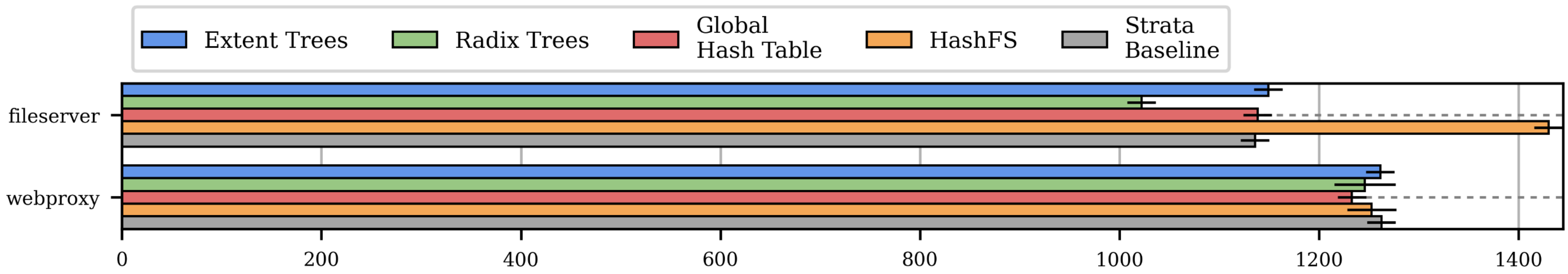

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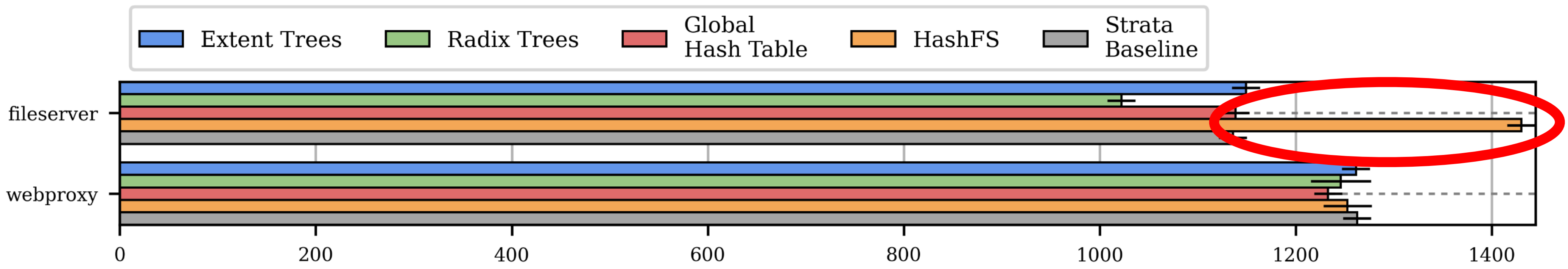

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HashFS provides +26% throughput!

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- We design two new, global file mapping approaches (cuckoo hashing, HashFS)

Conclusions

- We must re-examine file mapping specifically for PM file systems!
- A rigorous analysis yields insights into performance-shortfalls of existing mapping approaches
- We design two new, global file mapping approaches (cuckoo hashing, HashFS)
- HashFS (our new PM-optimized file mapping approach) outperforms the state-of-the-art by up to 45% in real workloads

Thank you!

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